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Looking at Shredding Plant Configuration and Its Performance for Developing Shredding Product Stream

(An Overview)

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Synopsis:

Nowadays more and more products are produced or manufactured to full-fill the consumption needs. More and more products are consumed due to increasing the world's population, technology development and emergence of new products, as well as willing for having better life style. However, sustainable development requires the optimal use and recycling of the natural resources and wastes respectively. In fact recycling is the final productive use of end-of–life vehicles (ELVs) and other obsolete appliances, as well as industrial and municipal wastes.

LEVs, obsolete appliances and industrial wastes have become major resources for production of iron and steels, aluminium, copper, and other metals, as well as composites. Shredding and recycling plants are built to first shred the obsolete goods in pieces and produce feed for subsequent processing plant where the feed from mixed scrap is processed to achieve high grade fractions of different material streams for metallurgical and other uses.

Currently, the rate of recovery for obsolete goods in shredding and recycling plants, around the world, reaches to maximum 75-80% and about 25% of the scrap is land-filled. However, due to social, economical and technical view points the recycling rate must be increased in an environmentally sound and technically viable manner.

Mapping and Development of Shredding Plant is part of MISTRA project in optimizing and improving the metal recycling for Iron and Steel industry in Sweden with general aim to improve recycling rate and to make a roadmap with respect to fragmentization and physical separation for shredding plants in order to have more efficient recycling plants in future.

This report is part of Mapping and Development of Shredder Product Stream that reviews the metal recycling, shredding plant and its constitutes, identification, sorting and separating techniques for different size fractions of raw material after shredding, and also processes for shredding residue. Finally the recycling scenarios with respect to the new EU legislations for ELVs and changing in cars composition by substitution of lighter materials like aluminium and reinforced composites instead of iron and steel are discussed.

Table of Contents

1- Introduction:

Due to the technology development, lack of high grade resources and, of course, environmental concerns, around the world we all know and talk about three Rs, i.e., Reduce, Reuse, Recycling. However, these three Rs have not received enough attentions by us as the society. These three Rs are ordered due to their priority, however, our life style, especially in western countries, seems to be against the first R. The affluent society in North America and Western Europe seems not to be ready for reducing consumption and over 2.5 billion Asian are going to join consumption rate race. The later has enormous impact on the world economy. Therefore the needs for raw material and final commodities, as well as global demand for recycling increase. It is interesting to address that the use of crude oil as a source of energy in US is about 70 barrels per capita per year. For Western Europe this consumption reduced to 35 barrels per capita per year, however, the average consumption of crude oil in undeveloped and under developing countries and especially China is just about 5 barrels. This indicates a huge potential for oil consumption in near future for social, cultural, and industrial development of these countries which means also a huge waste production and needs for recycling.

Reuse extends the lifetime of components and therefore decreases the market for new products, which does not particularly interest most original equipment manufactures. Reuse has a potential which means that the full value of the item or its components can be potentially recovered. Examples are to sell a new car for less than its cost in replacement parts, and antique dealers often sell items at premium to their original value. One example of successful reuse is multi-modal shipping containers that have slashed global transportation costs for manufactured goods and enabled shipping of low-value material and scrap. As a result of such cheap transportation system, Asian hand stands strongly and successfully competes against the advanced Western sorting technologies for recycling. There is no competition between reuse and recycling since anything which is reused still has to be eventually recycled to recover the value of its constructing materials.

With respect to the reduction, despite the fact that reduction is more effective in mitigating humanity's impact on the environment than recycling and reuse recovers more of the value, it is recycling that is matter of concern globally especially for environmentalists and regulatory agencies.

When one is talking about recycling, there are different words, like recycling, recyclability, recycled content, recycling rate, that are brought into consideration. However, they are not synonyms [1].

Recyclability refers to the potential market for the scrap of a given composition. There are more marketing options if the scrap is purer. Consequently, pure metals from primary smelter can be considered as the most recyclable metal composition.

Recycle content depends on the compositions of the desired alloy and the scrap. For example, in metal recycling, higher element concentrations in the alloy allow use of more scrap and if the scrap is purer than the alloy, then it can be batched from 100% scrap. Recycling rate and fraction recycled are not defined very well, especially when applied to a class of long-lifetime post-consumer products like vehicles. This is due to the fact that there is uncertainty regarding the life-time for a vehicle and also many out of order and no-longer-registered vehicles are not immediately scrapped.

The weight fraction that ends up as the recycled products in comparison to the weight of recycled goods is called the "fraction recycled". This can be determined by material mass

balance during recycling process. It is impractical to operate the entire recycling system in a mass balance test mode at all times. A better measure of fraction recycled would be to consider: (weight recycled)/(weight recycled + loss to the land filled).
Recycling, however, is act of material recovery from the scrap that depends on the existence of a complete recycling system, including legislation, regulation, education, collection, technology, and at last but not least, market for all types of recovered scrap. For a complete and efficient recycling system all the aforementioned components must be present and incorporate.
With respect to recycling of metals and other components, it is known that our modern society is characterized by the extensive use of complex multi-component consumer products, of which passenger vehicles, white electric appliances, and electric and electronic products are made of wide spectrum of raw materials to meet the highest consumer needs. These products at the end of their functional lives are discarded and return as complex multi-component materials that cannot be directly converted into new products. They must be first dismantled to recover re-useable parts and then the remaining must be comminuted to smaller sizes in order to separate different fractions for recycling. Dismantling, shredding, and separation plants play vital roles in recycling of End-of-Life Vehicles (ELVs), other appliances, and industrial waste. During last 20 years manufacturing of passenger vehicles has considerably increased and nowadays more than 58 million units are manufactured. This number will be more considering that the growth rate for car manufacturing during period of 1997-2020 is expected to be 32%. Certainly, considerable growth is seen for other end of life consumer goods. Nowadays between 22 to 24 million passenger cars are out of order and sent for recycling and due to the new legislation for European Community, by the January 2015 reuse and recovery target for ELVs must attained to 95%, of which 85% has to be reuse and material recycling. Certainly, harder regulations will arise for other end of life goods. Therefore, it is needed to reconsider all steps for dismantling, shredding and separation stages for more effective, environmentally sound and economically viable recycling chain and to make a road map for more efficient recycling procedure.

2- Globalization of the World Economy and Its Impact on Recycling:

Nowadays common global language for business, i.e., English, emergence of global multinational corporations more and more, instant global communications and electronic transformation of information and funds, computer sharing common software, as well as multi-modal shipping containers have all contributed to changing the world to a global village [1]. Many believe that recycling in general, and metal recycling in particular, enjoys a very bright future. Recycling or secondary metals compete with primary production which depends on the exploitation of non-renewable resources. Since mining companies are forced to resort to lower grade, more remote, and more difficult to process deposits, the cost for finished product will rise. Furthermore, rising energy costs and governmental policies forcing mining and metallurgical companies to pay the full environmental costs of their operations will accentuate this trend. This, in turn, will make the recycling more competitive and over time the relative importance of secondary metal production in supplying the trend for growing society.
A large portion of secondary metal production is based on the recycling of new scrap, which is constrained far more by the available supply of new scrap than by metal prices or

recycling costs. Production of metal from old scrap is more sensitive to costs and prices and would enjoy benefits due to a rise over the time for metal prices because of resource depletion and environmental policies. However, history indicates that during last century new technologies have had great impact on cost reduction for metal production and thereby on metal prices. Consequently, real metal prices have fallen during last decades.

According to Professor Robert Ayres [2], we are in a period of economic transition. The "Cowboy economy" of the past is obsolescent, if not obsolete. Environmental services are no longer free goods, and this fact is driving major changes. Recycling is the wave of the immediate future. The potential savings in terms of energy and capital lave long been obvious. The saving in term of reduced environmental impact are less obvious but increasingly important. Increasing energy and other resources costs, together with increasing costs of waste disposal, will favor this shift in any cases.

The above statement indicates that recycling, i.e., waste recycling in general and metal recycling in particular, will contribute an important part of society's future for supplying materials. But, whether recycling will account for a growing share of total metal production or not will depend, in part, on how active and how successful recyclers and secondary producers are in introducing new technologies and other cost reduction innovations in comparison to primary metal producers. However, there are other affecting factors beyond the control of recyclers and secondary producers.

The determinants of recycling vary from metal to metal. They also differ for secondary metal produced from new scrap, i.e., the scrap that arises in the course of producing new goods, and for secondary metal produced from old scrap, i.e., the scrap arises when products come to the end of their useful life.

Although, secondary metal produced from new scrap is often not treated as part of total metal supply or taken into account when calculation of the total supply of available metal but it would be inappropriate to ignore new crap, as it accounts for a sizeable portion of total secondary production. For example for the US, in recent years, new scrap accounts for 55% for iron and steel, 55% for aluminum, 66% for copper, 4% for lead, and 72% for zinc for portion of total secondary production [3-4].

Due to the fact that new scrap is easy to collect, easy to identified, and normally of high quality, its recycling costs are low, and almost all new scrap is recycled. Although, price for new scrap goes up and down with the market price of metal, these fluctuations have little or no effect on the amount of new scrap recycled. As a result it is said that the supply of secondary metal produced from new scrap is inelastic which means that changes in the market price of the metal has no effect on recycling of new scrap. Low cost for recycling new scrap allows recycling of them in respective to the price. It has been studied that if market price varies within a range the price fluctuations have little influence on new scrap's supply. However, changes in the amount of secondary metal supplied from new scrap occurs due to the changes in the availability of new scrap which, in turn, is because of shifting in the availability of new scrap constraint rather than changes in the metal market price. In long term changes in allocation of metal among its end uses and also changes in technology that alter the amount of new scrap generation in the production of specific metal-using goods determine whether secondary metal from new scrap accounts for rising or falling share of total metal consumption over the time.

In the case of old scrap, the costs of recycling vary greatly. Some old scrap is easy to collect, identify, and have good quality. Like new scrap, the high quality and easy to be

identified old scrap is widely recycled in respective to the price of metal. However, some old scrap is prohibitively expensive to recycle because it is widely dispersed and its collection costs are very high or because of its low quality. Except for these two extremes, large quantities of ordinary old scrap are economical to recycle at prices within normal range of metal prices. Generally, old scrap recycling is more sensitive to metal price. The later, in turn, is sensitive to the market, mineral depletion and more stringent environmental policies governing mining and land filling.
For recycling, the versatile reusable shipping containers are paramount important which made it possible to globalize the world of economies and manufacturing as well as the scrap market by slashing the cost of transportation. Having such economic transporting system has paved the way for free transport of recyclables around the world and has changed the trade structure. Asia in the beginning of 21st century has become the world's largest producers of steel, zinc, and almost all other metals and manufactured goods. This cheap labor cost has attracted a majority of manufacturers to invest in to manufacture goods for Asian hunger market as well as Europe and America.

3- Metal Recycling [3-5]:

Recycling, a significant factor in the supply of many of the metals used in our society, provides environmental benefits in term of energy savings, reduced volumes of waste, and reduced emissions associated with energy saving. Statistics indicates that in 2002 metal apparent supply in United States was 134 Mt. Recycling contributed 74.8 Mt to metal apparent supply which is equivalent to 55.6% of total supply.
Among metals, aluminum and iron and steel dominated the quantity of metals apparent supply and recycled materials. By weight, iron and steel accounted for the largest share of both apparent supply and recycled metal at rate of 88.5% and 92.3% respectively. However, aluminum accounted the second largest share of apparent supply and the second largest share of recycled metals by the weight. According to the information apparent supply and recycling rates for aluminum reached 6% and 3.9% respectively.
Measured by recycling rate, statistics showed that in USA lead was the most recycled metal at the rate of 71%. Iron and steel recycling has the second rank with the recycled rate of 58% and the least recycled rate belonged to tin and zinc with corresponding recycled rates of 20% and 26%.
Values for the recycled material are also indicating important numbers. In 2002, The United States exported 11.8 Mt of scrap metal which valued at $3.33 billion, however, the imported metal scrap reached 11.3 Mt having value of $2.18 billion. Again Iron and steel dominated the quantity of exports at 77.4%, however, the second and third places are held by nickel and aluminum at 9.08% and 5.21% respectively. With respect to the value, iron and steel scrap dominated the value of export at 41.2%, though; aluminum, copper and nickel held distant second, third and forth places at respective rates of 18.1%, 15.3%, and 15.2% of value of metal exported.
The statistical recycling data for some important metals in USA are shown in below:

3-1- Aluminum: in 2002 aluminum recovered from scrap decreased slightly to 2.93 Mt of which 60% was recovered from new (manufacturing) scrap and 40% came from old (discarded aluminum products) scrap. As reported by American Metal Market, purchase prices for aluminum scrap fluctuated. The price for mixed low-copper content aluminum, old sheet and cast aluminum, and clean, dry aluminum turnings, were between 51-52; 48-49, and 48-49 cents per pound respectively.

3-2- Chromium: the major end use of chromium is in stainless steel and this is the major form in which chromium is recycled. Stainless steel scrap can be substitute for ferrochromium as a source of chromium. There are two broad categories for stainless steel, i.e., austentic and ferritic, which are related to the molecular structure of the steel but also identify which grades require nickel (austentic) and which do not (ferric). Nickel content, however, increases the prices for both alloy and its resulting scrap. There are two different type of scrap. One is generated during the metallurgical process (new scrap) and the other one is from recycling of obsolete equipment (old scrap). Scrap from these two resources is collected and stored by grade. Scrap brokers play a role in trading these scrap. Steel industry consumes stainless steel scrap as a source for chromium and nickel.

3-3- Copper: according to International Copper Study Group, the total world production secondary refined copper in 2002 rose nominally to 1.86 Mt which indicates 12.2% of global world refined copper production. It is also reported that, additional 3.7 Mt of copper was recovered from the direct melting of copper scrap.
During 2002, secondary refined production in the US continued its downward trend by 59%. Copper recovered from all refined or remelted scrap composed 30% of total copper supply which had an equivalent refined value of $1.75 billion.
Copper-based products have a wide variety of life spans, i.e., from a few years in electronic devices, to over 100 years in architectural uses. Assuming an average life span of 30 years for most products, copper's truer recycling rate would be 85%.
Virtually all products made from copper can be recycled. Industry uses recycled copper as a major source of raw material. In some instances, recycled copper can be remelted and directly used without any further processing. In effect, copper can be considered as renewable since it can be recycled over and over again without losing any of its chemical or physical properties. Some countries' copper requirements greatly depend on recycled copper to meet internal demands. However, recycled copper alone cannot meet society's needs, so we also rely on copper produced from the processing of mineral ores.
Recycling is dependent on the efficiency of the scrap collection system, technological and economic factors, product design, societal values, as well as on the incentives and barriers introduced by society, including governments.
Copper Scrap is subdivided into different categories:
1- scrap from refined copper, 2- scrap from copper alloys, 3- old scrap, e.g. from used, worn out, or obsolete copper products returned from the market place e.g. castings, electronic scrap, Cu-Fe-materials, catalysts, and 4- new scrap, e.g. turnings, stampings, cuttings etc. and defective products i.e. Products that have never entered the consumer market plus manufacturing scrap and other scrap from first and second processing stage.
Copper waste and scrap is covered by four HS codes:
HS 7404.00 Copper and copper alloys, HS 7404.00.10 Copper, HS 7404.00.91 Copper-zinc base alloys, and HS 7404.00.99 other copper alloys
Furthermore, cuprous ashes and residues are covered by one HS code, i.e., HS 2620.30 Ashes and cuprous residues.
During 2002 production of refined copper in Sweden reached about 0.2 Mt in which 12.5% was from recycling sources.

3-4- Iron and Steel: the most widely used of all the metals is the iron and of course its refined product steel. Therefore recycling of iron and steel scrap, i.e., ferrous scrap is an important activity worldwide. Due to feasibility to recycle iron and steel by melting and recasting into semi-finished forms for use in manufacturing new steel products, a significant industry has developed to collect old scrap and new scrap. The recycling rate for iron and steel in North America has reached 71%. Statistics indicated that in 2002 the world scrap consumption in iron and steel production has reached 0ver 382.6 Mt. The world production of crude steel was 902 and 965 Mt for the 2002 and 2003 respectively indicating a growth of 6.9%, however, the average growth rate of crude steel production since the beginning of new millennium is estimated for 4.4.

For 2002 and 2003, Sweden had the production of 5.7 and 5.8 Mt of crude steel. In 2002 the consumption of scrap in Sweden reached 2.8 Mt, which indicates 49% of new crude steel production comes from scrap.

Steel scrap recycling conserves energy, landfill space, and raw materials. The remelting of scrap requires much less energy than the production of iron and steel products from iron ore. Each year, steel recycling saves the energy equivalent of the electrical power needed for I year by approximately one-fifth of the houses in the United States. Furthermore, consumption of iron and steel scrap by remelting reduces the burden of landfill disposal facilities and prevents the accumulation of abandoned steel products in the environment. Every metric ton of steel recycled saves about 1.134 kg of iron ore, 635 kg of coal and 54 kg of limestone that would otherwise be consumed to make the iron used that steel.

Vast quantity of ferrous scrap available for recycling comprises home, obsolete, and prompt scrap. Prompt or industrial scrap is generated from manufacturing plants that make steel products. Its chemical and physical characteristics are known and it is usually transported quickly back to steel plants for remelting to avoid storage space and inventory control costs. Home, or mill, scrap is generated within the steel mill during production of iron and steel. Trimmings of mill products and defective products are collected and can be quickly recycled back into the steel furnace because their chemical compositions are known. Due to emergence of new effective and more efficient casting methods the availability of home scrap has been declined. Major source of scrap steel is obsolete, old, or post-consumer scrap. Among different sources the largest one is junked motor vehicles followed by demolished steel structures, worn out railroad cars and tracks, appliances, and machinery. However, because of wide variety for chemical and physical properties of the obsolete scrap more preparation is needed to handle these scrap. Sorting, detinning, dezincing, etc., most be done in order to be able to reuse old scrap.

In the United States discarded automobiles are the single most important source of obsolete steel. It is said that of ferrous metals used to make a typical 2001 U.S. family vehicle, 45% was recycled metal. The recycling rate for the automobile scrap was 101% in 2002 which means that more steel is recycled from old automobile than what is used in the production of new vehicles. This is also resulted from changing technologies in car manufacturing and the use of other materials rather than steel or ferrous metals.

Steel products have a wide range of physical and chemical characteristics due to the relative content of the steel accounted for by the trace elements carbon, chromium, cobalt, nickel, manganese, molybdenum, silicon, tungsten, and vanadium. Furthermore, some steel products are coated with aluminum, chromium, lead-tin alloy, tin, or zinc. Existence of these trace elements as well as coating elements and alloys make it difficult to easily

recycle the obsolete scrap. Therefore, scrap dealers must carefully sort the scrap they sell, and steel makers must be careful to purchase and use scrap. For steel makers it is important to purchase scrap that does not contain undesirable elements, or residuals, that exceed acceptable levels that vary according to the product being produced.
Steel mills melt scrap in BOFs, EAFs, and to a minor extent, in blast furnace, BF. Statistics indicated that the amount of scrap was melted in BF and other types of furnaces, is insignificant in comparison with the scrap used in BOFs and EAFs.

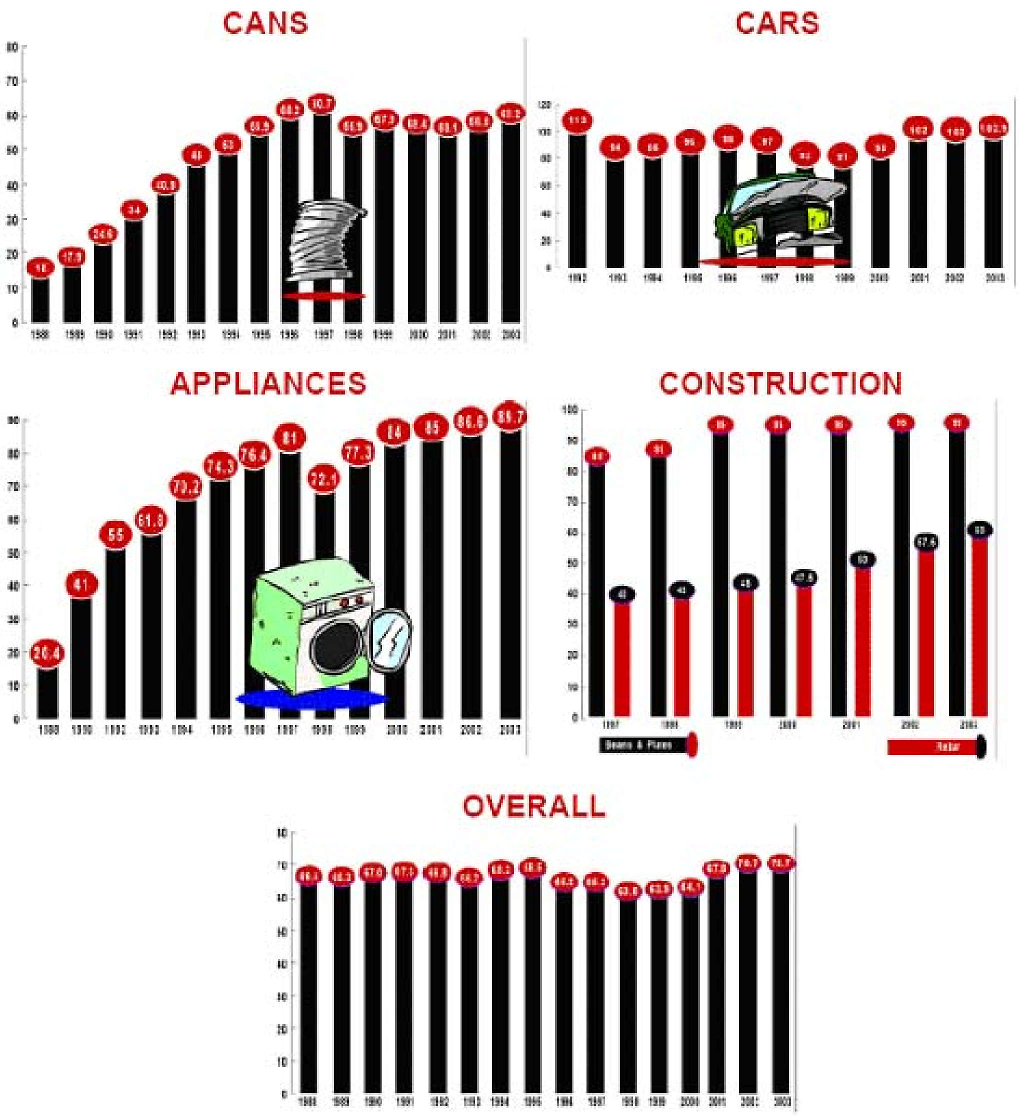


Fig.1- Steel Recycling Rates for different products

Except the fact that iron and steel scrap is an additional resource for steel makers, recycling of these scrap conserves energy, landfill space, and natural resources. For example recovery of 1 t of steel from scrap conserves an estimated 1.14 t of iron ore, 635 kg of coal, 54 kg of limestone needed to produce a single ton of primary steel.

According to American Iron and Steel Institute (AISI), the steel recycling rates in 2002 for the U.S. were 101%, 95%, 87%, and 57% for automobile, construction structural beams and plates, appliances, and steel cans respectively. These numbers indicates an average rate of 71% for total recycling of total scrap steel. For obsolete appliance scrap the rate of recycling has been significantly increased during the last decades of 20^{th} century. According to the information released by AISI the recycling rates for obsolete appliance scrap had increased to 81% in 1997 from 20% in 1988, then decreased to 72% in 1998 and bounced back to 90% in 2003.

3-5- Lead: in the United States about 81% of total 1.37 Mt of refined lead produced in 2002 was recovered from recycled scrap, of which the main source was spent lead-acid storage batteries. Just 6% of the recycled lead was recovered from other lead-based sources rather than batteries, including building construction materials, cable covering, dross and residues from primary smelter refinery operations and solder. The rate for lead recovery from different scrap at secondary smelter has met 89% during 2002.
In Sweden, total refinery production of lead in 2002 and 2003 were 69700 and 76200 t respectively, however, the contribution of scrap for such tonnage productions were about 57% and 68% for the same years.

3-6-Magnesium**:** typically, magnesium-base scrap is categorized into one of the followings six types.

Type 1: high grade clean scrap (generally such material as drippings, gates, and runners from die-casting operations that is uncontaminated with oils)
Type 2: clean scrap that contains steel or aluminum, but no brass or copper
Type 3: painted scrap casting that may contain steel or aluminum, but no brass or copper
Type 4: unclean metal scrap that is oily or contaminated
Type 5: chips, machining that may be oily or wet
Type 6: residues (crucible sludge, dross, etc.) which are free of silica sand

The most desirable scrap type is type 1 which is generated mostly during die-casting magnesium alloys. Scrap Type 1 represents 40-60% of the total cast weight, most of which consists of runners that feed the die cavity at it is injected with magnesium. This scrap is either reprocessed at the die-casting facilities or sold to scrap processors. Other types of scrap either sold to scrap processors or directly used in steel desulphurization.
Old magnesium-base scrap, or post-consumer scrap, consists of such material as automotive parts, helicopter parts, lawnmower decks, used tools, and the like, which is usually sold to scrap processors.
Significant quantities of magnesium are contained in aluminum alloys that also can be recycled. New aluminum-base scrap that is recycled primarily contains of, in decreasing order of importance, solids, borings and turnings, dross and skimmings, and other material, that includes foil and can-stock clippings. Because the main aluminum product that contains magnesium is beverage cans, the principal magnesium-containing aluminum-base scrap is can scrap skeleton from lids and can sheet clippings. This represents about one-half of the overall magnesium-containing aluminum-base scrap.
The most important magnesium-containing of aluminum-base scrap is UBCs. Due to high recycling rate, UBCs represent about three-quarters of the magnesium-containing, old aluminum-base scrap that is reprocessed. However, the magnesium in old and new

aluminum-base scrap is not separated from the aluminum alloy when it is recycled; rather, it is retained as an alloying component.
Sorting is done to separate the magnesium-base scrap in order to produce new raw material. Since magnesium and aluminum closely look like each other, a load of magnesium scrap may contain some aluminum scrap as well. The scrap is usually inspected visually. One way for identification is by scratching the metal by knife. In this way magnesium tends to flake, whereas, the soften aluminum is apt to curl. After separating, the sorted magnesium scrap is charged to a steel crucible that is heated to 675°C. The liquid magnesium at the bottom of steel container is then transferred to ingot molds.
Additional to melting, magnesium scrap can be recycled by direct grinding of the scrap into powder for iron desulphurization applications. Only specific types of clean scrap can be used for such applications.
The world production of magnesium in 2002 was 429000 t. According to the statistics about 22-25% of total magnesium production around the world is from magnesium scrap.

3-7-Manganese: there is no direct recovery for manganese scrap. Incidentally, manganese scraps is recycled as a minor component within scrap of other metals, steel in particular and of course aluminum to much lesser extent.
High manganese steel that has about 12% manganese content is recovered, but the quantity of such scrap in purchased steel scrap is believed to be less than 1%. The average grade of manganese in steel is considered to be about 0.7%.
During recycling of steel scrap in steelmaking plants the manganese content of scrap is largely lost because of its removal in the decarburization step of steelmaking.
Manganese is recycled by the aluminum industry as a component in the scrap of certain manganese-bearing aluminum alloys, principally as UBCs in which the manganese content is about 1%. Melting and processing of aluminum is non-oxidizing toward manganese; consequently most of the manganese is retained. During 2002, in U.S., the amount of manganese recycled from aluminum-base alloys was less than 1% of total manganese consumption. For the future another resource for manganese would be recycling of widespread dry-cell batteries.
The world production of manganese as metal was estimated to be about 7.6 Mt.

3-8-Nickel: austenitic stainless steel scrap is the largest source of secondary nickel production. In the United States about 86% of total 99800 t of recycled nickel during 2002 was recycled from austenitic stainless steel scrap. Additional 4% came from other alloy steel scrap. The remaining is from nickel comprises copper-nickel and aluminum-nickel alloys scrap (5%) as well as pure nickel and nickel-base alloy scrap (5%).
NiCd and nickel-metal hydride (NiMH) batteries have rapidly been collected and can be considered as other sources for nickel recycling. Just in U.S. a program has been released to recycle more than 75 million small sealed, rechargeable NiCd batteries sold annually.
In 2001, European commission drafted a directive that calls for the phase-out of cadmium in most portable batteries by beginning of 2008. The proposed directive also would establish a minimum recycling target of 55% for all collected batteries. Some 13000 t/yr of portable NiCd batteries and 3500 to 4000t/yr of industrial NiCd batteries are marketed in EU. Studies indicated that within EU only 11% of the portable NiCd and 53% of industrial batteries were being reclaimed.

During 2002 the world production for nickel was 1.34 Mt of which 10% was recovered from scrap. The total production of U.S. in the same year was 99800 t that was mainly recovered from scrap.

3-9-Tin: in 2003 the world production of tin (smelter production) reached 279000 t of which about 4.3%, i.e., 11900 t, was from scrap recycling. In the U.S. about 20% of domestic supply of tin metal was recovered from scrap. Old scrap is collected from different sources, like municipal collection-recycling centers and ditinning plants, whereas, new scrap is generated mainly in the thin mills, scores of can making facilities, brass and bronze plants, and also many solder-making operations.
Detinning facilities are unique to the tin scrap industry in that no other major metal industry has numerous large-scale plants to remove plated metal. Ditining operations are performed on new tinplate scrap from tin mills or can-making plants and no old tinplate scrap in the form of used tin cans. The bulk of secondary tin industry works with the various alloy forms of tin, like brass, bronze, solder, etc. Tin is recycled within its own product-line industries and the recycled tin is used to regenerate alloys.
According to the US Steel Recycling Institute the recycling rate for tin has significantly increased during last decades and has reached 59% in 2002 where it was just 15% in 1988.

3-10-Titanium: titanium scrap is sought as an alternative to titanium sponge and alloying materials in the production of titanium ingot. There are two different new and old scrap for recovering titanium. New scrap is generated during the melting, forging, casting, and fabricating of titanium, however, old scrap is recovered from used components, such as aircraft parts, heat exchangers, etc.
By using traditional vacuum-arc-reduction and cold-hearth melting facilities scrap is recycled into titanium ingot either with or without adding virgin metal. It is estimated that less than 5% of total titanium ingot produced in the United States is derived from old scrap.
Titanium scrap can be used by the steel and nonferrous alloy industries. In steelmaking, titanium is used for deoxidation, grain-size control, and carbon as well as nitrogen control, and stabilization. Titanium is introduced during steelmaking as a ladle addition often in the form of ferrotitanium because of its lower melting point and higher density when compared with titanium scrap. Ferrotitanium is also produced from titanium and steel scrap by induction melting.
Titanium scrap is consumed in nonferrous metals industry primarily for producing aluminum-titanium master alloys for the aluminum industry. Titanium in aluminum alloys improves casting and reduces cracking.

3-11-Vanadium: vanadium is principally used as an alloying element. Small quantities of vanadium, often less than 1%, are alloyed with other metals to produce various ferrous and nonferrous alloys. These alloys do not lend themselves to recycling for vanadium because having small quantities of vanadium. Vanadium is used as the catalyst also. It is estimated that catalyst composition accounts for less than 1% of total U.S. vanadium consumption

3-12- Zinc: Nowadays about 30% of world zinc production is from secondary materials, like brass, die casting scrap, flue dust, galvanizing residues, zinc sheet, etc.
In 2002 about 87% of recycled zinc in the United States was derived from new scrap, generated mainly in galvanizing and die casting plants and brass mills. The remaining 13% was obtained from brass products, flue dust, old die casts, and old rolled zinc articles.

The recycling processes of zinc-bearing scrap vary widely due to wide differences in the zinc content and quality of scrap. In most cases, clean new scrap, containing mainly of brass, rolled zinc clippings, and rejected die casting, requires only remelting. However, in the case of mixed nonferrous shredded metal scrap, zinc is separated from other materials by hand or other physical methods. Zinc from EAF dust is recovered mainly in rotary kilns by using the Waelz process. Due to the fact that most common use of zinc is for galvanizing, it is aimed to find new ways at stripping zinc from galvanized steel.

In 2002 and 2003 the world zinc smelter productions reached 9.65 and 9.88 Mt respectively of which 0.28 and 0.31 Mt were from scrap recycling.

4- Cycle of Materials:

In fact nature offers a perfect cycle. During spring and summer leaves grow on trees, then, they fall in autumn, decompose into humus, which then makes new growth possible. Human being has also a part to play within nature cycle.

In our life, raw materials, such as oil, ores, etc., are extracted and used as basic essentials. Primary raw materials enter the cycle and are used again. However, this cycle may be disturbed by the human beings in a way, which makes recycling difficult or combine them in such a complex way that subsequent separation is impossible or not economically viable. Besides these primary raw materials there are the secondary or reclaimed materials that are known as recyclables [6].

Products are made from primary and secondary materials, which can be recycled several times, or even forever. This is especially true for metals. They are so complex that their recycling is blocked. The cycle of materials use is not new; in particular metal recycling is as old as its use.

Different techniques have been invented to track down and open up the raw materials. However, these are generally different with the techniques that are used to turn used goods, consumer items, and capital objects such as buildings, industrial plants, and ships, into secondary materials. In fact, primary materials often consist of high-volume, more or less uniform materials, like ores. On the contrary, recyclables or secondary materials are not homogenous in composition. More often, they are combinations of different materials and in some cases complex mixtures.

Recycling processes, therefore, mainly concern of identification and quantification, size reduction or compacting, sorting and separating, as well as remelting/pulping, etc., of recyclables.

This must be taken into consideration that consumer products tend to become ever more complex. This can be easily seen in the case of car manufacturing. For car manufacturing, until World War II there were mainly few combinations of metals, however, the rise of synthetics has led to a spate of metal/plastic products. Nowadays, cars are made of more than 100 different materials, many of which are synthetics with diverse molecular structure and modifications which make recycling difficult. Therefore, recycling becomes difficult, not feasible, and sometimes impossible, by available technologies.

As mentioned, practical problems in recycling goods rise when combinations of different components, e.g., non ferrous plastic combinations (NFPCs). Polystyrene yoghurt cups with aluminum foil lids, circuit boards from electronic equipment, foam-filled aluminum mouldings, hypodermic syringes, etc., are examples.

Nowadays, there is less uniformity in productions and every factory has its own menu of application and combinations of materials. However, around the world, there is a willing to indicate the types used or the marking of parts. Successful and effective recycling requires minimizing the number of materials used in a product. In addition design for better recycling must be taken into consideration. For example, instead of riveting, welding, or gluing joints, connections should be employed wherever possible. In addition different types of plastics, textile, and alloy metals should be clearly marked, preferably with standardized symbols. Furthermore, due to globalization, companies manufacturing similar goods must have close collaboration to make use of common parts in production as well as common spear parts. In these ways the cost for recycling will be considerably reduced and the cycle of materials will be promoted. This will be discussed later in more details.

5- Concept of Recycling:

There is lack of uniformity of concept in recycling. Terms like “re-use”, “recycling”, “recovery”, “reclamation”, and “cycle” (of matter) are used interchangeably. Sometimes, terms such as “primary” and “secondary” are being confused. This happens for the words like “waste” and “residue”.

In previous part there was an explanation for primary and secondary raw materials. Here, short explanations for recover, recycling, reclamation, and re-use are given. Although these terms have different meanings, they are used interchangeably, usually for describing recycling.

Recycling is the entire cycle of matter, new-old-new and assumes a sequence of actions, i.e., collection, dismantling, subsequent sorting and processing, then returning for production, which makes new but secondary raw materials. Sometimes, a secondary semi-manufacture is made from recycling procedure.

Recovery forms part of this cycle, which excludes the production part, e.g., re-melting in iron and steel recycling.

Re-use is often used as a term for the concept of recycling. However, in more professional manner, re-use is using something again and certainly not reproducing it.

6- Processing Techniques for Metal Recycling:

When a product is at the end of its life service its recycling comes into consideration. The first step, then, should be dismantling and size reduction.

Since early times, hammer, axe and chisel, have been indispensable tools for metal processing. Until 1880 dismantlers mainly used crowbars, heavy sledge-hammers, tongs, chisels, and sometimes improvised drop-ball breakers for dismantling. However, cutting torches, water-jet cutting machines, abrasive disc cutting, shears, balers, flatteners (car flatteners), cable strippers, rotary shears or shredders are nowadays used in recycling plants for recovery of the materials [6].

7- General Configuration of shredding plant:

Shredding plant essentially consists of a heavy fast-turning rotor to crush the scrap fed into the rotor house, an air cleaning system for primary and secondary de-dusting, and a range of separating system to split the shredded materials into more or less clean streams of ferrous and non-ferrous scrap as well as coarse and/or fine residue that must be treated further, or dumped, or incinerated. Of course there are classification systems, like screening machine, to size the crushed scrap for better handling and separation. In addition there are different conveying belts to transfer materials from one place to another [6].

There is a large variety of systems and models of shredders which can be classified in different ways. However, in general, classification of shredding plants is done either by the size of plant or the plant's air cleaning system.

Classification based on size: Classification can be done on the basis of shredders and pre-shredders types, or based on shredding size, i.e., small, medium, large, and very large (mega) shredders. The later classification is due to the motor power installed for the shredding machine or its dimensions. Most of the shredding plants in Japan are small size, however, in Europe one finds mainly medium sized and some large sized shredding plants. It is not a surprise to know that most of the plants in North America are large and very large in size.

Classification by air cleaning system: air cleaning system is a vital part of shredding plant and plants are classified based on their air classification systems. Accordingly we have three different kinds, i.e., dry, damp or semi-wet, and wet shredders. Virtually, all newer shredders in North America and the UK are of the damp or semi-dry type, but the majority of shredding plants in Europe and Japan are dry.

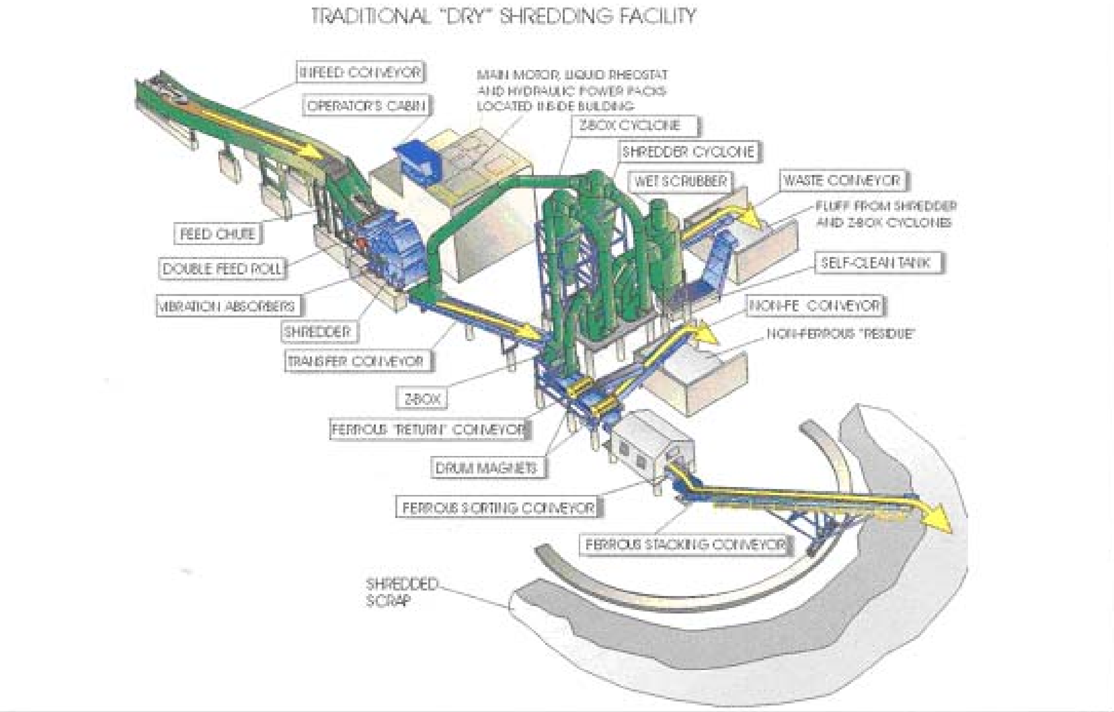


Fig.2- Dry type shredding plant

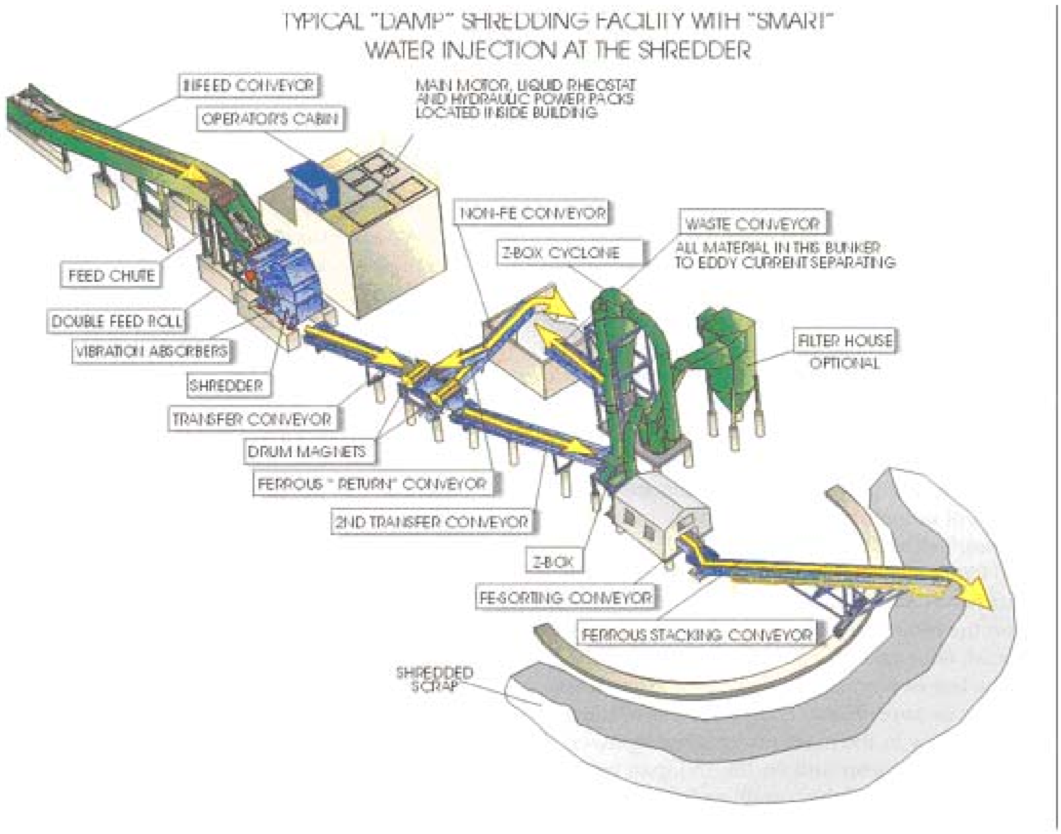


Fig.3- Damp (semi-wet) shredding plant

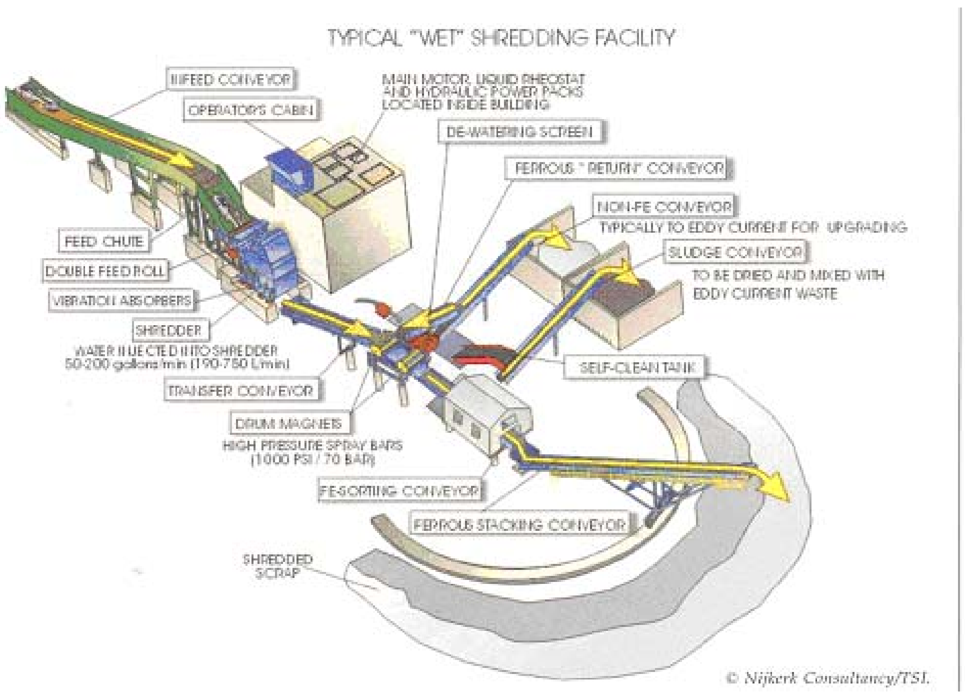


Fig.4 – Wet shredding plant

8- Shredders:

When one talking about shredders in recycling industry it usually means automobile shredders, machines that are able to swallow complete automobiles in one go and chop them into small, first-size chunk of metal. Therefore, the shredding machines are necessarily extremely strong. Except big automobile shredders, or fragmentizing machines that first came to the market around 1958, there are many other types in use. Shredders can range from the small, often portable, paper shredders in office to the mighty super heavy duty (SHD) or mega sized shredders with a motor power more than 7000hp. However, between these extremes, there is a wide range of shredders.

An automobile shredder is based on the principle of a fast-rotating rotor equipped with hammers which cut/shred raw materials and drive it through sizing grates, to further reduce the scrap to the desired size and density. Medium size shredder uses between 10 to 36 reversible hammers, each weighting 100kg or even more to pound and chop automobile hulks and domestic appliances to fist-size pieces [6].

Rather like coffee grinders, usually in the horizontal plane, shredders consist of a clamshell casing and rotor housing with heavy rotor turning fast inside it (usually about 500-600 rpm). First, very fast swinging hammers that are attached with an axle to the heavy duty steel discs or spider arms pulverize the metal object against an alloy steel breaker bar or anvil causing it to be fragmented or chopped into pieces. Then after, hammers drag the pieces of scrap around the housing as long as it takes for the pieces to become small enough to pass through the holes in the grates. During operation the scrap fragments have been rubbed small and fine, cut or grated between the hammers and the inner plates or the rotor housing. However, if a piece of scrap does not immediately fragment, the hammer can deflect backward, away from the scrap. This deflection can even bounce 360 degree, but, as the rotor revolve at high speed, it will always return to the extended position.

Mini-shredders generally have two rotors that turn in opposite directions in the horizontal plane, with fixed cutting/ripping discs, i.e., small rotary shears / shredders. These small shredders range from 300-1000hp and their throughput capacity differs from several hundreds kilos or a few tones per day to some hundreds or thousands of tones per years.

Medium-size shredders operate with a rotor turning in the horizontal or vertical plane, having motor power within range from 500-1000hp. They usually have free-swinging hammers attached to the main rotor by a shaft. In some medium-size shredders impact rings are installed instead of hammers. Medium-size shredders have a capacity between 10000 to 40000 tones per year.

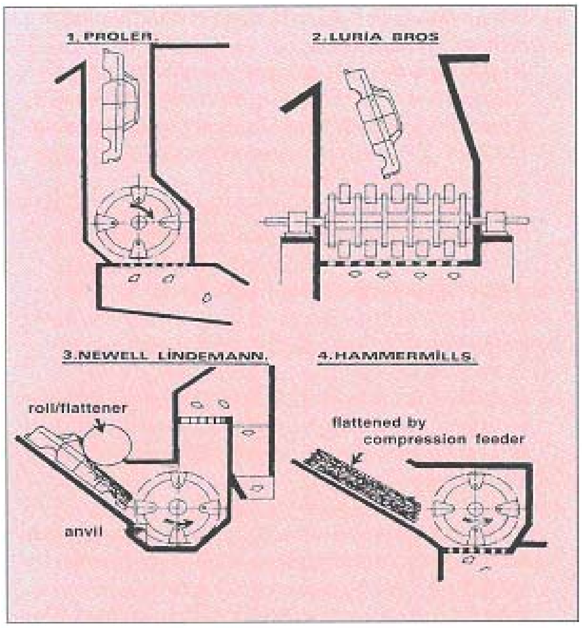
Large shredders are machines with the motor power ranging from 1000 to 3000hp or even 4000hp having input capacity from 40000 to 250000 tones per year. Currently the 1250hp shredder is very popular in Western Europe which has input capacity up to 125000t/y.

In North America, however, automobile shredders are classified by the diameter of the hammer circle inside the shredder, i.e., rotor with hammers extended, and also by nominal shredder width. For example when we talk about “80 104” shredder the numbers indicate that the machine has a rotor diameter of 80 inches and an effective inside width of 104 inches.

In general, large American shredders area bit bigger than European counterpart.

Very large shredders (heavy duty/super heavy duty/mega) have generally an installed motor power of 4000 to 7000hp with the input capacity of 200000 to 600000 t/y or even exceeding 600000.

Medium, large, and mega-size shredders can be designed and contracted as top discharge (TD), bottom discharge (BD), or in present day standard top and bottom discharge (TBD). According to US manufacturers a super heavy duty machine is not identified by its horsepower, but by its construction which in general entails a main-body of at least 4 to 6 inches. This means that super heavy duty machines are characterized by larger pin shafts and specially-designed hammers which allow to process very heavy scrap without damaging equipment.
It was first in 1920s that L.A. By-Products started to shear steel scrap in order to make use of ferrous scrap as leaching material in copper production. Ordinary rock crushers, like Turning and Arboga, were used for shredding scrap. It was in late 1950s that the new shredding machines came to the market since the concept of shredding was known in the recycling sector.
Automobile shredder appeared at the end of 1950s since the first batch of postwar automobiles was ready to be scrapped and recycled. In addition there was a need for better quality scrap than that steel industry had been supplied with (Fig.5).

