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Final Report on Scrap Management, Sorting and Classification of Aluminum

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FINAL REPORT ON SCRAP MANAGEMENT, SORTING AND CLASSIFICATION OF ALUMINUM

by

S. Bell*, B. Davis*, A. Javaid** and E. Essadiqi**

EXECUTIVE SUMMARY

In North America, the infrastructure for sorting aluminum from automotive scrap is fairly extensive with roughly 6000 scrap collection and dismantling yards, 200 scrap shredders, and ten sink-float plants currently in operation. Almost half of the aluminum contained in an automobile is removed directly in the dismantling yard and recycled. The other half is passed into the shredder. As a result of three separation techniques [magnetic, air, and eddy-current separation (ECS)], the composition of the scrap increases from 2.5-5 wt % to nearly 70 wt % aluminum. In some shredding operations, the aluminum content is further increased by an additional pass through an ECS machine. However, most of the aluminum is passed a sink-float operation where the majority is separated from the shredder scrap. Hollow aluminum scrap, which represents only a small percentage of the total aluminum in the feed material, is floated out in the second media stage along with magnesium and high-density plastics. An ECS system is then used to separate the floated material into metallic and non-metallic fractions. The metallic fraction from this step is a mixture of magnesium and hollow wrought aluminum alloys. These two metals can be further separated using colour-sorting technology. However, colour sorting is still making the transition from laboratory to commercial practice. Hand sorting is the only other method known for separating magnesium from aluminum alloys on an industrial scale.

The majority of the aluminum during the second media sorting stage sinks and is passed to the final separation step. In a media with a specific gravity of 3.5 g/cm^3, the remaining aluminum is floated out and concentrated using ECS. The end product is a mixture of cast and wrought aluminum alloys. Currently, the majority of the aluminum that is sorted at the sink-float plant is sold to an aluminum melting operation for the production of secondary cast alloys. Secondary wrought aluminum alloys cannot be produced from this recovered material because of the higher concentration of alloying elements present in the casting alloys in the mix. Dilution is the only method available to adjust the chemical content of the recycled aluminum alloys, which means that the production of wrought alloys from current aluminum shredder scrap is impractical.
The amount of wrought aluminum used in the production of the average automobile is expected to increase dramatically over the next two decades because of the incorporation of aluminum sheet into the automotive market. This will result in a substantial increase in the quantity of

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wrought aluminum in shredder scrap, and there will be more of an economic incentive to further sort this material into, not only cast and wrought aluminum fractions, but also into individual alloy compositions. This has spurred the development of several technologies over the last decade, such as colour sorting, laser-induced breakdown spectroscopy, and the hot-crush technique.

Colour sorting has been used industrially over the past decade at Huron Valley Steel Corporation (HVSC) to separate zinc, copper, brass and stainless steel. However, its potential for separating magnesium and hollow wrought aluminum from the second media sorting stage in current sink-float operations has only been realized over the past few years. HVSC colour sorters are capable of effectively separating magnesium from hollow aluminum and producing pure metal fractions of both metals. This process is currently used on an industrial scale at HVSC.

HVSC is also testing the capability of colour sorters to effectively separate different wrought aluminum alloys into individual alloy families. Using etching processes patented by Alcoa, wrought aluminum alloys are coloured by selectively etching them in three different solutions. Each solution promotes a unique colour change on the surface of a particular alloy, which is representative of the elemental composition of the alloy family. The colour sorter is then able to separate the scrap into the different alloy families. HVSC is currently proceeding with a pilot-scale development of this technology.

Laser-Induced Breakdown Spectroscopy (LIBS) is the only method available to separate both cast and wrought aluminum scrap into their individual alloys. This unique technique was first developed at the Los Alamos National Laboratory, and through active partnerships with Metallgesellschaft, Alcan Aluminum and HVSC, it has grown into the most comprehensive method for sorting aluminum. A pulse laser is used to illuminate the surface of the scrap and produce a spectrum that corresponds to its chemical composition. The chemical composition is what determines into which bin the piece of scrap is directed. The end result is that the cast and wrought products are separated into their individual alloys. HVSC is currently the leader in this technology and is testing this technique on a pilot-plant scale. X-rays are also used to illuminate the metal’s surfaces and are the basis for sorting scrap aluminum alloys using X-ray radiometric sorters. This type of sorter is used by Mtsensk Aluminum Works in Russia for separating the scrap into the different alloy families. Unfortunately, its ability to further sort the material into individual alloys has not yet been proven.

The hot-crush technique is a thermomechanical separation process for sorting cast from wrought aluminum alloys. It was developed by the U.S. Bureau of Mines and exploits the low eutectic temperature in all casting alloys. By heating the mixture of aluminum scrap to between 520-560ºC the casting alloys experience a dramatic reduction in mechanical properties because of the onset of intergranular melting, while