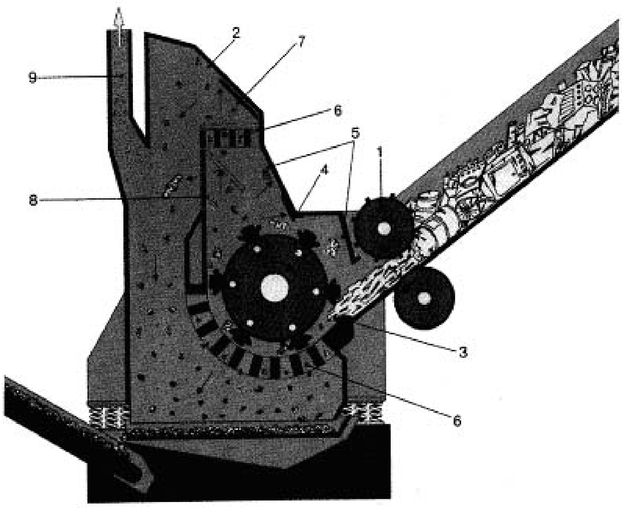


(1) and (2) development of shredding techniques in 1958 in which discharge was done through bottom grates.
(3) the second generation of shredders during 1970s, hammer mill with side feeding plus one or more flattering roll(s)
(4) hammer mills which introduced a compression feeder

Fig.5 – Development of shredding machines (1950s and 1970s)

Operations of the first series of shredding machines showed to be possible to completely shred automobiles with their very strong steel components; such as engines, gearboxes, spring, axles, etc., however, the needs for having extremely strong and well constructed housings and rotors were clearly understood. Therefore, heavy shredders were designed and constructed to process not only ferrous scrap and bulk automobiles, but automobile bundles even though they are densely compressed. In the main time a few rippers or pre-shredders were also designed and built in order to tear apart the heavy bundles to avoid undue strain on the shredders' rotors.
There were different companies that started to design and manufacture their own shredders in USA, UK, Germany, and Japan.
This must be noticed that normally the horizontal shredder rotor moves towards the inflow of material to chop it into pieces, but in some models, like Kondirator that was developed

by Svedala-Lindemann, the rotor turns the other way, i.e., in the same direction as the scrap. In this way heavy scrap can be processed without the danger of damaging the rotor by wedging forces. In these shredding machines, a special hydraulically driven, kick-out door, releases unshreddable pieces of scrap.
There have been lots of efforts to improve shredders performances and reduce the time needed for maintenance. For example one of the most important one was the hydraulic *clamshell* opening of the rotor housing in combination with alloy steel caps on.
Wet shredders also were introduced to the market, which precipitated the dust of the crushed, non-metallic parts and removed it with the water. These wet shredders made the possibility to dispense with the expensive dust collection units and reduced the chance of explosions. However, their disadvantages were inundation of the work floor, sensitivity to frost, loss of non-ferrous metals in the waste water, and the increased weight of the shredder residue to be dumped. These problems, however, were overcome by introducing semi-wet or damp shredders. Nowadays, computer-controlled semi-wet systems are the most popular technique for shredding plants.



(1) feeder roll(s)
(2) rotor housing
(3) anvil
(4) baffle plate edge for more fragmentation and pre-compression
(5) baffle plate, important means for achieving the required density
(6) top and bottom grates
(7) top lid (can be closed)
(8) emergency ejection door
(9) dust to dust collection unit

Fig.6- The top/bottom discharge zerdirator

Modern automobile shredders are customized and consist of a group of connected machines. There are different parts with the shredder as the followings:

(a) A sloping loading/feeding chute or feeder device
(b) A dosing system to feed the raw material gradually into the shredder, i.e., heavy feed roll(s)
(c) The strong rotor housing (equipped inside with one or more anvils or breakers and lined with alloy steel wear plates. Within housing there are also grates and emergency reject door for unshreddables, the main electrical motor, vibratory pan or oscillator to receive the shredded material discharged through the grates, etc.)
(d) A double pressure-resistant shredder dust collection or dedusting unit which is only for dry shredding system (the dedusting system often takes place at the top and also at the bottom of the rotor housing with general capacity of 25000 to 80000 cubic

meters per hour). Most often there is another dedusting system to clean the shredded material from non-metallic fluff with capacity of 40000-150000 cubic meters per hour. The dust collection unit works with wet and dry dedusting cyclones and venture scrubbers.

(e) An outflow belts with vibratory screen(s) and/or oscillator and/or screening drum, as well as vibrator or conveyor-fed drum magnet(s) over-band magnet(s), for magnetic separation, non-ferrous sorting belt, more often eddy current separator(s), and a swiveling radial stacker of various lengths for storage or direct loading of the ferrous scrap.

(f) Vibration dampeners installed under the shredder (to reduce or even avoid vibrations)

(g) An instrumented control cabin that holds command console

A complete automobile shredder installation with dust collection unit, motor housing, conveyor systems, foundations, etc., weighs several hundreds of tones and costs between $2.5 million and $5 million. However, additional hundreds of thousands or may be millions of dollars may be spent on feed conveying system, noise abatement and pollution control, as well as non-ferrous and rubber/plastic separation systems, front-end loaders or shovels, excavators, cranes and trucks.

There are other infrastructural needs, such as non-permeable surfaces and storage floors with oil separation and /or waste water treatment facilities (for wet shredding plants), rail connections, embankments, maintenance warehouse, pre-inspection installations for removing gasoline and avoid explosions, weighbridges, axle pullers, and spare parts. For aforementioned needs there are many variables for upstream and downstream parts of shredding plant.

Upstream equipment may consist of: engine pullers, petrol tank piercers, pre-shredders, hinged slatted steel delivery conveyors, etc. However, in downstream plant may have part or all the followings: drum magnets, separation and screening drums, air or water separation systems, eddy current separation system, etc.

However, there are other accessories, particularly for recording information and monitoring the plant such as: weighing equipment, continuous computerized recording equipment for visual and written recording of energy and water consumption, video cameras for monitoring all sections which enables to control whole the plant from control cabin. Nitrogen dampers to extinguish fires in the rotor housing, sprayers for introducing water into wet shredding system, de-watering apparatus, explosion hatches, axle pullers, vibration dampers, rotor caps, sensors, sound insulation walls, etc., are also classified as the accessories to be needed more or less.

Furthermore, shredder owners have added special and/or some home-made accessories to fulfill the needs. However, if further separation of non-ferrous fraction and also fluff fraction are aimed then sink-float systems, air classifiers or other wet/dry gravity separator, eddy current separator as well as image processing and color sorting facilities, and electrostatic separators may be considered.

9- Shredding Process:

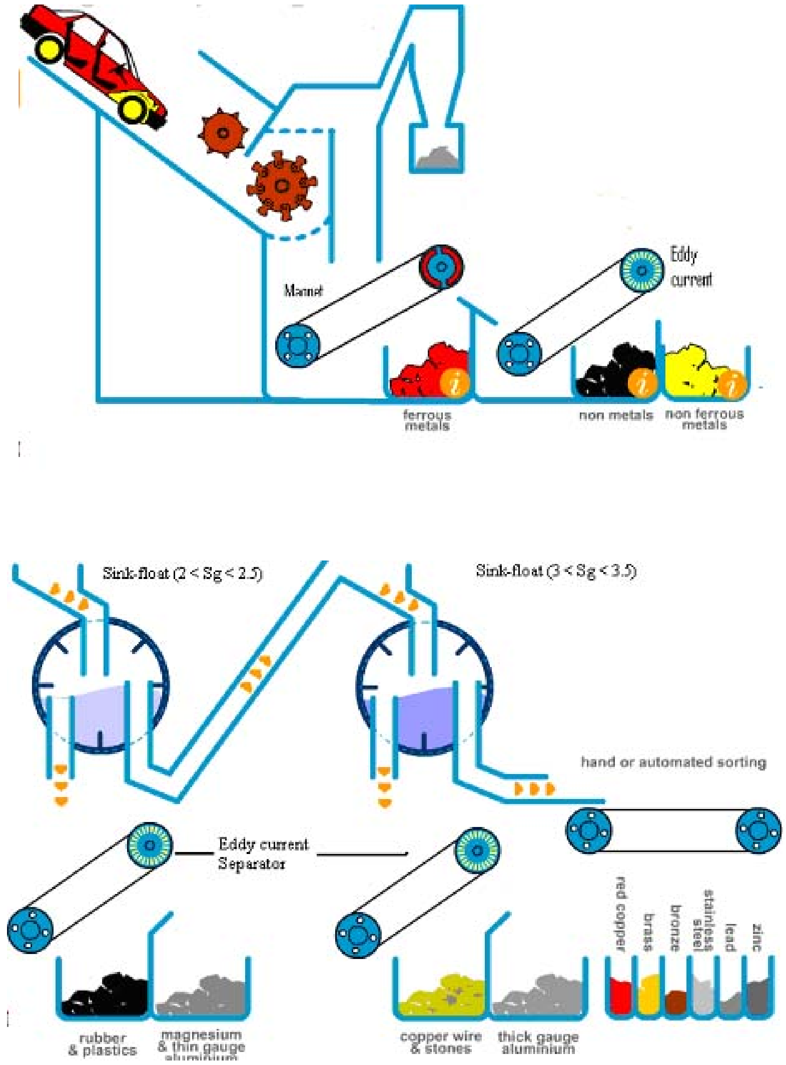
The following route must be followed by an object to be shredded [6]:

(a) weighing of the income old scrap
(b) inspection prior to shredding to remove hazardous, dangerous, and explosive substances, like radioactive materials, air bags, LPG and LNG in tanks, ammonia and CFCs in air conditioner, inflation capsules, etc.
(c) introducing scrap to the housing of the shredder (normally input roll system is used which squashes the feed which facilitates the action of hammers)
(d) by introducing the scrap raw material to the shredder the hammers first rip up the flattened scrap against the breaker bar or anvil that are positioned at the month of the shredder
(e) scrap is dragged deeper into the rotor housing by the motion of hammers and hammers reduce it further against the rotor housing wall and the cast steel grates until the scrap is small enough to be knocked through the holes in the grates
(f) light fractions are sucked by the heavy duty suction system installed at the top of shredder
(g) the chopped heavy fractions are screened and subjected to magnetic separation section
(h) the magnetic part will be purified further by either hand sorting or other separation techniques if requires
(i) non-magnetic part will send to eddy current separator for separating aluminum fraction (Al and Al alloys) from other non-ferrous metals and other non metallic fractions, such as stone, wood, plastics, and rubbers.
(j) light fraction is usually sent to sink-float separation and then after to other separation techniques, like eddy current for further separation,
(k) in modern shredding and recycling plants different fractions of non-ferrous metals, i.e., fractions containing aluminum, copper, zinc, and magnesium metals are further treated by other separation techniques, like optical sorting, electromagnetic sorting, image analysis, etc., for having different products made from different aluminum alloys, copper and its alloys, magnesium alloys, etc.
(l) for non-metallic fraction(s) further separation of different plastics, or rubber-plastic, etc., can be carried out by sorting techniques and/or electrostatic separation techniques.

This must be noted that for further separation of non-ferrous materials the non-ferrous fraction is usually screened into two but up to four different sizes, e.g., minus 12mm, 12-40mm, 40-100mm, and over 100mm.

Finally there is the shredder residue or waste fraction, i.e., fluff, which is generated at the dedusting unit at the discharge from the shredder housing, also above the conveyor belt just before the separation drum, and sometimes at the non-ferrous sorting stage, that will be land filled. To generate such fluff fraction as low as possible and also to treat it further for some special applications are issues to be challenged.

It must be noted that the dust collection system is driven by fairly powerful electric motor. Considerable amount of energy is consumed by whole dedusting system, in some cases up to 500hp. In fact thousands of tones of light fraction must be sucked away over a considerable distance and the ultimate aim is to leave no more than 20-30mg of dust per cubic meter of air after separation. Damp or semi-dry shredder is favorable for having better environmental condition and less dusty particles per cubic meter of air. Most problems with respect to dust and dust collection disappear by installing semi-wet shredder.



(a)
Shredder and its facilities for ferrous and non-ferrous separation

(b)
Heavy media (sink-float) separation in combination with eddy current separator for non-ferrous and non-metallic materials

Fig.7 – Configuration of shredding recycling plant with magnetic, eddy current, and sink-float separation facilities

As mentioned before shredders are introduced by their installation's power in horsepower or kilowatt-hours. However, the installation power represents the power exerted on the motor. In reality the total power of a shredder is much higher than due to many other electric motors involved in whole installation. Based on equipment type, rate of production and density of the shredded scrap, a good medium-size damp (semi-wet) shredding system consumes roughly 23-25 kW/t to chop scrap and about 5-8 KW/t for all other power consumption parts.

10- Wet versus Dry Shredding:

As mentioned before, shredding plants are classified in three types based on their air cleaning systems. Accordingly there are dry, damp (semi-wet), and wet shredders [6].

In wet shredders water is sprayed into the motor housing and then recovered.

In fully wet shredders profusion of water stream is injected through the rotor to prevent production of dust and also explosions. A semi-wet (damp) shredder in which a fine mist of water is sprayed into housing is another alternative. Finally dry shredders in which cyclones are installed above the rotor housing to collect dust are available and in use, especially in Europe and Japan.

The great benefit of wet and semi-wet shredders is that these systems work without need for dust cyclones. By having such system, i.e., wet or semi-wet, one can save part of investment and of course considerable amount of energy. Furthermore, due to the presence of the water, the possible dust explosions in the rotor housing are avoided or greatly reduced. In addition, in wet shredding the scrap is rinsed clean, although dirt will stick to the scrap again and the stock of shredder scrap will rust faster. The problem with wet shredders would be also the run of water on the ground and frosting happens especially for cold/very cold regions. In fact pure wet shredding has its disadvantages like:

(a) These plants use a lot of water that needs to be cleaned or recycled and if it is not carried out consciously the water becoming dirtier and dirtier. Therefore water purification system must be arranged, otherwise lots of water will be too much. In addition, water pours from shredder should be collected in a desirable manner which needs special construction.

(b) Soaking wet ground and big puddles of water around the shredder can lead to delays and environmental pollution

(c) Water from shredder may freeze, especially in cold regions, and causes related problems

(d) Dust is precipitated immediately but not sucked away which makes the shredder waste much heavier. This leads to pay more money for dumping dust. This problem is not completely solved even by squeezing the waste

(e) Small non-ferrous particles may easily stick to the wet stream with ensuing metal loss. In addition separation by magnetic drum may face problem or become complicated by wet or damp environment, although it is believed that the separation of non-ferrous metal is improved by wet system

(f) By emerging of steam cloud from the mouth of shredder it will not be easy to control shredding operation since the operator in command cabin can not see the scrap that are gone for shredding. Tom solve this problem needs to install special cameras like infrared cameras.

(g) Lastly, collecting the water and the amount of water used remains an issue. Not all the dust can be collected by wet system while too much forms a dust paste causing waterfalls to pour from the shredder

As like as wet shredders, there is no need for dedusting with semi-wet/damp shredders. However, there will be no run of water onto the ground but air may be used in downstream to clean both the ferrous and non-ferrous scrap. In fact most disadvantages regarding wet shredding plant have been solved by damp shredders and the dust collection plant can be often avoided with this system. In addition, nowadays, by having computer control system within the cabin control it is possible to regulate water injection. Advanced foam or water injection system serves also to suppress fires and explosions. Yet, problems of sticking dust or non-ferrous particles to the product stream remains.

11- Size reduction and Fragmentation by Shredders:

Due to sustainable development policies, especially for iron and steel industry, scrap will no longer be used only for producing alloy steels or lower market and carbon steel long products. The aim is to make use of scrap for production of higher grade carbon steels, as well as long and flat products. Therefore it is needed to improve the scrap quality to achieve the above goal.

The quality of recycling intermediate products created during shredding and physical separation is of critical importance to ensure that the feed to metal producing processes permits the economic production of quality metal. The liberation of materials during shredding plays a vital role in the composition and quality of intermediate recycling streams. Furthermore, the separation efficiency of physical beneficiation processes is to great extend depended on the liberation degree of the materials present in the obsolete scrap and its particle size during shredding. Moreover, the purity of material streams produced by separation and thus the metallurgical process efficiency and consequently the ultimate material recovery and recycling rate are affected by size reduction. This is why the comminution plays a crucial role in preparing of steel scrap and its recycling. The main objectives of comminution in recycling and reuse of scrap are [7-9]:

- to generate fragments exhibiting a proper size distribution in order to facilitates downstream separation or metallurgical processes
- to liberate the constituents of multi-component assemblies
- to remove of coating on the surface of steel and other metals or alloys

The choice of size reduction machine is critically dependent on the properties and bonding conditions of the components present in the waste or scrap stream. However, shredders have become an important part of recycling plants and are widely used for size reduction of different scrap. In size reduction of metal scrap by shredders pieces must be deformed. Sufficient deformation of the pieces of material, from bending to compacting, leads to cracking. Cracks can be enlarged by tensile loads in combination with bending and torsion which eventually lead to break-up of the metal pieces.

The selection of size reduction equipment is fundamentally determined by the material properties of the components forming the scrap and waste stream respectively, as well as bonding conditions between them. Swing-Hammer type shredders are widely used in shredding plants to shred and reduce the size of obsolete goods. In fact in comminution of ductile materials, such sheet and obsolete car scrap, scrap from household appliances and electrical devices, lead battery scrap, aluminum scrap, etc., Hammer shredders have proved to be practical [9].

Referring to their design, these kinds of shredding machines are in correspondence to the known hammer crushers in mineral processing technology. As shown in Fig.8, basically two different types of Swing-Hammer shredders exist. These are horizontal shaft and vertical shaft designs. Fig.8 depicts different kinds of horizontally and vertically shaft shredders designed by different manufacturers.

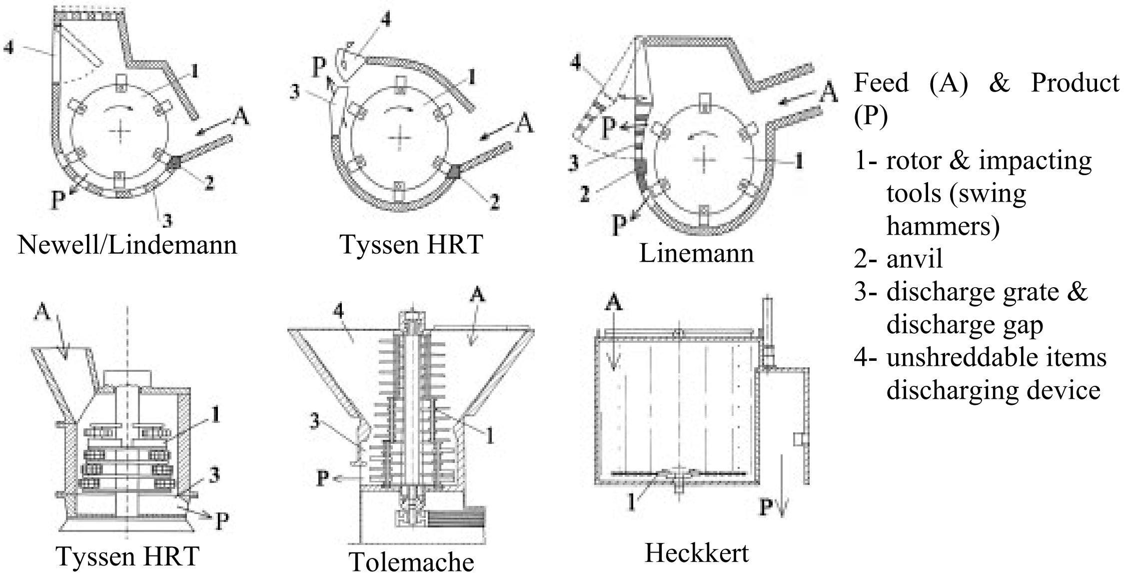


Fig.8 – Swing-Hammer shredders (horizontal shaft design a-c, and vertical shaft design d-f)

Horizontal shaft Swing-Hammer shredders are characterized by having rater narrow clearances between the impacting tools and lower part of housing. As a rule, relatively large void space exists inside the upper part of the housing. Material that must be comminuted is fed into the grinding chamber by means of the feed chute. The feed then is stressed within the zone adjacent to anvil by impacting tools, i.e., hammers; subsequently it is subjected to an intense deformation and comminution. However, unshreddable items, such as heavy parts, can be removed from the comminution chamber by swiveling flaps, which can be operated either manually or hydraulically.

In contrast to the horizontal shaft shredder, in the vertically designed shaft shredders discharge grates determines a much narrower design of the upper part of housing that, according to the manufacturers, results in a decrease in the specific energy needed for the comminution.

Another determining factor for shredders is the direction of rotor rotation. It can be as the same direction as the feed is passed through the housing or vice versa. Within the reverse direction of rotor the feed is carried into the space above the rotor. Therefore, unshreddable items are removed by means of the swiveling discharge grate before the material is transported into the narrower gap of the lower part of housing. Consequently, this is suited for the size reduction of those light steel scrap containing portions of thick-walled mixed wastes and scrap from demolished steel constructions.

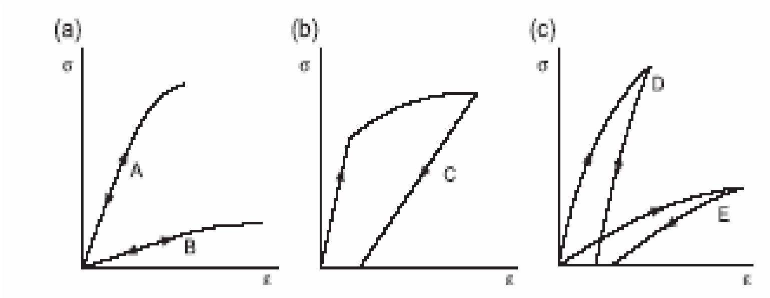
Further, the vertical shaft swing-hammer shredders do not possess discharge grates. In fact, the clearance between the impacting tools and the walls of the housing represents the criterion for discharge.

As a general role, horizontally rotor designed shredders are more appropriate for size reduction of metallic scrap, as well as processing of metallic cuttings, waste wood, paper waste, etc., however, the practical use of vertically mounted rotor shredders is mainly limited to already comminuted steel scrap and electronic scrap. In addition, vertically designed shredders are used for the secondary comminution of light steel scrap as well.

In general, the difference between the machines used for cutting and shredding scrap lies in the form of the tools suited for cutting, shearing or tearing, in the gap width in axial and

radial direction, and in the form of the anvil. Double rotor machines are also available in which the second rotor acts as a moving anvil. The gap width determines whether cutting, shearing, or tearing type of loading predominates [10]. Broader gap that is larger than material thickness in one or both direction, leads to a strong deformation due to bending.
According to some investigations on comminution of single particles for crack formation and crack propagation it has been found that with the beginning contact of the shear tool, rather large deformations occur in the wide radial gap before cracks open starting at the shear root edges and propagate towards each other parallel to the rotor axis. When the crack

11-1- Materials Characteristics in Shredding Plants: In fact most of the materials undergoing comminution processes in shredder plants show non-brittle or deformation behavior. In fact brittle and non-brittle materials are defined by elastic, elastic-plastic, and elastic-viscous behavior. Fig.9 depicts the material characteristics defining by these three models, however, in practice real materials exhibit more or less mixed behavior.
For example for metals, the term plasticity is often used. They show time dependence for dislocation movements in their lattices. However, it is small in comparison to viscous behavior of thermo-plastics [9].
Waste glass, rubble, as well as cast iron and cast non-ferrous metal scraps are considered as brittle materials. Whereas, steel and non-ferrous metal wrought alloys, plastic and rubber wastes, textile wastes, waste wood and paper, domestic and bulky refuse, as well as biological and organic wastes are classified as non-brittle materials.
Fig.10 shows the classification of comminuting machines that are mainly used for coarse and intermediate size of non-brittle materials.
Rotor shears are mainly used for household waste, waste wood, used tires. Radial gap rotor shears are better suited for finer and more defined progeny pieces than axial-gap shears. The tendency for the use of low velocity machines can be observed due to lower wear rate, lower specific energy, lower noise and dust emissions, and of course lower costs. However, a broad variety of materials are handled by shredders with tearing type of loading or swing-hammer shredders.
For swing-hammer type shredders which are widely used in scrap four different steps four size reduction have been recognized [8,10]. First it is needed to tear off one piece, for example out of a used car. The second step is characterized by decreasing of size but not in mass reduction, which means the pieces are only deformed and not cut or broken. The third step is characterized by real size reduction. In fact cracks are formed and propagated by increasing deformation due to bending, torsion, and impact. Step four can be seen if the residence time for the scrap is long enough. In this case deformation increases, especially by impact and the form of the pieces may change to spherical. Furthermore, materials removal from the surface can be observed. These four steps are shown in Fig.11 by plotting the mean fragment mass and mean fragment size as a function of the shredding time in horizontal shaft swing-hammer shredder



A- Brittle material
B- Rubber-elastic material
C- Plastic material
D- Elastic–viscous material behaviour at a high stressing velocity & a low temperature
E- Elastic–viscous material behaviour at a low stressing velocity & high temperature

Fig.9 - Stress–strain diagrams of materials showing (a) elastic–plastic, (b) elastic–viscous, and (c) material behaviour

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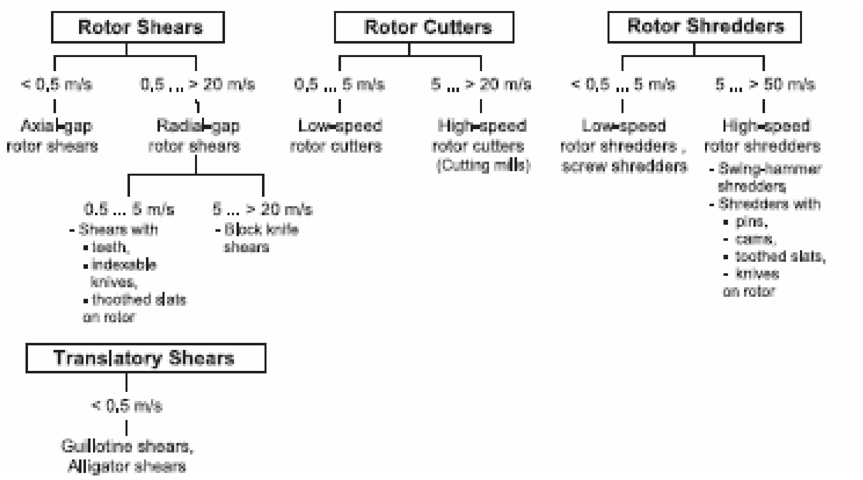


Fig.10- Classification of comminuting machines used for size reduction of non-brittle materials (based on dominating types of loading)

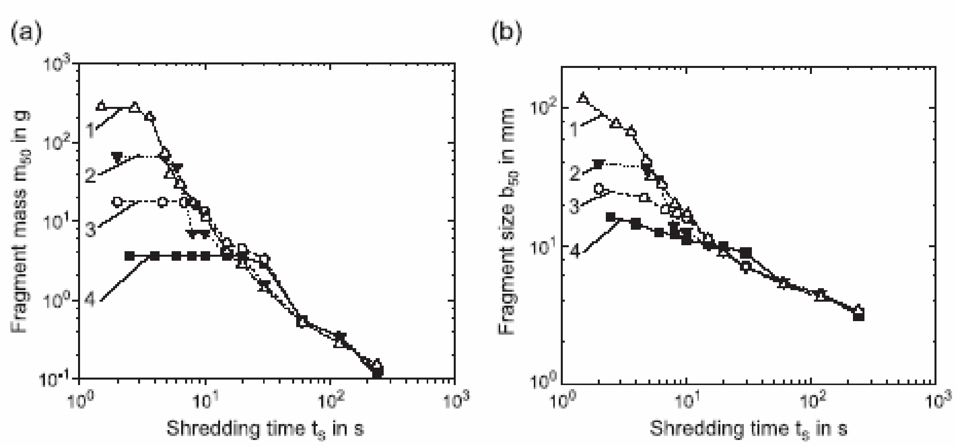


Fig.11- Fragment mass m_{50}, and fragment size d_{50} as a function of the shredding time for small scale horizontal swing-hammer shredder, batch testing of pure zinc with dimensions of: [1- $(200\times200\times1)mm^3$, 2- $(100\times100\times1)mm^3$ 3- $(50\times50\times1)mm^3$, and 4-$(25\times25\times1)mm^3$] (circumferential velocity of 50 m/s)

11-2- Parameters affecting size reduction of the scrap: Feed, process (operating parameters), and design parameters play important role during size reduction by shredders. Parameters regarding to the feed, i.e., feed size and its thickness, its shape, as well as its material(s), operation parameters such as mass flow rate, circumferential speed, etc., as well as machine design parameters, e.g., shape of comminution chamber, anvil's shape, etc., are paramount important influencing the success of comminution in scrap recycling [7-14].

11-2-1- Residence Time: Investigations were conducted to understand the effect of residence time in both horizontally and vertically designed hammer shredders. Fig.12 depicts the results from comminution of pure zinc at different residence time for two shredders at constant circumferential speed.

From the results it can be concluded to achieve a specific size reduction, i.e., to have an identical mean size, that a longer residence time is needed for the shredder with vertically mounted rotor. It means that more time is required to get equal cumulative distribution of the fragment size and fragment weight by vertically mounted rotor shredders. This is partly due to different design for the feeding devices. In comminution chamber of the shredder with horizontally mounted rotor the feed material is exposed to strong stresses.

For end of life goods, it was found that no distinguished differences can be found for the evolution of fragment size and mass with the shredding time. Based on the tests conducted on shredding end of life goods by using industrial scale machine at Centre Technique pour le Recycling de l'Acier (CTRA) it was found that the mean fragment size and mean fragment weight decreases during the first few seconds.

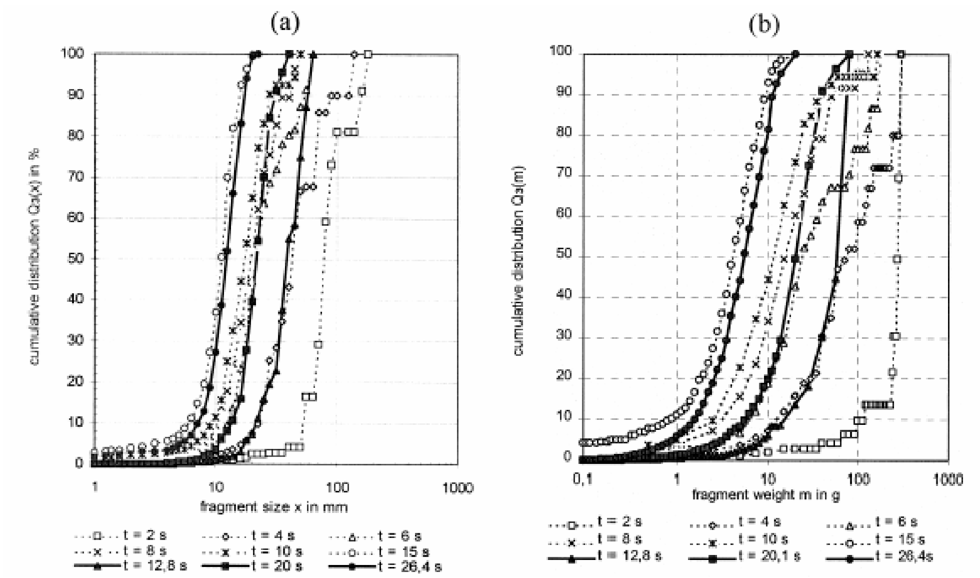


Fig.12- size distribution (a) and weight distribution for the pure zinc fragmentation with horizontally mounted rotor (fine dashed lines) and vertically mounted rotor (bold lines) at different residence time (circumferential velocity 50m/s, main dimension 200×200×1mm^3)

By prolonging the comminution time to 1 minute and then several minutes the size of shredded pieces decreases further and a large decrease of the mean size can be seen. For example as it is depicted in Fig. the mean size of shredded pieces of steel oil cans after 1 and 5 minutes considerably decreases from 57 mm to 10 mm.

It is worth to mention that based on tests conducted on different end of life goods, e.g., motors, transformers, and coils, it was found out that for totally separate steel from other materials the shredding time should be between 1.5 to 3.5 minutes. This time does not depend on the type of electrical component being shredded. In fact long time is needed for complete liberation, but, after 1 minute between 80% to 95% of the non-ferrous material is liberated from steel

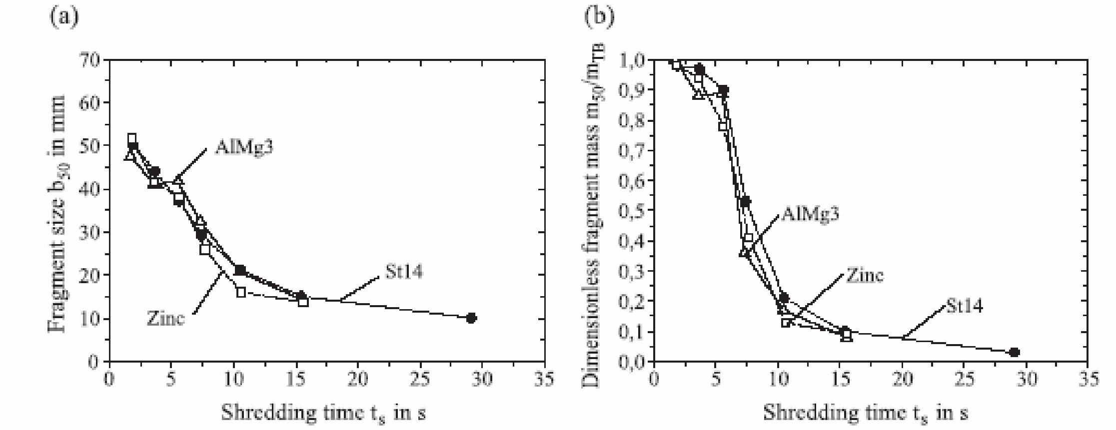


Fig.13 - Fragment size (a) and fragment mass (b) as a function of shredding time for horizontally rotor shredder (sheet made of different materials : 100×100×1 mm^3)

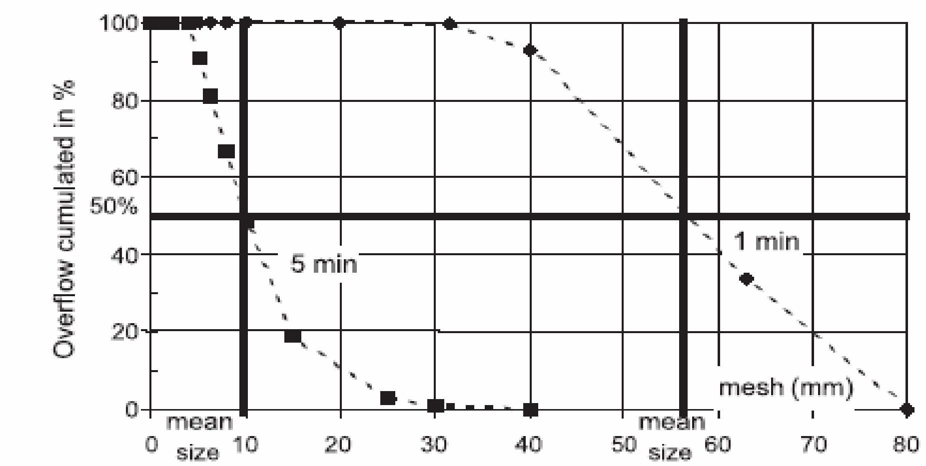


Fig.14- Size distribution of shredded fragments after two different shredding trails

11-2-2- Material Feed: The influence of feed material on the degree of comminution was also investigated with metal sheets of different thickness. Fig.15 shows the results for shredding of zinc sheets of dimensions 200×200mm^2 and different thicknesses, i.e., 0.5, 1, and 2 mm. The results indicated that for both fragment size and weight distributions smaller thickness for the plate results in smaller mean fragment size and fragment weight.
It must be added that less energy is consumed for shredding plates having smaller thickness. However, trends for energy consumption as a function of mean fragment size are the same for both horizontally and vertically mounted rotor shredders. This means that the mass related energy consumption for both shredders is almost the same.

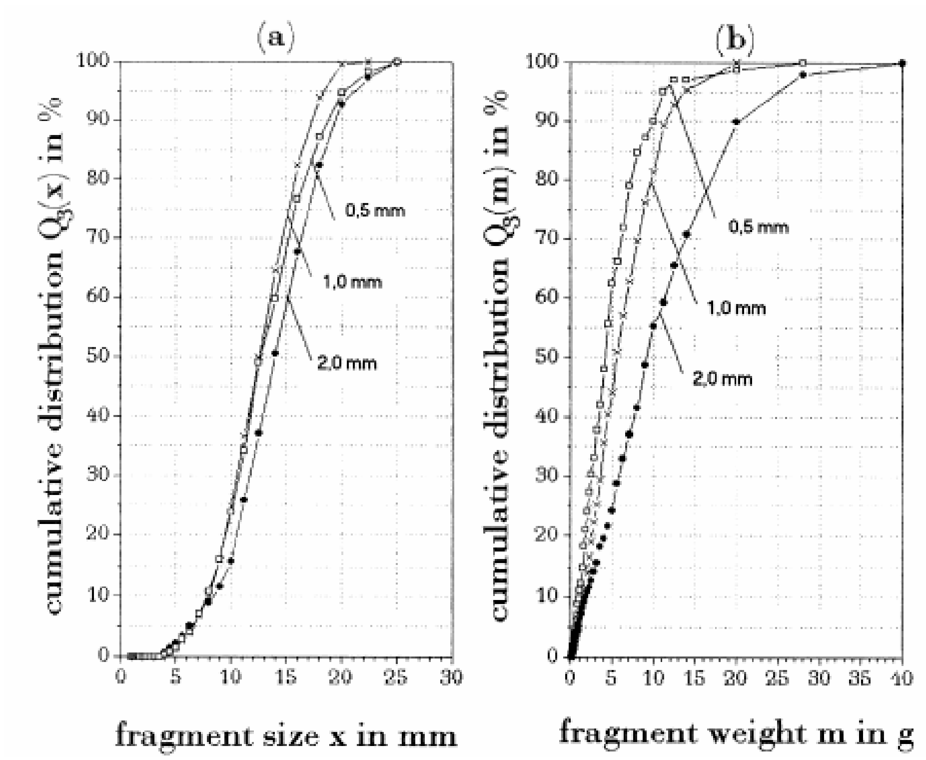


Fig.15- Size (a) and weight (b) fragmentation distributions for zinc plate of different thicknesses after comminuting with vertically mounted rotor shredder (circumferential velocity 50m/s, main dimension 200×200 mm)

11-2-3- Circumferential Speed: It has been found that there is a direct relation between the transmittable energy, W_B, during one stressing event and the stressing velocity and, thus, on the relative velocity of the impacting tools and the material, v_{rel}, in comminuting, i.e., $W_B \sim v^2_{rel}$. At equal shredding time the specific energy consumption rises strongly by increasing the circumferential velocity. Consequently, finer products are obtained.

Tests results have indicated that the circumferential speed has a great influence on the comminution results. However, this is more distinguished for shredders with horizontally mounted rotor. It was pointed out that both the mean size and mean weight of fragments decrease sharply with increasing the speed for the horizontally mounted rotor shredder. In contrast, by increasing the circumferential speed for vertically designed shredder the size and weight fragments decreases slightly. These are shown in Fig 16.

The reason for slight decreasing in fragmentation size and its weight for shredders with vertically mounted rotors is said to be because of the given ring-shaped gap at the bottom of the comminution chamber. However, by comparing the particle size fractions after shredding raw material with both types of shredders it can be concluded that with circumferential velocity between 50 to 60 m/s the two types of shredders produce products with almost same fineness.

With respect to the energy consumption, investigations revealed that in spite of the different design both vertically and horizontally designed shredders consume almost identical energy for size reduction. By plotting the mean fragmentation size or mean fragmentation weight against the mass-related energy for both shredders a straight line can be achieved representing performance of both shredders.

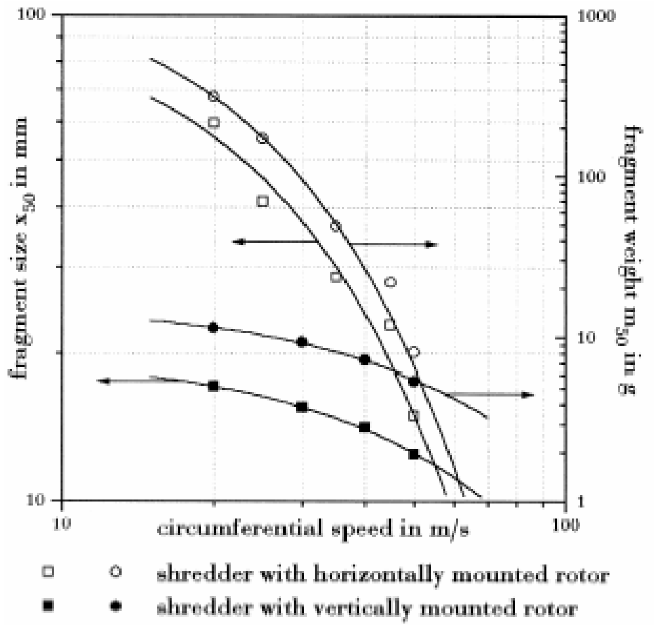


Fig.16- Fragment size and fragment weight of the product as a function of circumferential speed for small scale vertically and horizontally shredders
(zinc plate with dimensions of 200×200×1 mm^3)

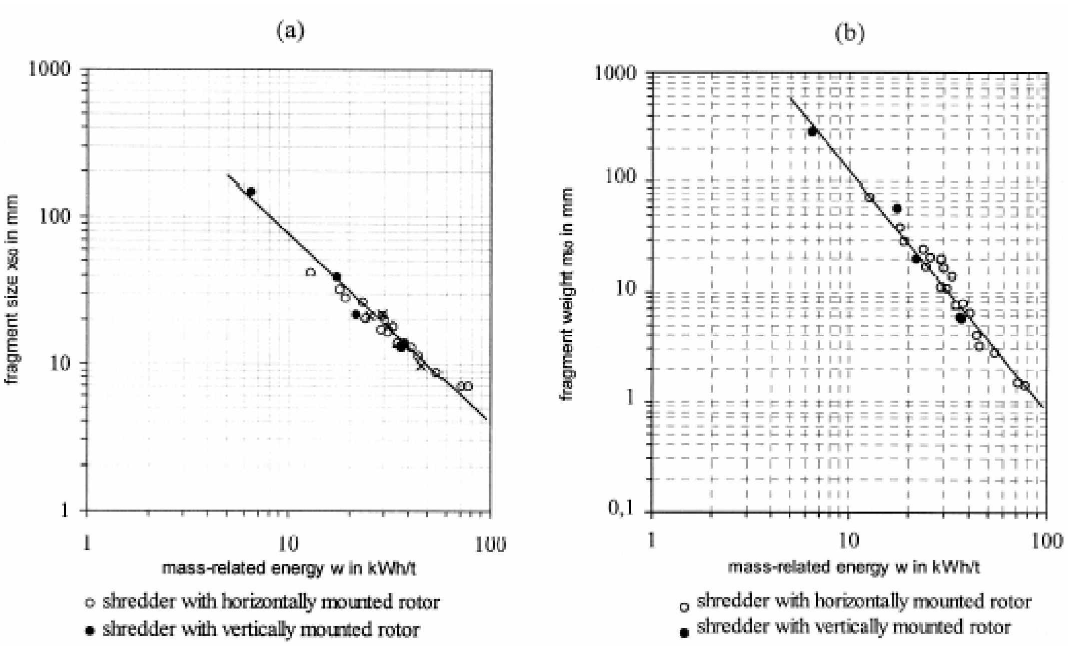


Fig.17- Fragment size (a) and fragment weight (b) of the products as a function of mass-energy consumption for small scale vertically and horizontally shredders (circumferential velocity 50 m/s, zinc plate with dimensions of 200×200×1 mm^3)

In addition, the specific energy consumption is increased by increasing the shredding time and circumferential velocity. The amount of energy required for the deformation preceding the comminution depends on the circumferential velocity. At equal shredding time, the specific energy consumption increases by increasing the circumferential velocity. As shown in Fig.18, at equal shredding time, the specific energy consumption increases with rising value for circumferential velocity v_c. As a result finer products are achieved. In contrast, if the mass fragment weight is plotted against the energy consumption one can observe that the comminution at higher circumferential velocity requires less energy.

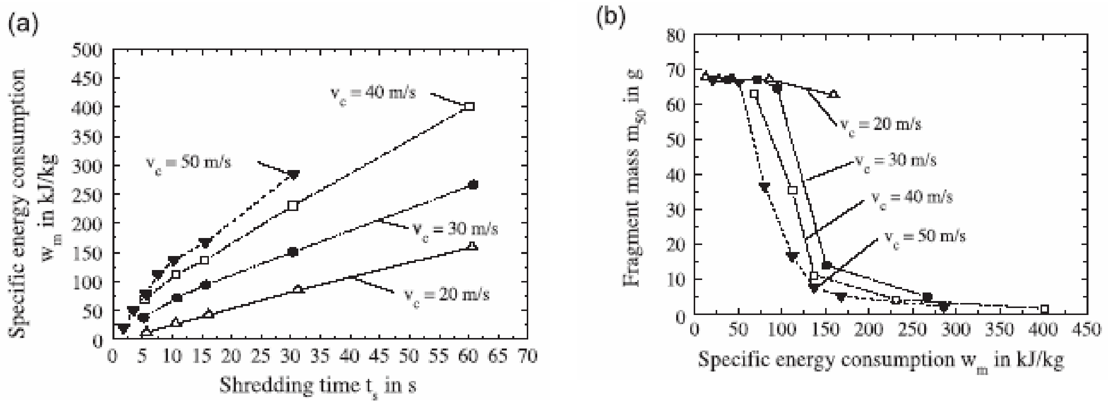


Fig.18- Specific energy consumption for horizontally swing-hammer shredder as function of shredding time (a) and fragmentation weight (b) for zinc plate of 200×200×1 mm^3

Since part of energy during comminution of scrap is consumed for deformation, it is obvious that for comminuting the bodies that are preliminarily stressed less energy is needed. According to the tests results, for the bodies that are not stressed before comminution the specific energy per unit increase in surface area is very high at the beginning. As the comminution proceeds, the energy levels off at constant value.

Furthermore, although the number of fragments for specific scrap material increases by increasing the specific energy for comminution but, less energy is needed to break down heavier fragments.

Generally, fragment size and mass distribution are greatly influenced by the circumferential speed of the shredder, but it does not seem that the speed has effect on the compaction of pieces. This can be probably due to the fact that the energy level of a single impact depends on the velocity of the hammer.

11-2-4- Anvil Design: Test results indicated that at the first stage of scrap comminution no noteworthy fragmentation takes place if the feed material is platy type. Therefore the effect of anvil design should present in further stages of fragmentation. Tests results by changing the clearance between the impacting tools, i.e., hammers, and the anvil as well as the feed chute angle indicated that when the fragmentation of platy type scrap is aimed the anvil design has no effect on size reduction. Only suggestion for improving the performance of the shredder is try to reduce the wear of anvil by optimizing its component. As shown in Fig.19, the design of the straight-edged anvil has no effect on the specific energy consumption of the shredder.

Furthermore, investigations revealed that a narrow clearance between anvil and hammers yield coarser fragments than a larger clearance of 30 mm. This means that only if the clearance is very small the comminution will be affected by it. Otherwise, the clearance has no effect on comminuting process. Since for industrial scale shredders the anvil-hammer clearance is larger than 30 mm, one can conclude that this parameter has no effect either on fragmentation size or energy consumption.

Since the anvil design has no significant influence on comminution process, it means that comminution takes place during the impact on the walls, rather than on the anvil itself.

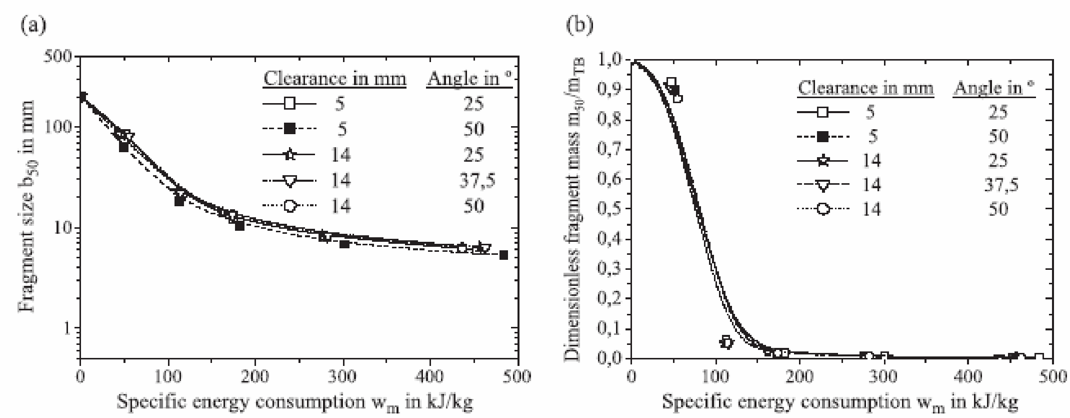


Fig.19- Fragment size (a) and fragment mass (b) as a function of specific energy consumption with the geometry of the anvil (zinc sheet: 200×200×1 mm^3)

11-2-5- Design of Lower Part and Upper Part of the Housing: research studies on the effects of lower part designs for the lower part of housing indicated that narrowing the gap causes a very limited increase in stress intensity. In contradiction, higher rates of size reduction is out come by the employment of the bottom parts having abrupt changes in clearance, which seems to be due to higher relative velocities between the fragments and the impacting tools as the consequence of the stronger deceleration of the material. Therefore, the energy transmitted per stressing event increases. In fact at the beginning of the comminuting process the effect of such design in fragmentation ids more evident; however, by increasing the shredding time finer or lighter fragments are produced by shredder having abrupt narrowing of the gap rather than the one with abrupt enlargement of the gap. On the other hand, there are no significant differences between the energy consumption of differently designed shredders when the evolution of the fragment mass as a function of energy consumption is plotted. The same trend should be considered for the size reduction since the size reduction is only influenced by the amount of specific energy consumed and is independent on the design for lower part of housing.

In the case of upper part design for housing, the results from investigations by using laboratory scale shredder revealed that more rapid size reduction achieved if the void space above the rotor decreases. In fact more rapid size reduction occurs by using annular gap shredder. Furthermore, finer and lighter fragments are achieved by this kind of housing design. By shortening of the mean clear path lengths of the material resulting from the smaller void space above the rotor causes a stronger deceleration by the more frequent fragment-fragment and fragment-wall interactions therefore, more stressing events occur per time unit (Fig.20).

The correlation between the specific energy consumption and the fragment mass for different tests results indicates that up to level of energy consumption of 150kJ/kg, the size reduction is more efficient if the standard design of the upper part of the housing shredder is employed. In this given range, material exhibits a higher degree of compaction and smaller fragment size too

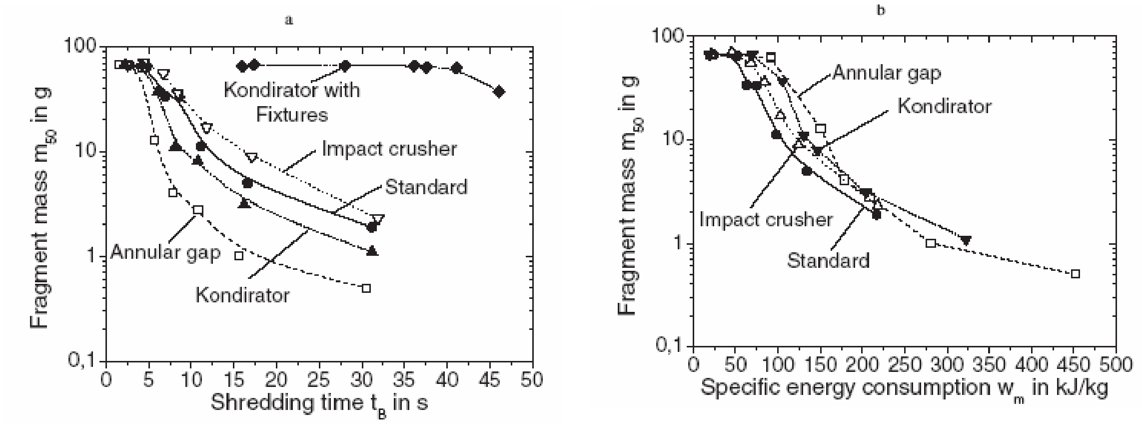


Fig.20- Fragment mass as a function of the shredding time (a), and of the specific energy consumption (b), for shredders with different designs for upper part of housing (feed is plate zinc material with the size of 100×100×1 mm^3)

As shown in Fig.20, the annular gap design machine exhibit the most unfavorable results with respect to fragmentation as a function of energy consumption. This would be because of ineffective friction processes between the feed and the housing causing the energy consumption to rise. The trajectories of the fragments inside shredders having a larger void space above the rotor result in higher relative velocities between the impacting tools and the materials. Thus, the fewer stressing events of higher intensity seem to be more effective for size reduction

11-2-6- Discharge Grate Design: tests results on the influence of different designs for grate have revealed that there is a strict correlation between the fragment mass and the specific energy consumed for different grate designs. Therefore, the differences in the fragment size distribution of the products are a result of a varying residence time of the material inside the grinding chamber. The latter, of course, is dependent respectively on the opening width and the portion of the opening area.

As a general role better liberation and finer pieces can be achieved by increasing the comminution time which, in industrial scale operations, can be achieved only by using smaller diameter grid holes.

Fig.21 depicts the amount of copper content of shredded scrap from washing machine for different discharge grid size. Copper and steel fractions are better liberated for smaller grid size.

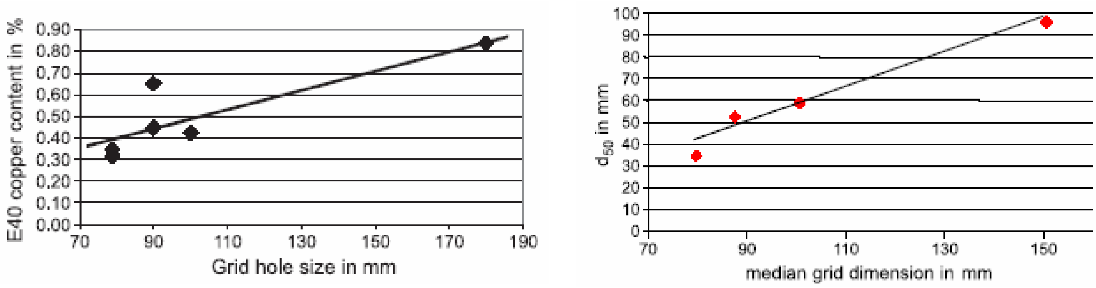


Fig.21- Copper content of shredded scrap from washing machine with different discharge grid size (left) influence of discharge grid size on mean size of shredded pieces (right)

12- Fragmentation Characteristics in Shredding End-of Life Goods:

Since the comminution plays an important role in the preparation of steel and other metal scrap and recycling in general, the main objectives of comminution are [15-16]:

- to generate fragments exhibiting proper size distribution to facilitate downstream separation or metallurgical processing,
- to liberate the constituents of multi-component assemblies
- to remove coating on the surface of fragments

Fig.22 depicts the general configuration of the swing-hammer shredder in which three different areas are pointed out, areas 1, 2, and 3.

According to a comprehensive study done by Russo, et al., the upper side of the anvil, called area 1, is a dead zone. Pieces can stay stuck on the anvil and they only move again if other pieces impact them. This cannot happen for industrial scale shredder since stuck pieces are pushed by the incoming materials. When a piece of raw material, e.g., steel can, reaches the anvil corner there are two possibilities:

-- either the can falls between two hammers and second hammer throws it around to impact the inner walls or the baffle plates in the upper corner

-- or the hammers impact the pieces directly that gives rise to two more possibilities, i.e., tearing happens if the clearance between anvil and hammers is narrow, but, compaction takes place with no fracture if the clearance is large. These two different possibilities are shown in Fig 23.

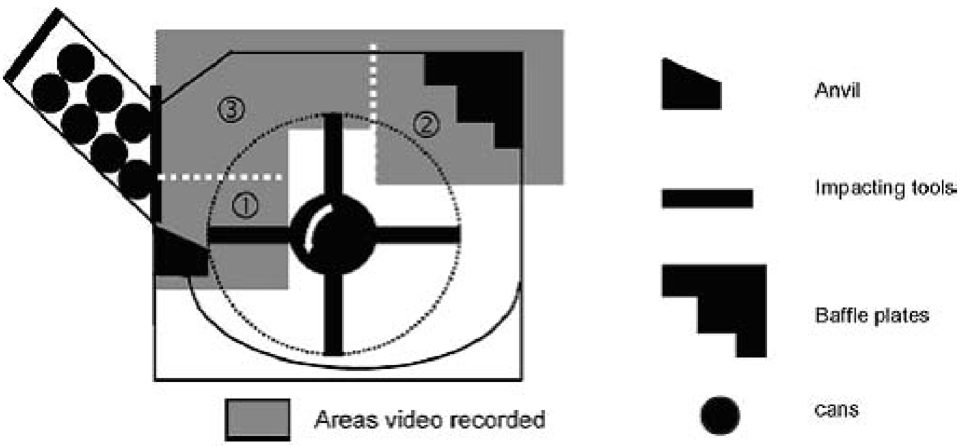
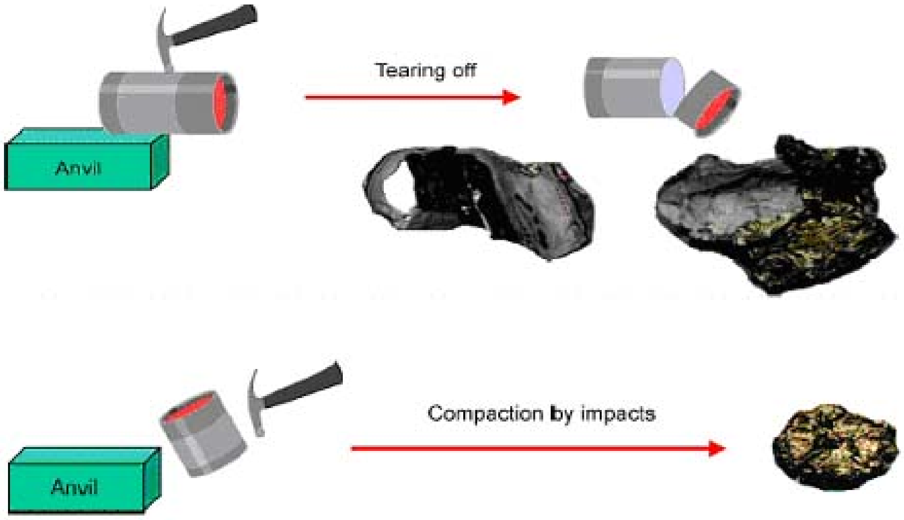


Fig.22- General configuration of the swing-hammer shredder and three different areas, i.e., side anvil, 1, effective comminution zone, 2, and area in which fracturing weak parts occur, 3.

As shown in Fig.23, most effective comminuting within hammer shredder is the region 2. Pieces of sheet or other scrap are bent when impacting the baffle plates with a high kinetic energy. Thereafter, pieces bounce around many times between hammers and baffle plates and fractures are caused by these shocks.



Narrow clearance between anvil and hammer, causing tearing

Large clearance between anvil and hammer, causing compaction

Fig.23 - Mechanisms of comminuting pieces with the shredders having narrow clearance (top) and large clearance (bottom) between anvil and hammer

After passing area 2, the pieces pass through region 3 on their way back to the anvil and are pushed by the hammers. In this area, occasionally fractures may occur in weak parts of scrap pieces. It means that thin metallic bridge between two major parts of a sheet fragment will break and pieces are produced by impacts (Figs.23 and 24). After passing the pieces through the area 3, the returning pieces impact the anvil or the incoming materials that restrain the feeding rate which can create drastic exit of some pieces through the feeding channel.

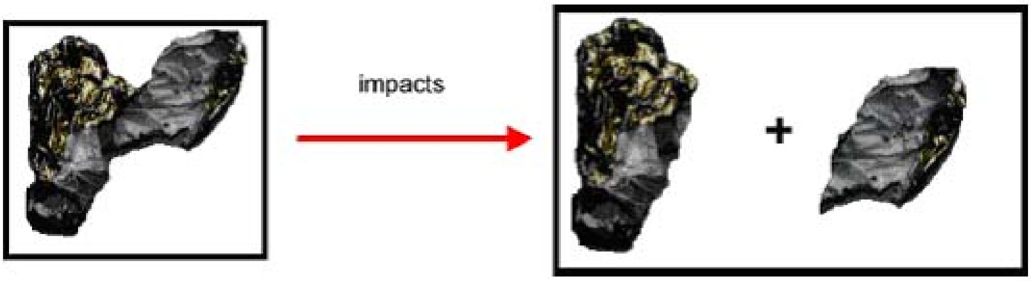


Fig.24- Fracture in weak area of the shredded piece (impact in region 3)

In fact if the clearance is too big or the raw material is too small to be held by feeding rolls, no tearing happens and the pieces are mostly compacted by impacts.
Characterization of the fragments produced by the swing-hammer shredder indicated that narrow clearance between anvil and impacting tools, i.e., hammers, yields coarser fragments than with a large clearance. This means that the comminution is only affected by clearance when it is close to zero. Otherwise, clearance has no effect on comminution. However, the circumferential velocity of the hammers affects both the energy consumption within a period of time and the size and mass of fragments. For identical specific energy consumption, the higher the velocity, the smaller and lighter are the fragments.
In order to have better liberation of different components it is suggested to grind pieces further until all pieces are below 60mm. This is especially recommended for removing

copper from steel and ferrous parts when large electrical components are processed. This found to be the major parameter affecting copper content of shredded scrap.
With respect to particle shape there have been lots of investigations to understand the granulometric property of the fragments after shredding. Generally, each fragment generally can be described three dimensions, a, b, and c ($a \geq b \geq c$) and determination of shape factors based on the evaluation of the triaxial dimension relationships, comparison between the properties such as area projection, volume, etc., of irregular shaped fragment and those of a geometric body, and evaluation of the change in particle behavior, such as settling velocity, resulting from irregularity has been suggested. This must be added also that the shape factors mentioned above are inadequate if characterization of shredded metals is aimed. This is due to the fact that the different fragment shapes are results of the varying states of compaction.
Schubert suggested assigning the fragment shape classification for evaluation the shredding process. Accordingly, shredded metals are classified by 6 different shapes as shown in Fig.25.
It has been found that for sheet plates the surface area is decreased by increasing the specific energy unit and the cracks length are shorter at lower levels of energy consumption. In addition, as the specific energy consumption increases the bending radius for scrap sheets are reduced. Degree of bending is also a function of energy consumption and the feed size. Irrespective to the energy consumption, the smaller fragments formed by breakage are hardly deformed. However, a higher supply of specific energy results in an increasing degree of bending in smaller fragments mass fractions.

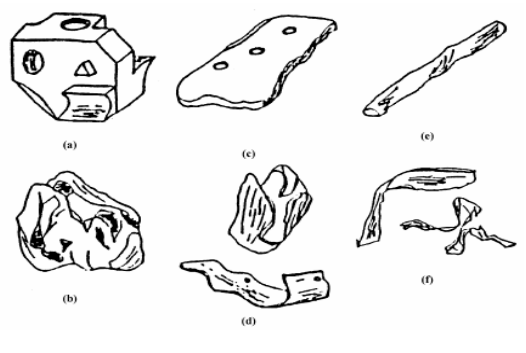
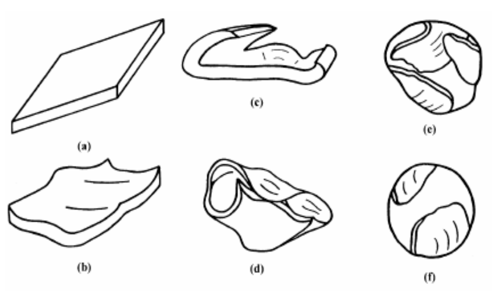
	
a- compact (cubic), b- compact (strongly), c- platy-even, d- platy-slight to strongly deformed, e- rod-shaped-straight, f- rod-shaped-slightly to strongly deformed	a- platy-even, b- platy-slight deformed c- platy-strongly deformed, d- platy-strongly deformed & partially compacted, e- compacted

Fig.25- Shape classification for characterizing of:
products of comminution (left) and comminution of sheet metals (right)

Furthermore, degree of compaction, which directly relates to the fragment density with respect to the material density, is strongly affected by the shredding time. By increasing shredding time the degree of compaction increases, thereby, more dense and compact fragments are produced.
Investigation on car scrap after using Lindemann hammer shredder indicated that in the case of steel and copper is preferentially found between mesh sizes 20 and 60mm, or in electrical wires, i.e., below 5mm mesh size. According to this investigation more than

20% of copper is found in size fraction below 5mm, however, more than 70% of total copper accumulated within particles having size fractions between 20 and 60mm. Accordingly if particles finer than 5mm and also particles within size fraction of 20 to 60mm are isolated the amount of copper in scrap would be reduced up to 90% of the initial amount, or even more [14].

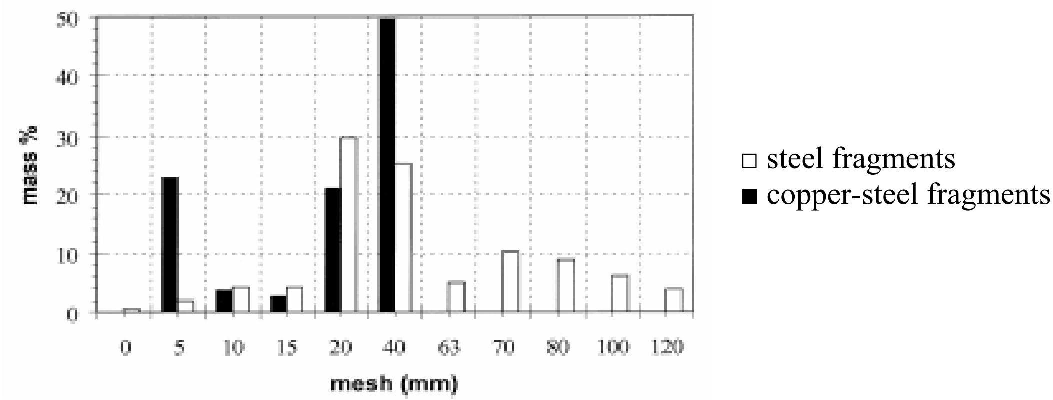


Fig.26- Mass distribution of pieces containing copper and steel from shredding ELVs

Similar study was conducted to scrap home appliances [14]. The results for stoves and refrigerators revealed that just by simple sieving most of pollutant could be taken off from the stream by appropriate sieving. This means that just by choosing proper sieving and classification system, and no special separating equipment, it is possible to have a quality product from scrap. However, the remaining part can be processed further by using different separation apparatus.

Although this looks very simple but the problem arises due to high interference between the size and shape of the mesh and the shape of the fragments. This is firstly due to the irregularity in shape of particles and second, sieving time. Size of fragments depends on the nature of the material, but also the design characteristics and operation conditions of the shredder. During shredding of scrap, for constant shredding time, the number of circular shaped particles increases by increasing particle size. However, small fragments tend to exhibit a more rectangular shape.

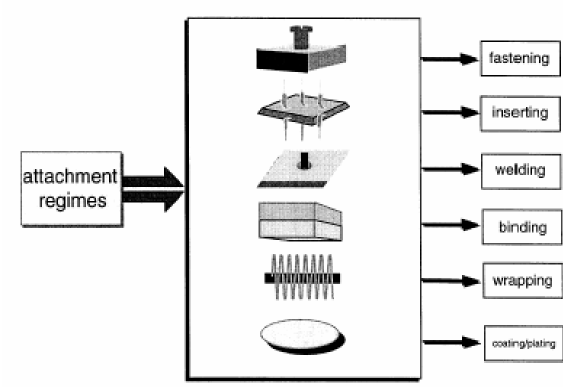
By analysis of different fractions of shredded scrap it was concluded pieces tend to ball shape at the beginning of grinding, however, after forming balls, if the particles are still in shredding chamber, shredder cut them into flat and rectangular pieces.

13- Liberation, Particle Size Reduction and Their Effects on Recycling Rate:

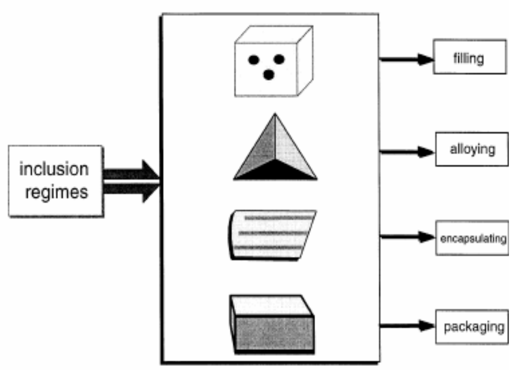
This has been a subject for lot of research programs to see what should be done for better recycling and recovery for modern products, such as car, that are made from various components. These components are combined and connected in many different ways making up a complex “mineralogy”. Over the time this mineralogy has changed and become more and more complicated due to emergence of new materials. From mineralogy and mineral processing view points it is known that the behavior of ore dressing equipment depends on the nature of individual particles to be processed. Particle size and its composition are two most important fundamental properties to be considered. These two properties are determined by the comminution process. Although there are differences between real minerals an ores with man-made products

in many ways, especially comminution behavior, but, the same principle for definition of the relation between particle size and liberation can be applied to describe the particle size related to the liberation for the modeling of the comminution and separation of end of life consumer products [16-18].
In closing material cycle of end of life goods material quality as well as type and shape at various stages in the recycling chain are paramount important. During shredding of end of life goods product design and material connections and combinations determine the particle size reduction and the degree of liberation which affects the composition of the intermediate recycling stream, i.e., composition and amount of non-liberated particles, and the efficiency of physical separation.
Based on basic mineral processing knowledge and computer simulation models have been developed to understand the complexity of breakage matrix for shredding modern consumer goods. Modeling of liberation for modern consumer goods revealed that, unlike minerals and ores, is not necessary true to grind pieces further and further to get liberation for shredding of end of life goods. The modeling for multi-component systems for liberation disclosed that during shredding, the major element composing the matrix of compound will be liberated, whereas, the other elements in this matrix become less liberated.
The foreign materials introduced into the recovered material stream due to incomplete liberation might become therefore irreversible contaminants of the recycled stream. As a result, the mineralogy of the recovered streams may not be sufficiently pure for the production of recycled materials with acceptable quality. Copper contamination in steel recycling and iron contamination in recycling of aluminum are two well-known examples. If the recycled materials are not pure enough to fulfill the needs for production of new materials then the highly pure raw materials must be added to dilute the contamination. This leads to a low resource efficiency of the recycling process, high production costs, and also further accumulation of irreversible contaminants in the resource cycles on time.
Although more extensive comminution may lead to higher liberation level which is needed for the recycling, but, the intensive shredding of recycling stream has some disadvantages. For example, intensive shredding is very costly and some types of joints cannot be destroyed by shredding. Plastic deformation of some pieces, caused by extensive shredding, may reduce the liberation level for some metals. Consequently, materials that were not attached can become entangled in a complex way. Furthermore, smaller particles exhibit higher specific surface area, which leads to additional oxidation losses for reactive metals like aluminum and magnesium.
Fig.27 depicts different kinds of attachment and inclusion regimes for end of life consumer products. As it is noted in this figure, from mechanical separation point of view, the locking patterns of components and materials in end of life consumer goods may be categorized into two regimes. To unlock the associated materials such as plastics, ceramics, glasses and metals with different mechanical properties, that are locked through fastening, by screws, clinks and rivets etc., inserting, wrapping and packaging, should be easier. However, materials locked by means of coating, binding, welding and encapsulating are relatively difficult to be unlocked and materials locked by alloying and filling can not be liberated at all by mechanical means [19].

The first classes of attachment regimes can be classified as the physical joints and the second classes can be named chemical joints also



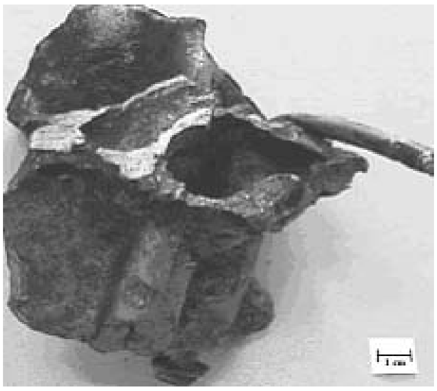
Physical joints



Chemical Joints

Fig.27- Physical and chemical joints for materials construction of end of life goods

In Fig.28 typical examples of non-liberated pieces from automotive wrecks are shown. Study on fragmentation of End of life Vehicles indicated that the non-liberated pieces in ferrous fragments are mostly associated with copper. However, non-ferrous fragments are constituted mainly of cast and wrought aluminum. It was also revealed that aluminum wrought particles that are originated from thin-walled components, exhibit intensive plastic deformation, while cast aluminum, that is less ductile and used in components with thicker walls, seemed to break preferentially by punching and cleavage mechanisms with limited plastic deformation.



cast aluminum with steel bolt attached

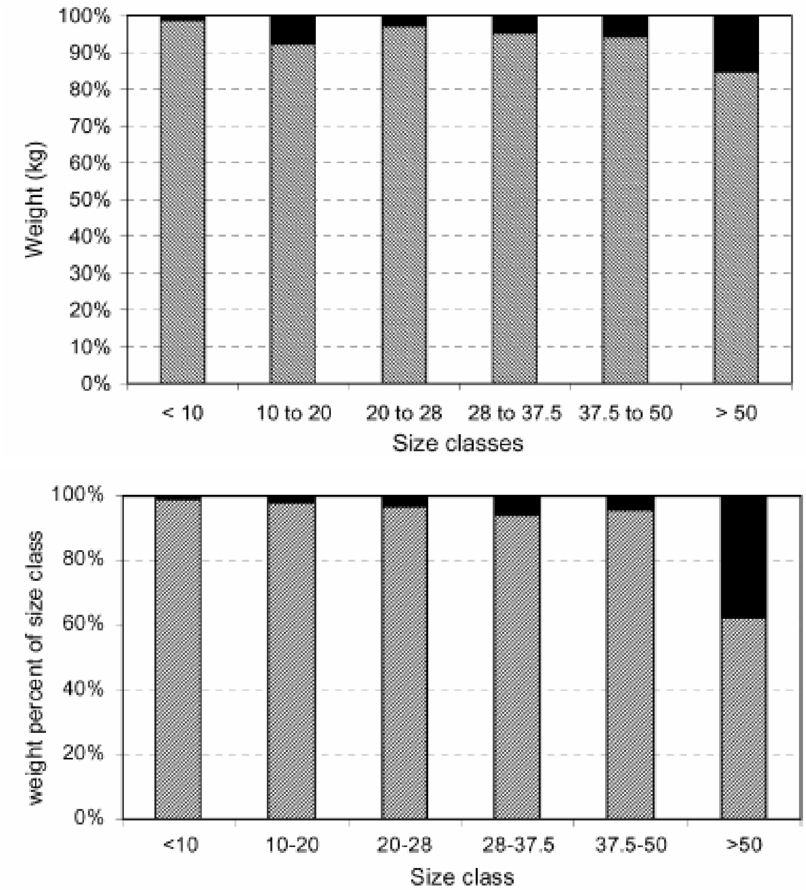
particle of aluminum with rubber insert

coil of electric motor containing cast iron and copper

door lock, made of zinc, stainless steel and brass

Fig.28- Non-liberated particles after shredding automotive wrecks

This means that different materials and different geometries lead to different breakage mechanisms and thereby different particle shapes.
Analysis of the liberation level per size class for ferrous and non-ferrous streams of end of life vehicles indicated that for both cases the smaller size classes show a tendency to attain a higher liberation level, while the larger size classes have increasingly lower liberation levels with an emphasized increase for the larger size class, in particle of non-ferrous stream. These are depicted in Fig.29.
Looking at the above figure indicates that the liberation for both ferrous and non-ferrous streams is not only affected by the degree of comminution, but other parameters such as joints used as well as physical properties of the materials and the geometry of product.



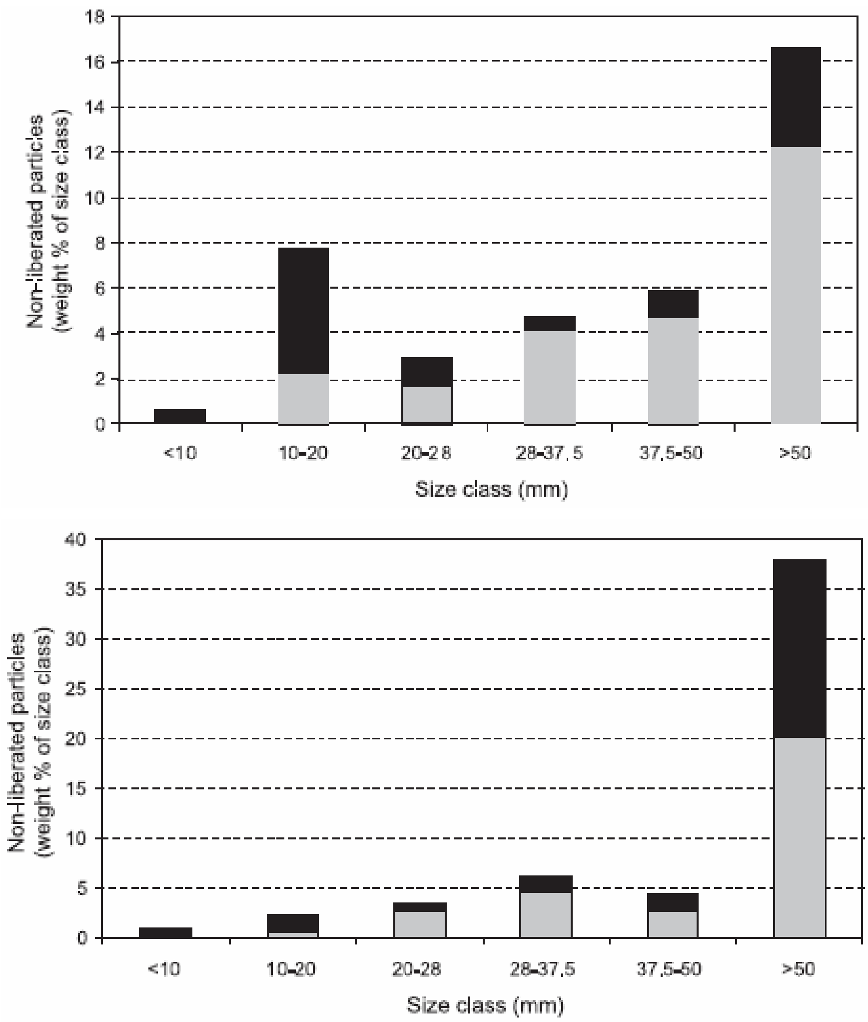
Liberation degree of the ferrous stream of ELVs
(■ non-liberated
■ liberated)

Liberation degree of the non-ferrous stream of ELVs
(■ non-liberated
■ liberated)

Fig.29 – Liberation degree of two different streams from ELVs shredding

Analysis of non-liberated particles has shown that on the basis of the joint principle and the interaction between the various materials two different joints exist, i.e., physical and chemical joints. As shown in Fig. , in spite of having fluctuation values, chemical joints are more significant in the case of smaller size classes for both ferrous and non-ferrous streams, whereas, physical joints tend to be more significant in the larger size classes.
In fact chemical joints are not wiped out by shredding since the attained size after comminuting is still larger than the typical chemical joint, e.g., alloying. In fact the

natures of joint and material combinations dictate whether the specific pieces can be liberated and sorted in one fraction or not?
Introducing copper in ferrous stream and iron or steel within aluminum stream are problematic for material recycling. However, for ELVs scrap the largest contribution to the chemical joints type was found to be the copper-tin combination, coming from radiators, which is not problematic since during copper recycling different metals can be separated by electrolysis.



Non-liberation from ELVs ferrous stream (■chemical joints ■physical joints)

Non-liberation from ELVs non-ferrous stream (■chemical joints ■physical joints)

Fig.30- Weight percent distribution of two different streams of ELVs shredding

Comprehensive simulation model of the comminution-liberation of stream recycling offered by Castro, el al., [17] indicated that when considering the joints size and liberation for the shredding stream the best liberation can be attained when the joint size distribution and the particle size distribution are as much as possible out of phase. As shown in Fig, this means that the distribution peaks for particle size and joint size must have distant from each other. Larger distance results in better liberation and therefore better recycling performance. while the shredding size distribution According to the simulation modeling done by Castro et al., the following guide lines are suggested for having favorable recycling of end of life consumer goods, especially, end of life vehicles.

- use of incompatible material combinations as much as possible
- avoid chemical joints between materials that are compatible for recycling
- use of physical joints as much as possible in order to minimizing chemical joints
- preferably use of one big physical joints instead of many small joints
- minimizing amount of joints used, in term of join mass
- choose joints and shredding parameters that produce a joint size distribution out of phase with the particle size distribution

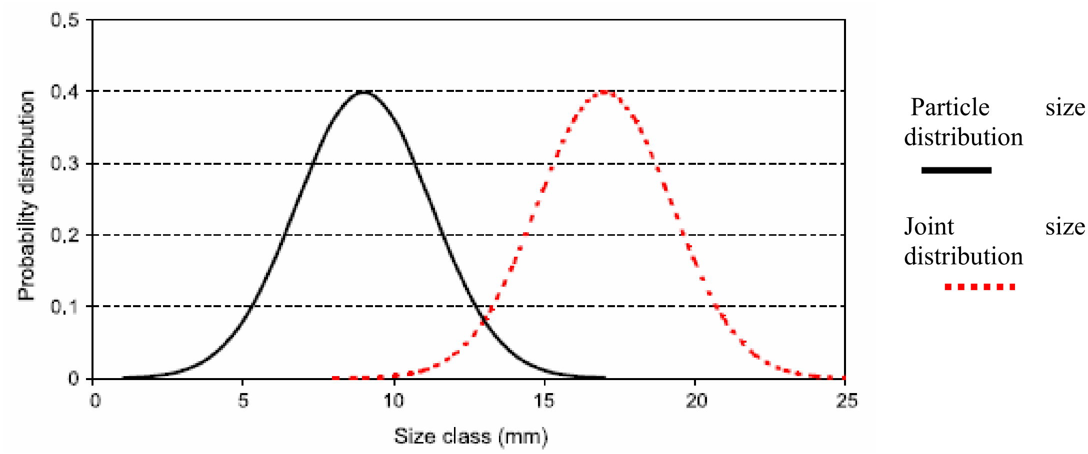


Fig.31- Joint and particle size distributions out of the phase that producing highest liberation degree and lowest contamination in recycling end of life consumer goods

Castro, et al., [17], applied a thermodynamic approach for evaluating of the compatibility of materials combinations for metallurgical recycling. This approach led to the construction of a decision tree model for the evaluation of the compatibility of materials combinations, the thermodynamic evaluation of materials combinations model. The objective of whole study was to minimize the recycling losses and contaminations as well as increasing the resource efficiency of product system. As it is obvious, lower contamination in products from shredding stream leads to better recovery and recycling processes with lower needs to energy. This leads also to a win-win situation to the industry and environment. Results obtained from this study were organized in Fig.32. According to Fig. there are three different options for recycling mixed metals [16-18].

The first option is "*Must separate*" which identifies a combination where valuable resources are lost or/and their quality is severely is damaged if the combination of the two materials is not physically separated. This means that efforts must be made either to physically separate the two materials or the combination should not be used in product design.

The second option called "Attention to losses" which means that more detailed analysis is needed to decide whether for recovery and recycling view points the combination of two materials, e.g., two metals, must be separated or not. Combinations within this category must be looked at carefully. In some cases the combination would be good and in other cases it might be a combination to avoid. It may be beneficial to physically

separate material combinations that are listed in this category. Therefore, it can be said that these combination "should be separated".
The last option called "Don't separate" that means the combination has no consequence for recovery and recycling of the resources or even the combination possibly has advantages for both material streams. This means that, before metallurgical processing, there is no need to physically separate the two combined metals and they can be separated from each other during metallurgical processing. Since end of life vehicles and other appliances are made of different metals and plastics and their combinations, for recovery and recycling of the materials, especially metals, there is important to understand metallurgical processing of which combinations is allowed and for which ones it is avoided. The material combination for vehicle as well as its input stream and the industrial streams for the metals with respect to the thermodynamic analysis of metal recycling are thoughtfully shown in Fig. This figure again demonstrates the important role of liberation and comminution for efficient recycling and recovery of wastes from ELVs and other obsolete appliances.

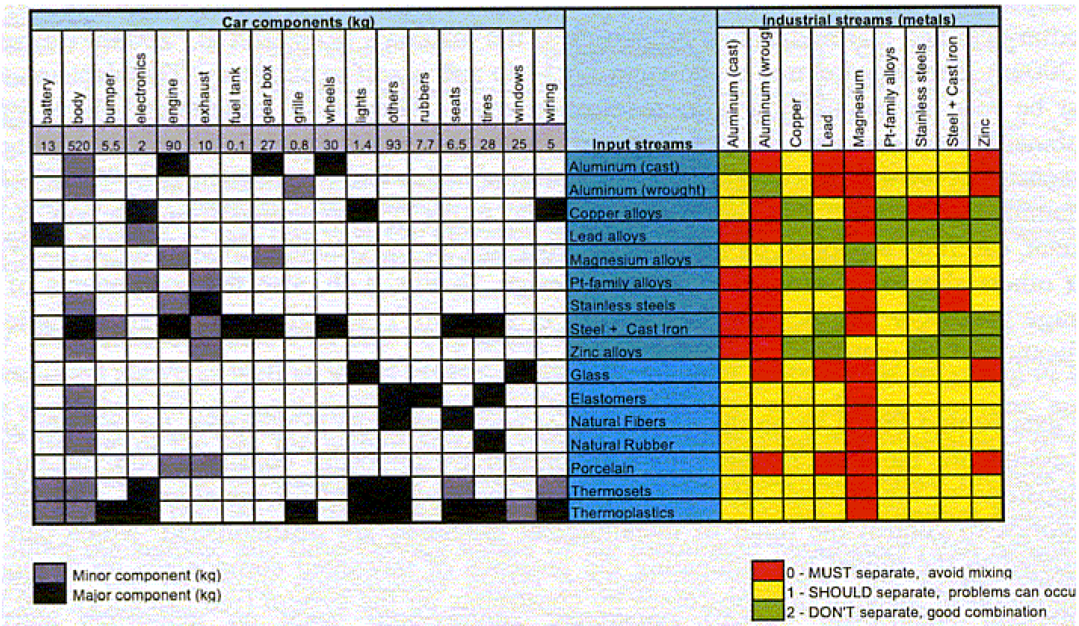


Fig.32- Matrix of materials combination with description of average passenger vehicle on the right side

14- Identification, Separation and Sorting:

Since secondary materials are usually inhomogeneous, apart from various processing procedures, there are needs for further sorting and separation prior or after processing. For example, when processing of the appropriate materials from domestic waste is aimed, one must apply an extensive range of sorting and separation techniques to recover different streams of materials.
In shredding plants a combination of processing techniques is used for recovering of ferrous and non-ferrous metals as well as non metal fractions. For example, liberation of materials by shredder is followed by mechanical separation of the various materials. Comprehensive study revealed that more than 30 materials are used in automobile which can be recovered [16-17, 19].

In shredding plants, mechanical separation mainly concerns dust extraction, magnetic separation of ferrous fraction, hand picking, screening and separation of the non-ferrous mix into individual metals, such as copper, brass and zinc.

Sorting and separation, preceded by identification, are used in particular for the recovery of discarded consumer products. It must be mentioned that until comparatively recent decade's identification, sorting and separating procedures for recycling materials were done entirely by hand. But because of growing technology and having huge amount of different components within the stream, i.e., hundreds or thousands of different metal alloys, then the use of fast and exact identification machines is inevitable.

Although still manual identification and sorting is employed and in some special applications, such as sorting old textile and paper stock, the human eye and human hand are essential but, to some extend, the manual operations have been replaced by machines, tools and recently automated sorting technologies. However, these new techniques still need to be improved and developed.

For physical recycling of end of life goods there are four different necessary stages, i.e., dismantling, sorting, separation. Although, techniques used for these four stages often overlap but still there is possibility to make these stages. Dismantling to large extend may fall into separation and sorting but, it can be considered as a separate stage. Logically, identification must be done prior to any separation or sorting but it may be employed wherever is needed [6].

Identification and sorting are necessary not only due to technical view points but also for increasing the value in recycling. Although for recycling some materials the identification is done prior to size reduction and/or sorting/separating stages but in shredding facilities the procedure starts with size reduction and then sorting or separating light fractions by air suction. Then magnetic separation followed by classification is done. For further purification other mechanical separation and hand sorting will be carried out. Therefore, procedure commences with shredding and separation.

Identification and sorting are often linked. Metal detectors for separating different metals and their alloys, image analysis for color, shape and morphology separation, mechanical identification using XRD and XRF, or other spectroscopic techniques, etc are used. Furthermore new techniques based on laser, e.g., Laser Induced Fluorescence (LIF), Laser Induced Break-down Spectroscopy, Laser Induced Heat, etc., are nowadays used for identification and sorting of different minerals, metals, metal alloys, plastics, etc [21-22].

Before 1970s or even before 1980s sorters just had few main tools to aid identification, e.g., a magnet to determine the presence of iron, and ferrous metals, like nickel and chromium, and optical sorting to characterize bright and dark pieces. Other techniques used may be gravity sensor and γ–ray sensor, modern image analysis technique for characterizing pieces by their color and shape, even their hue and shade when their colors are relatively close, modern IR and FTIR spectroscopy for identification of different plastics, as well as XRF.

In separation and sorting stage, there are a broad range of equipment can be employed. Separation can be done in both dry and wet modes.

Within following section different stages needed for recycling end of life goods are described in details:

14-1- Dismantling [23-30]: Modern consumer goods have become complex therefore there is a need for dismantling them prior to mechanical processing.

The dismantling of worn-out motor vehicles is as old as motor transport itself since dismantling parts can be sold and it has been a trade. But man must consider that vehicle dismantlers usually remove those parts that can be sold on the second-hand market. From dismantlers point of view it is better to dismantle modern models are mainly since the parts can be sold easier. Therefore, as a general rule, older cars are sent directly for shredding. In addition, low-value materials, such as paint, upholstery, plastics, glass, and rubber are generally not dismantled. These materials remain in the waste fraction after shredding and in some cases amount for 25% of the shredder input. The disposal of these materials after shredding called fluff. Although fluffs have relatively potential to be used as fuel but due to having high content of non-ferrous metals together with inert materials, like, sand and dirt, from environmental view points it is difficult to directly burn them. In most cases fluffs contain of 30-50% of inert materials and non-ferrous metals. Hence those materials must be separated before in order to obtain a clean fuel fraction [23].

Needs for dismantling goods risen since different end of life goods are used and left in wastes containing valuable metals and/or plastics or even precious metals, especially in the case of electric and electronic scraps. Increasing collection of non-metals have led to the development of new tools for vehicle and other consumer goods, such as TV sets, photocopiers, fax machines, computers, refrigerators, etc.

The most prevalent method for dismantling is hand dismantling however, due to the needs different machines were invented for automatic dismantling of consumer goods. The first special equipment for dismantling was developed to enable tapping off all automobile fluids. In addition, ever larger mobile dismantling units were built as well as entire demolishing streets with tap-off points tripping installations and crushers, etc.

Another considerable concerning when old refrigerators are going to be recycled is the presence of CFCs in old refrigerators. Various systems have been developed to tap off the CFCs and oils quickly in an environmentally friendly manner. In addition mechanical solutions were found for handling relatively high proportion of CFCs remaining in the insulation of walls and doors of refrigerators.

As a general rule, better and accurate dismantling prior to shredding and processing lead to better recovery and recycling of consumer goods and also higher benefits.

In car recycling, dismantlers mainly operate with the capability to receive discarded automobiles and process them for usable parts, provide containment of environmentally critical fluids, and perform scrap material recovery. Removal and sale of parts for use in other vehicles is the most profitable activity for the dismantler. Some of these recovered parts are "re-manufactured" and include clutches, engines, water pumps, starters, power window motors, and alternators.

Of the estimated 10,000 dismantlers in North America, 2,000 are more advanced dismantling operations targeting later model cars (autos less than four years old).

From the perspective of the dismantler, the key decision point analysis focuses on economic factors. As shown in Fig.33, for a vehicle dismantler, the following decision points are available for each separate part or part assembly handled in the dismantling process:

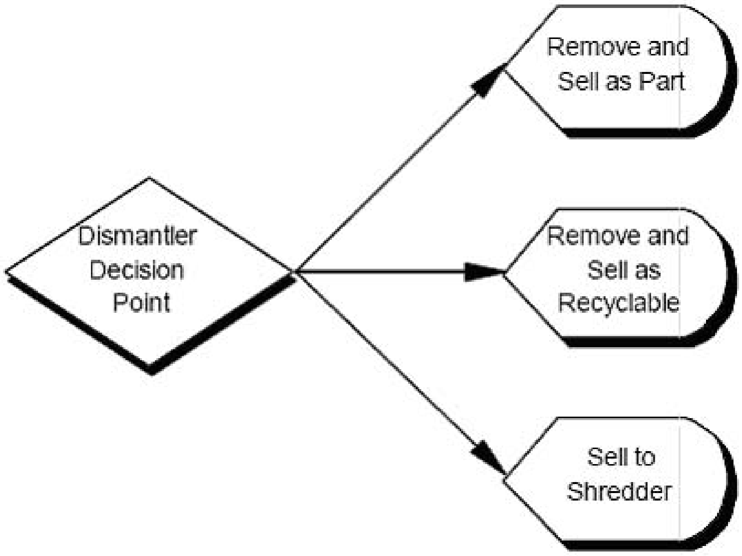


Fig.33- Dismantler recycling decision point options

Recycling of parts in different end of use consumer goods has become important due to energy and environmental aspects and was found to be an important stage of recycling and reusing of. According to an investigation done at Osaka University it has been revealed that by having a comprehensive and sophisticated dismantling plant the recycling rate for end of use vehicles is significantly increased. This study showed that if the aim is to increase the recycling rate from current ratio of 75-80% to more than 90% or even 95% careful dismantling of liquids and different parts of vehicles must be considered.

By having the new dismantling technology at WARC (West-Japan Auto Recycle Co., Ltd.) not only the rate of recovery increased but also purer streams of iron, aluminium, and copper were prepared for metallurgical processes. To have such a dismantling facilities need to invest a lot and dismantling operating cost per vehicle by this technology reaches close to 20000¥. But, the recovery rate is considerably increases and the final concentrating of Cu in iron fraction will be less than 0.3%, which is perfect for direct use of the scrap in metallurgical processing without any problem. In addition more than 85% of copper content will be recovered. Fig34 depicts the details of the dismantling plant; however, general flow recycling process versus the West Japan Auto Recycle process is shown in Fig.35 [25, 28].

According to the investigation carried out by Osaka University, the new dismantling system brings a benefit of more than 20000¥ per vehicle and leads to considerably decreasing in final disposal residue

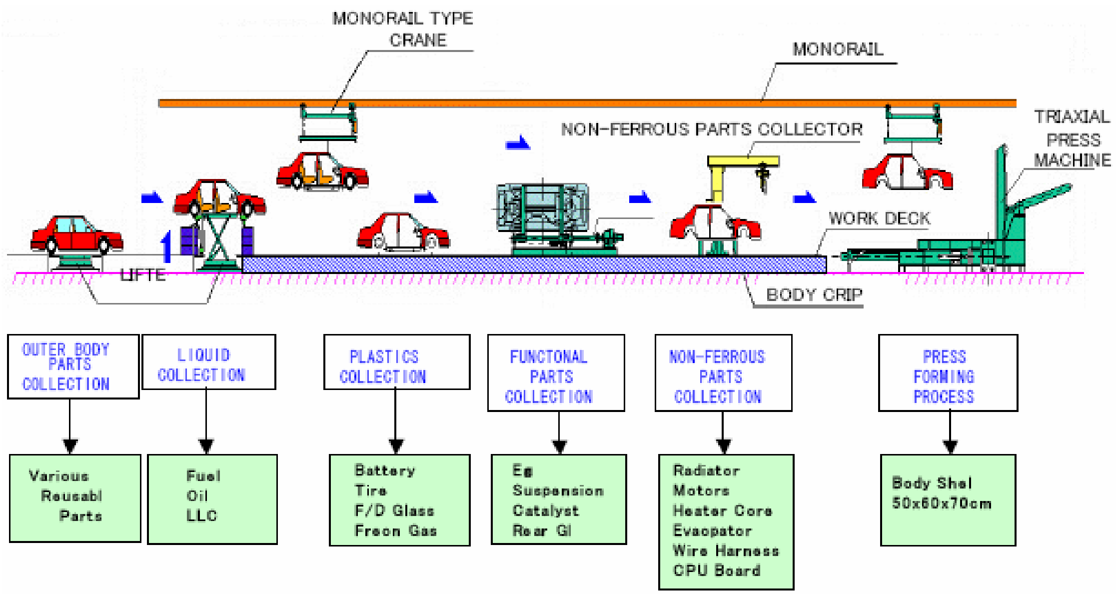


Fig.34- Dismantling vehicles plant at WARC (West-Japan Auto Recycle Co., Ltd.)

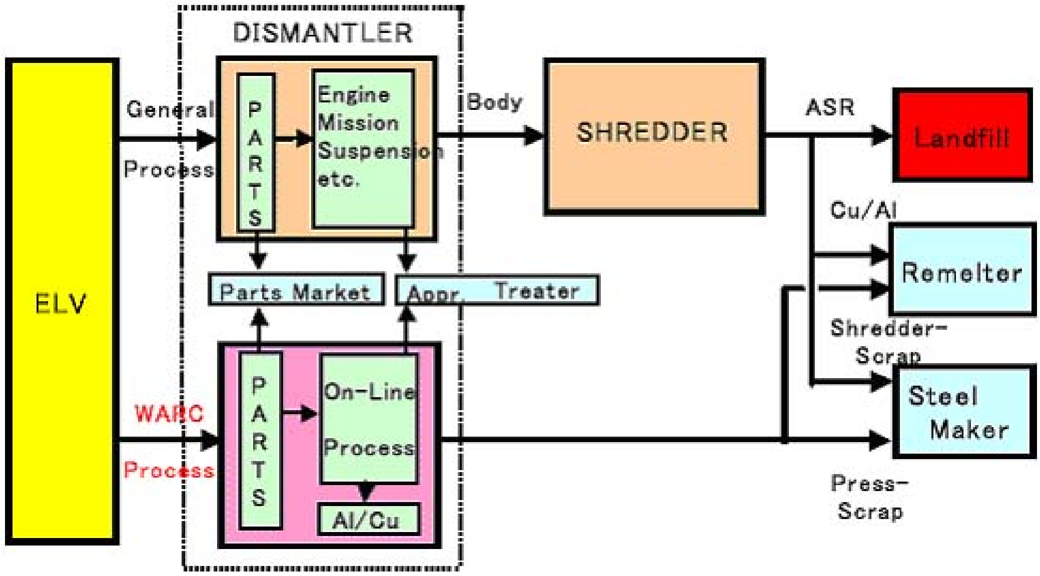


Fig.35- General flow recycling process vs. West Japan Auto Recycle process

The same procedure for dismantling end of use home appliances has been suggested. Dismantling improves the recycling efficiency and part of dismantled can be used directly as replacements or spear parts or even can be used as a part for manufactured appliance.

The study was done by Hirosawa [30] for development of an integrated treatment and recycling system for post-use electric home appliances indicated that it is better to have accurate and sophisticated dismantling system. Fig.36 depicts the assumption for dismantling plant for home appliances.

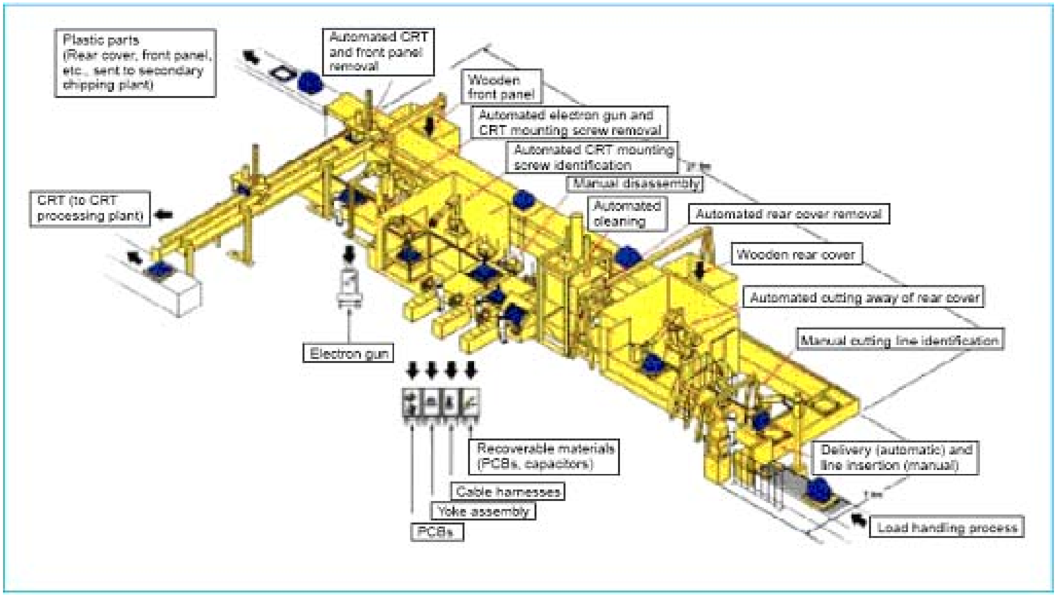


Fig.36- The primary TV dismantling line

Fig.36 illustrates a primary disassembly line for TVs. The TV is clamped at four corners. The pallet has number flags identifying the pallet and the appliance it is carrying, and flags for managing the pallet's flow through the various processing stations. Points on the TV's rear housing need to be identified to guide the subsequent cutting process. The teaching process used to locate these points only needs to be conducted once for each product model. The longer the line runs, the smaller the proportion of TVs requiring teaching. Fig. 4 shows the change over time in the number of teaching operations conducted during line testing. The teaching data provides work coordinates and cutting-pattern data that guide operation of a six-axis robot with a saw head. The saw cuts the rear panel free, allowing its removal. Personnel at manual work stations remove components not amenable to automated handling. Control screens allow easy control of cut height, depth and other cutting parameters. Teaching is used to identify the location of the electron gun for crushing and removal, and to determine the location and type of the screws that attach the CRT to the chassis. Each TV must be measured individually to accommodate variations in screw position among products with identical model numbers. The electron gun is removed by crushing it and vacuuming up the fragments. The crusher is inserted into the gun, and delivers shocks to the gun, bending and breaking it. The crushing and vacuum work together to capture fragments of the gun and surrounding glass from TV. The CRT mounting screws are loosened, the CRT is held and lifted out of the chassis by a suction head, then is sent to a secondary processing plant. The remainder of the front panel is removed and sorted based on panel materials.

Primary Disassembly Line for Refrigerators: An incoming refrigerator and its pallet are turned onto their side and the refrigerator alone is carried into the line by a special conveyor with a tilt mechanism. The pallets are sent back to the sorting line. The location of the individual refrigerators on the line is electronically tracked. Coordinates needed to guide a saw for cutting the compressor mounting plate are performed at a

teaching station that takes measurements in three dimensions. CFC refrigerant gas and lubricating oil are extracted together from the refrigerator’s compressor. Each model requires a slightly different procedure. Three extraction stations make it possible for this relatively lengthy process to keep pace with the line. The extraction unit is semiautomatic. The operator places the head of the extraction unit at the lowest point of the cylindrical part of the compressor and drills a hole from which all contents in the refrigerant circuit are extracted. Heating and agitation are then used to separate the CFCs from the oil. At the compressor removal station an automatically controlled cutting robot uses coordinates from the database to cut the compressor free from the chassis and then uses a hand to push the compressor down and out.
Additional Information Technologies: The disassembly support system automatically issues disassembly instructions for TVs, refrigerators, washing machines, and air conditioner indoor and outdoor units. Fig.37 summarizes its functions. The transport support system provides a video monitor to assist workers loading appliances onto the sorting line. The materials-balance management system computes the relative weights of the post-use appliances going in versus the separated materials coming out of the chipper during the test operating period. Statistics are collected on product disassembly for various weight classifications. The weight classifications correlate with changing proportions of the product's constituent materials, and allow weight of the materials to be calculated from the weight of the product. The weight of materials recovered from secondary disassembly processes is also factored in.

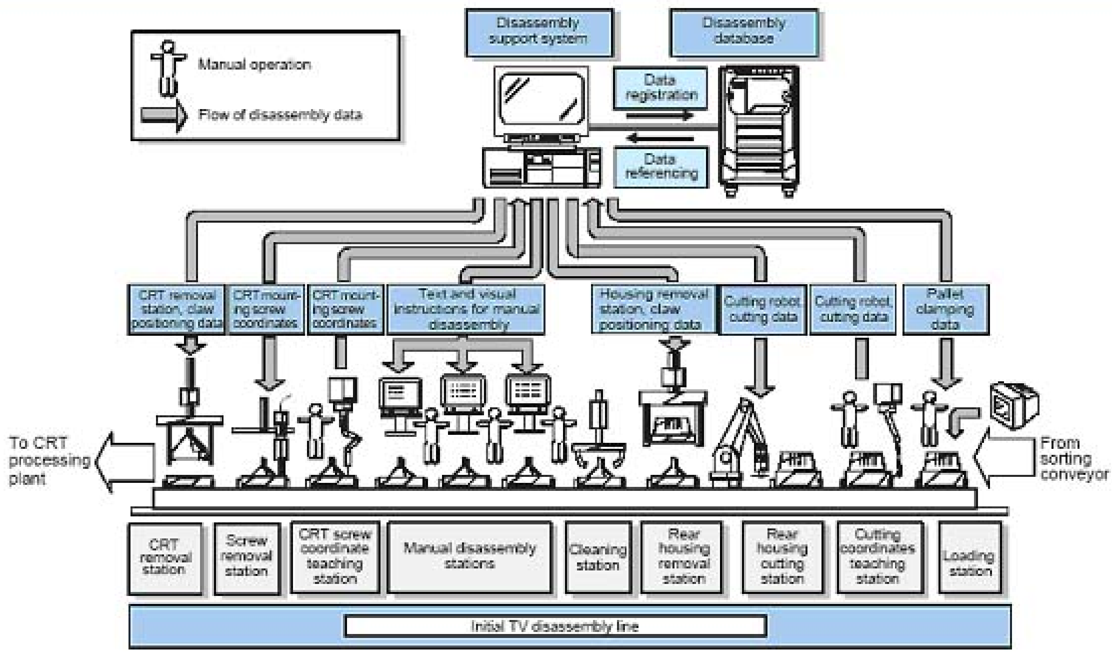


Fig.37- Function of the dismantling support system

14-2- Separation(Processing)[6,31-33]: Although there are attempts to separate different fractions from shredding plants by dry separation techniques, but the use of wet processes is inevitable, especially when comes to separation of light fraction.
In dry processing of shredded scrap, gravity, magnetic, electrostatic, image processing or sorting techniques can be employed.

Classifiers: The first stage of dry separation would be classification by size which is done by screening. In fact during screening particles are classified by the aid of gravity. Screening is an essential in processing of many materials from scrap.
Multiple deck sieving machines are mainly used at the first stage for classification different sizes of shredded scrap.
***Separation by density*:** Density separation can be accomplished by centrifugal force. Air cyclones are widely used either to concentrate solid particles to obtain a product or to clean air from dust. However, reducing in particle size and decreasing density diminish the efficiency of cyclones. In shredding plants, under appropriate conditions, air cyclones can be used to separate light fractions from heavy ones. As like as other separation techniques, the performance of cyclone would be better if narrower particle size range is processed. This means that for better separation result sizing of the feed is necessary step.
Air classifiers are other separating machines and can be used to recover light materials after shredding to obtain coarser or heavier fraction of materials. Vertical, horizontal, inclined, and rotary types of air classifiers are available in the market. Vertical and zig-zag air classifiers are more in use at different processing plants.
Friction separators and Shaking tables: For material mixtures having large differences in shape or density, the inertial or friction separator is a simple device to pre-concentrate materials or to generate final products.
Example is separation of mixture made of stones, copper wire and circuit boards to obtain a copper reach fraction and a reject fraction containing stones, and remaining metals. This device can be used as a completing stage for processing rejects from eddy current separator that is used for separating aluminium in automotive scrap separation.
Shaking tables have many applications in recycling branch. For example separation of electronic scrap and cable granulates are done by shaking tables. In addition, shaking tables can be used for separating particles having the size fraction finer than 4 mm.
Air table consists of a porous deck through which air is blown. The deck is inclined several degree toward the light fraction outlet and is vibrated perpendicularly to the feed stream. The air picks up small and light particles and forwards them to the light fraction product discharge. The large or/and heavy particles, on the other hand, remain in contact with the deck and are transported by the vibration toward the heavy product discharge.

Dry separation with magnets: there are two different separation techniques that make use of magnets. First is traditional magnetic separation in which magnetic particles are separated from non-magnetic ones and the other is eddy-current separator in which particles can be separated from each others due to their conductivity. In fact when a conductive object is passed across a changing magnetic field, eddy current will arise in that object, generating a magnetic field that opposes the field applied. Thereby, the eddy currents can be generated in a conductive particle by changing electro-dynamic magnetic field or by moving permanent magnets.

In recycling plant after the scrap being shredded the heavy fractions are classified and then are passed through the magnetic separators. Although, there are magnetic separators in which the magnetic fields can be regulated for better separation but, in shredding plant ordinary magnetic separators having fixed field intensity are used.

Magnetic fields can be obtained using permanent magnets or electromagnets. However, from economic point of view permanent magnets are found more feasible.

High intensity magnetic separators can be used for recovering ferrous metals from the scrap. High intensity magnet is also able to remove irony aluminium, a complex material consisting of aluminium and magnetic parts mechanically connected.

Eddy current separating device is then used to separate the non-magnetic parts. In shredding plants eddy-current separator are mainly used for recovering aluminium and its alloys from copper, brass, stones, etc.

In general magnetic and eddy current separators have the same basic design features. However, the rotation of magnet in magnetic separators is considerably lower than that for eddy current separator (about 60 rpm for magnetic separator and 1500 to 4000 rpm for eddy current separator). Therefore the forces exerted on the magnets lying on the drum in a magnetic separator are about 0.6 times the gravity force, whereas for an eddy current separator the forces on the magnets can be as high as 1500 times the force of gravity.

Although the basic concept of design for both magnetic and eddy current separators is the same it is impossible to design a separator that performs optimally both as a magnetic separator for magnetic materials and as an eddy current separator to beneficiate non-ferrous metals.

In eddy current separator a force is induced in a conductive metal particle by the magnetic field. The magnetic field must change either by the movement of a particle or by movement of magnet with respect to the particle. Due to different rates of acceleration for different particles in magnetic field their trajectory will be different. That makes separation of particles having different properties, i.e., different conductivity. At low frequencies, the variation is mainly due to the difference in conductivity of the particles. In fact this is the conductivity that divides particles by density. For example, for pieces of copper and aluminium, the acceleration of the aluminium piece is twice that of copper particles with the same dimensions. However stainless steel and lead react hardly to a changing magnetic field and their acceleration is negligible. Insulator or non-conducting particles like stone, wood, plastic and glass, are responding nothing at all to the alternate magnetic field of eddy current separator. Table 1 consists of the eddy current induced in different selected metals and materials.

Table 1 – Sensitivity of different materials to eddy current

	Al	Mg	Cu	Ag	Zn	Au	Sn	Pb	Stainless steel	Glass	Plastic
Conductivity/density ($s/10^3.M^2/V.kg$)	14.0	12.9	6.7	6.0	2.4	2.1	1.2	0.45	0.18	0.0	0.0

Rather than conductivity, particle size also plays an important role in accelerating particles during separation by eddy current. Even if we have aluminium or any other metal particle which its size is smaller than that of pole size of the magnet the acceleration for that particle will be almost zero. This is the reason that eddy current separator cannot be employed for separating particles finer than 1 mm. On the other hand for particles larger than pole size the acceleration will be constant. This means that when a metal piece is subjected to eddy current force it is accelerated and its acceleration is increased by increasing its size. This increasing continues till the size of particle equals the pole size of the magnet. After that there will be no increasing in acceleration for metal particle which means size independent of separation. This is important for metal separation.

Considering that we have two particles, P_1 and P_2 that are made of same material, and P_1 has a particle size of half of the pole size of the magnet but, P_2 being just as large as the pole size, in an eddy current separator the acceleration of P_2 would be two times larger than that of P_1. If, however, P_1 is an aluminium particle and P_2 is a copper or brass particle then the acceleration of two particles is equal. This means that the separation is not possible if these particles have the same shape.

Shape of particles is another determining factor. This means that separation of one metal particle from another is not only influenced by their size but also by their shape.

Frequency of the magnetic field is another determining factor during separation by eddy current. Modern eddy current separators have 6 to 18 poles and even more and are operated at frequencies of the magnetic field of 300-900 Hz. This is worth to mention that at high frequencies, the density of the metal becomes the separation criterion.

From industrial view points, eddy current separators can be divided into two categories based on their design. In one design the direction of magnetic field is perpendicular to the surface of conveying belt, i.e., two alternate magnetic fields perpendicular to the direction of moving belt. With another design, the magnetic there are three magnetic field adjacent each others. Two of those are perpendicular to the surface of conveying belt but the middle one is in parallel with the conveying belt. In this design the magnetic materials will travel with the magnetic drum to the point where the distance between the inside drum and the belt is too large to hold the particle. Further, material falling on the inside of the belt will not stick to the supporting drum of the conveyor belt due to the fact that the magnetic field is only partially present.

During treating non-ferrous car scrap by eddy current separators the process ends with three different fractions. A week magnetic fraction that are transported by magnet to the end path, a non-conducting fraction such as glass, plastics, and stones as well as small metal pieces and the reminder of the weak magnetic stainless steel that are accumulated in middle bin, and finally a fraction of conducting materials or metals, mainly aluminium.

In combination with heavy media separation, eddy current separation is used recycling non-ferrous metals. Aluminium and its alloy as well as magnesium are the first products from a heavy media plant primary fed with materials from automobile shredders. The product from heavy media contains some materials that still respond to the same density range at which the heavy media plant operates. These are stones, glass, copper wire and some other complex materials and 10% aluminium within the size range of 10-65 mm. Using eddy current separator make it possible to have an aluminium fraction and the remains can be processed by another method like using friction separator.

In order to obtain metal concentration according to their properties, the heavy non-ferrous fraction obtained from media separation can also be processed by the eddy current separator. The main part of heavy non-ferrous fraction contains of copper, stainless steel, zinc, brass, and lead. Although theoretically these metals can be separated from each others since they have different sensitivities for eddy currents, in reality their grade and recovery during eddy current separation are considerably affected by shape factor. Fig.38 indicates the best condition for having different metal fractions from the heavy non-ferrous metals obtained by media separation. As it can be seen several stages of eddy current separation is needed to obtain high grade metals.
Another option may be the use of eddy current separator to produce pre-concentrates for sorting machines. This is reported that two companies have such facilities to use the concentrate of eddy current separator as a feed for sorting stage to get very high quality product. Theses two are Huron Valley Steel Corporation in USA and Overpelt in Belgium with Union Miniere as partner [6].
It must be added that by improving the quality of magnets and enhancing the magnetic field by mechanical modeling, to be possible to improve the performance of eddy current separators.

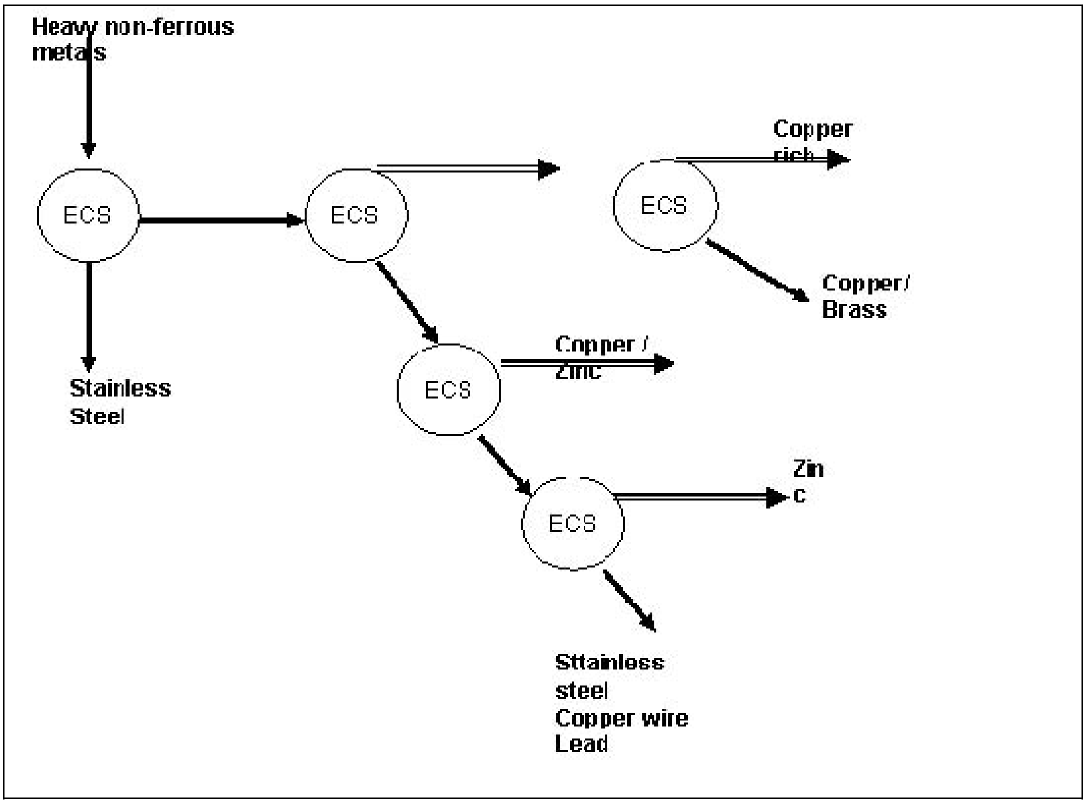


Fig.38- Processing of sink product with eddy current separators to get high grade non-ferrous metals

Electrostatic Separation: Although the basic principles of electrostatics have been known for more than 2500 years the application of electrostatic separation in waste recycling, separating metal/plastic and plastic/plastic, is rather new   To separate particles by electrostatic, first particles must be charged and then passed through an electric field. Three kinds of separating devices are available to separate different particles which are corona or high tension, conductive.-induction, and triboelectric

separators. Corona or high tension separators are used to separate conductors from insulators, like copper from plastics in chopped wires. However, triboelectric separators are able to separate insulators from each other, e.g., plastic/plastic separation in waste recycling.
In recycling industry triboelectric separators are used for separating plastics. Mixed granulated plastics, with particle size up to 5mm or even 10 mm, are charged by contact electrification and then are separated base on their acquired charge. For separating two insulators it is important to have a tribocharging medium that has a work function between the particles to be separated.
To simplify separation of different plastics different triboelectric series are established that indicates the sequence of charging from positive to negative. It means that the material located in top of series is apt to be charged positively when contacts material which is in lower part within the series. This is worth to mention that in almost all series established by different researchers the position of PVC is at the end of series. This means that in almost all cases PVC gains negative charge when contacts other plastics.

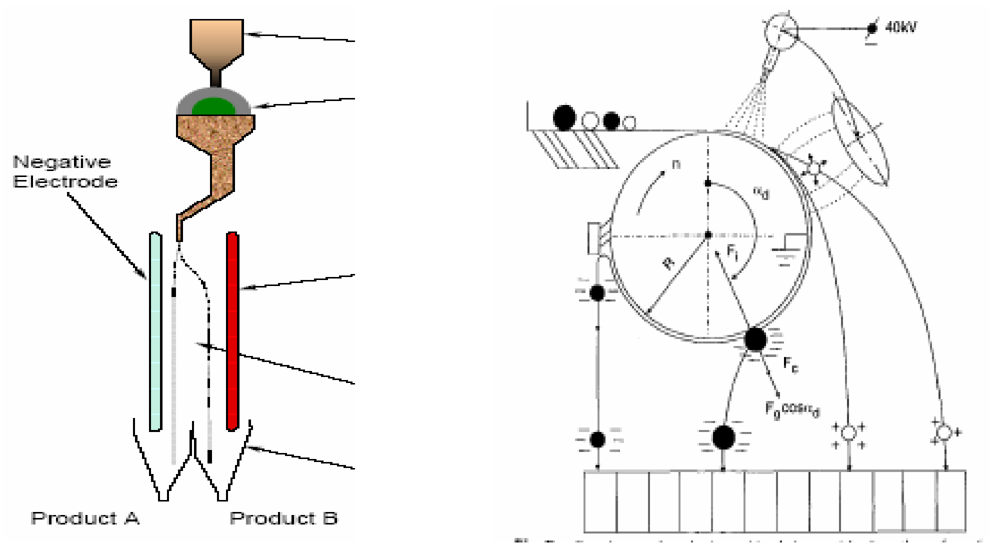


Fig.39- Configurations of triboelectric (left) and corona (right) electrostatic separators

For separating of conductors from non-conductors, e.g., metals from plastics, corona or high-tension separator can be used. Nowadays, corona type separator is widely used in the wire chopping industry to separate metals, i.e., copper and aluminum, from polymers in the 0-5mm size range. By corona charging metals gain charges very fast and lose it when contacting the electrode having opposite charge and gain the opposite charge after a while. Therefore they will be deflected by that electrode.
However, non-conductors gain the charge by corona and do not lose this charge by contacting the opposite electrode. Therefore they attached to that electrode and traverse the opposite direction with respect to the conductor. Consequently, conductor particles can be separated from non-conductor particles.

In recycling industry there are possibilities for using electrostatic separators further. One option may be separating of particles based on their shape since the charge acquisition by particles changes due to their shape.

Other dry separation techniques: There are other separation techniques that work in dry mode. Metal detection and sensing systems based on light are examples. These techniques can be categorized as sorting methods. Metal detection, sensing systems based on light, and other sorting systems will be described in details in another chapter.

14-3- Processing by Wet Separation:

In waste separation by wet methods, flotation, jigging, sink-float separation and separation using hydro-cyclones and raising currents can be used.

Separation using rising currents: In rising current separation, a continuous rising column of a liquid, usually water, is pumped through a pipe and the feed is introduced in the rising water column. Particles that sink faster than the water column rises, falls to the bottom of the separator while the particles that are raised by the column of water are separated from the water by screening.

In hydro-cyclone separation water, or heavy media suspension that called heavy water, is brought to rotation in a piece of equipment that combines a cylindrical and a conical part. As a result, larger and heavier particles first move to the wall and then sink along the wall to the underflow or apex in the bottom. N the contrary, smaller and lighter particles remain suspended and leave the cyclone via the overflow.

New type of cyclones, called three product cyclone, is introduced by the University of Cape Town, South Africa, that is able to separate very fine particles from medium and big size ones.

Flotation: Although flotation method has been widely used in mineral industry its applications in waste recycling in mainly limited to de-ink paper. However, cleaning of contaminated soils and separating plastics can be carried out by flotation. The process can be used for recovering fine particles usually in the range of 20-500μm, but for plastic separation the particles may be up to 10mm (2-10mm is usual size for plastic flotation). In the case of flotation hydrophobicity and hydrophilicity of particles play a major role during separation. These properties for different particles can be artificially modified by using different chemical agents.

Jigging: In gravity separation jigging is one the oldest methods for separating particles. Relatively coarse particles down to 3 mm having reasonably different density are used to be processed by jigs. The method is favorable for materials having fairly close size distribution.

Within the jig, separation of materials having different specific gravity is carried out in a particle bed that is periodically fluidized by pulsating water current. The bed is lifted as a mass on the pulsation stroke; then, as the velocity of the water stream decreases, the particles fall with different speeds to the bottom, based on their density.

By repeating the aforementioned action, stratification of different materials takes place in relation to their density. Therefore materials can be recovered by jigging. In shredding plants the use of jig is mainly for separating plastics from the metals [6, 34-36].

In recycling technology, gravity separation are still dominant and widely used due to the facts that they are robustness and relatively inexpensive. Fig.40 depicts the general configuration of continuous wet jig.

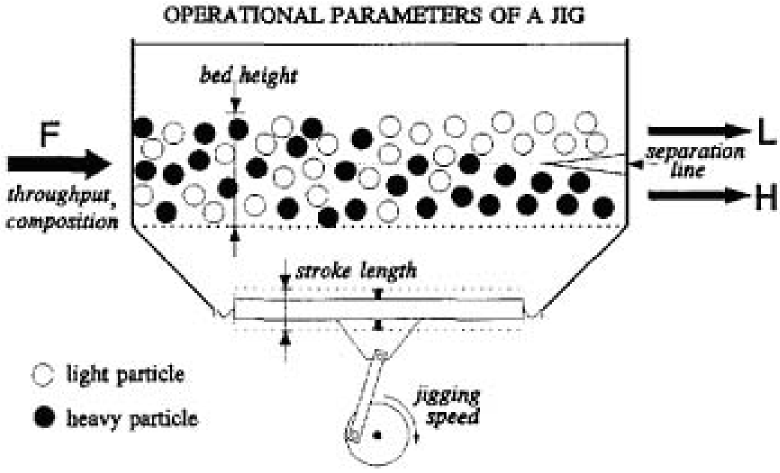


Fig.40- General configuration of wet jig

In addition to metal/plastic separation, jigs can be used for plastic/plastic separation. In fact when plastic particles immersed in water the corresponding differences in their apparent densities are considerable resulting in remarkable good jiggability.

According to a general rule the aptness of gravity separation can be judged by the ratio of the apparent densities of the materials to be separated. Therefore the jiggability of a binary mixture is defined as:

$$Jiggability = \frac{\gamma_1 - \rho_w}{\gamma_2 - \rho_w}$$

where, ρ_w, γ_1, and γ_2 are densities for water, material 1 and material 2 respectively. According to the above equation if jiggability for materials 1 and 2 is bigger than 2.5 very good separation of binary mixed is expected generally by gravity separation techniques, including jig. Whereas, for jiggability less than 1.2 the separation faces problem and poor separation is achieved. In the intermediate range, i.e., 1.2 < Jiggability < 2.5, gravity separation techniques were found to be possible and beneficial.

For plastic mixtures the jiggability values were found to be from 1.5 to 5, indicating rather good separation of plastics mixed by gigging. In addition, plastic mixtures from shredding plants have generally uniform shape that facilitates separation.

For materials having specific gravity higher than water the separation by jig is based on a differential settling of particles in a pulsating water flow. This differential settling is caused by differences in density, screen size and shape between the particles. If the differences in shape and size are small, density is determinant factor for separation. In this case one-screen gigging machine can be used for separating different materials. Examples are separating of PVC from lighter plastics such as ABS and PS. However, it is reported that clean PS fraction could be obtained from plastic mixtures containing mainly of PS, PVC, rubber and metals, made from shredding of end of life refrigerators.

Inverse jigging that was patented by Delft University of technology in 1999 can be used in reclamation of light organic materials where the cut specific gravity below 1 is required. Example is the case of polyolefin's foam plastics and cork. Inverse jig is like on-screen jig which is turned upside down. Within inverse jig, separation takes place beneath the grate, i.e., screen, rather than above it, therefore, the feed is introduced underneath the grate. The transport of particles through the equipment is facilitated since the grate has an upward slope towards the product discharge. Since the particles to be separated are lighter than water, the inverse jig makes use of the differential floating of particles that are triggered by an oscillating movement in water. This is very helpful for separating particles having specific gravity close to the water, for example PE and PP.
Due to sensitivity of the jig performance to particle shape two particles of equal density and size can end up in different product streams of the jigging process if there is enough difference in their shapes. Due to the theoretical settling velocity for the potential flow regime, the sensitivity of jigging performance to particle shape can be illustrated by the following equation, where A_p, C_D, V, v_s, ρ_f, and ρ_s are the projected area, drag coefficient particle volume, settling velocity for fluid, and settling velocity for solid respectively.

$$V(\rho_s - \rho_f)g = C_D A_P \frac{\rho_f \quad v_s^2}{2} \Rightarrow v_s = \sqrt{\frac{V(\rho_s - \rho_f)g}{C_D A_P \rho_f}}$$

Considering two particles, e.g., an aluminum sphere with density of $2.7 t/m^3$ and a copper wire with density of $8.96 t/m^3$, both settling in free liquid. The sphere has a diameter of 6.5 mm and the copper wire has a total length of 75 mm and diameter of 2.5 mm. The calculated settling velocities for both particles according to the above equation are almost same, i.e., 0.554 and 0.553 m/s for aluminum and copper. This means in spite of having high difference in densities, both particles will settle at the same rate. Particle drag is the primary reason for particle shape sensitivity in separation by jig. However, acceleration and hindered settling also influence particle settling during jigging process. Regardless of their density, in practice the metal wire pieces are found throughout the bed during jigging process.
Jigging effectiveness is often estimated by calculating the settling ratio of two different materials. For the potential flow regime the settling ratio is calculated by the following equation where, V_h, V_l, are the volumes for heavy and light particles, v_h and v_l are the settling velocity for heavy and light fractions, ρ_h, and ρ_l are their densities, A_h and A_l are projection areas for heavy and light particle, and finally C_{Dh}, and C_{Dl}, are their drag coefficients respectively.

$$\frac{v_h}{v_l} = \sqrt{\frac{V_h(\rho_h - \rho_f)A_l C_{Dl}}{V_l(\rho_l - \rho_f)A_h C_{Dh}}}$$

By considering the same volume, projection area, and drag coefficients for the both light and heavy particles then the settling ratio simplifies to the concentration criterion. Only if the settling ratio is well above unity, in most cases 2 or even higher, the two particles can be separated by jigging.
In the case of intermediate layer for the jigging, the third layer, having settling ratio between the heavy and light fractions, is added to the feed which forms a layer between

the heavy and the light product. This layer, then, will be separated and recycled to the new feed by some means, e.g., magnetic separation. Fig. shows the general flow-sheet for such process.

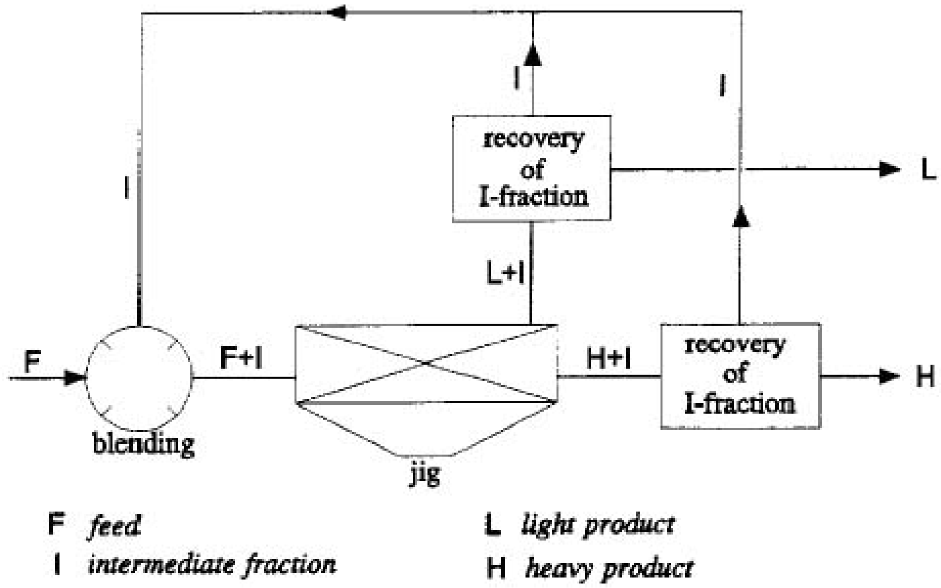


Fig.41- Continuous jigging with an intermediate layer & recycling of the intermediate layer

Condition for the formation of intermediate layer is that the settling ratio for the intermediate layer and light fraction, v_l/v_i, as well as settling ratio for intermediate layer and heavy fraction, v_i/v_l, are approximately equal and not too small. Besides improving of recovery and grade of separation, the existence of intermediate layer helps to control the jigging process. It means that higher variations in feed and feed composition can be tolerated by jig. To have more efficient separation, except the equipment parameters such as jigging speed, the properties for intermediate layer should be optimized based on the feed characteristics and other effective parameters. The optimization covers variety of parameters for intermediate layer, containing particle shape, kinetics of the stratification, diameter, density to diameter ratio, layer thickness, etc.

In general jigs are suitable for separating grainy materials, although flaky particles such as shredded rigid plastics from packaging are also processed by them. However, jigs are less suited to process foil type feeds, unless they are mixed with substantial amounts of flaky or grainy particles. In some cases screening of the feed for jig processing is needed. In this case optimal screen size of the feed depends both on the shape factor of the particles and on the density difference between them. For processing flaky materials the screen size lie between about 2 to 7mm, whereas grainy particles can be handled up to a screen size of about 10 to 12mm. During jigging it is needed that all particles become completely wet to avoid air bubble attachment. Agglomeration and alteration of the specific gravity of the particles happen if bubbles attach the particles.

Due to its simplicity and robustness, separation by jig may be preferred but, this must be mentioned that for density separation higher efficiency is achieved by sink-float separation. With respect to capacity, industrial jigs are able to handle several tones per hour per meter equipment width when processing grainy particles. For inverse jigging although the industrial scale equipment has not come to the market but pilot scale tests indicated that with flaky feed materials a throughput of about 1 tone per hour per meter equipment width can be achieved.

According to study done by de Jong and Dalmijn [34], separation of non-ferrous fraction from shredding plant can be carried out by jigging for the size fraction of 4-16 mm. Density separation of non-ferrous fraction by jig results in two different products. The lighter product consists of aluminum, glass, and stone, but the heavy product consists of heavier metals, like copper, brass, lead, stainless steel, etc. During jigging process, turbulence and irregularities in feed composition result in poor grade and recovery of the products. However, both grade and recovery of the products will be improved if the intermediate fraction is continuously recycled. Intermediate fraction should form a distinct layer between the heavy and light non-ferrous fractions during jigging, which enhancing the separation result. This intermediate fraction could be recovered from both light and heavy products, for example by means of a magnetic separation, and recalculated.

Different shredding plants classify their shredding fractions differently. But, one popular classification is to size non-ferrous feed into 4 different fractions, i.e., 0-4mm, 4-16 mm, 16-60 mm, and >60mm. particles bigger than 16 mm are usually sorted manually or automatically, or processed with heavy media separation. However, for size fraction of 4-16 mm density separation can be used to produce light fraction containing mainly of plastics, magnesium, middle fraction containing aluminum, glass, and stone, and a heavier fraction product contain of stainless steel, copper, lead, and brass. Of course after this separation step the products will be processed further to gain high quality product of aluminum and other non-ferrous metals.

Wet jigs have been applied for density separation of 4-16 mm non-ferrous fraction due to their advantages, i.e., robustness, large capacity per unit surface, low operating costs and suitability to process large amounts of small particles. However, there are some disadvantages regarding using jigs, e.g., jig's sensitivity for particle shape and size, as well as some difficulties to control jig's operation. Therefore, one must be careful when processing raw material comes from shredding plant due to deviation in particle shape of components.

For removing of dense particles from jig there are two basic methods, i.e., on-screen and through-screening jigging. On-screen jigging is applied to larger particles; both, the dense and the lighter particles remain on the screen, which has a smaller aperture than the smallest particles in the mixture. Then, the dense particles are removed by means of a controllable gate or a variable-speed star valve. Through-screening jigging, also known as hutching or English method, is applied to smaller particles. The dense particles pass through the screen, which has a larger aperture than the diameter of the largest dense particles. Subsequently, they are removed from the hutch by means of mechanical discharge. A layer of large particles, a ragging with diameters substantially larger than the screen aperture, is kept on top of the screen. The dense particles percolate through this ragging. The ragging often consists of materials such as hematite, steel shot, galena, or feldspar.

The 4-16 mm non-ferrous fraction from shredding plants is most favorable for on-screen jigging. The average particle size for this non-ferrous fraction is rather coarse in comparison with many minerals. In addition due to characteristics of materials come from shredding plants, many materials, especially wires, would hinge onto the screen

instead of passing it. Thereby, through-screen jigging is not suitable for processing 4-16 mm of shredded non-ferrous fraction.
It was shown that by adding an intermediate fraction to the shredded feed, jigging operation of heavy and light fractions can be improved. It also facilitates the jigging control. This intermediate fraction must be continuously added to the feed and withdraw from both products. To improve the jigging operation, this intermediate fraction should ends up in a layer between the light and heavy products, enhancing the splitting of those two products. To facilitate the recovery of intermediate fraction from both heavy and light products and to recycle it into the jig it is suggested to choose a magnetic intermediate fraction, for example iron bearing pellets that can be recovered through magnetic separation.

Sink-Float Methods (Heavy Media Separation, HMS): Sink float methods are the only true density separation in which separation of particles is achieved by a difference in their specific gravity only. Sink float method is suited for use in both the gravitational field, i.e., static bath, and the centrifugal field, i.e., hydro-cyclone and centrifuge. Either true liquids, e.g., water and salt solutions, or aqueous suspensions of fine particles of a heavy solid can be used as the separating medium. In recycling plants usually static bath method is employed called heavy media separation (HMS).
The main application of HMS in recycling is the separation of non-ferrous mixed produced by automobile shredding plants. Non-ferrous fraction from shredding plant is processed in two steps at different medium densities. At first step a magnetite suspension medium having density of 2-2.4 t/m^3 is applied to separate magnesium (density of 1.74t/m^3) together with heavy plastics and rubber. In the second step, separation of aluminum (density of 2.7t/m^3) from heavy non-ferrous metals, mainly > 7 t/m^3, is achieved by fixing the medium density at 3-3.3 t/m^3 using ferro-silicon suspension. Furthermore, sink float media separation is widely used to separate shredded plastics in a water medium into a mixed polyolefin float product, like PE and PP, and a sink product containing heavier plastics, such as ABS, PA, and PVC. The method is also used to clean granulated construction and demolition debris.
Fig.42 depicts the general configuration of HMS device used for non-ferrous metal separation from shredding plants. However, the sink-float plant’s flow-sheet is shown in Fig.43.
Heavy media are obtained by suspending fine solid particles in water normally up to 35 vol% of solids can be added. It must be noted that progressively increasing of solid content above that level limits the maximum suspension density obtained. The heavy media suspensions have to be stabilized to minimize settling effects. Stabilization is achieved by adding chemicals or by creating conditions of hindered settling in which particles are so close that their settling rate is much lower than in free fall. Suspension stability is promoted by adding fines at high solid content. Increasing solid content causes to increasing in viscosity of the medium which is not good for separation, therefore, optimum conditions is achieved by compromising between suspension stability and viscosity.

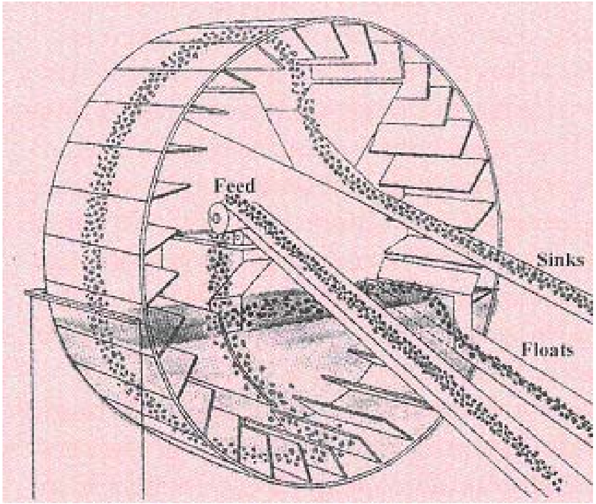


Fig.42- Heavy medium separation

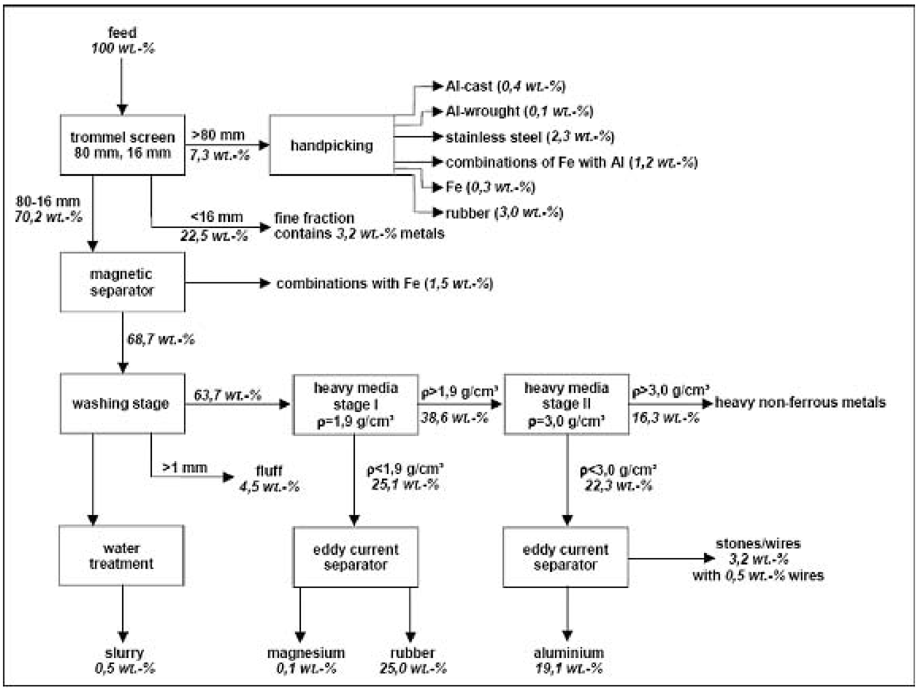


Fig.43- Flow-sheet of a sink-float plant for the processing of non-ferrous metal

Despite the worldwide application for long time, there are shortcomings with respect to the heavy medium separation such as introducing pollutions by oil and fine dirt released from the surface causes changing in density, viscosity and stability of the suspension. Furthermore, wet particles can carry fine suspension particles with themselves when discharging from equipment. Thus, extensive auxiliary equipment is needed to recover heavy medium and to reduce the losses and the continuously regenerate the suspension to avoid excess contaminations. The medium is recovered by rinsing the separated products with water If magnetite or ferro-silicon is used as the suspension wet magnetic separation can be used for regenerating. However, in the case of non-magnetic material, like barite, as the suspension material then hydrocyclones are used for medium recovery. Losing medium in HMS is costly and the average medium losses during processing of end of use vehicles or other appliances vary between 4 and 10kg per ton of processed material that contribute to the operational costs. Another major drawback for HSM, or in fact other gravity methods, is unavoidable misplacement of off-gravity materials, such as hollow metal pieces, insulated copper wires and other undesirable particles.

As mentioned above the main use of heavy media/sink-float separation in recycling of obsolete cars and other goods is mainly to recover aluminum. Sink-float plants are either in association with shredding plants or separately. Therefore, after separating ferrous fractions from shredded materials the non-ferrous fraction is sent to sink-float plant. For separating aluminum, magnesium, and other non-ferrous metals from each others at the first step the raw material screened mainly into three fractions, i.e., >80mm, 16mm< < 80mm, and <16mm.The coarse fraction is handpicked aiming to separate aluminum and its alloys, stainless steel, iron, and combinations of iron with aluminum. The latter usually goes back to shredding plant for further liberation. The fine fraction is sent either for handpicking (export to the Southeast Asia) or to other separation process suitable for processing finer particles, like shaking table [37].

The fraction between 80 and 16 mm is processed in the core element of the sink-float plant, a two stage heavy media separation. During processing of this size fraction, material is cleaned by washing to omit the problems with respect to dust and fine particles attached to the metal surfaces. In addition, materials finer than water, like light fluff, are separated by feeding the water overflow from the washing stage, however, this water will be treated and fed back to the circuit. The first heavy media stage has a density about 2 t/m^3 is used for magnesium separation. However, the float fraction of this stage containing magnesium and plastics will be sent to eddy current separator for separating magnesium from non-metallic materials. The sink product from first heavy media separation stage will be fed for further separation to the second stage in which a medium with a density about 3 $t/m^3$is used for floating aluminum and stones. The heavy fraction from the second stage of media separation is then processed for recovery of zinc, copper, brass, lead as well as stainless steel. The floated aluminum and stone fraction will be also fed to an eddy current separator in order to produce a clean aluminum fraction that is the main product of sink-float plant.

Distributions for aluminum contained in obsolete cars after shedding and in the non-ferrous metal fraction after processing in the sink-float plant are shown in Fig. 44.

As it can be seen from the Fig.44, about 81% of total aluminum in obsolete cars are found in non-ferrous fraction. The steel fraction recovered from the obsolete cars contains about 0.6% of total aluminum and about 18% of the aluminum is gone with the shredder residue (ASR). Further process of the non-ferrous fraction results in recovery of aluminum in the forms of Al-fraction and other forms and just 1% of aluminum is lost as in fluff and rubber fraction. As it can be concluded from the Fig.42, about 67% of total aluminum can be recovered as the Al-fraction in sink-float plant.

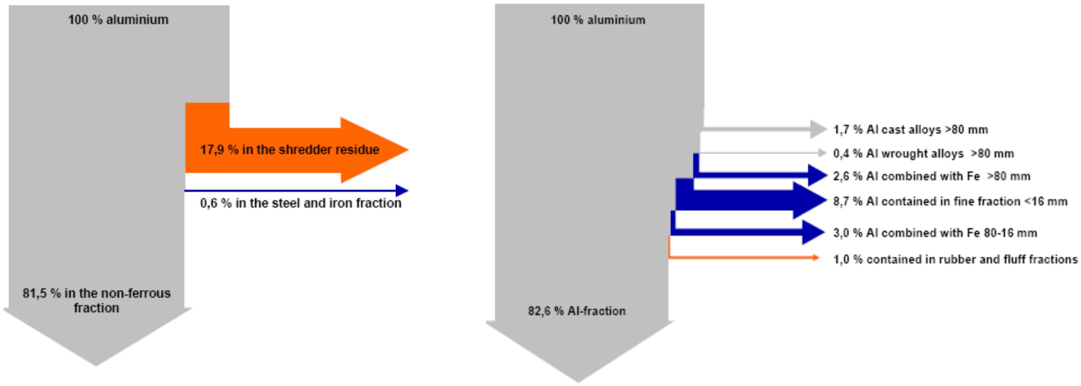


Fig.44- Distribution of aluminum contained in obsolete cars (left) and in the non-ferrous metals fraction after processing in the sink-float plant

Analysis the data from the sink-float process indicated that the average cost for the process is about 207 US$/t and the revenue will be 309 US$/t that finally leads to 68 US$/t of profits. This calculation for the profits is based on assumptions concerning the prices for the products and a non-ferrous metal fraction containing 45% of metals. Table contains of some technical and economical data for a sink float plant in Germany.

Table 2 – Technical and economical data regarding sink-float operation plants in Germany

Economic data	
Investment	About 1.4-1.7 Million US$
Operational cost	92-103 US$/t
Price for raw material (non-ferrous fraction from shredding plant)	172 US$/t (103-287 US$/t)
Disposal cost of waste	92 US$/t
Revenues	1.15 US$/kg of aluminum & 0.85 US$/kg of other non-ferrous metals
Recovered aluminum per tone of raw material	196 Kg/t
Recovered of other non-ferrous metals per tone of raw material	191 Kg/t
Technical & ecological data	
Energy needs	15-18 kWh/t
Solid waste arising	325 kg/t (rubber, fluff, etc.) & 5 Kg/t of hazardous waste
Area covered (sealed)	24000 m^2, including storage
Used water (fresh water)	$0.085 m^3/t$
Sewage water	Varying (based on rainfall)
Magnetite consumption	2-2.5 Kg/t
Ferrosilica consumption	2-2.5 Kg/t

Due to the fact that the price for non-ferrous metal fraction is based on the metal content, the sink-float processing is a kind of wage-processing. Therefore, the process is economically feasible as long as the framework, especially the possibilities for the deposition of the occurring waste materials, is reasonable. According to some technical data, the demand for energy in sink-float process is about 15-18 kWh/t and the consumption of heavy media amounts to 2-2.5 kg/t magnetite and ferrosilica respectively. However, according to the close water cycle the demand for fresh water is estimated to be as low as $0.085 m^3/t$. It is also estimated that on the basis of raw material containing 45%, or even little higher, of metals during sink-float operation an average of 325 kg of solid waste material arises. This amount will be even more if the metal fraction in raw material fed to sink-float operation contains less than 45% of non-ferrous metals.

Some Other Technologies: New technologies have been developed or being under development that can be considered for recycling of materials. One example would be the development of eddy current separators. Using conventional eddy current separators was found to be beneficial for particles bigger than 4 mm, however, Steinert GmbH is nowadays offering an eddy current separator capable of separating particles down to about 1mm. Obviously, further development of this technology should focus on measures to increase capacity [6].

Magnus separator: To achieve the above goal wet eddy current separator based on Magnus effect was designed at Delft University of Technology with a possibility to separate electric and electronic scrap, to removal of metal particles from incineration bottom ashes, and to concentrate of alluvial gold down to particle sizes of 0.5mm. By using wet eddy current separator wide variety of material mixtures can be treated in which a conductive non-ferrous metal such as copper, zinc, or gold can be separated. A simple experiment with a copper cylinder, a ramp made of cardboard and a small transparent vessel filled with water shows a force of surprising strength (Fig. 45)

It can be seen in Fig.45, while the cylinder rolls down the slope, its angular velocity grows proportional to its speed. As it then enters the water, its rotation creates a lift force that eventually reverses its horizontal motion.

The Magnus effect has been known for a very long time [38], yet apart from manipulating the trajectory of the ball in sports like golf and baseball, few applications of the effect have been recognized. It was recently discovered, however, that the effect can be used to separate fine non-ferrous particles from a mixture, for example pieces of copper and aluminium from the bottom ashes of municipal waste incinerators [39-40].

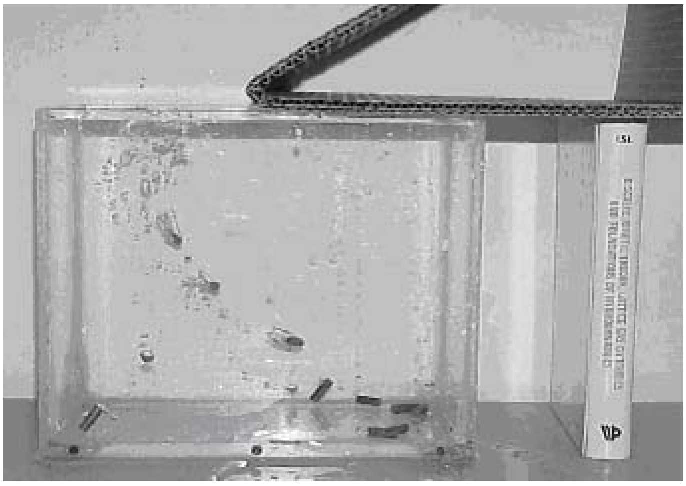
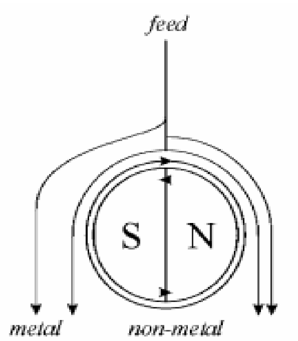


Fig.45- Magnus force (copper cylinders deflected by the Magnus effect in water)

The principle of this kind of separation is shown in Fig.46. As it can be seen from the figure, rotating particles are deflected by the Magnus effect as they fall through the water. By selectively bringing the non-ferrous particles into rotation with the help of a spinning magnetic field, these particles are removed from the feed stream. The particle size for a wet Magnus separator is typically between 1 and 10 mm. Particles smaller than 1 mm have a relatively small terminal velocity which makes the process less attractive, while particles larger than 10 mm can easily be recovered by standard eddy current separators. In principle, Magnus separation can also be applied as a dry process. Since the terminal velocities of particles are higher in air than in water this could be an option for smaller particle sizes, typically from 0.2 mm up to 2 mm. Several issues need to be resolved, however, in order to create a practical process. It is not clear, for example, how the material should be fed into the field region and whether the separation should be effected while the particles traverse the rotating magnetic field or afterwards



Note: in wet Magnus separation non-metal particles are accumulated in a bin close to the drum magnet if the feed particles traverse the rotating magnet, otherwise, this is the metal fraction that accumulate in a bin close to the magnet. raw material is fed when

Fig.46- Principle of wet Magnus separation using a dipole magnet rotating within a counter-rotating shell. The shell transports most of the non-metal particles to the right.

In practice rotating magnet induces selective spinning in well-conducting particles, usually non-ferrous metals that are present in the feed mixture. Therefore metals can be separated from non-metals or, more generally, from poor conductors. This should be noted that for particles bigger than 4 mm in size the direction of rotation of the magnet is very important. There is also an eddy current effect that opposes the Magnus effect in one direction and adds to it in other direction of rotation. Since this effect is negligible on particles smaller than 4mm, size fractions bigger than 4mm can be fed into either side of the equipment. Therefore, in certain situation, there is possibility for increasing the capacity of the separator by feeding the equipment from both sides. On the other hand, for the feed consisting mainly of big particles that also contains magnetic materials, it is more efficient to introduce feed onto the top of the magnet rotor.
The availability of techniques to separate metal particles in the range size of 0.5 to 10mm opens the door for processing residues from wire chopping, electric and electronic scrap, fines from car scrap, as well as foundry sand and even contaminated soils. Another possibility is the use of Magnus separation for treating the fine fraction of incinerator bottom ash to recover metals.

14-4- Automatic Sorting:

Progresses in advanced characterization and identification technologies have led to emergence of new sensing devices in order to identify and sort different components based on their physical and chemical properties. Sophisticated more accurate and more reliable sorting equipment, then, developed on the basis of these characterization and identification techniques in combination with advanced computing technology, especially over the 1990s. During 1980s, attempts to design fast and sophisticated sorters by using microcomputers were failed due to limited data processing rate. However, the problem was solved through special interfacing and soft-wear

development during 1990s. Nowadays, consistent, adaptable and cost-effective sorters are made and available to use for different purposes [21-22].
Numerous physical features of objects can be used either individually or in various combinations in order to enhance processing rate and sorting possibilities. Based on new technologies available, sorting criteria can now be established by logging the data for the desired product(s) directly on production machine. In other word it is possible to teach the machine which particles are acceptable and which ones shall be rejected. Several different programs can be easily established for sorting purposes since the sorting parameters and their criteria are soft-wear based. These soft-wears make machine extremely user friendly with many automatic checking features.
Sorting machines are generally able to characterize and sort particles with the range of 2 to 300mm, which matches the size range produced by shredding of end of life consumer products. However, for recyclables automatic sorting is not generally applied. Despite the availability of various sorting systems, the use of sorting techniques for waste recycling is limited to automotive removal of metals by metal detectors, colour sorting of glass cullet, and some colour sorting applications in processing non-ferrous metals and plastics.

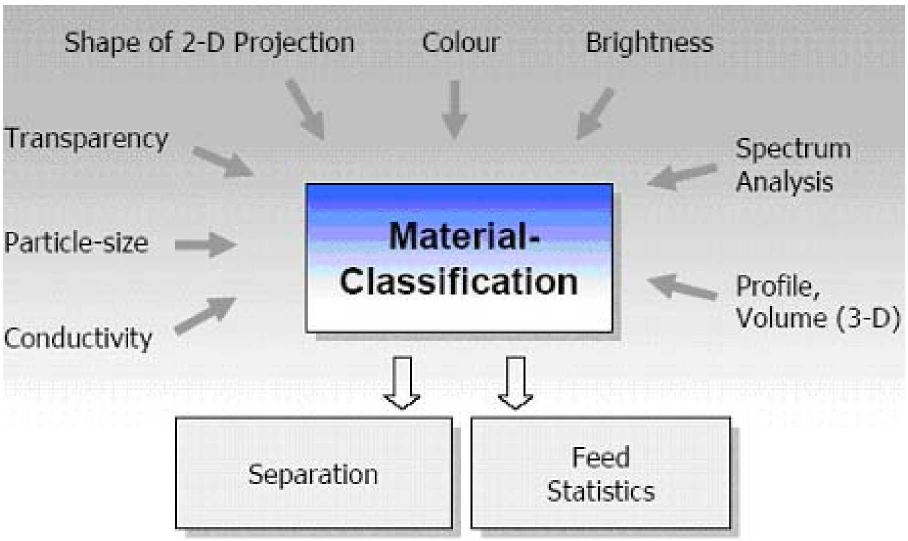


Fig.47- Material feature that can be collected for identification and sorting

A comprehensive study on application of sorting techniques and their applications revealed that sorting techniques offered today have capability to sort a wide range of minerals and wastes. Optical sorting in particular has a great potential due to the advances in optical technology. Optical devices are able to characterize particles not only by colors but also buy shapes, structural analysis, hue, and brightness. More than 40 millions of colors combinations can be recognized by the new developed optical systems. Moreover, sorting systems based on laser has found their way to characterize and sort wide range of metals, plastics, and minerals and food. Laser based sorting machines are nowadays in practice for sorting and separating different aluminum alloys and plastics in waste recycling industry. However, X-ray based sorting devices, i.e., sorting machines base on XRD and XRF spectroscopy can be other choices. However,

X-ray microthomography has been used for particle size and shape characterization and seems soon will be an accurate method for particle characterization and sorting.
It is also obvious that using multi-sensing system makes better identification and recognition of the pieces. Therefore attempts have been made to develop new sorting machines in which two or more sensing systems are combined. New technologies now are available that make use of multi-sensor systems. Machines having both optical sensors and metal detectors are nowadays in the market. Therefore, one area for further development of the sorting machines should be to find the best combination of several sensing systems for different applications. Then, more efficient and accurate sorting of mixed materials can be provided by using machines having multi-sensing recognition systems.
With respect to machine configurations, the mechanics of sorting processes are divided into four subcomponents as shown in Fig.47. All automated sorting machine are designed accordingly. These subcomponents are presentation or feeding, sensing or recognition, electronics, and separation.
Although, the sensing division or component is paramount important and provides the information for sorting and separation of different particles, but for successful sorting all components of the machine must perform accurately and efficiently.
First of all presentation or feeding system must withdraw feed from some bulk source, orient the particles on a sufficiently separated basis to allow examination and carry the particles through the sensing zone to the separation position. Sensing zone must be designed properly to examine particles individually. Seeking for differences among the properties of the particles in raw material must be done and identification of each particle must be completed by sensing system. Electronics part of machine must be bright enough to interpret the data received from sensing zone and make the decision in order to recognize wanted from unwanted particles. At the same time the electronics must control the separation zone too. Finally in separation zone accurate removing/collecting of the selected pieces from the bulk of the feed must be accomplished. The brain of sorting machines is sensing or discrimination techniques that are applied for determining a certain property or combination of properties that will distinguish specific material pieces from others in a raw material assemblage. Based on the complexity of the materials being examined it may be needed to sense more than one property or a ratio of specific characteristics. When sorting process is employed for treating raw materials, difference(s) in some detectable property must exist. Furthermore, since individual pieces are examined, sufficient liberation must be provided in the feed to allow such discrimination. Finally a sensing device must be able to recognize the designated distinguishing features and produce an electrical signal to indicate that the identification has done.

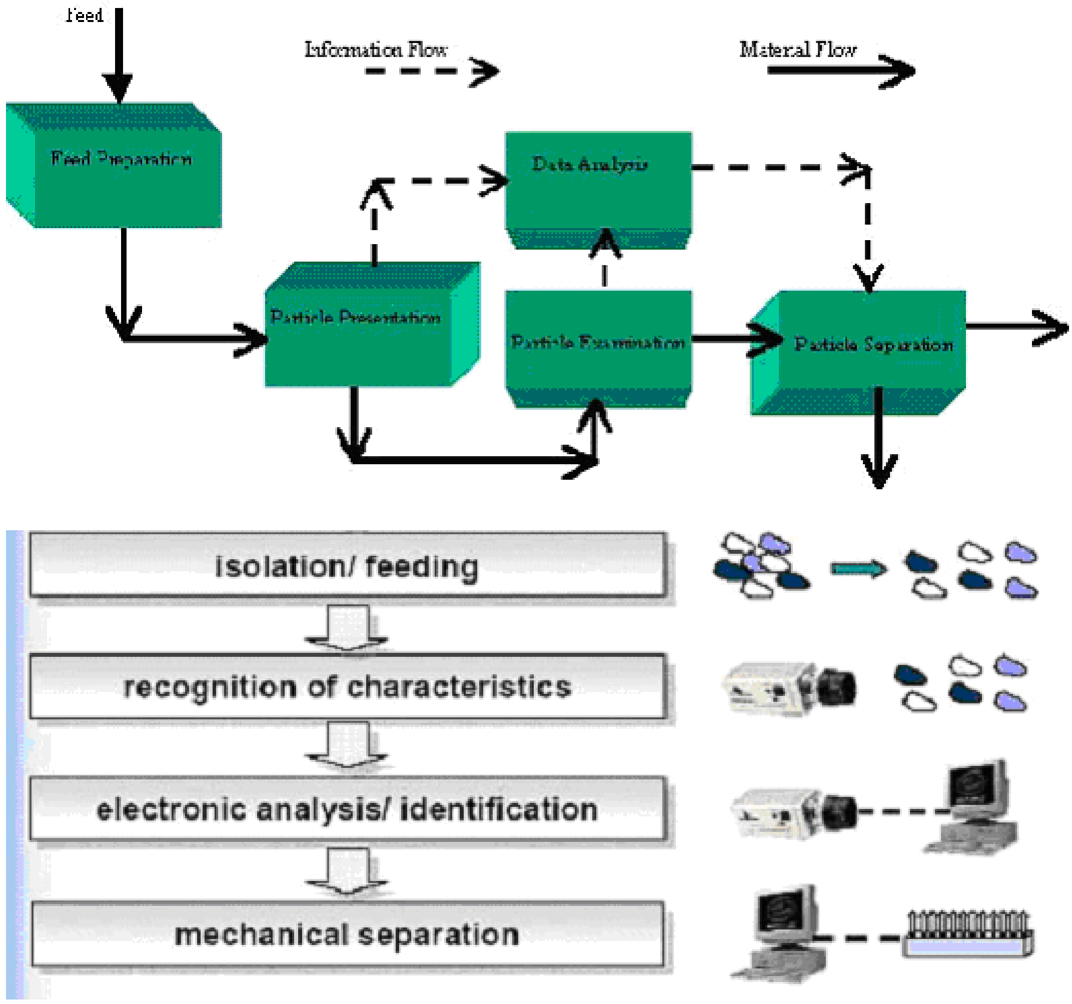


Fig.47 - General configuration of sorting machine (top) and sub-process for sorting

Before a sensing system becomes operative, a detectable property and a device for discriminating that property must exist. Therefore sensing is presently restricted to properties detectable with existing devices. However, the environmental regulations are nowadays another determining factor in order to choose a proper discriminative technique. So an environmentally sound and economically viable detecting method must be chosen. General perspective on sensing can be achieved by relating the sensing to the electromagnetic spectrum. Table 3 indicates the relation between the sensing device and the sensed property.

Table 3 - Common sensing methods for sorting and related sensing device

Property to be sensed	Sensing Device
Natural Radioactivity	Scintillation counter and pulse analyser
Induced Radioactivity	Scintillation counter and pulse analyser
X-ray transparency	Scintillation counter and pulse analyser
X-ray fluorescence	Phototube
Ultraviolet fluorescence	Phototube
Visible reflectance	Phototube
Visible transparency	Phototube
Differential heating	Infrared scanner
High voltage conductance	Resistance/conductance or current flow network
Low voltage conductance	Resistance/conductance or current flow network
Laser induced fluorescence	Optical receiver (fibre optic)
Laser induced plasma	Optical receiver (e.g., photodiode)
Laser light scattering	Optical receiver
NIR identification	Reflected light scanner
SG (Specific gravity)	Gas pycnometry

Sorting in Recycling: For sorting machines, nowadays, several industrial applications are found in mineral processing and recycling. Apart from colour detection, more advanced techniques were developed for metal alloy and plastic identification. Examples are the Metallgesellschaft system for aluminium alloys sorting based on laser ablation and successive emission spectroscopy, or the laser induced back spectroscopy (LIBS), used by Huron Valley Steel Scrap, laser induced florescence (LIF) for identification and sorting mass product, as well as new electromagnetic identification and sorting for different metals. However, due to advances in optical sorting by using sophisticated colour cameras and image analysis system, as well as X-ray image and spectroscopy make it possible for accurate and fast identification of different objects and thereby the use of optical sorting machines for mineral processing and waste recycling. Some recent, accurate and reliable sorting systems that are used or have potential to be used in waste recycling are named and described:

X-ray fluorescence: Practical current use of x-ray fluorescence as a means of discrimination is its application to diamonds. Feed is exposed to a beam of high-intensity x-ray in complete darkness. Photomultiplier tubes are focused on this irradiation area and visible light emitted by the diamonds under the stimuli of x-ray is believed to be due to the ionisation of the air surrounding the diamond particles.
Such a system was developed in which mineral irradiation is achieved by bombardment of the pieces with either high–energy electrons, usually derived from radioisotopes, or with x-ray. To prevent the biological effects from scattering and in order to direct shielding, it is needed to direct the x-ray to the irradiation point a careful shielding system must be provided. Sensing devices are usually focused on the same point or in the same plane as the irradiated devices because of immediate emission of the materials passing through the x-ray irradiation. Pieces having high-density will interrupt the x-ray to a greater extent than low-density pieces and thus different electrical signal may be derived.

Another system based on x-ray fluorescence using high-energy electrons derived from radioisotopes has been developed. Some electrons are scattered and those that penetrate produce beam directed to a scintilla-meter. To identify the x-ray beam emitted from the sample a pulse height analyser can be instructed. This technique is only suitable for detecting elements above atomic number of 36 due to the fact that the x-rays emitted from low atomic number elements are readily adsorbed by air.

Two types of analyser based on principal of x-ray fluorescence, i.e., Beltcon 200, and x-ray back scattering, Beltcon 100GS, have been developed by Outokumpu Oy Electronics Co. The isotopes used in these analysers are americium-241 and caesium-137. The capability of the analysers for continuously analysing the total metal content of the bulk solid materials directly from a conveyor belt has been proven by the X-ray. Especially, good result has been achieved with the elements having the atomic numbers between 20 and 30, e.g., Fe, Cr, Mn, Co, Cu, Ni, and Zn [17].

By the beginning of the 1980s the successful development of on-line analytical equipment for separating lumpy radioactive and non-ferrous ores enable the investigators to concentrate their efforts on the creation of an industrial unit using x-ray fluorescence for sorting metals according to their chemical elementary composition. X-ray fluorescence method, which in some cases is called as x-ray radiometric, depends on differences in the energy and intensity of the characteristic radiation of individual chemical elements irradiated by soft or x-ray radiation generated from tubes or independent radioisotope sources.

When a piece of material is irradiated by high energy electrons derived from radioisotopes, some electron are scattered and those penetrate produce characteristics x-ray from the piece and are sensed on a selected beam directed to a detector, e.g., scintillometer. A pulse height analyser may be also used to identify the x-rays emitted from the sample. On the basis of the x-ray fluorescence or x-ray radiometric technique different machines have been assembled. Nowadays this technique was found useful for separating different scrap alloys, especially different aluminium alloys. Recently new x-ray fluorescence sorting machine has been developed and patented which has a capability to identify different pieces within few milli-seconds. The sorting is accomplished within 15 milli-seconds by air ejectors using 60-90 psi air pressure. Fig.48 depicts the general configuration of the x-ray fluorescence sorter for separating and sorting different aluminium alloys.

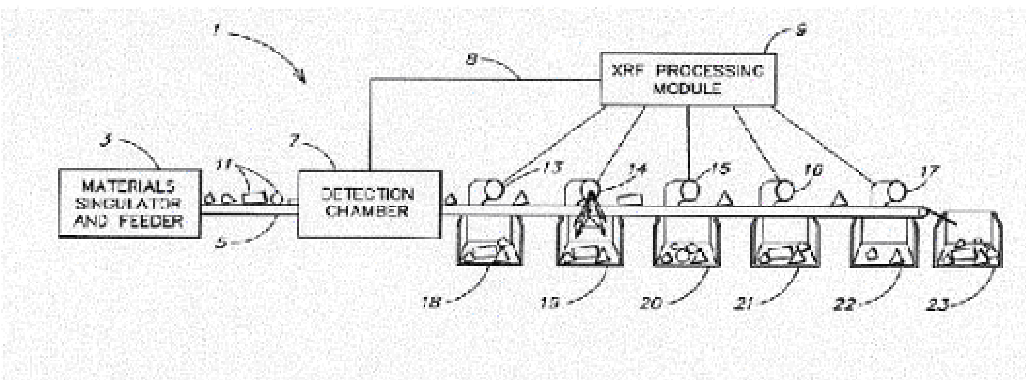


Fig.48- High speed XRF sorting apparatus

Laser Sorting: Laser is one of the most fantastic and versatile tool invented, although its story began with luminescent phenomena, which have been always at the centre of curiosity of mankind since ancient time. However, the important aspects of the luminescence have been discovered in the 19^{th} century, and only during the 20^{th} century basics and technical knowledge coalesced for the realization of the first laser device. During the last century after the first step of understanding laser was passed the field exploded almost exponentially.
In order to identify different materials using laser, different features of the laser can be employed. From chemical analysis point of view it is possible to identify the chemical composition of a matter by laser. For example laser induced breakdown spectroscopy (LIBS) and laser induced fluorescence (LIF) are a well established, simple and rapid analytical technique for performing elemental analysis.
Laser light can be also employed as an optical tool for characterizing different materials. In fact laser is scattered when hitting different materials. Each object has its own optical characteristics and reflects laser lights in a different way, e.g., some particles reflect the laser while the others defuse the laser light. In fact optical emission spectroscopy for sorting minerals, metals, scraps and fruits is established based on the respond of different materials to a laser beam when the beam hits them. By collecting the emitted beam from that surface of the material which is irradiated by laser the identification of the surface is provided. Another area where laser beam can be employed for characterization of different materials is to induce heat on material's surface by laser beam radiation. The method has been used for identification different plastics. In fact based on adsorption coefficient, thermal conductivity and thermal capacity of the material the temperature distribution on its surface can be scanned and then material can be recognized.
Laser optical sorting (based on scattering): As shown in Fig.49, in this method a laser beam is chosen to emit light at specific spectra range. This laser beam is reflected by a revolving multi-faced mirror onto the material. That part of the beam which is reflected back by the material surface passes on an adjacent facet on this rotating mirror drum, and is finally picked up by the photomultiplier tube.
The optical signals are converted by photomultiplier to electronic signals that are then transmitted to the electronic processor.

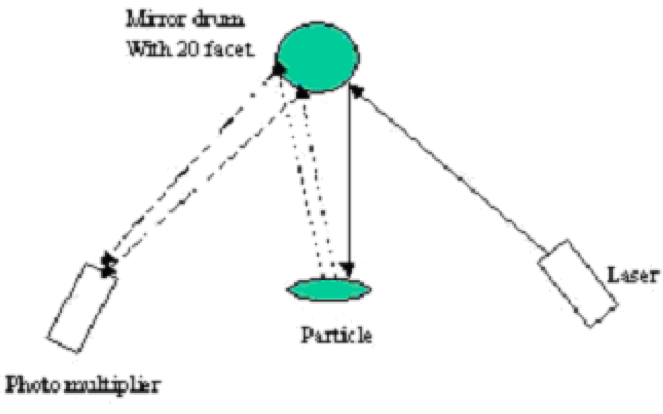


Fig.49- Laser scanning principle for laser sorters

The laser light also is scattered when hitting the product. As an example; a potato and a stone are scanned. The stone (A) will reflect the laser light, with none or no scattering, while the potato (B) will defuse the laser light.
Each object has its own optical characteristics and reflects lights in a different way. The operator can set a threshold zone for each product.
Based laser scattering method different laser photometric sorters have been manufactured. Examples are the Ore Sorters laser photometric sorter [42] for minerals and Barco laser sorter [43] for ore and food characterizing and sorting.
Based on laser scattering optical sorting of coal from associated minerals and rocks has been carried out at Callide Coalfield Pty. Ltd., Australia. The tests results, using Barco's laser optical sorting machine, revealed the possibility to sort coal.
In fact laser beam can rapidly scan a piece of product to determine the surface characteristics. Though, the laser is a concentrated source of light, the system can only view the surface of product and tries to determine the consistency of the entire sample from the scanned surface. Then the surface characteristic of each piece is evaluated by using a series of pre-programmed criteria to determine acceptability.
The size fraction of the feed for laser sorting tests was –75mm +8mm, however; different particle size fractions were examined, e.g., +9.5 mm –25 mm, +25 mm –50 mm, etc. Tests results indicated that moisture has effect the process by causing fine dust to adhere to the larger particles, and thus create an erroneous message.

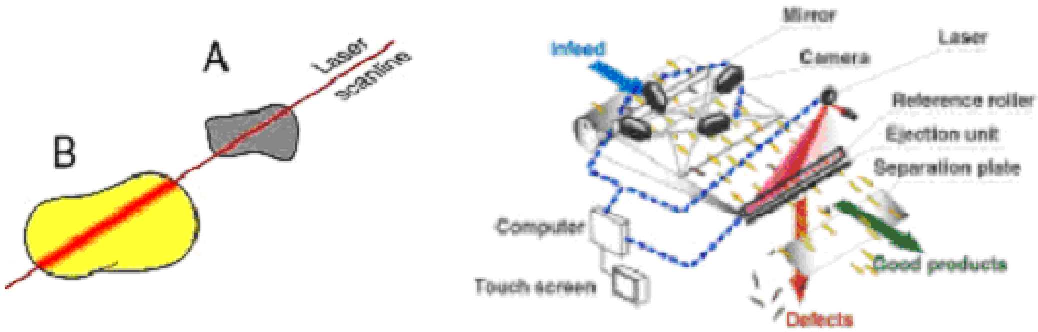


Fig.50- Laser scattering method for material sorting (left) and Barco laser sorter (right)

Simplicity of the process, no need for water and therefore no need for dewatering of the final product, minimal manning requirement, low operational cost, and reduced environmental impacts are the main advantages with respect to the use of laser sorting for coal beneficiation. However, the process is not suggested for fine particles. The optimum size for best performance was found to be for particles > 25 mm [44].
Laser scattering method also was found very efficient for sorting different scrap alloys. Especially different aluminum scraps can be successfully sorted from each others using laser based sorting machine.
The method of sequentially sorting of material in real time into output bins where each piece has a composition defined by a plurality of control elements is developed by Gesing et al., [45]. The method makes use of laser induced back scattering (LIBS) technique to identify different aluminum alloys. Fig.51 depicts the general configuration of the sorter.

There are some advantages that can be gained using sorting machines for aluminum scrap, especially when LIBS technique is used. The first is possibility of sorting aluminum scarp into at least 2 fractions, i.e., wrought and cast alloys. There will be no longer down-cycling of valuable wrought alloy into cast aluminum which means added value to the aluminum fractions. And, old scrap from shredding can be used for production of wrought-alloy at remelter or directly at the production.
The laser sorting technique for replacing the handpicking of the non-ferrous metal from auto shredders was first introduced in 1990. The process make use of atomic emission spectroscopy induced by lasers to identify scrap particles and sort them with adequate separation system into main fractions of Al, Zn and Cu alloys, as well as steel and lead [46].

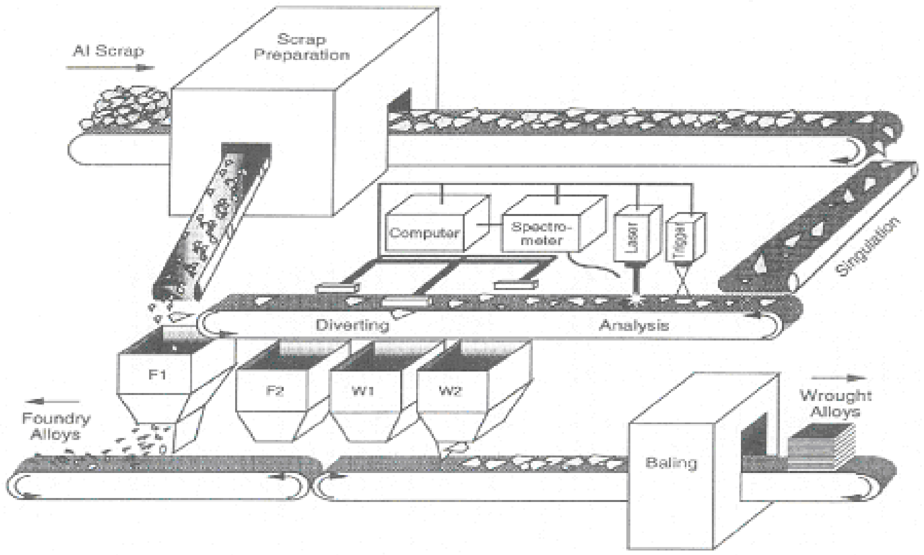


Fig.51- General configuration of laser based sorter for aluminum scrap and other materials

However, the system, especially analytical detector, was further developed in order to have more efficiency and higher reliability, less maintenance problem, and minor sorting errors. The developed laser based sorting machine was found very beneficial to sort different aluminum alloys. The excimer laser was used as a source for radiation the particles and fiber optics coupled with three spectrograph unites were installed to receive the emission from particle surfaces. The analytical information detected by the optical system are processed and used as a tool for particle characterization. The process showed successful identification and sorting of different aluminum alloys. According to Saltter just 1.8% of the particles could not be identified by the system [47].
As shown in Fig.52, phototubes (photomultipliers) are used to detect and monitor the emitted laser from the surface of the material after they are radiated by laser beams. Laser induced optical emission which makes use of laser beam to identify different alloys, especially aluminum alloys, was also tested by Rosenfeild and his colleagues [48-49].

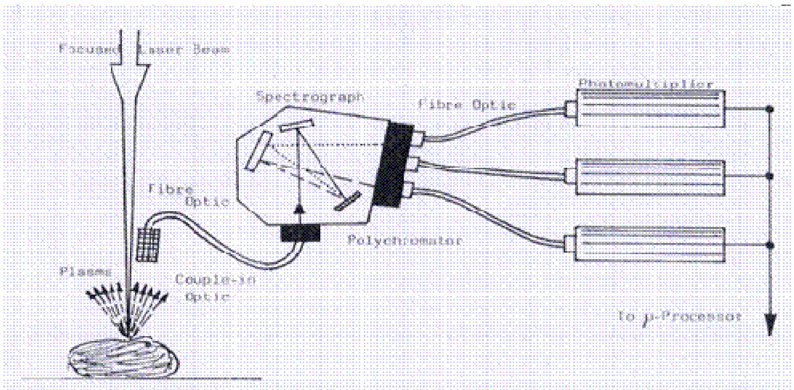


Fig.52- Laser induced plasma and phototubes for detecting emitted beams

Schematic diagram of the process is shown in Fig.53. Using Nd:YAG pulsed laser to irradiate the particles at specific wave-length and then monitoring the emitted light by the photo tube are the basis of the analytical system for characterizing different alloys. Proper scrap preparation was found as the key for a successful sorting procedure. It means to guarantee the best identification and sorting a narrow particle size fractions and clean surfaces of the material to be sorted are needed.

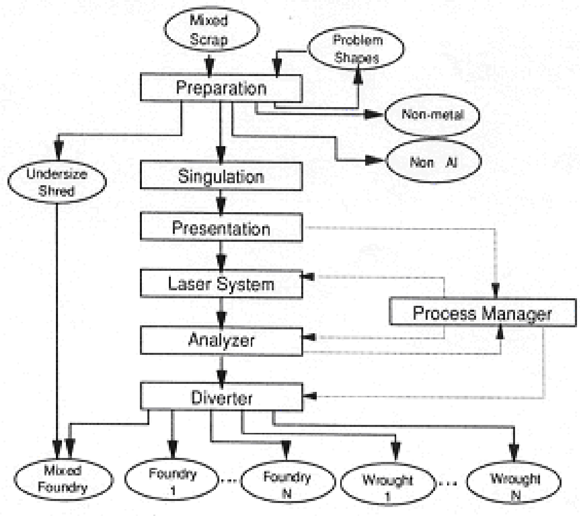


Fig.53- Schematic process flow for the alloy sorting system

Laser induced heat: Due to increasing efforts for the realization concerning plastic recycling, a method has been developed for efficient automatic identification and sorting of different plastics using laser beam. Within a few milliseconds a spot on the sample, which has to be identified, is heated by a laser beam, however, based on different and specific chemical and physical properties of the examined sample different temperature distribution on the sample's surface can be scanned. This identification can be carried out by an infrared thermografic system.

CO_2 laser is usually used for targeting the objects. This laser emits monochromatic infrared radiation at a wavelength of 10.6 µm. Energy amount of 4.6 J/cm^2 is projected onto the sample for few milliseconds with a laser capacity of 240 W, and a non-concentrated beam diameter of 8 mm. Within 0.01 s, material specific surface temperature of 300ºC can be achieved, with plastics [50].
Non-contact absorption of thermal energy, high velocity of energy adsorption due to short laser pulses, good reproducibility of energy adsorption, high parallel emission of infrared radiation, low interaction with environmental air, are the advantages using laser beam for characterizing different plastics.
When the laser radiates a surface the beam is scattered. The scattering processes, which are responsible for the reduction of radiation intensity, are due to structure of molecular chain of the plastics, crystalline region in the amorphous phase and aggregates that are embedded in the polymeric matrix [50].
Depending on the properties of the radiated materials there are different adsorption coefficient concerning the interaction with CO_2 laser. In addition, adsorption of laser beam causes heat distribution in the samples. This heat distribution is different for different samples based on sample characteristics and its thickness.
In fact heat distribution is dependent upon the temperature gradient, specific thermal properties and thermal conductivity of the sample. Therefore, plastics having different thermal conductivity, adsorption coefficient and thermal capacity, can be identified and thus sorted. The general configuration of the apparatus and its principle of the laser aided material identification are shown in Fig.54.

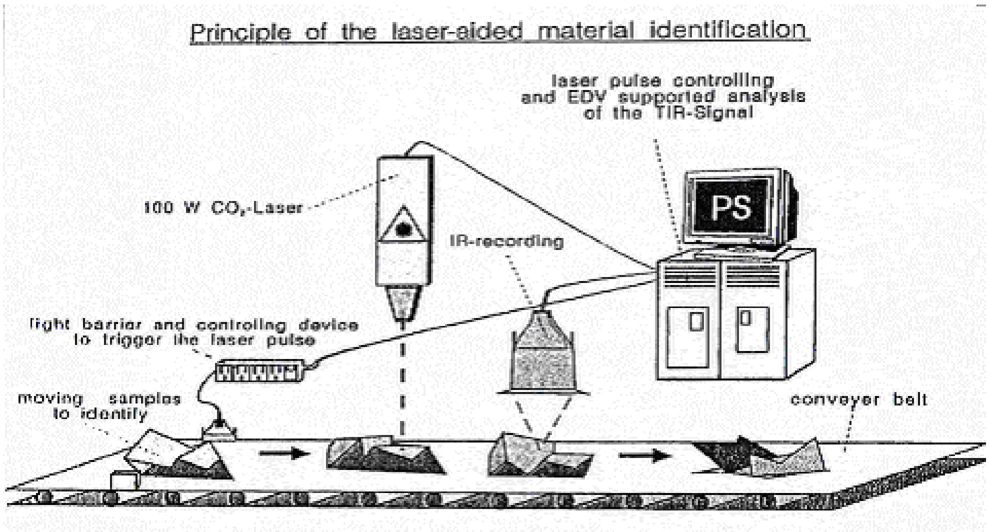


Fig.54- General configuration and principle of the material identification and sorting

Fig.55 shows the transmission grades of different plastic samples as a function of the material thickness. Generally, more surface adsorption than volume adsorption takes place because of relatively short adsorption length in the term of micro range. In proportion to the thickness of the material, only a very small surface layer of the radiation material absorbs radiation.
Using laser power only about 60 W the surface temperature of the plastics are heated up to 260ºC within 0.01 s. The temperature curve is material identification. Therefore by monitoring the surface temperature of the plastics within 0.01 s the great differences

between the plastics in the stream of wastes are remarkable. Since the energy input is small the only little damage may occur on plastic surface. In addition thickness of the plastics has no any role in plastics identification.
There are other Laser spectroscopy identification techniques that can be used for characterizing and sorting different components. For example physical property of matter can be exploited in laser induced fluorescence (LIF) analysis. The photoluminescence of different elements can be exploited by this method. Fluorescence is defined as the short-lived form of photoluminescence in which matter emits visible radiation during and after irradiation with light. This fluorescence generally is of a longer wavelength than the irradiation. The fluorescence of matter can be described by four main items, i.e., the adsorption spectrum, the emission spectrum, the decay curve, and the quantum efficiency

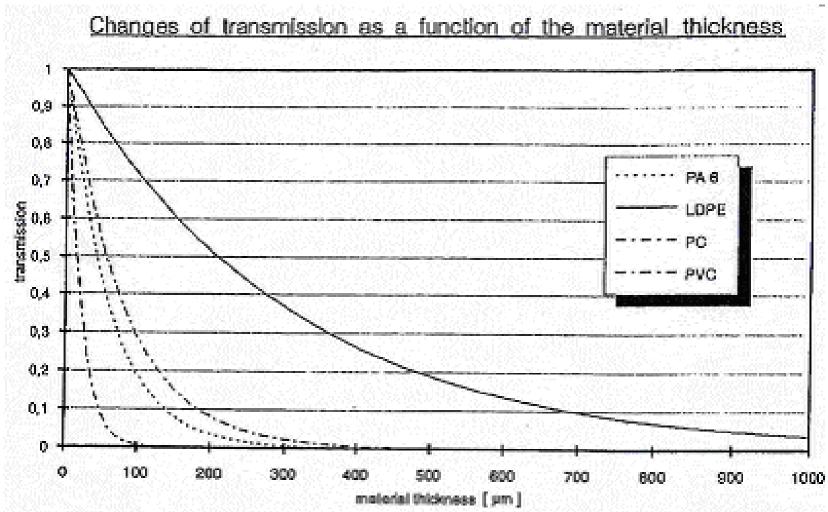


Fig.55- Change of laser transmission as a function of material thickness for different plastics

The adsorption spectrum indicates the fluorescence intensity in a fixed spectral band as a function of the excitation wavelength, while the emission spectrum shows the fluorescence intensity at varying emission wave-lengths for a fixed excitation wavelength.
Laser induced fluorescence is a toll enabling to measure and evaluate the quantum efficiency, and to find the important fluorescence signals in the upper UV range when materials are irradiated with deep UV laser light. In fact different rocks, different ores, or even ores of different degrees of oxidation, and ores of different degrees of alteration fluoresce differently. Therefore different rocks and minerals, even one mineral from different resources having different impurities in their crystal lattice, or different alteration degrees can be identified by laser induced fluorescence technique. However the shortcomings of the fluorescence analysis, including LIF analysis are realized as [51]:

■ LIF is a special form of optical sampling that is limited to what can be seen on the surface of the investigated material. Thus, any typical coating will impede the identification of the material proper

■ photoluminescence in minerals is predominantly caused by minute quantities trace elements that disturb the electromagnetic field force in the crystals and facilitates an electron shift higher energy levels by electromagnetic irradiation, i.e., light, and the subsequent luminescence during the electrons return to their initial energy level. The presence of trace elements varies from one deposit to another; therefore, minerals from one deposite may fluoresce totally differently than the same minerals from another deposit(s).

■emission spectra of minerals have half-band widths of 100 to 300 nm, and they often are the summation of spectra caused by various anomalies in mineral's crystals. Heterogeneous rock always produces cumulative emission spectra. Therefore, with the exception of two component mixture, it generally is impossible to directly relate the fluorescence intensity to one element or to one mineral present in a heterogeneous rock.

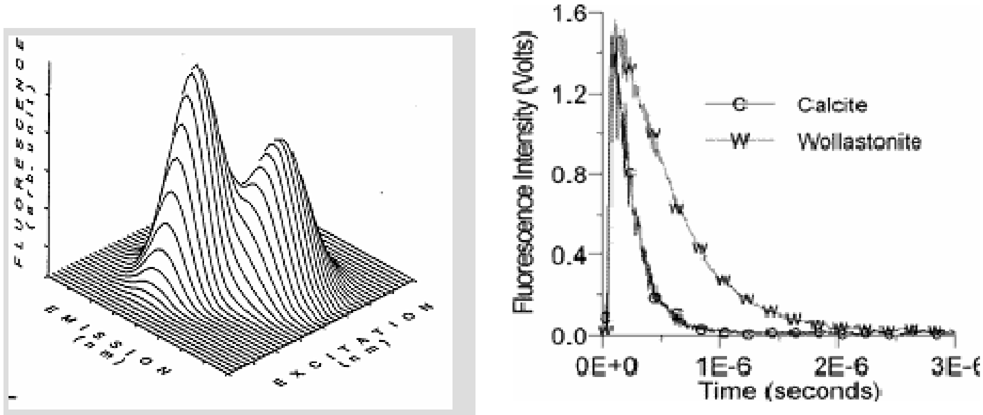
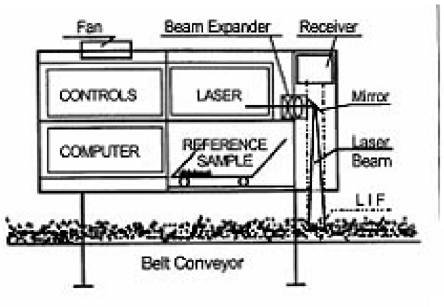


Fig.56 - Fluorescence as a function of excitation and emission wavelengths (left) and decay curves for calcite and wollastonite minerals fluorescence (right)

Laser induced fluorescence is a fast process. Duration of irradiation with pulsed laser is only a few nanoseconds and the duration of fluorescence of many minerals is generally less than 5 μsec, the total measurement takes less than 10 μsec. Irradiation at various wavelengths with different energy densities and observation in various spectral bands at different points in time leads to multiple fluorescence signals from a given mineral specimen or type of rock. These signals are the basis for a fluorescence signature typical for the specimen.

For identification of a sample first the LIF of the material is measured, the LIF signature is derived and compared with the reference data, the corresponding class is assigned to the material, and the information is passed to the processing management system or displayed for the operator. However, the quality of the reference data determines the accuracy of the method. LIF analysis can be used for quality control proper and for bulk sorting materials and ores, blending, and process control. Since 1998 a unit of LIF analyzer has been installed at Kiruna mine, Sweden, where the bulk sorting of low grade and high grade phosphorus iron ore is sought. Fig.57 shows the general configuration of the LIF analyzer.



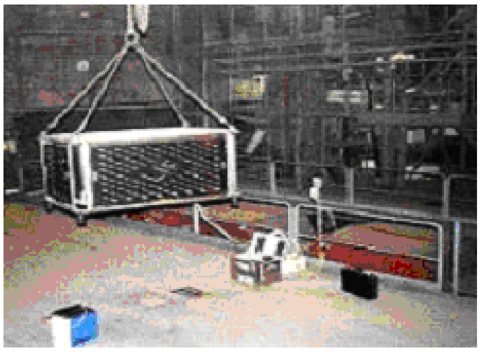


Fig.56 - LIF analyzer schematic (left) and real LIF analyzer (right)

Optical Sorting: Since the early 1970's photometric sorting machines has been used for eliminating waste material at very high rates of throughput. However, the most recent enhancement is the new photometric sorter technology brings the optical sorting possibilities closer to the capabilities of humans and in some cases beyond what the human may be able to perceive.

The first photometric sorters, derived from foodstuff sorters, were applied to black and white minerals such as magnetite and limestone vs. dark amphiboles. More advanced sorters were then developed specifically for minerals using fast computer chips and lasers as well as modern line scan cameras for more delicate applications where reflectivity differences were less distinct, or colors may overlap. During 1980s attempts to design fast and sophisticated mineral sorters by using microcomputers failed in particular because of limited data processing rate. This problem was solved through special interfacing and computer programming development during 1990s. A consistent, adaptable and cost-effective sorter technology was made available. Numerous physical features of materials to be sorted can be used either individually or in various combinations in order to enhance processing rate and sorting possibilities [52, 53].

The first series of optical sorting machines usually used the laser beam; however, because of the monochromatic nature of a laser the recognition of color variation is impossible. Several early generation of photometric sorters employed scanning video cameras

Today, data processing methods, that are not originally developed for sorting applications, enabled use of microcomputers for high-capacity sorting of different materials. Sorting criteria can now be established by logging the data for the desired products directly on the production machine. In other words, it is possible to "teach" the machine which rocks are acceptable and those that shall be rejected. Several different programs can be easily established for sorting purposes since the sorting parameters and criteria are software based. The software is menu driven, making the machine extremely user friendly with many automatic checking features. New optical sorters are more accurate and reliable since:

- the systems are based on a custom parallel computer.
- full color sorting is possible.
- several camera images can be taken and jointly analyzed.
- interfaces are optical and therefore very reliable.

■ PCBs are good industrial and newest design and allow custom machines.
■ the ejection systems are improved.
■ hardwear and software are flexible, being software configurable whenever useful
■ electronic is absolutely secure in use, not being critical for interference and disturbances.

Recognition of slight variations in surface properties along with brightness levels, color differences, and potentially small variations in colored stone are permitted, using high resolution optical systems. Today, line-scan video cameras are used not only for monochromatic applications but also for all types of optical sorting.
To add the aforementioned, sophisticated image systems are nowadays available to scan materials through the conveying system. Charge coupled device (CCD) and highly sensitive TV cameras are used to identify different particles based on their colors, their sizes and shapes. The sorting can work in either reflective or translucent mode. Furthermore, image analysis system is now available for perfect recognition of the objects. Particle recognition based on a complex shape and color analysis can be carried out by the image analysis system. Color analysis is done by converting video signals to RGB components and further to HSL, i.e., hue, saturation and lightness. Hue is the parameter related to the color frequency, however, saturation is decisive for color intensity and the light parameter, or lightness, is connected to the total intensity of pixel. The color analysis is done separately for each pixel. In addition to color, there are number of parameters describing material particles when using image analysis technique. For example, more than 50 parameters are normally used for particles shape identification.
Optical sorters having more than one camera are nowadays manufactured in order to improve the sorting efficiency. More information can be gained and therefore more accurate recognition can be done if each object is monitored from different sides. In addition the information gained by the first camera can be completed by the second, third, or even forth camera. In addition several cameras having different principles for material characterization may be employed within one system.
Some recently developed optical sorters that are used to characterized and sort different components in food, mineral, and waste recycling industries are listed as the follows. Based on author experience these sorting machines can be used in recycling different metals and plastics from shredding end of use consumer goods.

TiTech Sorting Machine: TiTech has recently developed a system for separation of different plastics based on color sorting. The system makes use of an advanced color camera to identify ever-increasing range of colors. The system is able to recognize and identify many different colors. For example, green or transparent from light blue. Fig.58 depicts the optical sorting machine manufactured by TiTech for separating plastics [54].

Principle: A fast-scanning spectrometer analyses the moving objects by reflected near-infrared light (NIR). It rapidly recognizes the unique molecular structure that identifies commonly used materials. The detectors generate a two-dimensional image and the software analysis determines whether the desired material, or combination of materials, is passing, the position of the object of the selected material and the size and shape of the object

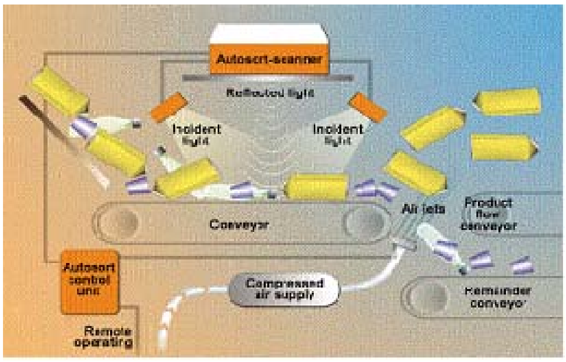
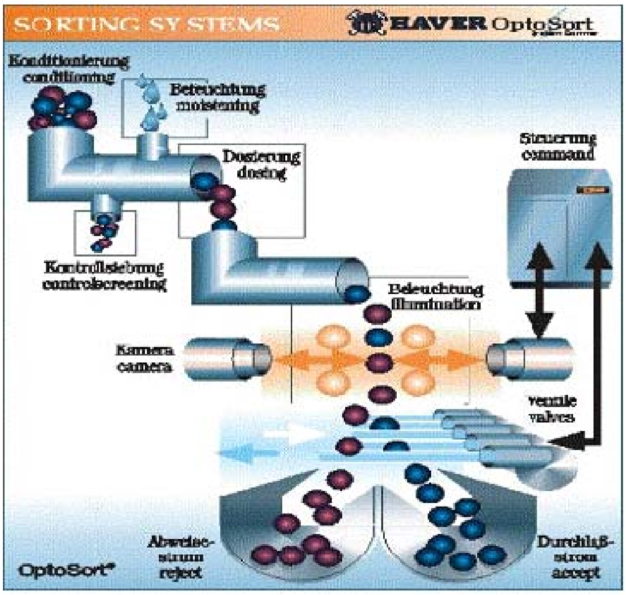


Fig.58 - TiTech sorting machine

Haver&Boecker Optical Sorter: the company provides a different optical system, which employs cameras to estimate particle size and shape. The system measures free-falling non-agglomerated particles that are passed randomly through a line scan camera. The used camera is able to measure 10000 individual lines and allocates the particles to 2048 size fractions. One or two high-speed RGB digital cameras are set and every electronic eye is calibrated to recognize distinctive characteristics of the particles as well as several million color shades. These two in combination with the control system are the basis of the artificial intelligence of the sorting unit [55].



Principle: Either one or two high speed RGB digital cameras are used to detect objects. Every electronic eye is calibrated to recognize distinctive characteristics as well as several million color shades and, in combination with control system, are the basis of the artificial intelligence of the sorting unit. By using self-learning software, adaptation to different product types is done in a matter of minutes. Optical signals up to 10 million pixels are evaluated by computer program and are converted into impulses. Pulses are transmitted to a jet strip to eject wanted/unwanted particles. Up to 4000 particles per second can be rejected.

Fig.59- General configuration of Haver OptoSort machine

Optical Sorter Based on Image Analysis: Another color based optical sorter with the aid of image analysis system has been developed by SINTEF. The sorter is able to separate minerals, scrap alloys, scrap wastes, etc., based on color, shape, or pattern recognition. Fig.60 shows general configuration of this optical sorting system. It is claimed that the sorter has a capacity of 500t/h by using a conveyor belt of 2 m width and the liner velocity up to 4 m/s [56].

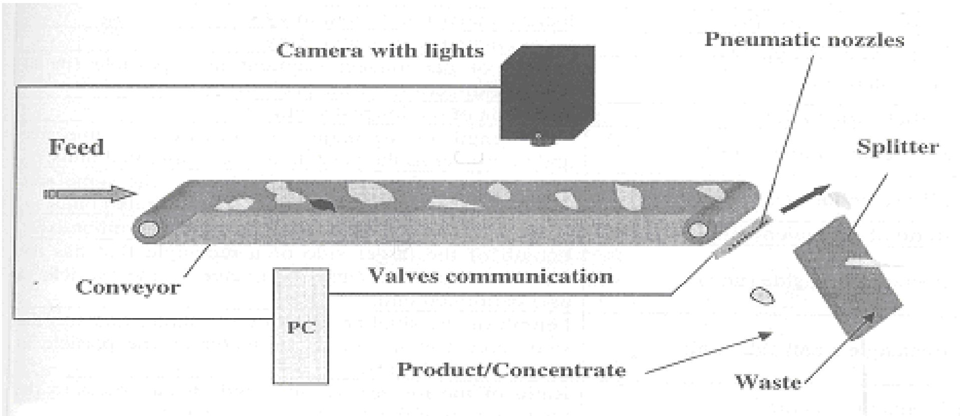


Fig.60 - SINTEF Image Analysis Optical Sorting

MikroSort (Mogensen Sorter): Mogensen sorting is another well-known optoelectronic sorter. The machine, named MikroSort, makes use of two high resolution CCD cameras in order to identify different particles. Image capture is performed by one or both CCD color cameras each with three color channels for the primary colors, i.e., red, green and blue. Each color channel has a resolution of 8 Bit with the result that up to 16 million colors can be produced. Extremely accurate color sensing is provided even if this resolution capacity cannot be fully utilized in practice. The color sensing system scans the surface of the particles to be sorted over its entire width. The product stream moves at a speed of 1.5 m/s. The particles are evaluated by means of transmitted light in the case of transparent particles and by means of light reflected from the particle's surface in the case of non-transparent ones [57-58].

The horizontal resolution of 0.5 mm for a width of 1000 mm, up to 5000 lines per second, processing of a maximum 30 million scan per second, high light sensitivity, and optional single or multi sided image capture, are the machine's capability when it is utilized. Wide selection of sorting criteria is offered by the machine. It means that sorting based on real color, particle size, brightness and shape or any combination of theses parameters can be considered. However, the efficiency of the system rests on the combination of these criteria. Even relatively insignificant optical nuances can be taken into account [58]. Fig.61 depicts the MikroSort sorting machine.

To summarize it must be noted that sophisticated image analysis systems are nowadays available to scan materials through the conveying system. After taking images by the camera(s) the images are processed to identify even small differences in optical characteristics of the pieces to be sorted.

In waste recycling optical sorting has found its place in sorting and purification of different materials, especially for purification of non-ferrous metals fraction from shredded scrap. After first series of separation of shredded materials, where magnetic and heavy media, and eddy current separation are used, products from first separation stage(s) can be forwarded to sorting facilities to obtain high quality product(s). In fact sorting and separating of different aluminum alloys as well as other non-ferrous metals can be completed by theses machines. In addition sorting machines can be used for separating different plastics and also colored glass.

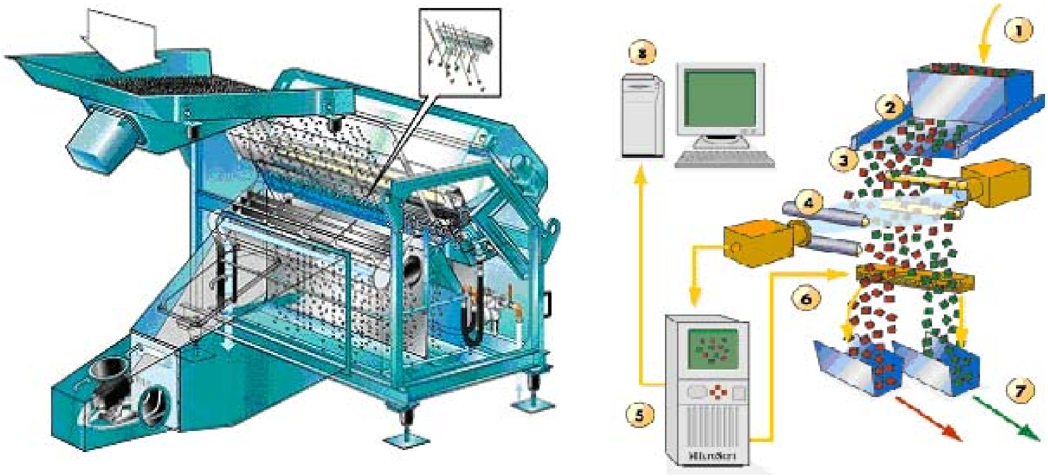


Fig. 61- Configuration of the MikroSort (left) and principal of color sorting process (right)

Sorting Based on Conductivity: Different materials exhibit conductivity to some degree or another. It means that there is no either perfect conductor or perfect insulator. So it is possible to sort materials base on their conductivity/resistivity.

In mineral industry the first serious effort to use this technique was in the early of 1930´s but no practical and accurate system was developed until the early of 1970's.

For minerals and rocks, conductivity sorting works based on low and high voltage sorting. Low voltage sorting is used in certain situation involving damp feeds; one application being the separation of hematite and shale and another is to porous materials where the porous lump retains more water by which their conductivity increases [59].

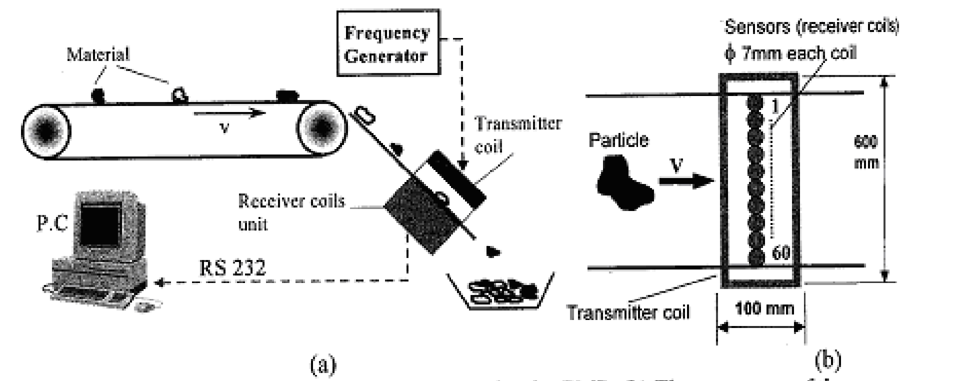
High voltage sorting can be only used on dray feed and potential of 5 to 20 kV is used with transformers or induced coil. The sensing system contains a simply measuring the current flow through the feed pieces when they pass between the grounded and suspended electrode. In fact sensing among different materials of different conductivity can be achieved by varying the voltage. High voltage sensing becomes operative where an ionizing discharge is produced between electrode and material.

Use of metal detector has been investigated as a possible way for pre-concentrating of base metals ores [60]. Metal detector, capable of reacting with noise of different levels depending on conductivity, was used to separate two base metal ore. The tested minerals were two ores from Sweden, a complex pyritic sulphide ore from Falu mines, in the size range of 10 to 70 mm, and a copper-cobalt ore from Håkansboda, in the size range of 5 to 20 mm. Successful and promising results were achieved for Falu ore, however, the sorting results for copper-cobalt ore showed no promising [61].

Sorting lumps by detection of the variations in frequency as conductive material is brought into electromagnetic field was also used. As examples, copper bearing ores have been sorted by techniques known as beat frequency and induction balance. In this case a detector is first energised with high frequency alternating current and then any frequency variation that occurs when a lump containing conductive material passes

through is detected [62-63]. In this method the detector is first energised with a high frequency alternating current and then any frequency variation that occurs when a lump containing conductive material passes through is detected.
A laboratory unit based on induced balance was developed by US Bureau of Mines and was tested on –2.5 +1.3 cm ores from Upper Michigan native Cu. The Cu recoveries of about 80% were obtained in the sorted portions, while rejecting about 80% of the sorted ores. Sorting of coarser fragments, i.e., -10 to +5 cm, led to higher Cu recoveries with about 60% of the ore being rejected. Based on this method the International Sorting Systems Corp. developed a sorter to separate ore containing native copper. One serious disadvantage of the machine was that it did not detect copper grains of less than 0.5 mm in the lumps. To overcome this problem, application of the induction balance, using two planer coil, one for excitation and the other for detection, is suggested where a voltage increase occurs in the detection coil if the electrically conductor lump passes through the coils. The induced balance technique has been reported to be beneficial for sorting some other mineral systems including electrically conductive and magnetic minerals such as magnetite, hematite, galena and copper sulphides.

Metal Sorting based on conductivity and induced eddy current: Recently an electromagnetic sensor has been developed at Delft University of Technology in co-operation with the German S+S Metallsuchgeråt und Recycling Technik GmbH. The sensor induces eddy currents into metals as a function of their electrical conductivity by using an alternative magnetic field [64]. As shown in Fig.62, the sensor has too main parts, i.e., the transmitter coil that generates an alternative magnetic field and the receiver coil unit, which measures the interaction between a metal particle and the field. The data are sent to a computer program that analyses the recorded parameters, i.e., the variation of the voltage amplitude from the receiver coil (U) and the phase shift (φ) between signals from the transmitter and the receiver coil. The transmitter coil is connected to a signal generator, which provides a frequency (f) that can vary from 100 Hz to 10 kHz.
The number of windings and the magnitude of the voltage supply of the transmitter coil give the field strength at a fixed frequency. The receiver coils are placed in adjacent to each other to form a line of coils. These coils are connected to the processing unit to determine U and φ. The sensor has a resolution of 1 mm/ms.
In this system the difference between the effective penetration depths of the eddy currents into metals (δ_C) at different frequencies is detected. According to the study, shown in Fig.62, higher and lower penetration depths were detected for low and high conductive metals respectively. Therefore metals, or generally materials, can be classified based on δ_C. In fact for a metal the eddy current penetration depth at different frequencies is depended upon its electrical conductivity and particle geometry. In addition at low frequency, e.g., 700 Hz, there is a big difference between the measured voltages of high and low conductive metals. However, by increasing the applied frequency, e.g., to 5 kHz, there is no significant difference between the measured voltages for these two categories. In fact at low frequency the conductivity,σ gives a stronger response for U than other parameters affecting δ_C. When there is no particle between the transmitter and receiver coil, the sensor provides a fix amount of U. This value changes as a function of conductivity when particles pass through the receiver coils.



Principle: system contains two main parts: transmitter coil unit to generate an alternative magnetic field and receiver coil unit to measure the interaction between a metal particle and the field. Computer analyses the recorded parameters, i.e., the variation of the voltage amplitude from the receiver coils (U), the phase shift (φ) between signals from the transmitter and the receiver coil.

Fig.62 - Experimental set-up for EMS (a) and sensor geometry (b)

Particle geometry is another determining factor. Small particles with low conductivity can be detected only at high frequency application. The particle's shape is defined by the phase shift (φ). Variations ofφ, in degrees, is in accordance with particle thickness, d, its surface area, A, as well as its conductivity and applied frequency. At specific applied frequency, φ shows its maximum value when d is very close to penetration depth of eddy current, δ_C. Experiments results revealed that errors occur due to the distribution of Eddy current into the metal for $d < \delta_C$.
This new designed electromagnetic sensor allows the classification of scrap metals in three different groups of high, medium and low conductive with a capacity of about 3-4 t/h at 1m width of conveying belt. Working at two different frequencies allows a good identification of medium conductive metals, such as yellow brass or bronze, from high conductive metals.
This sorting equipment has a potential to be used in waste recycling.

Sorting based Hall effect (i.e., conductivity, ferromagnetic property): Holder presented an apparatus for separating particular metal fraction from a stream of various metals, which works on the basis of ferromagnetic property of metals. According to that method a detection zone is established within the stream of particles and a static magnetic field is established within the detection zone. The static magnetic field is able to induce an opposing magnetic field in the particles of metal in the stream. The presence of a particle within the detection zone is detected, and changes in the magnetic flux density of the field are measured as the particle passes through the detection zone. The measured changes then compared with a predetermined change pattern for the pre-selected metal fraction to be removed, and the particles whose passage through the detection zone change the magnetic flux density of the field due to the predetermined change pattern are separated from the stream [65].
The invented apparatus contains a conveying system by which materials are transported through a gap where the infrared emitter(s) and detector(s) present in order to detect the stream of materials. In association with the infrared detection system, a magnetic field is assembled. The magnetic assembly unit contains permanent magnet(s), preferably

rare-earth magnets, and a conventional Hall-effect sensor, or any other magnetic flux density sensing system, to detect changes in magnetic flux. However, depending on the desired separation efficiency and volume of the stream of materials to be separated a number of Hall-effect sensor can be employed.
The magnet assembly utilizes a static magnetic field having field strength of about 1200 gauss in the vicinity of the Hall-effect sensor.
The created static magnetic field induces an opposing magnetic field of such strength as to cause the particles in the stream to move. Thus by measuring and detecting the changes of magnetic flux density of the static field as the particle passes through the detection zone, it is possible to identify different kinds of metals presenting in the stream. The data achieved from the Hall-effect sensor is then converted to signals and amplified in order to interpret the results by translating the amplified voltage from analog to digital form.
If a dielectric particle passes through the detection zone, it passage will not appreciably affect the magnetic flux density. However, any electrically conductive particle will affect the magnetic flux density upon passage through the static magnetic field due to the creation of eddy current for conductive particles.
When non-ferromagnetic, non-ferrous metallic particles such as aluminium, lead, or zinc particles, are introduced to the separation apparatus, the magnetic flux density of the field will change. At the beginning the magnitude of the field is reduced while the particles are within the field and pass the centreline of the field. Thereafter, this magnitude will tend to increase. Consequently, during the time of passage of such particles, the magnetic flux density decreases to reach its minimum and then increases to gain its maximum value.

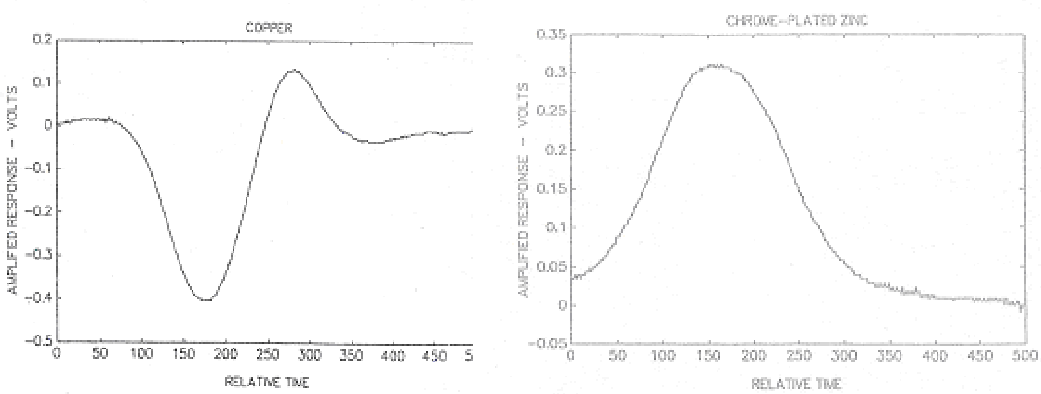


Fig.63- Spectrum of the hall-effect measurements for chrome plated zinc and copper

In contrast, ferromagnetic particles, even a weakly one, such as stainless steel or chrome-plated zinc, indicate markedly different characteristics. It means that the higher magnetic permeability of the ferromagnetic particles cause to an increase in the magnetic flux density of the field in the vicinity of the particle. This increasing overcomes any reduction in the flux density of the field caused by eddy currents. Therefore, a bell–shaped curve is created by plotting the changes in flux density detected by the sensor as a function of time during the passage of ferromagnetic particles.

Although the invented apparatus is preferably suggested to sort non-ferromagnetic, non-ferrous, metals from ferromagnetic ones but, since the time duration in which the materials reach either the maximum or minimum flux density as well as the magnitude of these maximum and minimum points differ from one metal to another the invented method offers a possibility to sort different metals from the same class. To achieve the maximum sorting efficiency pre-selection is suggested in order to have a narrow particle size fraction within the stream.
Moreover, since the changes in the magnetic flux density depends on the magnitude of the eddy current created by a particle when passing through the magnetic field and the former is a particle size dependence, it seems that sorting of materials on the basis of particle size fractions can be possible.

Other Sorting Techniques: There are other sorting methods that make use of different electrical properties of the materials to be sorted. For example sorting based on dielectric constant value or capacitance of materials would be one.
Consider a condenser having two parallel plates in a vacuum that is electrically charged at a distance d apart, therefore, an electric field proportion to the charged plates will rise. This electric field induced a potential V between the plates. When the vacuum is replaced by gas, liquid, or solid the potential between the plates as well as the electric field decreases. This decreasing is in direct relation with the dielectric value of that material passing through the electric field. Theoretically, if pieces of different materials were placed, one at a time, between the parallel plates of Electrical Q-meter, i.e., a capacitor, the voltage on the circuit changes based on the electrical characteristics of the material. In fact when stream of solids, with its own dielectric constant, passes through the medium of the condenser, each solid absorbs electric energy at its own specific rate, to a definite amount and restore the absorbed energy at different rates. The capacitance of the condenser depends on both the geometry and nature of the material between the two conducting plates of condenser. The dielectric constant property of a solid is independent of the strength of the electric field over a wide range but in the case of alternating fields, it depends on the frequency and also other factors such as temperature. It must be added that because of high dielectric constant value and low resistivity of the water the existence of the water is troublesome. It means that the dielectric constant, dielectric loss, and the conductivity of a sample are dramatically increased if the sample contains considerable amount of moisture. Particle size is another determining factor when sorting based on dielectric constant values of different minerals is sought. In fact dielectric constant value for specific material, e.g., rocks and minerals, decreases by decreasing the particle size.
Another way of using dielectric constant and its related properties, like, loose factor, conductivity, etc., in characterizing different materials would be determining the microwave characteristics of the matter. If a piece of material is irradiated by microwaves the adsorption of microwaves by the piece is a function of its conductivity, dielectric constant, loos factor. Therefore materials can be identified and sorted by microwave irradiation.
To determine the dielectric properties of different components microwaves are an effective and non-destructive tool. Microwave analysis is fast, easy to implement and has been extensively used in mineral research. Reflection and/or transmission of the microwaves within the material can be measured to determine the dielectric properties

of materials. This can be done in laboratory by packing the material into waveguides or coaxial transmission lines. The advantages and disadvantages of both methods are described by Cutmore, et al., [66-67]. In addition when materials are emitted by microwaves they become hot based on their dielectric properties. The heating characteristics for different material can be recognized easily by thermal imaging technique. So there are two different possibilities for identification and discrimination of different materials in a mixture by using microwave technique. Based on microwave heating and thermal image technique a successful discrimination and separation of kimberlite from gabbro and other wastes, such as quartzite, had been carried out by Salter and his colleagues, at De Beers Diamond Research Laboratory [68-69].

Later on in May 1987, based on microwave attenuation test results for different rocks, a single particle laboratory sorter was commissioned to evaluate the dynamic response of the microwave attenuation discrimination system. The unit used a microwave beam at 5 m/s with power of less than 100 mW, and was able to work with the rocks having particle size fraction of –60 +300 mm.

Recently, CSIRO recently studied and developed a technique for ore characterization and sorting based on microwave properties of minerals, called *dielectric spectroscopy and ore classification,* This research study was focused on some different iron ore samples in order to characterize their dielectric constant and loss factor values and to see how these parameters can be helpful if sorting of different ore samples is aimed [66-67]. At the first step dielectric constant and loss factor for ten different iron ore were studied. These parameters for all ore samples were measured and the measured values were normalized. Then the data acquired from these measurements were analysed in order to classify the ore samples. This classification procedure was made by using PCA (principal component analysis) and ANN (artificial neural networks). The classification was constructed based on microwave transmission and reflection coefficients for a microwave signal passed through the waveguide. The method suited to the analysis of crushed ore, without any special sample preparation, and is a bulk analysis over the entire sample volume Due to increasing the use of microwaves in daily life, development of this method in near future may open a window in fast identification and sorting of different components.

In waste recycling, after size reduction and liberation of ferrous and non-ferrous metals as well as non-metals, various sorting methods can be applied to concentrate metals and other materials. However, at the time being, metal detectors and optical sorting based on light are the most convenient methods to be used. Sorting metals from a stream of mixed by metal detector and then sorting different metals due to their respond to a source of light based on light scattering, transmission, or image processing are nowadays applicable in waste recycling industry.

As an example, Huron Valley Steel Corporation has an image processing system for the material concentrated by eddy current separator. The material concentrated by the eddy current separator is fed to the image processing plant for further purification.

It must be noted that very fast identification and sorting of selected particles are done by automatic sorting machines. However, preparing feed, feed size, and the way of presentation in which each individual particle can be seen, detected, and analyzed are paramount important during sorting. Fig.64 depicts the time frame for automatic sorting.

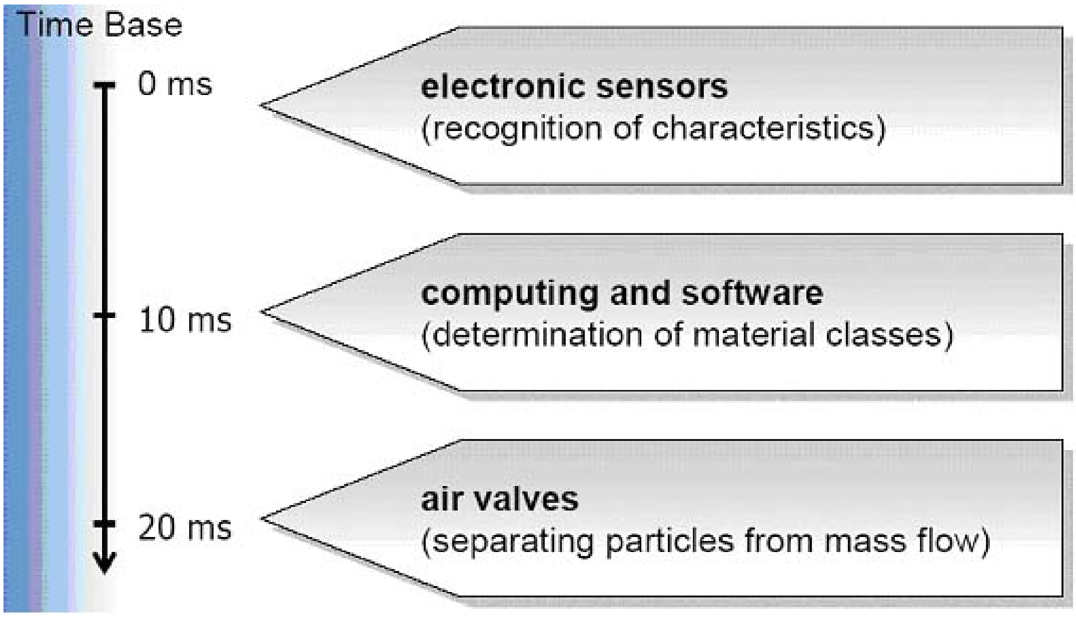


Fig.64- Time frame for automatic sorting of pieces

Sorting Using Multi Sensors: Majority of operational sorting systems is equipped with a single sensor array. However, it is obvious from signal processing theory that a classification of particles fundamentally improves as the number of independent features increases. One way to obtain this improvement is to extract several features from one sensing system like camera. However, the disadvantage with this regard is that measurable data, which cannot be seen by the applied sensing device, remain hidden for the system. It is theoretically understood that a simultaneous detection of several features with sensors of different detection principles improves dramatically the quality of the classification. However, considerable engineering efforts are needed to realize such systems and explore the benefits of multi-sensor detection and sorting system [70].

May be development of *Magnetophotometric* sorter for separating wolforamite from its associated minerals and rocks, developed by Fengnian by the end of 1970s, was the first attempt to make use of two different sensing system, i.e., magnetic and optical sensing, in sorting and separating minerals.

Another attempt was the use of different optical sensing system in combination with eddy current sensor for sorting PBCs from electronic scrap. Color image sensor, range image sensor, a high resolution image sensor, and an eddy current sensor were assembled to provide the necessary information about the electronic components on the printed circuit boards. Fig.65 depicts the flow chart of this sensor fusion approach [71]. In fact new sensor system can be added or deleted without any problem through a modular design of the sensory systems that are integrated as individual experts. Much complementary features as possible about size, shape, color, and material properties of the electronic components can be obtained.

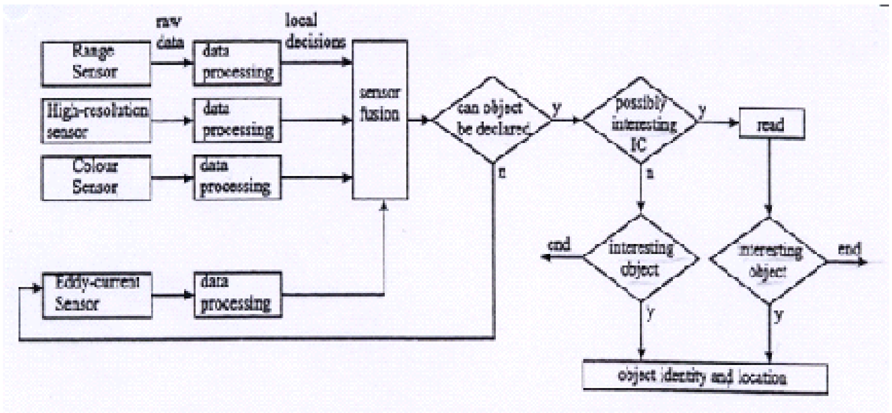


Fig.65- Flowchart of multi sensing approach

Research at Delft University has led to invention of a sorting device for glass culet and metal alloys by using line-scan camera and laser transmission sensor. However, a system utilizing a spectral range from UV to near IR for reducing disturbing reflection from the metal surface is combined with conductivity image generated from eddy current sensor has been developed for sorting different aluminum alloys and magnesium metal, etc, [70].

In industrial scale Barco's dual sorter is available in which both camera images and laser scanning system are used for detecting different materials. The sorter can be used in different applications.

Binder+Co manufactured sorting machine especially for culet glass sorting. The machine utilizes the laser color sensing system as well as a metal detector for sorting glass culets [72]. The newest generation of waste glass separation machines named "CLARITY plus" is manufactured by Binder+Co. The machine is the first three-way system available on the market. Both the color separation of waste glass and the removal of impurities, such as ceramics, stone, and porcelain (CSP), can be managed in one machine (Fig.66).

Mogensen also developed a multi sensing sorting machine in which cameras are available for optical characterization and a very sensitive metal detector to detect both ferrous and non-ferrous metal in bulk stream. It is claimed that the metal detector is able to detect a steel ball of I mm in diameter which is included in a plastic matrix cube of 1cm^3.

SSE´s Metal X Ccombi Sense machine is also available. This machine uses both color and electromagnetic sensors for identification different materials, especially scrap alloys and metal sorting [73]. The machine is able to sort materials having particle size fractions bigger than 10 mm with a capacity up to 15t/h.

TiTech's NIR and Image analysis sorter is another double sensing machine for identification and sorting different plastics. The machine is able to identify and sort wide range of plastics. The machine is made very flexible and easy to operate. Even identification of different PVCs, PEs, PPs, etc., can be carried out by this machine [54].

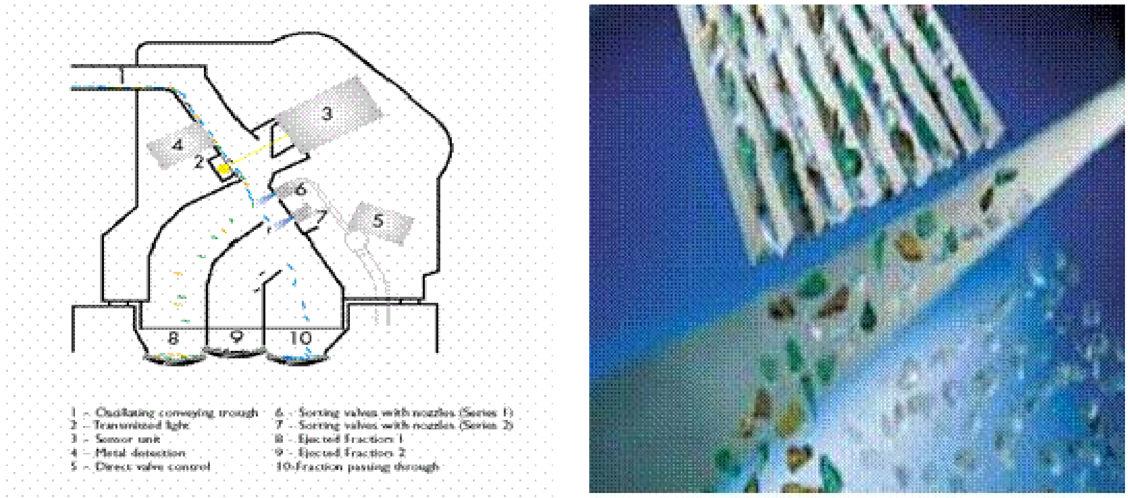


Fig.66 - Configuration of clarity plus sorter (left) and its color characterization system (right)

Nowadays optical sensing sorters, especially sorters utilizing cameras, are the most popular sorting devices. With a camera several features of the pieces can be extracted. Size, texture, edge-structure, homogeneity, color patterns, hue, and so on can be detected by camera. By employing additional sensors for high selectivity, such as metal detector, light transmission, spectral reflection, electromagnetic detector, or conductivity detector, and higher selectivity can be achieved and all needs for sorting complex feeds can be fulfilled.

In fact complexity of the material to be sorted needs to have several features for their classification. Classification improves as the number of detected features increases. The future of the sorting technology hangs partly on development of multi-sensor detecting systems in order to improve the accuracy and efficiency of the sorting. Such a system can be developed either for specific application or as a general for different uses. In addition flexibility of the machine to accept different sensing system must be considered for further development of sorting technology.

Due to dependency on legislation, political issues, and other non-technical factors, it is not easy to forecast the future development in processing of secondary materials. However, it is obvious that having more effective, sophisticated and cost effective processing systems will be helpful to make use of secondary resources more and more. For recycling industry the next step seems to be the make use of cost effective techniques that are able to identify and sort different metal alloys fast and accurate. The same should be the trend for non-metal and plastic separation. Therefore advances in instrumentation and computing system sound to be an ideal situation for recycling industry.

To conclude this part it must be mentioned that when the use of sorting machine for specific material is aimed there are some parameters to be considered. These include particle size for the raw material, particle shape, crushing and milling conditions, surface conditions for particles to be sorted, feed variability, sizing of the sorter, sensitivity criteria for the sensing device, etc. It should be considered that the maximum and minimum sortable size fraction is very important criterion to be considered for a successful sorting procedure. In fact the maximum particle size is mainly determined by the capability of mechanical ejecting system. For today's sorting machines this maximum size is about 250 to 300 mm for common ore and raw materials. However, this maximum size reduces if high density feed is considered and for sorting heavy metals the maximum size would be bout 150 mm. For the minimum size, optical and other kinds of sorters are able to deal with particles down to 2 mm. However, this is the value of raw material or/and product(s) which defines the minimum particle size suitable for sorting purpose. Furthermore, for an efficient sorting it is vital to process narrowly size fractions. Typically, a top to bottom size ratio ranging from 3:1 to 2:1 is satisfactory. This rang of ratio could be relaxed due to the precision requirement and the mass distribution of the wanted and unwanted fractions.

With respect to the shape, thin flaky materials are less pleasant for sorting, especially optical sorting, than the materials with near cubic dimensions. This indicates how the comminution process affects the sorting efficiency.

Surface condition for the particles is another issue. In fact the partial's surface must be clean enough to be detected and identified. Masking of the surface by dust, dirt, mist, etc., prevents the effective detection of the particles. As an example, in most applications but not all, when optical sorting is utilized, dry surface distorts the true identification, however, the most effective optical properties are revealed by the moist rock surface. On the other hand extreme wet surface is not good. This may mask the surface properties by having too high reflectivity that blinds the optics. In some cases feed should be near dry or bone dry. This is important when small sized material are processed as surface tension effects due to free moisture cause particles to stick together and/or take on unpredictable trajectories within the sorting machine and hence cause blast losses. Finally, it must be mentioned that surface conditioning, using some chemicals, is suggested and applied in some circumstances for better identification of the particles. This has been examined for sorting aluminum alloys as well. In sorting procedure, it is really no reason to expect 100% efficiency for a sorting machine and so the use of two or more passes of the material may be considered. An efficient sorting can be achieved using correct discriminating criteria with properly maintained sorter. Furthermore, to avoid any unsatisfactory condition, one can consider variation in raw material when the primary evaluation test is carried out. This allows for fine-tuning of the sort criteria ahead of anticipated operation. The sorting process will be more effective and accurate if there is no big variation in fed material. Another issue is sizing of sorter. Sorting machines are normally sized to accept as much of the plant throughput as is economic due to high capital cost for installation of sorting machines. Typically the capital cost of a given sorting machine per tone per hour feed varies inversely as the square of the geometric mean of the feed mesh size for a single or multi-stream machine or inversely as the arithmetic mean of mesh size for random stream machines.

15- Automatic Quality Control & Integration of Sorting Technology with Quality Control:

Most of recycling plants have no systematic quality control systems to control input and output. In fact main effort is to see that the input material contains no hazardous component like radioactive material. Therefore when materials are sent for shredding, sensors are placed to hinder introducing radioactive materials to the plant. After that usually there is no in-situ quality control for different processing stage, even final

products. In fact the raw material comes in and goes out after processing and will be sold for further processing, usually metallurgical processing, by experience. If there is any control for the quality the specifications are attained by time-consuming manual sampling and subsequent chemical analysis.
Having process control and engineering system provides detail information not only about the feed and final products but also about whole plant performance. Any deterioration in product quality can be observed very soon, allowing re-adjustment of the process. Furthermore automatic control systems are helpful for plant management. For example they assist in purchase strategy.
Reliable information regarding the inputs and outputs from shredding and recycling scrap provided by automatic quality control leads to better relationship between buyers and seller.
Advanced particle sorters, without ejection, can operate as reliable automatic quality control systems. However other kinds of analytical methods can be matched with sorting technology for accurate quality control.

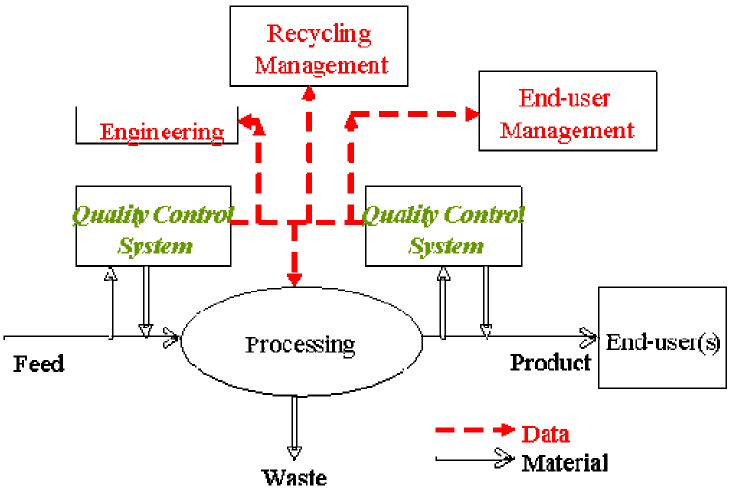


Fig.67- Automatic, continuous quality control for recycling process

16- Processing and Recycling of End-of-life Vehicles and Other Goods:

The processing of scrap and scrap cars starts generally with size reduction by hammer mill or other shredders. After shredding, the fractionation of the crushed material is done and the separation of different materials within the shredding stream. As like as mineral processing, better separation, and therefore, higher grade and recovery are achieved if the raw material is better liberated. This means that the degree of liberation is defining factor for better separation.
The separation of magnetic fraction from non-magnetic one is first achieved by using magnetic separator(s). After magnetic separation, usually the magnetic fraction is send for hand sorting in order to remove un-wanted non-magnetic particles, like copper wires, etc. However, it is supposed that by having a precise dismantling system prior to the shredding there will be no further need for hand sorting after magnetic separation.

The non-magnetic fraction, which contains of different metals and alloys as well as plastic, stone, and glass, is sent for further processing. In fact the increase in plastic fraction has a negative effect on the recovery of metals and waste production.
In most processing plants, the non-ferrous fraction is screened further and each fraction is processed separately. Generally, non-ferrous part of obsolete goods is divided into 3 or 4 different fractions. These are 0-4 mm, 4-16mm, 16-60mm / 16-100mm, and fraction over 60 or 100mm [20, 35, 74-76].

16-1- Processing of the +60 or +100mm fraction: The processing of the particles bigger than 60 or 100mm can be carried out by hand. By hand sorting different metals can be separated from each others or other waste. However, the remaining can be sent for land-filling.
Alternatively, particles bigger than 100mm can be send back to the shredding machine for further comminution and liberation. In this case the grade and recovery of the metal fractions are enhanced since further liberation of oversize is essential in order to improve the efficiency of the mechanical separation process.

16-2-Processing of the 16-60mm size fraction: The metal content for this size fraction varies from 45 to 65% on the basis of the efficiency of the air suction in the shredder. Powerful air suction leads in having less metal in this size fraction. Therefore optimization of air suction's power maybe needed for better recovery of metals. Increasing costs for land-filling is a motivation for shredder operators to reduce the air suction from shredder, or in some cases, oven turn it off completely. As a result the non-metals concentration is increasing in this product and the metals concentration of the feed material to the metal concentration plant is lower. This leads also to an increase in amounts of rejected material. In addition, the feed material, which will go to a density separation, still contains light materials such as wood, plastic, etc. Pre-concentration of the raw feed by a rising current separator may be a necessary step to avoid high ferro-silicon losses and also increases the throughput of the heavy-medium plants.
Due to the combination of shape factor and density the overflow from raising-current separator contains aluminum sheet material, hollow pieces of material, and pieces of magnesium. These metals can be recovered by an eddy current separator. The reject fraction from eddy current separator still contains some metals like copper wire, thin pieces of stainless steel, and other small metal particles. Even a metal detector can be installed after to separate metals from the over-flow of raising current separator or even for separating metal pieces that cannot be separated by eddy current separator.
The underflow of the raising current separator is fed to the heavy medium plant for recovery of non-ferrous metals. In previous section the operation in heavy-medium plant was explained in details, but as a reminder, it should be mentioned that two steps of heavy medium separation are carried out. First, a heavy medium separation is done for separating magnesium and its alloys as well as plastics, composite materials, and rubber, and within second step the sink-float separation process is completed by separating aluminum from other non-ferrous metals and stainless steel.
The float fraction from first stage of media separation can be processed further to separate magnesium from non-metal particles. This can be carried out by using eddy

current separator. The reject fraction of this stage still contains some metals with a potential problem for environment.

During the second concentration step the mixed non-ferrous metals, along with some other materials, are separated at a higher density, e.g., 3 to 3.3, for recovery of aluminum. The recovered aluminum can be separated again at a lower density, e.g., 2.8 to 2.9, for the separation of the un-liberated aluminum which is mainly contaminated with iron such as bolts and other connected materials. This fraction can be comminuted further for the liberation of iron and other materials or even processed separately, for example in a Coreco smelting furnace.

The aluminum fraction still contains of glass, copper wire and some other complex inter-grown material, whose overall concentration can be as high as 10 to 15%. Eddy current separator can be employed for upgrading the aluminum fraction. This leads to have a product containing about 99% or even more aluminum with high recovery. The reject product from this stage still contains a high percentage of copper wire and other metals mixed with plastic, such as printed circuit which can be recovered by a friction separator. The rejected product from friction separator has to be sent for land-filling.

The sink fraction from the second stage of heavy medium separation contains the bulk of the heavy metals, i.e., tin, brass, copper, stainless steel, etc. This heavy non-ferrous metal fraction at present amounts to more than 200000 tons per year in Western Europe.

Emergence of metal detectors was a great step in improving the recovery of the metals within shredding streams and also to reduce the potential problem regarding the rejected materials for land-filling. The use of metal detectors or other recognition and sorting machines has been considered by auto shredders and other non-ferrous processing plants in order to improve the recovery and grade of products and to reduce the waste which goes for land-filling. Some new shredding plants, like Huron Valley Steel Corporation have started using of metal detectors, image processing and other sorting machines to improve the grade and recovery of their products from obsolete goods.

Cleaning of aluminum fraction obtained from the heavy-medium separating stage can be done by eddy current separation in different stages or combination of eddy current separation with image analysis processing, metal detectors, or other sorting machines. In this case almost pure aluminum fraction, containing >99% aluminum, is achieved.

Fig.68 depicts different alternatives for processing of 16-65mm size fraction after heavy medium separation.

Nowadays, in all beneficiation plant for non-ferrous fraction from shredding plants eddy current separation process plays a vital role. In fact separation of different non-ferrous metals from each others and also from non-metallic particles within the eddy current separators is achieved due to conductivity, diameter, shape and magnetic field strength. A basic element of the separation plant can be found in Fig.68c. In this element eddy current separators, with different in magnet configurations can be used for better separation.

The image processing is based on color detection of the particles on a transporting belt. The quality of copper, brass, and zinc products is unusually over 98% purity and improving in processing is still being made by emergence of high resolution scanning cameras.

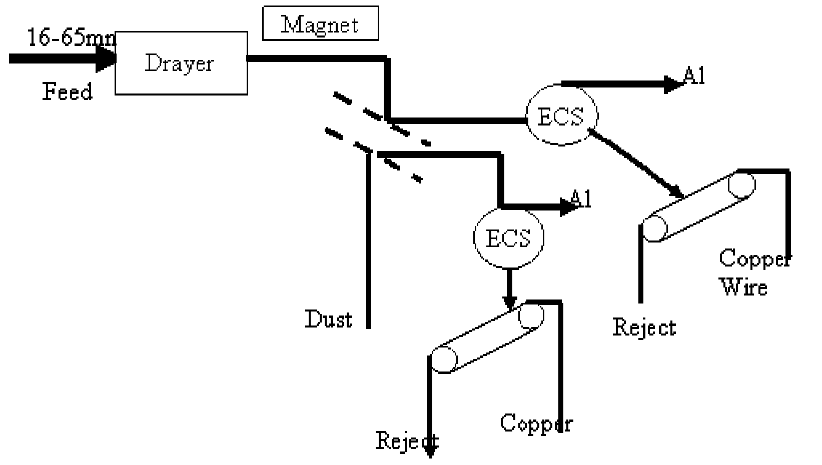
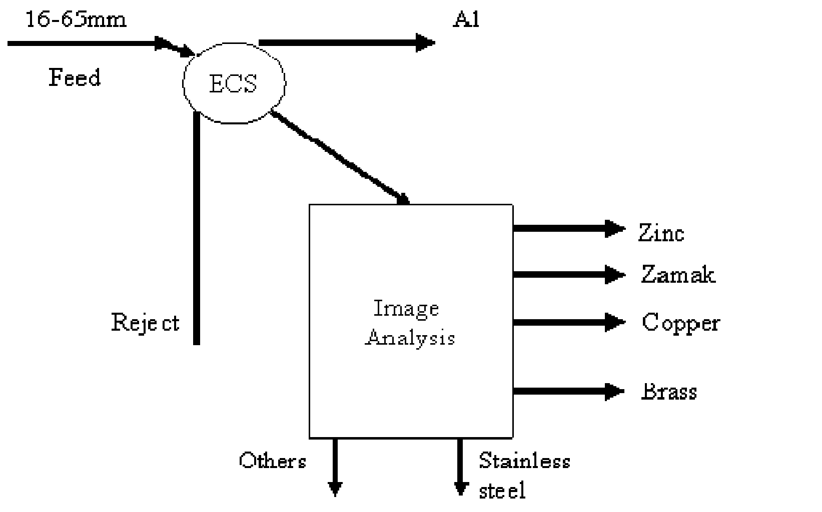
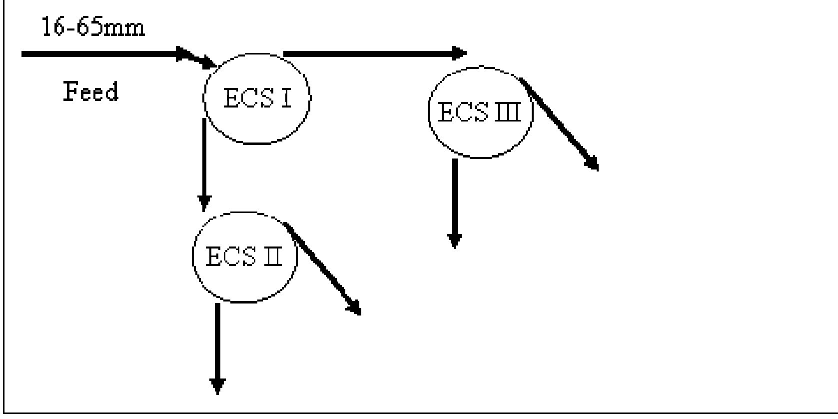
<table>
<tr><td>
</td><td>a- Dry separation for non-ferrous fraction with one magnet and two eddy current separators in combination with screening</td></tr>
<tr><td>
</td><td>b- Separation of non-ferrous fraction by using eddy current and image analysis</td></tr>
<tr><td>
</td><td>c- Separation of different non-ferrous metals by using three or more eddy current separators</td></tr>
</table>

Fig.68- Three different flow-sheets for beneficiation of non-ferrous fraction (16-60mm)

An alternative dry processing may be considered for processing of 16-60mm size of non-ferrous fraction. For using dry mechanical separation techniques the first step would be the size reduction to about 30mm. Although the further comminution to reduce the size causes metal losses but on the other hand the liberation is improved and the grade of the recovered metals is enhanced. In this case, after comminuting materials to about 30 mm, screening is needed to have three different size fractions, i.e., +30mm. 10-30mm, and -10mm. The coarser fraction, i.e., particles >30mm, can be beneficiated first by air classifier and then by eddy current separator in a closed loop with the shredder. Middle size particles are processed by air tables and eddy current separators again in a closed circuit. Fig.69 depicts the general flow-sheet for such a dry process.

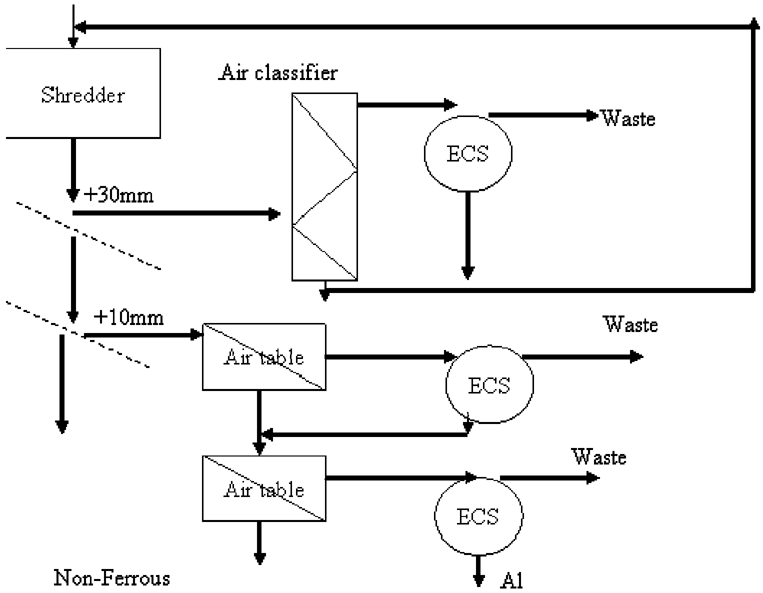


Fig.69- Alternative dry processing for non-ferrous fraction with the size of 16-60mm

This processing procedure can be used not only for beneficiation of out of life vehicles, but for the shredded consumer goods after magnetic separation and air classification for the removal of dust and foils.

Another processing procedure was developed by Metallgesellschaft, namely a dry separation system for the fraction of 16-65 mm. This process relies on a metal/non-metal separation and the sorting of all metals by the combination of a pulsed laser and an atomic emission spectroscopy. The emission spectroscopy can rely on x-ray or laser based spectroscopy. Fast and precise identification and detection speed are benefits regarding using such a system.

Due to lack of water, especially in arid areas, needs for water treatment after wet processing, and the subsequent disposal of metal sludges, dry separation processes of non-ferrous metals from shredding stream are growing in importance.

16-3- Processing of 4-16mm size fraction: Due to lower production of metals in the minus 16mm fraction and increasing sedimentation time with decreasing particle size, this size fraction is less attractive for heavy media separation. From process to an economic point of view a favorable alternative processing for the size fraction of 4-16mm would be jigging in combination with metal detector and/or eddy current separation. Fig.70 depicts a combined jigging, metal detection, and eddy current separation for such a size stream from shredding plants.

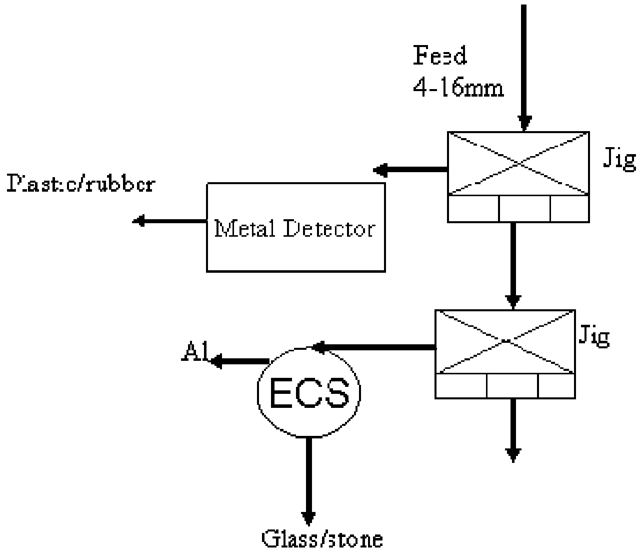


Fig.70 Flow-sheet for processing of 4-16 mm fraction of non-ferrous materials

According to this flow-sheet at the first stage of jigging, the rubber and plastics arte separated from the metals as a light fraction. Since this light fraction still contains light and thin metals, further process of this light fraction can be carried out with the use of metal doctor and/or eddy current separator. In this case fine, thin, and light metal pieces are separated from rubber and plastics. The heavy fraction from the fist jig is then fed to the second jig, in which glass, stone, and aluminum are separated from other metals. In this stage heavy fraction contains non-ferrous metals and the light fraction consists of aluminum, glass, and stone. An eddy current separator is installed after to separate aluminum from stone and glass in light fraction. The heavy fraction can be processed further to separate copper from zinc, stainless steel, lead, etc.
The advantage of the use of jig is mainly due to simplicity of its construction and easy to work with in combination with its high capacity per square meter of jig surface, which is up to $15t/h/m^2$. A drawback of jigging is the amount of water consumed for the separation system; as a consequence, large water treatment and sludge removal systems are needed. However, the feasibility of such a process has been proven by different operators.

16-4- Processing of -4mm size fraction: Processing of this size fraction is omitted in most shredding and beneficiation plants. It means that stream of particles within size fraction finer than 4mm is damped. Due to environmental concerns, however, the beneficiation of this size fraction by different means has been considered and being under investigation. Shaking tables would be an option, however, other gravity separation techniques, like spiral and Multi Gravity Separator (MGS), may be possible choices. Even flotation of fines has been considered, especially for plastic separation. The choice of process technique is mainly depends on the composition of the raw material. Beneficiation of fine fraction from shredding streams needs to be investigated in more details in order to find an environmentally sound economically viable technique(s) for further processing of such fraction.

17- Scrap Recycling and Increasing Elemental Impurities:

Sustainable development requires increasing the recycling rates of metals. The benefits of recycling various materials at the end of their life cycle are more and more realized and especially with respect to energy saving the data have shown considerable reduction in energy consumption for production of metals from scrap. Energy savings of 96% for Aluminum, 87% for copper, 74% for steel, 63% for zinc, and 60% for lead have been reported through recycling of these metals.

Although metal recycling has its own benefits, but extended use of scrap for metal production in some cases leads to increased levels of impurity elements in final product. During scrap handling, difficulties of obtaining complete separation of various metals may lead to the introduction of significant amounts of impurity metals in the re-melting vessel. Certain impurity metals are difficult or extremely costly to eliminate by the use of refining processes and will thereby accumulate in the product. There exists a limit where the content of certain impurity metals will exceed what is acceptable for the quality of the end product. In order to keep the contents of the trace impurity within limits, the metal then has to be diluted with cleaner scrap, if available, or with virgin metal. However, alternatively, the metal can be used in other applications with different specifications for trace elements content. Elements that are classified as impurities in certain qualities may be also added as alloys in others. Thus, these elements in the scrap are then regarded as a source [77].

The implementation of adequate solution to the problem of impurity elements is largely a matter of cost. If recycling is not supported financially, scrap with high impurity content will not be processed if the cost of reclamation exceeds that of primary metal production. Improved scrap handling, hydro or pyromettallurgical pre-treatment of scrap, improved refining methods, improved casting and metal working methods, new alloys allowing higher impurity contents, and design for recycling are solutions to be considered in order to minimize the effects of impurities in metal recycling. However, with respect to shredding plant performance and physical separation of different streams come from shredding plants, better dismantling and comminuting in order to have higher liberation degree, and improved separation facilities to have purer fractions of different ferrous and non-ferrous metals are necessary steps. Improved in separation of scrap can also be aided by product design that facilitates recycling. Design for recycling means that fever alloys and combinations of different materials are used in production, metals and materials in combinations must be chosen in a way that they have less competition with each other, different parts must be easily identified, dismantling must be facilitated, and total energy use during the total life cycle has to be minimized.

17-1- Scrap Quality for Iron and Steel Production: High quality scrap contains fewer impurities, however, for considerably reducing of the level of impurities, especially the majority of elements used for coating like Zn, Sn, etc., and product manufacturing such as Cu, cannot be reduced significantly for steel scrap by physical separation techniques. Therefore in some cases pyro- and hydrometallurgical methods are needed. For steel making from scrap the copper content in scrap should be $\leq$ 0.35%, and maximum Sn content would be 0.025%. In fact physical properties of the steel is affected by introducing tramp elements, i.e., Cu, Sn, Cd, Cr, Ni, As, Sb, Zn, Pb, Mo, and Bi. In fact by presenting tramp elements the steel elongation, its fatigue strength, toughness, hot and cold workability, weld-ability, isotropy and heat treatment response is increased. However, steel's yield point and its tensile strength are reduced.

17-2- Scrap Quality for Aluminum Production: Share of aluminum and its alloys come from shredding streams is the largest among other non-ferrous metals. This share has been increased during last decade due to increasing the consumption of aluminum in cars and other electric appliances. The composition of some aluminum products are listed in Table 4

Table 4- Composition of selected aluminum products

Product	Al %	Other elements %
Roofing sheet	98	Mn 1, Fe, Si
Flag poles	98	Mg, Si
Road signs	97	Mg 2.5
Car radiators	95	Si 2, Mn 1, Sb 1
Power cables	99,5	
Household foil	98	Fe, Si
Ladders	98	Mg, Si
Doors and Windows	98	Mg, Si
Car engine	84	Si 10, Cu 3, Zn 2, Fe 1
Cast Al alloy 380	≥82.5	Si 7.5-9.5, Fe 1, Cu 3-4, Mn 0.5, Mg, 0.1, Ni 0.5, Zn 2.9
Cast Al alloy 390	≥75	Si 16-18, Fe 0.6-1, Cu 4-5, Mn 0.1, Mg, 0.5-0.65, Zn 0.1
Wrought Al alloy 6063	≥97.8	Si 0.2-0.6, Fe 0.35, Cu 0.1, Mn 0.1, Mg, 0.45-0.9, Zn 0.1
Wrought Al alloy 5182	≥94	Si 0.2, Fe 0.15-0.35, Cu 0.1, Mn 0.28-0.4, Mg, 4.25-4.85, Ni 0.05, Zn 0.2

Although the trace elements in secondary aluminium production may originate from the master alloys as well as the fluxes, but the introduction through the recycling streams is the most common source. This can be due to the form of alloy cross-contamination or contamination by foreign compounds. Fe, Mn, Mg, Cu, Si, and Sb are the most concern trace elements in aluminium production from secondary resources. This means that separation of aluminium and its alloys from the shredding stream must be done very carefully, even separation by type of alloys, to reduce these elements. This indicates also the need for optimum comminution in order to have sufficient liberation for physical separation. Otherwise, for production of aluminium and its alloys from scrap source addition of primary metal or/and refining is needed.

17-3- Scrap Quality for Copper Production: after aluminum, the second important non-ferrous metal in shredding streams is copper. In contrast to most other metals, copper is mostly used in its pure form rather than as an alloy. Materials containing a minimum of 99.3% weight percent copper are designated as "coppers". The most commonly used materials is known as *"electrolytic tough pitch"* copper, which consists of extremely pure copper that has been alloyed with oxygen in the range of 100 to 650 ppm.

Since the usual commercial supplies of pure copper are used for the most critical of electrical applications, therefore, it is important that purity is reproducibly maintained in order to ensure high conductivity, consistent annealability, and freedom from breaks during rod production and subsequent wire drawing. For this purpose, either primary copper of the best grade, or uncontaminated process scrap, or other scrap that has been electrolytically refined, is used. In fact the presence of any undesirable impurities can

bring problems such as hot shortness, which causes expensive failures during casting and hot rolling. Consequently, for the same reason, scrap containing impurities must be well diluted with good quality copper.
Except for electrical purposes, copper used for plumbing, roofing sheet, and heat exchangers, etc. For these applications, high electrical conductivity is not mandatory and other quality requirements are not so burdensome. Secondary copper, still within stipulated quality limits for impurities, can be easily used for the manufacturing these materials.
In the case of copper alloys there are different categories, i.e., copper-brass alloys, copper bearing materials that is alloyed with aluminum, steels and cast irons that are improved by small addition of copper, and Monel that is a mixture of copper and nickel in which nickel dominates.
Old scrap comes from old used cars, appliances, or other resources contained impurities. Radiators, electronics, cables or tubes, etc., cannot be directly remelted for production of copper. Old scrap is mainly used for production of copper alloys rather than pure copper. Depending on material impurities, copper from scrap must be processed in an anode furnace, a converter or a shaft furnace. Then electrolytic refining is needed. Since the same electrolytic refining must be done for copper produced from ore, therefore the risk for impurity build up is minimized when old scrap is used for copper production. Just it should be considered that by increasing the number and amounts of impurities the energy consumption for refining is increased.
Form electrical conductivity point of view, it has been shown that additions of solute elements decreases the conductivity in copper linearly. Tying up the impurities in precipitates or oxides can minimize the detrimental effects. In general, impurities such as Ag, Pb, Ni, Sn, Al, Sb, Mn, Cr, As, Si, Fe, and P can be found in copper. Introduction of these elements reduces the conductivity for copper. Within the series, however, Ag has the less effect and P the highest effect in reducing copper conductivity. The limits for having these impurities in pure copper vary but the maximum acceptable would be about 0.2%.
For mechanical properties of rod copper elements such as Bi, Se, Te, Pb, Sb, Ag, Ni, and Fe were found to be more effective.

17-4- Scrap Recycling and Radioactive Sources [78-79]: At least 65 confirmed events reported where radioactive materials were individually mixed with metals for recycling since 1983. In many of these cases radioactively contaminated metal resulted. Problem is worldwide, with the iron and steel industry and the aluminum industry being the most seriously affected, however, other industries, like copper, zinc and lead, even gold and carbon, have also suffered. In spite of the widespread use of radiation detectors by recycling industries, radioactive sources do slip through, and can cause serious economic impacts if a source is contravened or melted.
Not only because of the potential health, safety, and environmental consequences, but also due to large economical impacts, metals manufactures are afraid of the consequences of inadvertently melting of radioactive source. For example, it is reported that by use of scrap that contains radioactive material accidental melting of radioactive scrap costs an average \$12 to \$15 Million per event for steel milling.
Sometimes, the radioactive trace binds with the metal matrix, contaminating the metal product. Other times, the contamination follows the by-products of the metal making

operation, such as the furnace dust or the slag or drosses. Due to insufficient knowledge, it is not easy to determine where the radioactive material will accumulate and how the radioactive material will partition itself in the metal making process. The effects of inadvertent melting of radioactive contaminants for industry and radioactive material melted are shown in Fig.71.

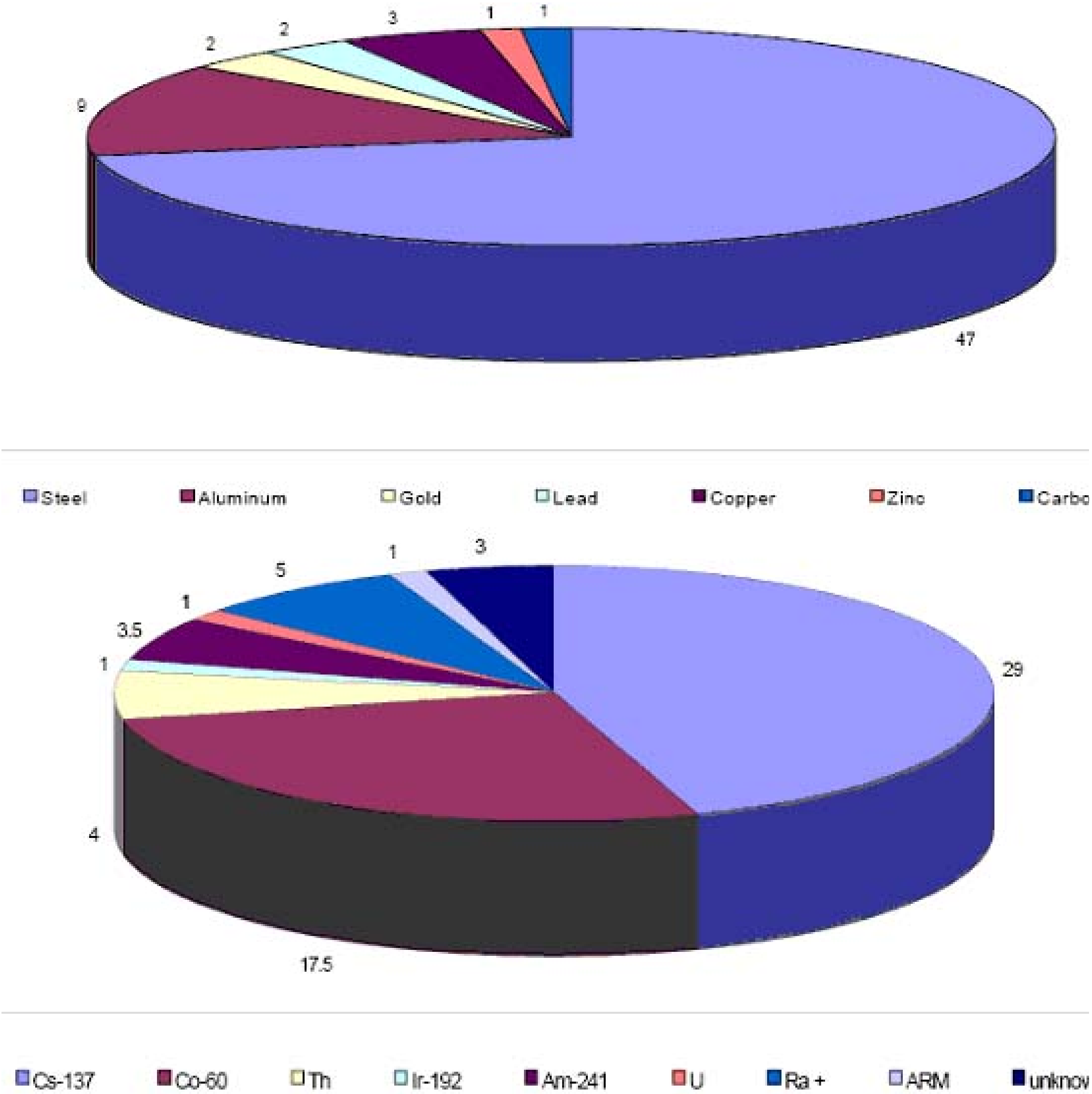


Fig.71 Inadvertent melting of radioactive materials: Industry affected (top) and Material melted (down)

The impacts of radioactive materials in recycling fall into three broad categories, i.e., effects on the recyclers, on the government and its agencies, and on the workers and general public. With respect to recyclers impacts arise mainly from the costs. For example costs for detection, transportation of contaminated source, decontaminating of source if it is breached, waste disposal, etc. For government and its agencies there will costs to respond to these incidents and from the diversion from normal or routine activities. There is also a loss of public confidence and safety credulity, etc. However,

from workers and general public points of view, the impacts arise from actual exposure or contamination of the workers. There may also be radiation exposure from the source itself or from contaminated products and by-products of the melting. Local environment and community may be affected by the radioactive source as well.
Therefore, efforts must be made to control of sources of radiation. These efforts must be made by government and its agencies as well as companies dealing with scrap materials.
Currently, potential sources of radioactive scrap metal include nuclear power plants, nuclear fuel cycle facilities, weapon production facilities, research and development reactors, high energy accelerators, industrial sterilizer plants, industrial radiography equipment, medical facilities and equipment, and petroleum and phosphate rock extraction equipment. Millions of metric tones of scrap iron and steel, stainless steel, and copper, as well as lesser quantities of aluminum, nickel, lead, and zirconium are likely become available in the future as these facilities are withdrawn from services. Radioactive scrap can be classified in four major groups by their anticipated levels of radioactivity, which depends on facility design, operation history, maintenance, decay time, and decommissioning strategy. These four groups are suspected radioactive, surface contaminated-removable, surface contaminated-fixed, and activated. Table 5 describes these groups in details.

Table 5- Radioactive scrap metal classification based on their activity

Calss	***Description***
Suspected radioactive	Components with no significant surface contamination or activated. These components generally come from systems that are not associated with the reactor fuel or primary coolant systems (example: cooling water system and electrical generation and transmission systems)
Surface contaminated-removal	Components may have significant levels of surface contamination that can be removed to a level permitting unrestricted use, however, extensive decontamination may be required. Metals come from building and systems that are, or could be, exposed to primary coolant or fuel during normal operations or during any leaks or spills (examples: reactor building crane and contaminated building liner, etc.)
Surface contaminated-fixed	Components with significant levels of surface contamination that penetrates or is bound to the metal. There may also be some metal activation. Sufficient decontaminating process for unrestricted use is unlikely.
Activated	Components with significant levels of activation. High level of surface contamination expected. Decontamination alone is not expected to be sufficient for reuse of these components.

Estimation of potential quantities of radioactive scrap metals potentially available worldwide is hindered due to lack of published data and also uncertainties associated with weapons facilities. Nuclear power plants, fuel cycle, and weapons production along with naturally contaminated petroleum extraction equipment and piping are supposed to be the main sources for radioactive scrap metals. According to the data, more than 9 million tons carbon steel will be available from nuclear power plant and uranium enrichment plant dismantlement. For copper and stainless still the estimations are about 2 and 1 million tons respectively. The quantities of other metal types are much smaller. However, the inclusion of scrap from weapons facilities along with that from other sources would probably more than double these estimates, therefore, the total inventory of potential metal scrap is on the order of 30 million tons. This means that, on an annual basis for over 50 years period, the inventory could produce recycling flows of 500000 t/y of iron and steel, 100000 t/y of copper and 40000 t/y of stainless steel.

Considering these numbers, shredding plants, recyclers, and also the metallurgical plants using scrap should be very careful regarding how to deal with scrap coming from different resources. In fact serious monitoring and identification for the input raw materials and output products are needed to avoid any undesirable problem with respect of handling radioactive contaminated scrap.

18- Auto Shredder Residue (ASR) and Its Recycling:

By weight, about 75% of End-of Life Vehicles (ELVs) is currently recycled in EU countries and North America. The remaining part, i.e., about 25% by weight, that is called Auto Shredding Residue (ASR) or fluff is land-filled mainly due to the complexity of its composition and difficulties to separate different fractions within the fluff. Since the new EU policy for car recycling indicates that by the year 2006 only 15% of the shredding residue can be disposed of as landfill and by 2015 this amount shall be reduced to 5% there is certainly need for considering these facts and try to recycle fluffs. In addition the aforementioned new EU policy states that 10% of ASR can be incinerated, which means the composition of the fluff to be combusted must be good enough to avoid any environmental problem.

By increasing the world's population and therefore increasing the consumption, the quantities of scrap and thereby the shredder fluff are likely to increase within coming years. On the other hand, increasing the use of composites in manufacturing car caused an increasing in production of ASR.

There have been several research and development projects to see the possible ways for recycling ASR. Both industries and research centers are impatiently looking for an environmentally sounds economically viable method(s) to deal with ASR. However, differences in composition of ASR from different shredding plants make it difficult to find an integrated process for beneficiation such material. Therefore, it may be needed to deal with ASRs in different ways. For this reason characterization and identification of the ASR composition is a vital step.

According to statistics, in the last 20 years the automobile manufacturing has increased dramatically, reaching about 58 million passengers car units in 2002. The expectation for growth is about 32% from 1997 to 2020. This leads to have about 11 million ELVs for Europe in the year 2015 [80]. Fig.72 shows the recovery routs for ELVs with respect to shredding residue. According to this figure, currently, there are six different considering ways to deal with shredding residue, however, some of these ways have common points, e.g., using fluffs as a source of energy [81].

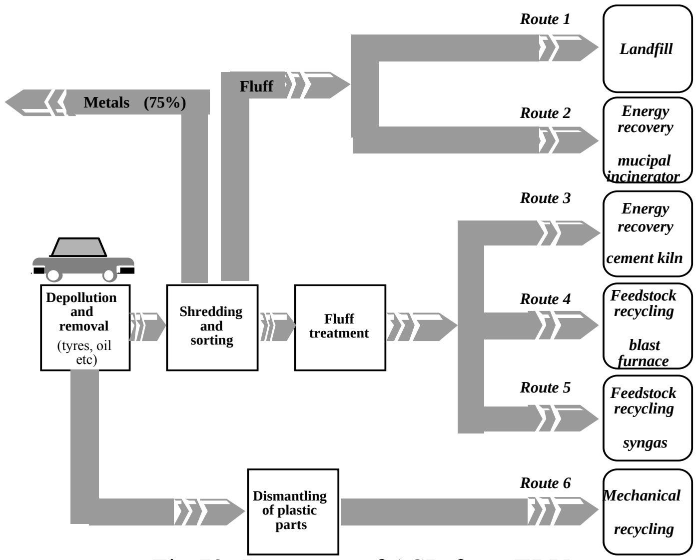


Fig.72- Recovery of ASR from ELVs

18-1- ASR Characteristics: The shredder residue (ASR) or fluff is a fraction that is obtained from the process of shredder of cars and other appliances. In shredding and processing of ELVs and other end of used appliances, the main focus is to recovery of metals, whereas, other materials in the form of fluff are land-filled. The quantities of shredder fluff are likely to increase in the coming years because of the growing number of cars and other appliances being scrapped, coupled with the increase in the amount of plastics used for manufacturing cars and other appliances. Currently the content of plastic is about 12% of vehicle weight [82]. Accordingly, about 3 million tones of ASR are generated annually in North America [83] and it has been estimated that the generation of ASR in Europe to be about 2 million tons per year. In Sweden, the flow mass of these materials is about 100 000 tones per year. Most often, ASR is land-filled, but currently there are other alternatives, e.g., to incinerate the fluff as a source of energy or to use it as fuel in rotary kilns in cement manufacturing [84].

ASRs have been found to be extremely heterogeneous materials having different compositions. By approximation, roughly 50% of ASR is combustible and 50% non-combustible. However, the organic matters, i.e., plastics, rubber, and fibrous materials are estimated to be about 40-65% of ASR total weight, having an interesting heating value of 15-30 MJ/kg. Although, incineration can recover part of this energy, with subsequent reduction in the volume of material to be land-filled, but it provides only about 40% energy recovery and incorrect combustion conditions could lead to production of dioxins due to the future uncontrolled amount of PVC and other organic chlorinated matters in the plastic part of fluff.

Statistical estimation of the fluff indicates that it contains of 40% of plastics; 21% elastomers represent, 10% textiles, 3% ceramic and electric materials, and 5% paint protecting coating. Light and heavy fractions represent about 20.5% and 4% of the total weight of fluff (Olivier, 2004, Kim et al, 2004). The plastic material are mainly composed of poly propylene (C_3H_4, 35%), polyurethane (CHON, 14%), polyethylene (C_2H_4 10%), and PVC (C_2HCl 7%). The electrometric materials instead are mostly due to the EDPM ($C_{10}H_{12}$ 39%), natural rubber (C_8H_{12} 25%), and styrene-butadiene ($C_5H_{6,5}$ 23%), polypropylene (C_3F_3 2.3%) fractions. Fig.73 depicts the statistical analysis of fluff by elements and composition of materials [85].

C	51.3%
H	5.4%
O	10.2%
N	2.2%
Cl	2.6%
F	0.4%
Others	28%
Heating value	16.51 MJ/kg
Density	0.262 t/M^3

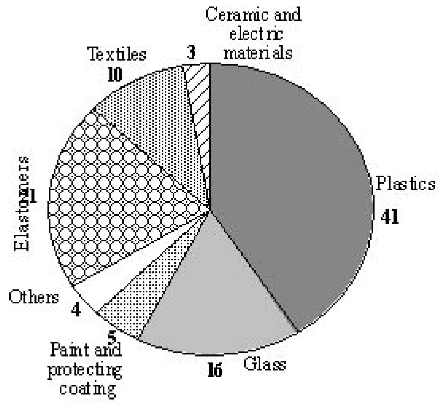


Fig.73- General composition of the fluff (Statistics data)

Day et al., [86] indicated that ASR from Canadian shredding plants contains 6% moisture, 18% of coarse material (> 25mm), 37% fines (< 2mm), with calorific value of 11.8 MJ/kg. This material contains of different metals, such as zinc, lead, and copper (1% Cu and Zn, 0.25% Pb, less than 0.05% Cd and Cr).

Composition of fine fluff, i.e., < 2mm in size, is reported separately by Mirabile et al., [85]. According to their study data still considerable amount of iron can be found in fine size fraction of fluff.

Table 6 – Characteristics of fine fluff (< 2mm in size)

C (%)	49.5	P (%)	0.7	Fe (%)	25.7
H (%)	5.3	Cr (%)	0.08	Ti (%)	0.9
O (%)	6.9	Cu (%)	1.2	H_2O (%)	2.2
N (%)	4.5	Zn (%)	1.9	Ash (%)	36.2
Cl (%)	0.5	Ni (%)	0.07	Volatile matter (%)	54.18
S (%)	0.2	Pb (%)	0.2	Heating value (MJ/kg)	16720
F (%)	0.05	Si (%)	2.1	Density (t/M^3)	0.359

Detailed physical and chemical characterization of ASR also done by Lanoir et al [8]. According to their study there are two ASR fractions from shredding yard. The one is the light fraction obtained during shredding of the raw material and is vacuumed by the vacuum machine over the shredding machine and the second is the residue obtained after physical separation of crushed material and separating iron and other non-ferrous metals. The study concerns the first fraction which is obtained by vacuuming the light fraction through shredding operation within size fraction of 5-20mm. This fraction contains of rigid plastics, coating and textile plastics, foams, different rubbers, magnetic and non-magnetic metals, wood, glass, stone and earth, etc. The results from characterization of this fluff are summarized in Figs74-77.

According to Lanoir, et al. [87], the principle components of light ASR residues are plastics and metals. The majority of metals found to be iron, aluminum, and copper. This study revealed that with specific energy of 19MJ/kg and an ash content of 38% it is feasible to incinerate this light fluff. However, regulation of some operational conditions for incineration may be needed to avoid any unwilling emission of toxic effluents.

Study on characterization of automotive shredder residues from two shredding facilities with different refining process in Sweden indicated that the heat value for different size fractions of ASR, i.e., < 6mm, 6 mm< <12mm, and > 12mm, are 5.9, 14.0, and 20.7MJ/kg respectively. Accordingly materials with size fraction bigger than 6 mm were found attractive for characterization study with respect to energy recovery. Table indicates the fraction of total input for two different plants, P1 and P2, in Sweden [84].

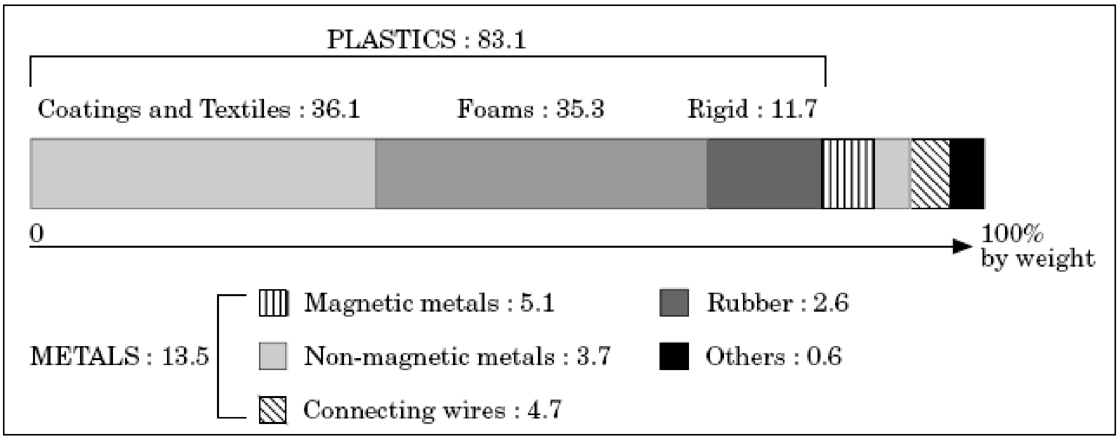


Fig.74 - Macroscopic determination of fluff

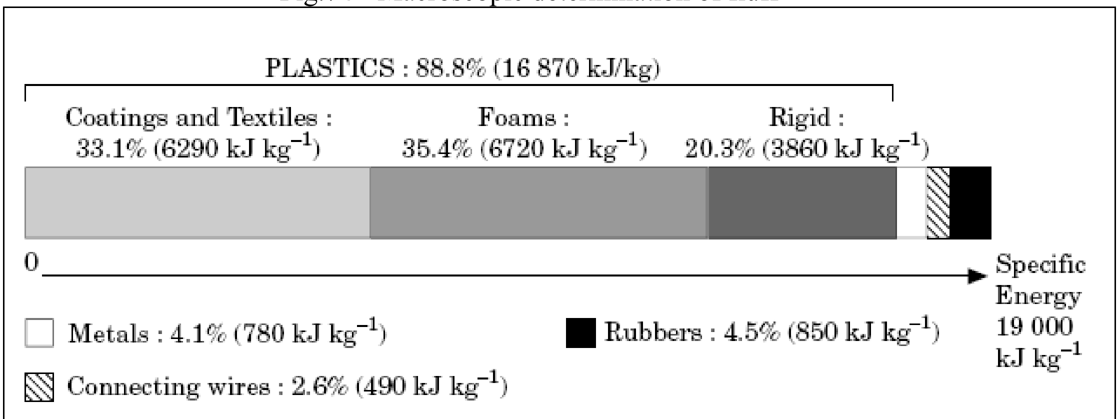


Fig.75 - Specific energy determination of fluff

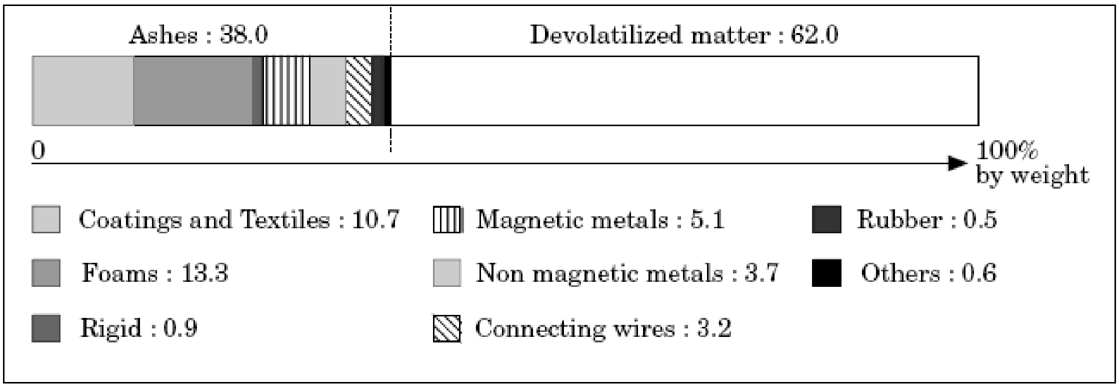


Fig.76 - Ash content determination of fluff

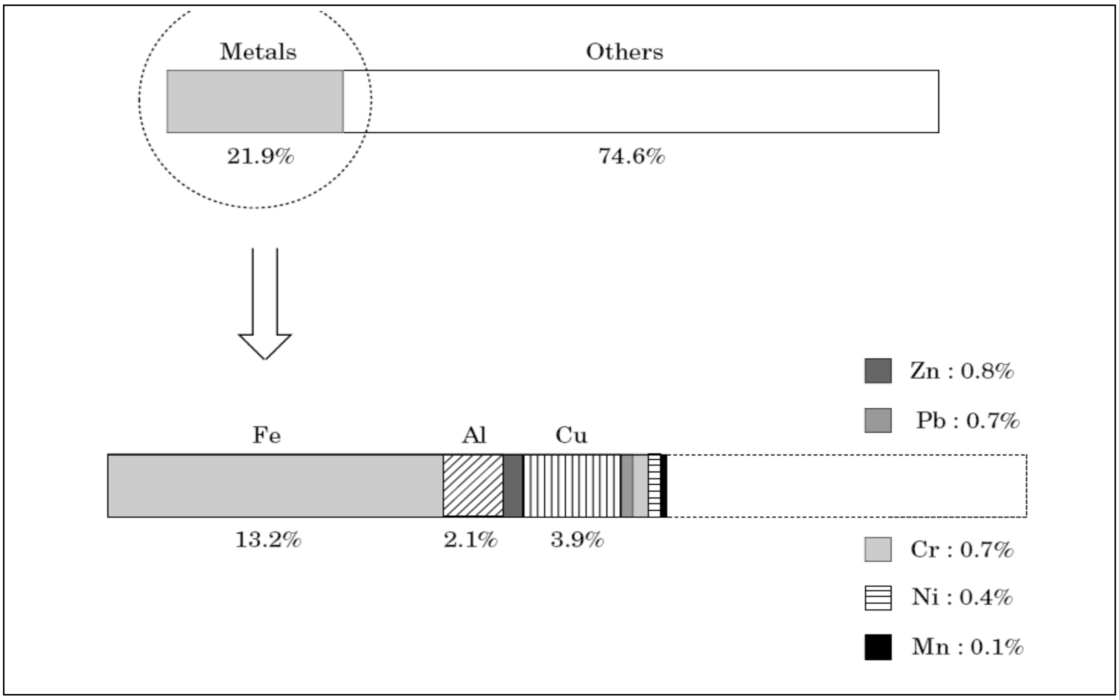


Fig77- Heavy metal content determination of the fluff

Table 7 – Fractional of total input for different shredder set from two plants in Sweden.
(Fuel fraction = material both from SR and NF, Disposal fraction = sieved SR< 17/10 mm and NF < 10mm)

Set	*Fuel % of input*	*Disposal % of input*	*Metal recovery %*
P1 half dism	11.2	13.0	75.6
P1 full dism	13.9	15.3	70.8
P1 mixed cars	15.5	12.6	71.9
P1 mixed waste	12.3	9.6	78.1
P1 white goods	16.2	8.9	74.7
P1 industrial waste	6.5	7.4	86.3
P2 half dism	9.5	9.3	74.9
P2 half dism	7.6	8.9	76.9
P2 full dism	8.0	7.3	76.7
P2 mixed cars	12.5	10.8	69.3
P2 mixed waste	7.1	9.9	78.0
P1 white goods	4.5	11.6	76.9
P1 industrial waste	2.9	7.0	83.0

According to the study, the heat values in the fuel fraction vary between 17 to 26MJ/kg, which was considerably higher than the values for disposal fractions, where the values vary between 4 to 12MJ/kg. Ash content of the fuel fraction originated from ELVs was about 15 to 30% by weight. However, the corresponding ash content for white goods or industrial wastes was higher, at about 30-70%. The ash content is mainly depends on the amount of metals exist in fuel fraction. The sulphur content of the raw material is low enough, i.e., between 0.2 to 1.1 mg/kg. The amount of chlorine in fuel fraction of ELVs varied between 1.9 and 2.8% by weight. However, the fuel fractions from white goods and industrial waste contain higher amount of chlorine, up to 5% by weight. But, in disposal fraction the chlorine is less than 1%. For metals, the most abundant one in all fractions is the iron and its content varies from 4 to 234g/kg in fuel fractions. The second abundant for metals went to copper which its amount differed from 20 to 70g/kg in fuel fractions. For aluminum the amounts between 6 and 26 g/kg in fuel fractions were reported. With respect to the heavy metals, the contents of Cd, Hg, Pb, and Zn in fuel fractions were found to be lower than disposal fractions from both shredding plants. But, if incineration of the fuel fractions is aimed the content of heavy metals must be generally reduced. The levels of polychlorinated organic pollutants were investigated in different samples, i.e., both fuel and disposal fractions were found to be not high to cause environmental problems during incineration. However, the levels of PCBs were found to be higher, especially when dealing with white goods and industrial scrap.

This study suggested that because too much energy potential would be lost by direct incineration of this shredder residue it is not recommended to merely incinerate it. High content of inert materials, such as copper and heavy metals will probably remain in the ashes after incineration. Therefore for better handling environmental problems arising form incineration it would be better to separate the non-metallic part from metallic one by gravity separation or solvents.

Liu et al., [88] did a comprehensive study on ASR sample collection and characterization for late models of Chrysler vehicles, named as C-ASR, and comprised the achieved data with two other feed, i.e., shredding of different ELVs, named as E-ASR, and another sample from routine shredding operation at DJJ plant that contains of 70% ELVs and 30% other scrap that named R-ASR. After shredding the samples the shredded materials were processed to separate the ferrous and nonferrous metals from ASR and the remained ASR samples were screened to obtain four different size fractions, i.e., $p< 15.9$mm, $15.9<p<50.8$mm, $50.8<p<101.6$mm, and $p>101.6$mm. The results indicated that:

1- The mass of materials with particle size $15.9<p<50.8$mm is 85.5%, 89.8%, and 92.6% for C-ASR, E-ASR, and R-ASR respectively. This size fraction of ASR materials are fairly homogenous and therefore more focus most be given in characterization of this size fraction.

2- The constitute of smaller particles, i.e., $p<15.9$mm, from total wastes were found to be 27.8% for new Chrysler vehicle models and 27.9% for other ELVs.

3- The ASR fractions with particles $50.8<p<101.6$mm and $p>101.6$mm were very heterogeneous. However, total amounts ASR materials within size of $50.8<p<101.6$mm were found to be 11%, 9.1%, and 6.7% for of these two size C-ASR, E-ASR, and R-ASR respectively. The bigger size fraction constitute of 3.5%, 1.0%, and 0.7 of total weight for C-ASR, E-ASR, and R-ASR correspondingly.

4- The average value of percent combustible in fraction with particles $15.9<p<50.8$mm was 61.5% for C-ASR, 56.5% for E-ASR, and 46.4% for R-ASR. These numbers indicated a significant difference in amount of combustible materials in R-ASR from those of C-ASR and E-ASR. Furthermore, the amount of combustible materials in fine fraction, i.e., p<15.9mm, of routine shredding operation R, was smaller than those of found by new Chrysler vehicles and normal ELVs, which is believed to be because of the input materials for routine shredding operation that consists only 70% ELVs.

According to Fisher and Mark [89], although potential differences between feed streams to shredder, type of shredding operation, and mixing of different ASR streams are known to occur, a review of the ASR literature and the findings from different investigations indicating that that the basic property for unprocessed ASRs can be considered as the followings:

Heating value between 13-17MJ/t, total metals content from 3 to 15 wt%, heavy metals content ranging from 1.2 to 2.2 wt%, and chlorine from 0.4 to 3.6 wt%. However, the contributions for lights and heavies ASR in total residue streams are found to be between 80- 90 and 10-20 respectively by the wt%.

Another study done by Meyer [90] indicated that the plastics take the biggest part of the whole residual waste with over 50% in all particle sizes. However, the amount of plastics increases with increasing particles size. 10% of the fluff is made of glass, whereas the part of glass enriches in the fine fractions, i.e., particles smaller than 10mm. The amounts for metals and wood remains almost constant for particle size with a range of 20 to 70mm and the amount of thread is increased from almost zero in fine fractions, i.e., <2-3mm, to more than 20% in biggest size fraction, i.e., 30 to 90mm.

18-2- Processes for recycling and reusing ASR: There are different ways for treating residues from shredding plants which result in material recycling or energy recovery or both. Most of the treatment methods are chemically oriented methods, however, there are some physical separation techniques in order to reduce the amount of metals content and some other reusable materials in order to improve the combustibility of the organic matters and protect the environment. Herein, different processes for treating ASR are reviewed.

18-2-1-Physical separation to enrich the ASR for thermal treatment or other uses: Due to differences among the density of materials within ASR it should be possible to separate some components from other by density separation. Plastics, rubber, wood and paper have densities below 1.5, however, stone, glass, and metals hold considerably higher density values. For separating metals from plastics and other lighter materials, first the comminution of fluff may be needed. After further comminuting of fluff and screening the crushed material air classification can be used to separate metals from organic parts. In fact two products are achieved by air classification, metal enriched and organic enriched products. The process can be adjusted in such way that a clean metal free, organic fraction is produced within specific particle size range. The iron fraction can be separated from the metallic fraction by using magnetic separator. In addition for coarser fraction which is rich in metals a heavy media separation system should be considered for separating light metals from heavy metals. Fig.78 depicts the general configuration of the process [90].

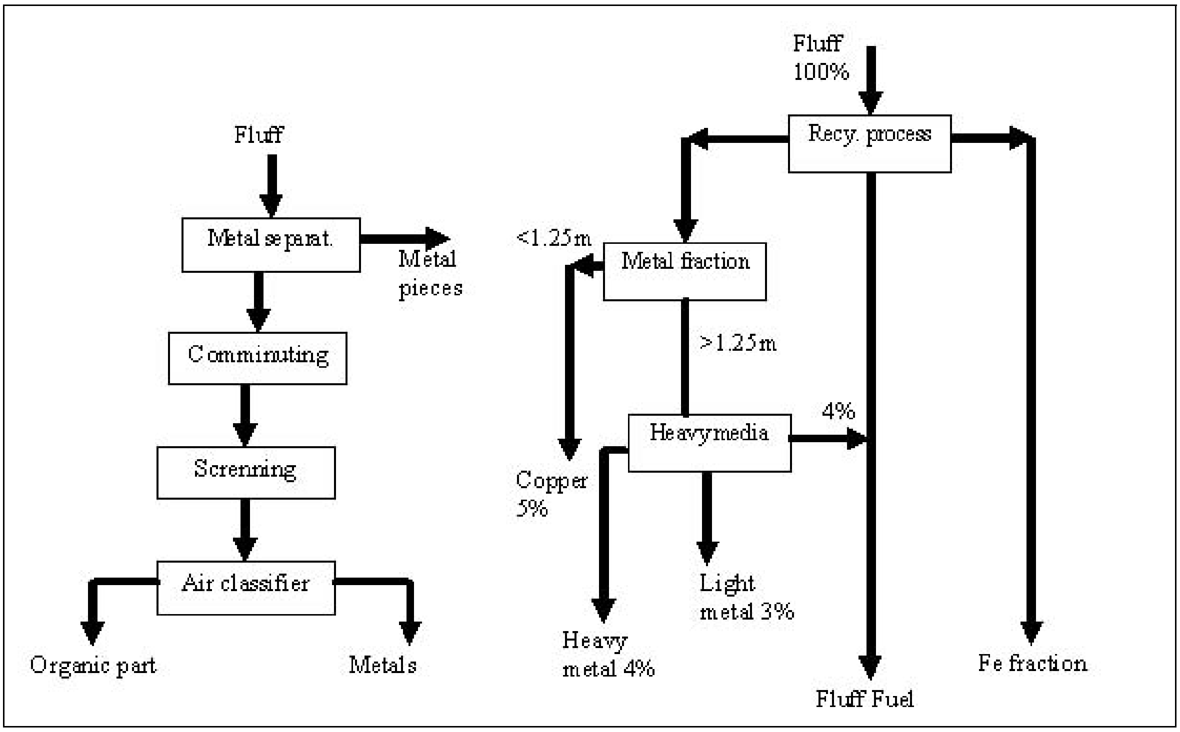


Fig.78- Flow-sheet of fluff recycling with product balance of recycling

It is reported also that the fluff fuel produced by this processing procedure has a low ignition temperature of 230°C that indicates a high reactivity. This is due to the fact that the fluff fuel has a large surface area and also a high portion of volatile constitutions of 57%. The calorific value of the fluff fuel was found to be 17.5MJ/kg good enough. However, high ash content of 30% and chlorine content of 2% are negative factors that should be considered.

Daniels et al., [91] at Argonne National Laboratory, USA, illustrated a method for material recovery from shredder residues with a target for recovery of clean polyurethane foam, conditioned iron oxides, and selected high-volume polymers including polypropylene, polyethylene, EPDM, ABS, HIPS, nylons, PVC, and polyester TP. However, there are ferrous and non-ferrous metals that can be recovered as by-products during recovery of targeted materials. The principal residue material remaining is a plastics concentrate that includes more than 20 different types of lower-volume automotive materials.

At the first stage of processing procedure, bulk separation is accomplished using a specially designed two-stage trammel that yields three product fractions, i.e., fine, dirty polyurethane, and a plastics concentrate. The fine fraction includes the oxides having particles finer than 0.25 inch, the foam fraction contains large, light materials, and the last fraction which makes the balance of the raw ASR contains plastics. These three streams are then forwarded for further processing.

The polyurethane fraction is entrained oils, dirt and some metals. In addition the foam pieces are different in size from 1 up to 8 inch. To produce a marketable foam product the foam is first sized by a secondary shredder to produce consistently sized pieces about 1×1×4 inches. Shredding also facilitates liberation of entrained metals and dirt. Thereafter, the foam stream is screened and washed. Within washing tank heavy components such as rubber compounds and non-ferrous metals are recovered and the cleaned foam is produced. The foam recovery is about 50%.

Fine fraction consist of about 40% of the shredder residue which contains metal oxides, dirt, glass, sand, and residual amounts of organic including oils and small particles of polymeric material. Magnetic separation of this material followed by wet sink-float separation can produce a high-quality iron oxide concentrate; having more than 60% iron and low concentration of alkali metals and residual organics; that can be used as an alternative source of iron in cement production. This concentrate is typically one third of the weight of fine fraction from ASR.

The mixed polymer concentrate from first stage of bulk separation is further processed to recover selected polymers. The mixed polymeric material is first granulated in order to have consistent particle size of about 0.25 inch for subsequent separation. Then wet sink-float separation process is employed for separation of different polymers. That also includes froth flotation for separation of equivalent-density polymers from each other. Two-stage sink float system is used for production of three initial cuts, i.e., light, middling, and heavy fractions. Rubber compounds, such as EPDM and polyolefin, accumulate in light fraction. These rubber compounds can be separated from each other by flotation. The middling fraction contains of polymers such as ABS, ABS-PC alloys, SAN, PC, and HIPS. Froth flotation can be used for separating HIBS from others, whereas, PC, ABS, and SAN are compatible materials and can be recycled without further processing. PVC is concentrated in heavy fraction with other high-volume/high-value materials such as nylons and polyester TP. Sink float and flotation processes can be used for recovery of these polymers. By the aforementioned processing stages more than 65% of mixed-polymers can be recovered and the remaining is concentration of twenty different polymers. It is also worth to mention that according to the detailed studies, recovery of these materials from Shredder residue can result in revenues in excess of $150 per ton of raw throughput.

Gallo Plastics, the recycling group of the Gallo Group in Halluin, France, has been successful in marketing its black PP compounds that is a recycled material from ASR [92]. Separation of ASR starts with grinding the ASR to around 25mm bits. The ground material goes through a large trammel where the raw material is classified into a light thermoplastic fraction and heavy thermoset fraction. Thereafter, air classifier is used to remove textile and PUR foam. The remaining thermoplastics and thermposet rubber are processed by eddy-current separators to remove copper. The thermosets are used by Gallo as fuel. The rest plastics are sent for heavy media separation in four different stages, i.e., different density separation of 1.6, 1.25, 2.2, and 3.2t/m^3 using modified ESR dynamic media separation. Organic from inorganic materials are first separated by using at density of 1.6t/m^3. Organic materials are floated and thereby separated from inorganic. In second stage of sink-float separation PVC is separated from other plastics at a medium of 1.6t/m^3. The third and forth media, i.e., 2.2, and 3.2t/m^3, are used to reclaim valuable metals from a fraction containing engineering plastics like ABS and nylon.

According to the data realized by the company, this process is able to concentrate 90% of the thermoplastics in a fraction constituting 10% of the original mass. It is said that metal recovery pays for the process up to this point, including transportation of thermoplastic pre-concentrate to Gallo Plastics, where it goes through a proprietary static dense-media separation in which materials between 0.9 and 1.5t/m^3 are separated with precision of 0.002t/m^3. Here PP is separated from PE and PS, while ABS and talc-filled PP are separated from the remaining plastics of 1 to 1.1t/m^3, which are land-filled.

Sorting, compaction and solidification technology for ASR: In order to increase recycling rate and reduce waste volume, Kusaka and Iida [93] studied a method for improving of sorting precision for metals and glass contained in ASR by employing a sorting system including slant roller separator. In addition compaction and solidification for ASR were studied and optimum conditions were found.

Fig.79 shows the flow diagram of the process with its equipment. The process can be roughly divided into two processes, the sorting process and the compaction and solidification process. The use of sorting equipment is to distinguish and sort the iron, steel and non-ferrous metals, as well as glass and plastics from ASR stream by employing multiple sorting and classification methods that utilize the theories of weight differences (slant roller), shape differences, particle differences, wind force (cyclone), magnetic force(eddy current and magnetic separator), etc. The compaction and solidification equipment takes the sorted plastics and solidifies them, so the processes consist of two group compaction and solidification. First the residue is dehydrated by the compaction machinery, i.e., heater and compactor, and turns into semi-solid. And the within the next step a single axis screw type hydraulic solidification equipment solidifies the residue for energy utilization.

The results from the study indicated that after sorting stage using slant roller separator, magnetic and eddy current separators, and wind force separator, about 11% of different materials including glass and sand, iron and steel, copper, and aluminum, were collected. This also was understood that to be difficult to sort metals due to tangling with flocked residues. However, the experimental results indicated that about 11% of iron and steel, 65% of aluminum, and almost 100% of copper remained in the residue after sorting.

In the case of compaction it was found that ASR having lower than 10% moisture is best, however, medium moisture, i.e., about 15%, can be also acceptable to be compacted but at higher temperature. For material with moisture content of 20% or more the latent heat of vaporization becomes great and the material temperature would not rise to allow forming to be accomplished. To obtain satisfactory formed products for combustion it is needed that the temperature of the compacted and solidified products respectively rises to 135°C or higher and 150°C or higher. It must be added when dealing with low moisture content residue the possibility of hydrogen chloride formation must be considered at temperatures higher than 160°C, whereas, formation of hydrogen chloride is hindered at elevated temperature if the shredder residue contains more than 15% moisture.

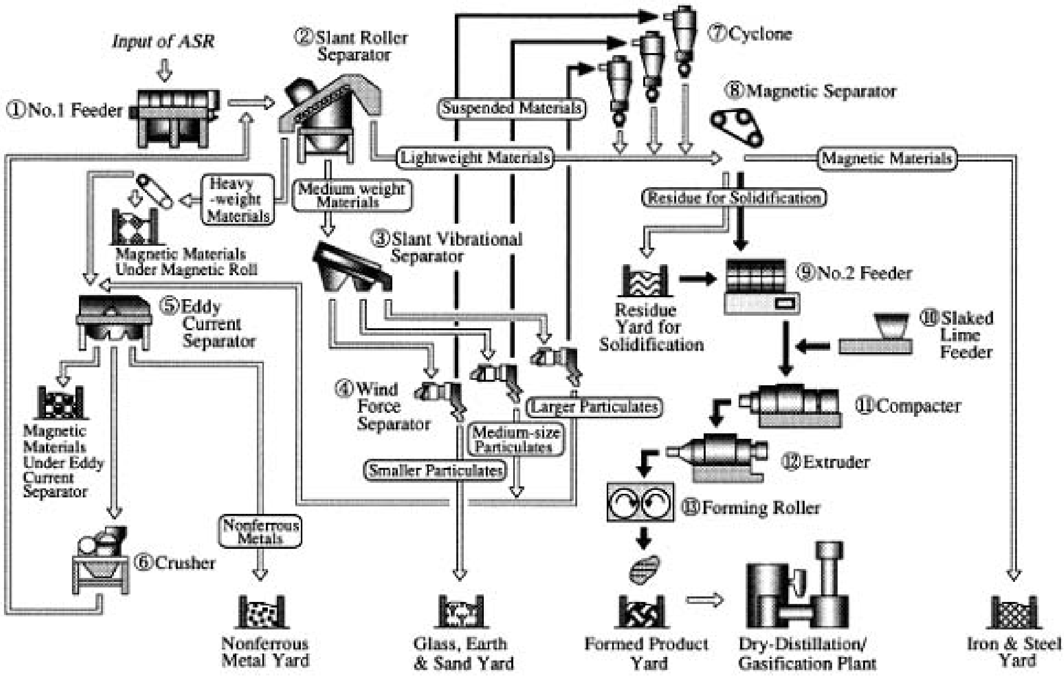


Fig.79- Flow diagram of experimental plant for sorting, compaction and solidification of ASR

***18-2-2- Argon process for ASR recycling*:** According to Bassam et al., [94] the process is suited for sorting plastics contained in the ASR. Within the process recovering of polyurethane foam PU, Poly propylene PP, PVC, and ABS can be completed in four different steps. Drying, physical separation, solvent extraction, and solvent regeneration are important steps for recovery of thermoplastics. Density separation is first used for separating PU through special screening system. To avoid moisture, fluff must be dried prior to separation stages, however, drying maybe costly if fluffs containing high quantity of moisture are going to be treated. Fig.80 depicts the designed laboratory classification column for PU separation. In addition to PU separation the classification system provides two other products called plastics rich and fines.

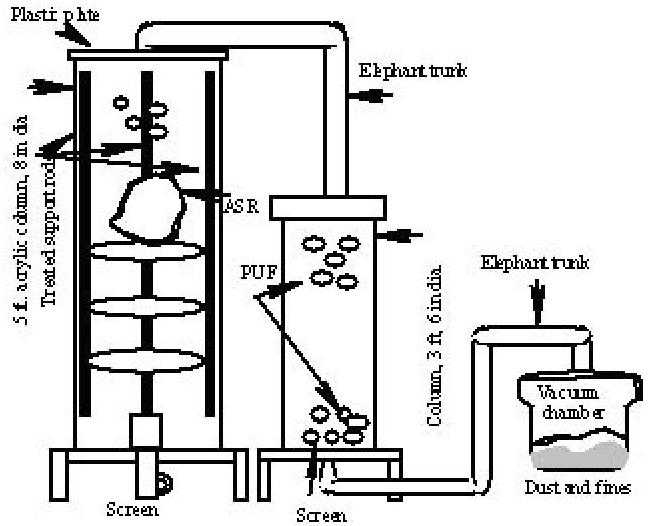


Fig.80- Setup for physical separation of PU, plastics rich, and fines from fluff

18-2-3- Pyrolysis process for recovery materials from fluff: Pyrolysis resulted from reaction of water with any polymeric material under specific pressure. The process is activated by an electrical input. Free radical species, then, are produced by reaction(s) under pressure of less than 69KPa [95]. It is claimed that the gases generated from this process are almost exclusively H_2, CO and CH_4. The gas produced can be used as a fuel. Later on it was explored the possibility of disposing of both pyrolysed sheet molding compound and pyrolysed automotive fluff in the concrete.

According to Shen et al., [96] by fast pyrolysis of ASR at atmospheric pressure and high temperature between 700 °C and 850 °C for a short residence time, i.e., 0.3 to 1.4 seconds three main products can be achieved. Theses three products are: Solid residue for 59-68 wt%, pyrolysis gas (dry) 13-23 wt %, and pyrolytic water 4-12 wt %. The pyrolysis gas mainly contains of CO, CO_2, CH_4, C_2H_4, and C_3H_6. In addition it is said that ASR having high organic content gives less solid residue and more pyrolysis gas. The pyrolysis of ASR in hot used motor oil to recover valuable oil products generates 68% of oils, 15% of non-condensable gases and 27% of non - liquifiable solid residues (Lin et al, 1996 and Galvagno et al, 2001) [97-98].

Raus and Pollesel [99] have explored the pyrolysis of Italian ASR using thermogravimetric, FTIR and system thermal diagnostic study (STDS). According to their study the calorific value for Italian ASR estimated to be 28.3 MJ/kg that is in a range of common coal. For fluffs high deviations in chlorine content have been reported. The chlorine content for different fluffs may vary from 0.5% to about 17% by weight with an average of 3.4%. The high evolution rates at low temperature suggest a good reactivity for ASR. The most important products found are saturated hydrocarbon compounds, however, HCl, nitrogen-derived substances, and oxygen-containing gases, e.g., CO, CO_2 and SO_2, are other products resulting from ASR pyrolysis.

*Pyrolysis with the aid of microwave for fluff processing***:** Microwave and plasma-arc thermal destruction processes can be used for treating fluff [99-100]. During pyrolysis by make use of microwave energy reactions occur at the molecular level. This process is the chemical decomposition of a substance by heat at temperatures within range of 275 to 300°C).

ASR is fed to the system of through a feed locks procedure and nitrogen is used to purge the feed in order to prevent the combustion of carbon. Then, the vapor steam produced and condensed, and the water is removed. The fuel - oil obtained is sent to the storage tank. In the bottom flow, carbon black is taken out at 300°C and is cooled to 50°C. The products are passed through magnetic separator to take out magnetic fraction. The non-magnetic fraction is crushed to fine particles to make uniform mixture and the carbon black is obtained by screening the fine mixture material. It was claimed that no toxins such as dioxins were generated from this process. It is reported that one pilot scale plant is testing this process.

*Vacuum pyrolysis of fluff***:** Within this process the pyrolysis procedure is carried out at 496°C-524°C under total pressure of 1.2 - 4.7KPa. The gas and vapor are removed and cooled down in two condensers set in series. Different fluff samples from Europe and America have been tested by this method in pilot scale. According to the results it looks that vacuum pyrolysis is an interesting process for ASR treatment in comparison to land-filling and incinerating [75]. Valuable ferrous and non-ferrous metals can be separated from the residue after pyrolysis. According to the information released, about 52.5% of solid residue, 27.7% of organic liquids, 13.2% of water and 6.6% of gas are produced by vacuum pyrolysis.

Fast and conventional pyrolysis: There are other pyrolysis processes that can be used. Marcello et al, [101] have comprised the performance and products yields in conventional and fast pyrolysis of ASR. Both conventional and fast pyrolysis processes offer an attractive solution for the recovery of energy from ASR. The investigation revealed that for both conventional and fast pyrolysis more than 80% 0f carbon is converted to gaseous and liquid products at temperature ranging from 500°C to 800°C. The yield for char decreases in the temperature range 500°C to 800°C from 55% to 40% in the case of conventional pyrolysis. Whereas, for fast pyrolysis the char yield is lower and decreases from 48% to 25% at elevated temperature. The tar yield is increased from 35% to 58% for conventional pyrolysis but, for fast pyrolysis the tar yield is decreased decreases from 25% to 20%. The gas yield increases in both pyrolysis procedures but increasing for fast pyrolysis limited from 5% to 10%. It has been noted also that the higher heating value for gases produced by conventional pyrolysis were observed which ranges from 8.8 to 25.07 MJ/Nm^3. On the contrary oil produced by fast pyrolysis was found to have higher heating value ranging between 28.8 and 36.27 MJ/kg.

Catalytic pyrolysis of ASR: Argon national laboratory in USA [102] has developed a pyolysis method for ASR. During processing, a synthetic ASR made up from pure materials was pyrolised in a ceramic tube reactor inserted into the 30-cm heating zone of an electric furnace. The catalytic pyrolysis of synthetic ASR was performed in the presence of several oxides such as: MgO-ZnO, ZnO-TiO_2, TiO_2-SiO_2, $MgZrO_3$, $MgTiO_3$, Fe_3O_4, CuO, Montmorillonite K10, ASR char, and ZnO-Al_2O_3.
After processing the liquids are collected in a series of three condensers, the first condenser is water-cooled, both the others are cooled by glycol at –20°C.
During pyrolysis, usually, the uncatalyzed reactions of the synthetic ASR generate between 6% and 9% of CO_2. However, using catalysts increases the production rate for CO_2, for example in the presence of Fe_3O_4 and oxidation of carbon by the metal oxide the reaction generates about 18% of CO_2. Use of catalysis is beneficial in order to lower the decomposition temperature due to lowering the activation energy [102].

18-2-4- Injection of ASR into blast furnace: It has been proven that blast furnace process is able to accept and recycle beneficiated residual materials with sufficient energetic potential [103]. In practice, ASR, having standard specifications, can be injected into blast furnace as an auxiliary reductant. But, certain parameters must be considered, such as physical properties, energy content and chemical composition of ASR, as well as its non- ferrous metal contamination. In addition the amount of ASR must be continuously available as product. Based on pilot scale tests it has been shown that temperature and atmosphere characteristics for blast furnace allow the complete destruction of organic compounds and avoid the formation of dioxins, therefore, ASR can be injected to the blast furnace. Furthermore, heavy metals are dissolved in the hot metal and in the slag [85].

The use of ASR as the reducing agent by injection into blast furnace is also reported by Takaoka et al., [104]. Based on new recycling process, ASR is separated into plastics as float material and sediments which contains of metal, glass, and stone. The remaining metal can be used for steel-making; however, the plastics part is injected into blast furnace. The recycling process called Thermo-bath process which uses coal tar based oil as the reductant in blast furnace.

18-3- Thermal treatment of ASR: Fig.81 shows the thermal treatment of shredder residue. During thermal processing, the organic constituents are destroyed at 1300°C [105]. Accordingly the volume of ASR is minimized and the only problem is to purify the flue gas products. The gas flue resulting from thermal treatment of ASR needs to be treated to avoid hazardous emission. The thermal treatment of approximately 1.2 million m^3 of fluff, yields about 97 000 m^3 of glassy slag plus 66 000 m^3 of metals plus 15 000 m^3 of flue gas. On the other hand, mineralization of this material yields a glassy slag, and residual metals are separated and returned to the materials cycle.
There are different ways for thermal treatment of ASR. For example, ASR can be combusted successfully in a conventional fluidized-bed combustor between 677°C and 866°C, with carbon combustion efficiency in the range of 75.2% to 89.2% [106]. Since the process is affected by different parameters, such as fractional excess air, fluidizing air

velocity, bed temperature and the feed rate, it is important to consider all these parameters and find an optimum combusting condition.

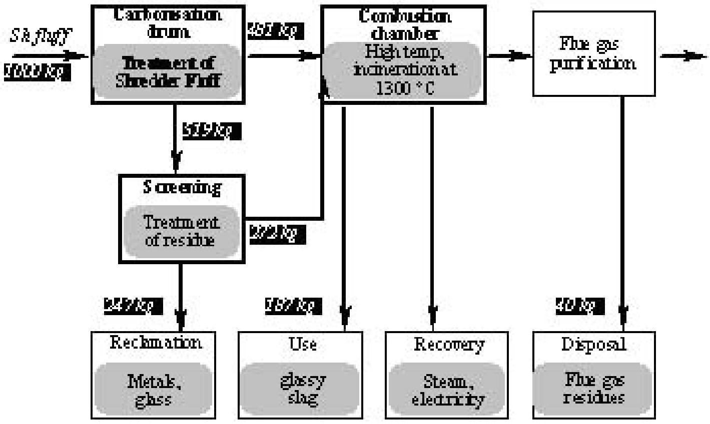


Fig. 81- Thermal treatment of shredder fluff and its material stream.

Citron's solution for ASR: Citron has a recycling plant in France to recycle more than 10000 tons of ASR. The plant makes use of new thermal process, called Oxy-reducer process that was developed to recover the metals. The organic components are then used for their calorific content and their reducing potential [107]. A rotating furnace is used for heating and pyrolysis of the organic compounds, reduction of metallic oxides to their metallic states, and their separation from Fe, Cu and Mn fraction at high temperature and the oxidation of the process gases. This process is controlled by temperature, concentration of oxygen and retention time. During processing, about 45% of total ASR feed is recycled as material and 50% is recycled for its calorific energy to use instead of natural gas. Fig.82 depicts the general configuration of Citron process.

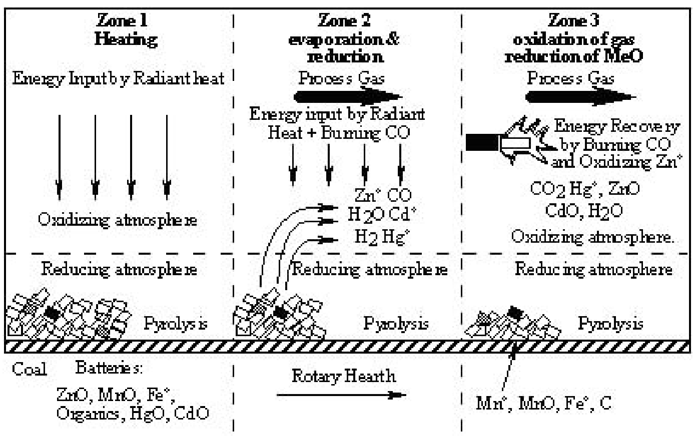


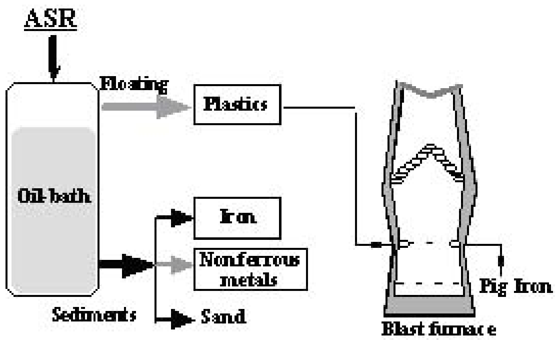
Fig.82 - Citron's Oxy-reducer technology for recycling and reusing ASR

***18-4- Other options for utilizing ASR*:** The followings are other options for utilizing ASR.

Using ASR as a binder in asphalt: ASR can be used in asphalt as a binder and aggregate. The compatibility between ASR and asphalt by differential was tested by different methods, such as scanning calorimeter, polarized light microscopy, and visual compatibility testing. In addition the viscous and elastic behaviors of different binders were examined by dynamic shear rheometer and aging susceptibility by recording infrared spectra (FTIR). The results concluded that there are certain advantages to use ASR as an asphalt modifier, such as a reduction of the oxidation of asphalt and longer elastic memory, and preventing fatigue cracking [108].

Utilization of ASR as filler in concrete: It has been reported that the residue obtained from pyrolysis of ASR can be utilized as filler in concrete [108-1110]. It was claimed that the finest fraction, i.e., <250 μm, which contains mineral, metallic and organic can be valorized as filler in plastics, concrete, asphalt. The fine residue material, obtained after pyrolysis of the ASR, offers interesting properties due to the fact that it contains of lot of fibers. This has been proven by using SME technique.

Thermo-bath process for recycling ASR: Japanese developed a new process in which ASR is heated up in oil-bath using coal tar based oil that is a by-product of steel works as a heat medium [111]. Within process procedure, ASR is heated quickly in oil-bath at 280°C. During heating the organic plastic floats and thereby can be easily separated by gravity. Inorganic metal and materials sink. The floating plastics can be fed into blast furnaces as a reducing agent and the metal can be recycled. Fig.83 depicts the general configuration of the process.



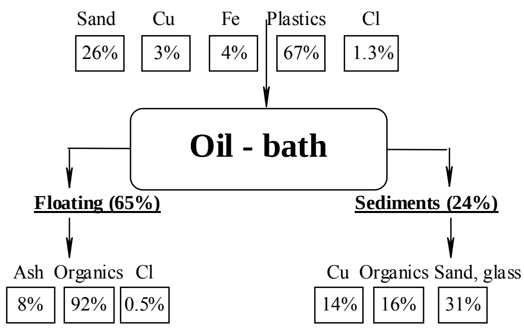


Fig.83- Thermo-bath process for recycling and reusing ASR (left) and its material balance (right)

Japanese have built a pilot plant and made experiments on ASR recycling by Thermo-bath process. The material balance obtained from their experimental results is also given in Fig.83 showing that ASR is easily separated into floating material and sediments within a time of 20 min. From oil–bath separation, they obtain about 65% of material in floating and 24% in sediments. On the other hand, Fig.83 shows that the floating part of ASR contains of 92% of organic, 8% Ash and 0.5% Cl_2. The sediment part contains 16% of organic, 39% iron 14% Cu, and 31% of sand and glass. According to Ichiro et al, [109] in regard to EU directive, 95% of an ELV must be recycled of which maximum 10% for energy recovery in 2005, consequently a total ELV recycling ratio of 96% can be achieved by this method.

TwinRec Process: TwinREc process was introduced in 2000 by EBARA Corp. for SR treatment [112-113].The process was first developed by Japanese in 1995 and was designed to treat shredding residues, swage sludge, fly ash waste plastics, liquid waste medical waste and municipal solid waste. The process works based on fluidized bed gasification in combination with ash melting. The apparatus has two main systems, the fluidized bed gasifier and the cyclonic combustion chamber.

Shredder residue is directly fed to the gasifier which is a proprietary internally circulating fluidized bed of compact dimensions operating at temperature between 500-600°C. During process, fine particles are entrained into the gas flow and leave the gasifier together with the resulting fuel gas. The main function for gasifier is to separate the combustible portion and the dust from the inert and metallic particles of the SR. Metals like Aluminum, copper, and iron can be recycled as valuable products from the bottom off-stream of the gasifier since they are neither oxidized nor sintered with other ash components. Together with these metals larger inert particles are removed. However, smaller inert particles are returned to the gasifier where they serve as bed material. The inert fine particles are blown out of the gasifier to enter the next stage.

Thereafter, fuel gas and carbonaceous particles that have been produced in the gasifier are burnt in the cyclonic combustion chamber at temperature between 1350-1450°C by addition of secondary air. Within combustion chamber, the fine particles are collected on the walls, where they are vitrified and proceed slowly through the furnace. The molten slag is quenched in a water bath to form granulates with excellent leaching resistance and sent for application in construction. It is claimed that high combustion temperature doest not allow to

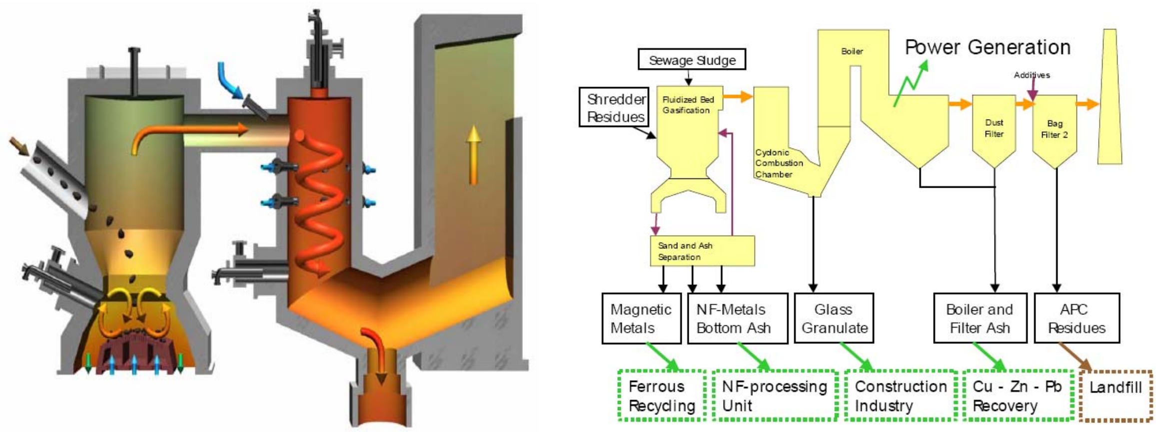


Fig.84- TwinRec core components, gasifier and ash melting furnace (left) & Combined energy and material recycling from ASR at Aomori plant using TwiRec (right)

According to EBARA Corporation, TwinRec generates different product streams from recycling ASR that can be used for different purposes. Pure metals and alloys are recovered from gasifier. This product can be treated further by physical separation techniques to have ferrous and non-ferrous metal products. Inert mineral material is cleaned from dust and organic matter to make it suitable for recycling, for example can be used as the filler.

Mineral dust and metal oxide powder are vitrified into the glass granulate and recycled afterwards. Harmful organic substances are completely destroyed and the total organic content is transformed to the energy. Volatile metal salts are concentrated into the secondary fly ash and are available for zinc, lead and copper recycling in the zinc industry. The amount of final residues for land-filling is reduced considerably. Fig.85 depicts the total cycle for car recycling by using Twinrec for ASR treatment. As it can be concluded from the figure from 25% of ASR, 10% can be recycled as metals, inert minerals, etc., 12.5% can be as energy recovery and just 2.5% is land-filled. This means that 90% recovery and reusing from ASR.

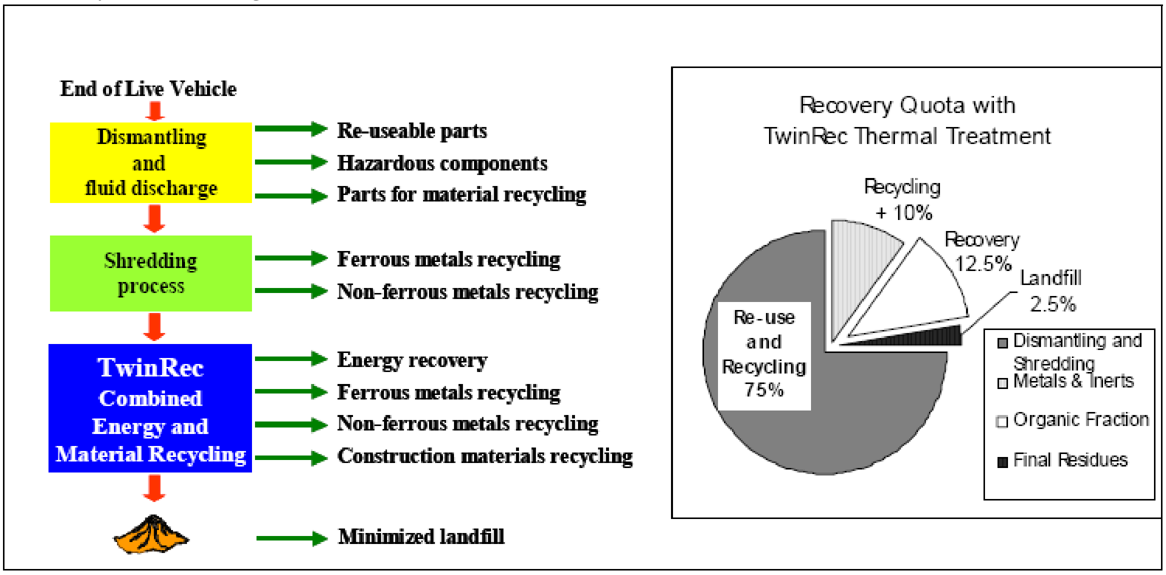


Fig.85- Improving recycling and recovery of ASR by TwiRec

<u>19- Recycling Scenario With Respect to the New EU Legislations [114-115]:</u>

Nowadays, in automobile recycling infrastructures in both America and Europe approximately 75% of the material content of a vehicle, i.e., metallic portion, is recovered, and the remaining, i.e., 25%, is typically land-filled as the ASR. Over the last few decades, various economic parties within the recycling infrastructure itself have operated solely for the purpose of profitability and have largely been unrestrained by legislative requirements. Recently the new law for ELVs recycling has been passed within EU parliament and therefore, there is a need to reform the economics and management of ELVs. This new law will impact automotive manufacturers worldwide since grater percentage of a vehicle's mass must be recycled or reused at its end life. Therefore, specific pre-treatment of materials prior to shredding is nodded that includes handling and removal of hazardous materials.

The low indicates that by beginning of January 2006 vehicle reuse and recovery, including energy recovery and material recycling, must reach a minimum of 85% by the weight per vehicle, of which 80% will have to be reuse and material recycling. However, by January 2015, ruse and recovery target will rise to 95%, of which 85% will have to be reuse and material recycling. By this new legislation, entire life cycle of a vehicle in Europe, or even worldwide, will be affected, from design to its end of life, including the infrastructure that dismantles and shreds vehicles. The new legislation falls under the growing number of product stewardship or extended producer responsibility policies that will force the automakers to assume a grater financial cost of the end of life management of the product.

The priority within the new EU legislation is the prevention of waste from vehicles, however, the objective is to encourage reuse, recycling, and other forms of recovery. Producers are the most important definition in this legislation. The directive covers vehicles and end of life vehicles, including their components materials. The use of hazardous substances is limited by the rule since the recovery target is to gain 95%. The design of the new car must be reconsidered due to the needs for having facilities for better and faster dismantling. The quantities of recycled materials have to be increased in order to develop the market for recycle materials. Since July 2003, the materials and components put on the market has not to be able to contain lead, mercury, cadmium, or hexavalent chromium other than in the cases allowed by the low (for example less than 0.35% lead is allowed in steel, and 0.4% in aluminum, less than 2gr per vehicle of hexavalent chromium).

According to the EU law end of life vehicle will be stripped before further treatment. Hazardous and components will be removed and segregated so as not to contaminate shredder waste from ELVs. Stripping operations and storage will be carried out to full fill the suitability of the vehicle components for reuse, recovery, and recycling.

Lastly, the law says that the original equipment manufacturers have to produce dismantling manuals to facilitate the identification of components and materials that are suitable for reuse and recovery. It is also needed that producers publish a report on the design of the vehicles and their components viewing the recoverability and recyclability of their product.

Studies on economics of dismantling automobiles have disclosed that disassembly of non-metals to increase recycling is largely uneconomical in the current market conditions of North America. Disassembly of parts from automobiles is labor intensive and thus expensive and traditional dismantling procedure sounds to be economically not feasible. Even if the recycling price for non-metals increases dismantling of non-metallic parts for recycling would be uneconomical.

According to the study by Johnson and Wang for evaluation policies and automotive recovery options according to the EU directive on ELVs, it was found that:

a- The 85% recovery rate for the year 2006 cannot be met without energy recovery if no parts are resold and the tyres are shredded.

b- 85% recovery achievement is possible and it will be economic through a combined effort of International Dismantling Information System recycling, tyre recycling and remanufacturing, without a need for energy recovery from ASR.

c- The requirements of 85% recovery rate, by the year 2006 are attainable by assuming 5% recovery of energy from ASR.

d- Too much disassembly may lead to an unprofitable demanufacturing situation. Therefore, optimization between recover rate from shredding and dismantling is needed. According to the purposed model, to achieve 85% rate of recovery it is just needed to dismantled just 9 components among the 42 that are suggested by International Dismantling Information System for dismantling.

e- To improve recovery rate and improve ELV economics, tyre recycling must be done since provides a valuable resource. However, if tyres are shredded the recovery rate for ELVs does not improve.

f- The requirements of the 95% recovery rate in the year 2015 are not attainable for current ELV. The maximum recovery rate possible for the vehicle without resale assemblies, i.e., true ELV, will be 88.2%.

g- The10% energy recovery allowance by the year 2015 will lead to a decrease the umber of polymers dismantled for recycling. This is counterproductive decision to the International Dismantling Information System program and the recycling of polymers.

h- Resale of automotive components provides the greatest economic and recovery benefits.

i- Remanufacturing can lead to substantial values in ELV components even if the components are a fraction of the original resale prices.

In general, to gain better rate for recycling and recovery of ELVs there is a need for coordinated efforts among recyclers, dismantlers, shredders, and automakers to create economical markets and used for recyclable materials, in particular polymer and glass material streams. Otherwise, plastics and glass materials will drain the recycling infrastructure. Number of automobiles that are able to meet the legislation for the year 2015 will be considerably constrained, therefore, there is a need for a close and constructive negotiation between the car manufacturers and the policy makers to see all the possibilities clearly and to address all the issues of non-compliance of recovery rates, etc.

20- ELV Recycling With Respect to Its Composition (New generation of vehicles):

The composition of a typical car has changed substantially in recent years. For example, ferrous metal content has significantly decreased as lighter; more fuel-efficient materials such as plastics are incorporated into vehicle design. An analysis of vehicle manufacturer data for around seventy popular 1998 car models indicated that a car contains of about 68% ferrous metal, 8% non-ferrous metals, 9% of plastics, 5% rubber (including 3% tyres), 3% of glass, 2% fluids, and finally 1% of electrical parts, carpet, process polymers, battery, and other materials respectively.

Table indicates the composition of an average automobile with material recovery/disposal rates at each recycling stage (considering that disposal is by recycling and land filling combined).

However, there is another classification for the cars based on the ferrous metal, non-ferrous metals (mainly Aluminum), and polymers or composites. Accordingly there are three types of cars, steel intensive, aluminum intensive, and finally composites intensive cars. Fig.86 depicts the average percentage of different materials used in these three kinds of cars.

Table 8- Composition of an average car along with material recovery through recycling

Type of Material	*Weight (lbs)*	*Material Recovery /Disposal Rate (weight %)*		
		Dismantling	*Shredder*	*Non-ferrous separation*
Carbon Steel	**1526**	35	64	1
High Strength Steel	**369**	35	64	1
Cast Iron	**350**	90	9	1
Cast Al	**178**	15	20	65
Wrought Al	**52**	15	20	65
Plastics	**342**	0	90	10
Magnesium	**5**	0	20	80
Copper	**45**	20	0	80
Zinc	**15**	0	0	100
Other Materials	**358**	50	50	0
Total Weight	**3240**			

According to this classification, vehicles that contain more than 24% of aluminum are considered as the Al-intensive vehicle, however, having about 26% polymers means that car is composite intensive. Therefore, different cars must be treated differently during recycling [116].

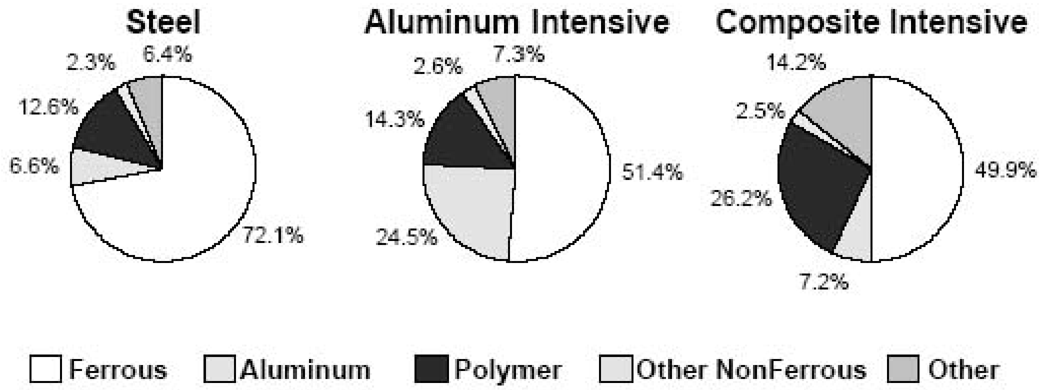


Fig.86 - Mixtures of different vehicle designs based on main components

Demands for more fuel-efficient vehicles to reduce energy consumption and air pollution are growing fast which is a challenge for automotive industry. Aluminum is a good replacement for heavier metals like steel and copper in automotive industry due to its characteristics regarding high strength stiffness to weight ratio, good formability, as well as good corrosion resistance and recycling potential. According to a research study done by Miller et al., the consumption of aluminum for European automotive industry reaches to 1.9 million tones in the year 2005 in comparison with its consumption of 0.675 million tones in 1994. This means an increasing of 200% within 10 years. Due to recent information the total consumption of aluminum in a car will rise considerably from 110 kg in 1996 models to 250 or 340 kg, with or without taking body panel or structure applications into account, by the year 2015 [88, 116]. There are strong predictions for aluminum applications in hoods, trunk lids and doors hanging on a steel frame. With this respect significant increase in sheet aluminum consumption will be expected for automotive industry in Europe. For casting aluminum a key trend has been

the switching the use of cast iron for engine blocks to aluminum, resulting in significant weight reduction. It was expected that more than 50% of motor engines change to aluminum blocks in 2000.
This must be noted that although aluminum has a realistic chance to capture a grater share in car body and motor applications, but, its penetration in automotive industry has been limited up to now due to factors like, raw material cost, manufacturing cost, industrial structure, recycling, regulations, etc.
A comprehensive study was done by Das and Curlee [118] regarding recycling of new generation vehicles, in which the lightweight materials such as aluminum, magnesium, carbon-reinforce polymer composites, glass-reinforced composites, and ultra-light steel, are substituted for heavier materials such as steel and iron components. The target mass of new generation vehicles is 1960 lbs, as compared to the average current vehicles that weights 3240 lbs. Accordingly two different models for the cars is expected, either aluminum intensive or composite intensive automobile.
Therefore, a spreadsheet cost model of the automobile recycling infrastructure was developed to estimate the potential effects of new generation vehicles on the future economic viability of the recycling industry.
According to the model purposed, the profitability of dismantlers, shredders, and non-ferrous separators under the base case conditions using the recycling infrastructure model are 30%, 64%, and 14% respectively. The total cost breakdown of various processing steps of the recycling was found base on the study which is shown in Fig.68.

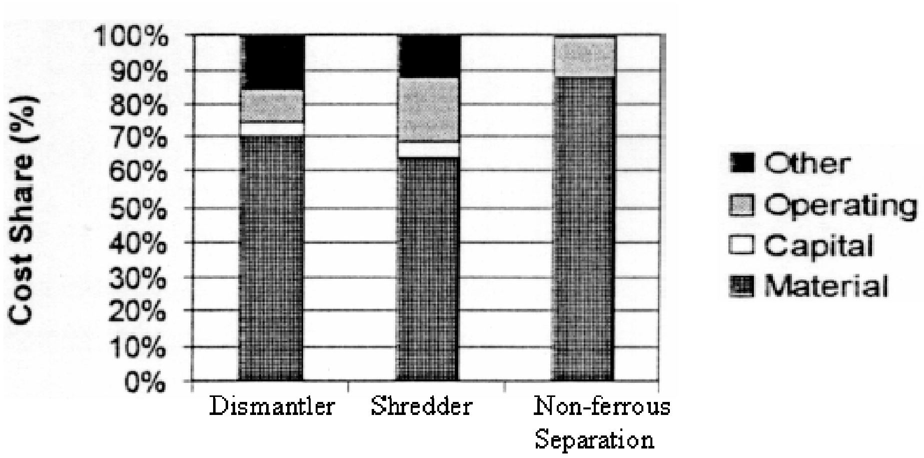


Fig.68- Cost structure of the automobile recycling industry

From the figure it is concluded that for all processing steps the material cost contribute more than 60% which reaches its maximum, i.e., 90%, for non-ferrous separation step. Capital is small share of the total cost, especially for non-ferrous separators, where it accounts for less than 1%. Most of the cost at non-ferrous separator stage is due to two components, i.e., materials and operating costs. On the other hand, shredders have the largest share of operating costs that is estimated to be 19% of the total cost due to extensive maintenance required for the wear of contact parts. It is also concluded that since the capital cost is small part of total cost at each step, therefore, any change in the infrastructure due to potential changes in material composition of automobile will not be large as compared to other potential impacts.

According to this investigation, substitution of ferrous materials by aluminum in vehicles has effects on the profitability of the automobile recycling. It was assumed that each pound of aluminum replaces 1.45 lb of steel, i.e., 45% weight saving. It was also presumed that potentially serious technical problems, e.g., incompatibility of cast and wrought aluminum, contamination from paints and adhesives, likely to be faced with increased use of aluminum do not alter the current economics of the industry. However, the effects of altering economics were examined also.

At the dismantling stage the substituted material parts continue to be recycled for parts reuse, whereas the recycling share of the remaining materials at the next two recycling stages is assumed to be the same as under the base case.

Increasing share of aluminum has positive impact on the viability of dismantlers. It means that if more parts are made from aluminum the dismantling rate will be significantly higher than the today's 15%. The profitability will increase to 50% or even more by 55% aluminum substitution.

Shredders will also experience an improved profitability due to lower hulk weight and increased revenue from aluminum. With 15% aluminum substitution, the profitability of shredders will increase by 40%. However, the effect of non-ferrous separators is positive but not as high as shredders and dismantlers. By considering the current technology used for non-ferrous separation, it is assumed that the aluminum scrap is sold as a mixed scrap. However, if the separation of different aluminum products is achievable the profitability will be considerably enhanced. Today the recycling rate of automotive aluminum is estimated to be between 85 and 90%, and the product of recycling secondary foundry alloy casting constitutes fully 60-70% of the aluminum used on current vehicles. The sheet and extrusion scraps which form the minority portion of the total weight measured, are recycled into casting alloys because secondary casting in general have a greater tolerance for alloying elements and impurities than do sheet or extrusion products. With increasing growth in the use of sheet and extrusions there will be a need to separate sheet, extrusions and casting during the recycling process. Then sorting is needed for separating different aluminum alloys. Since it is projected that the need for primary casting alloys, i.e., sourced from virgin primary metal, significantly increase during 1990-2010 in comparison with the need for secondary castings, i.e., growth of 451% for primary casting in comparison to 79% for secondary casting, then the recycling of more than 805 aluminum can be achieved only with new low-cost aluminum separation technologies. Besides the difficulty in the separation of wrought vs. cast alloys, potential problems during recycling include the paint/coating and adhesives used to join different aluminum components.

Fig.69 shows the profitability of achieved by the substitution of aluminum instead of ferrous metal at current economic situation.

In the case of composite intensive vehicles it has been indicated that the substitution of composites, only glass-reinforced composites, for ferrous materials will affect the profitability of the current recycling industry to a great extent. Each pound of such composites is assumed to replace 1.6 pounds of steel, i.e., 60% reduction in weight. If the current economics is considered then by increasing use of composites the recycling for parts reuse at the dismantler stage will increase for sure. However, it seems that the recyclability of the composites in two other stages, i.e., in shredders and non-ferrous separation either decrease or in the best case remains constant. As shown in Fig. the profitability of dismantlers will increase because the value of composite parts is assumed to be higher than corresponding steel parts. On the other hand, shredders' revenue will decrease as they will have fewer products to sell, although their operational costs will also decrease because of the lighter material. Here, however, the exception is the land-filling cost that will increase because of the additional amount of ASR. If the rate of substitution of composite for ferrous metal is 25%, the profitability of shredders decreases from 64% to 60%. But, the rate of decreasing in profitability of non-ferrous separation is comparatively less than other process components. The profitability for non-ferrous separation stage drops below 10% with a 25% substitution of composites for ferrous metal.

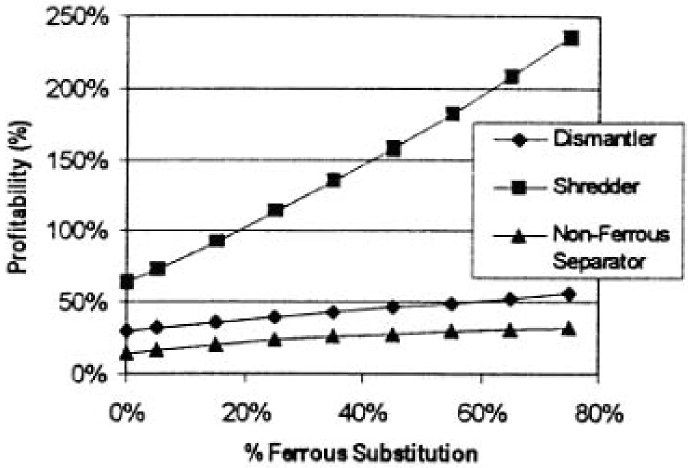


Fig.69- Effect of aluminum-for-ferrous substitution on vehicle recycling industry

Fig.70 depicts the profitability for dismantlers, shredders, and non-ferrous separators by substitution of ferrous with glass reinforced composites. It must be added that currently no cost effective composites recycling technology exists. Therefore, the total profitability for shredders will be affected by land-filling cost, which in some cases covers almost 50% of operating costs for some shredding plants.

Fig.71 depicts the profitability versus land-filling cost for two different types of vehicles, base case and 50% composite intensive. It can be seen from the figure that without having cost effective composite recycling technology the land-filling cost plays a major role in deciding whether the composite intensive cars would be an option or not.

In conclusion for this part it must be mentioned that, at current situation, the positive impact on the recycling industry can be seen by substitution ferrous metal with aluminum due to higher value of aluminum. This gives an opportunity to develop effective separation technologies for sorting and separating aluminum by type. Easier disassembly and larger homogenous parts offer new opportunities for profit from intrinsic material value in addition to traditional parts recovery by the dismantler.

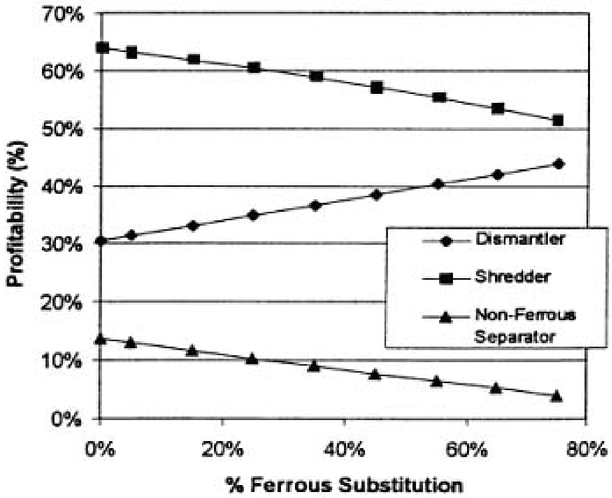


Fig.70 - Profitability of different operational stages by substitution ferrous with glass-reinforced composites for vehicles

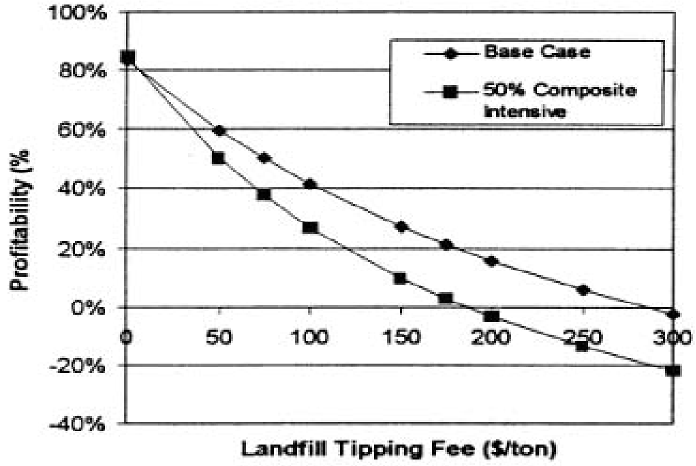


Fig.71- Effect of Land-filling tipping fees effect on profitability of shredders for two cases

Effect of large quantities of aluminum from automobiles on primary and secondary aluminum markets and the extent of separation between wrought vs, cast alloys are determining factors for the aluminum value. Yet, the recycling of aluminum will be limited to large extend on the availability of cost-effective separation technologies for different forms of aluminum, i.e., wrought vs. cast. It seems that development of cost effective aluminum scrap sorting technology is crucial for separating sheet or extrusion from casting, enhancing the value of separated alloys, allowing for continued use of current recycling infrastructure, i.e., shredding followed by separation, and finally achieving more than 80% recycling goal since the market for mixed scrap is limited to the automotive market. Aluminum separation could be done either at dismantling or the separation stage, or both.

In the case of composites, by substitution of composites for ferrous metal the economic viability of the current automobile recycling industry will be diminished. Although in the case of dismantling profitability will increase but this increasing is strongly dependent on ease of parts removal. However, the recycling infrastructure beyond dismantlers will be affected harshly. In particular shredders are threatened since their revenue will decrease while their associated cost with respect to ASR disposal will increase. The separation stage also will be affected strongly as well.

Therefore, replacing ferrous metal by composites is not a good option for new generation of passenger vehicles at least for near future.

21- Remark and Conclusions:

The followings can be concluded from the report:

1- Production of iron and steel, as well as aluminium, copper and other metals and materials from obsolete goods not only saves the resources and conserve considerable amount of energy, but also protects the environment.
2- For production of iron and steel, copper and aluminium, as well as plastics from recycled materials industrial waste, obsolete appliances and ELVs are important sources. With this respect shredding and processing plants play vital role in preparing raw materials from scrap for metallurgical and other industries. Shredding plants in combination with processing facilities make different streams for further utilization in recovery of materials.
3- Prior to shredding the important stage is dismantling. More careful dismantling leads to better recovery of material with less number of processing stages. In addition, dismantling by itself is a profitable process.
4- Shredding plants are divided in three main groups based on the vacuum facility installed. They are wet, semi-wet, and dry shredding plants. However, the dry plants are predominant around the world.
5- During shredding and processing of scrap for further utilization it is important to have maximum liberation degree. Better liberation leads to better separation, and therefore, have higher quality of different streams. This means that scrap must be ground to finer sizes, however, excess in grinding produces more fines and difficulties with respect to beneficiation of fines. Therefore optimum grinding is needed to overcome aforementioned both problems.
6- During shredding of scrap by horizontally or vertically designed shredders four different stages are recognized, i.e., tearing of pieces, size decreasing but not mass reduction, real size reduction, and finally, increasing in deformation.
7- Different parameters have effects on shredding procedure and therefore, it is important to optimize these parameters for better performance of shredding plant. Theses parameters are: residence time, anvil design, discharge grate design, feed material, circumferential speed, housing design. However, among these parameters the first three were found to be more effective and important.
8- Since the comminuted scrap should be classified for further processing, it is important to optimally design the screening facilities that fit the down stream processing. In addition it seems if the classification is done perfectly part of product(s) can be obtained without any further processing. Therefore it is important to study the shredded product in details and to characterize each size fraction and its constitute in details.
9- Having narrower size fraction facilities the downstream processing and thereby the recovery rate improves.
10- Both wet and dry processes are used to beneficiate shredded stream. However, dry magnetic and eddy current separations and wet heavy media or sink-float separation

are three important stages that can be seen in almost all scrap processing plants. In other words to have these processing facilities in modern plants is almost inevitable.

11- For eddy current separator the size fraction of the feed plays an important role and the pole size for the eddy current magnet must be chosen accordingly.

12- Sink-float separation is also affected by size fraction. Having too fines make problems in processing and cause losses.

13- The use of sorting techniques in mineral and waste beneficiation has been considerably growth during last few years. Either optical classification or sorting by using high resolution cameras, or other sorting techniques like XRF, LIBS, LIF, and also sorting by use of metal detectors have capability to identify and sort different pieces with high accuracy. The use of sorting techniques in waste recycling seems to be an ideal option especially in nears future. In addition sorting machines using multi-sensors are now available in market for producing high quality materials. Certainly, sorting techniques have a promising future and they will be utilized in processing plants more and more especially for identification and sorting different alloys from specific metal, like aluminium alloys.

14- It is also important to note that for sorting purposes it is very important to have narrow particle size fraction of the feed. This means that sorting machine performs better if the ratio between the coarsest and finest particles in one fraction be 2 to 3. This again reveals the importance of screening.

15- For processing of shredded pieces it is suggested to size the particles accordingly, i.e., 0-4mm, 4-10mm, 10-25 or 10-30mm, and 30-65mm. +65mm is better to ground further. However, if it is necessary it should be possible to have 30-100mm as the coarse fraction. Thereafter, the processing facilities must be designed to handle these size fractions according to their material constitutions.

16- Studies have revealed that nuclear power plants, fuel cycle, and weapons production along with naturally contaminated petroleum extraction equipment and piping are supposed to be the main sources for radioactive scrap metals. On an annual basis for over 50 years period, there is a potential for recycling flows of 500000 t/y of iron and steel, 100000 t/y of copper and 40000 t/y of stainless steel from these resources. Considering these numbers, shredding, recycling, and also the metallurgical plants using scrap should be very careful regarding how to deal with scrap coming from different resources. Therefore reliable quality control system is needed to avoid any problem in handling radioactive contaminated scrap.

17- Auto shredder residue (ASR) is another discussing problem, especially from environmental points of view. ASR makes up to 25% of the total feed to shredding plant, which is mostly land-filled nowadays. But, increasing costs and also environmental concerns will avoid land-filling in near future. Many research and developing projects have been devoted to solve this issue. Until now, there has been any integrated method to overcome problems with respect to ASR. Although, different physical and chemical techniques are suggested and used to handle ASR, it seems a combination of both methods is needed. With respect to physical techniques, gravity separation in combination with sink-float and flotation are considered.

18- Finally, investigation on substitution of lighter materials, like aluminium and composites, in stead of iron and steel used in car manufacturing revealed that aluminium is favourable material for replacing iron and steel. The substitution not only helps for decreasing the energy consumption and protects both environment and natural resources, but also dismantlers, shredders, and recyclers are benefited. However, substitution of iron and steel by composites will not be good option. In addition, evaluation of EU Directive on ELV and its recovery options indicated that it will be hard to achieve the aims by 2015.

22- Future Planning (what should be done):

The following is planned for completing this study:

1- Study on the plants flow-sheet to define the bottle-necks.
2- Sampling from shredding plant (samples from shredder machine and different separating streams)to identify different fractions physically and chemically.
3- Study on size reduction and liberation degree for different components and to define the optimum size reduction for higher liberation and better performance with respect to energy, etc.,
4- Study on the different parameters affecting sample size and shape through shredding machine (circumferential speed, discharge grate design and its size, anvil design, etc.).
5- Identification of different size fractions after screening (e.g., to investigate the accumulation of different components in different size fractions, etc.).
6- To see the possibility to sort out some fractions without applying any separation technique.
7- To investigate of changing parameters of separation devices to improve the assay and recovery of different streams (e.g., changing magnetic forces for magnetic and eddy current separators, etc.).
8- To improve the recovery rate for heavy-media separation by changing different parameters and/or using new separating machines.
9- To see the possibilities of employing different sorting techniques to sort alloys, plastics, etc.(testing and maybe feasibility study)
10- To investigate the possibilities of using electrostatic separation techniques for separating conductor/non-conductor and insulator/insulator particles from each others.
11- To see the possibilities for sorting components by shape.
12- To look at the ASR composition to see which physical separation technique(s) can be offered for improving rate of recovery for shredding fluffs.
13- To see what should be done to meet the new EU policy for ELVs shredding and recycling.
14- To set a policy for handling different kinds of end-of-life goods (for example for ELVs there are different kinds of vehicles, i.e., iron intensive, aluminium intensive and plastic intensive vehicle products).
15- To make a road-map for shredding plant's fragmentization and physical separation.

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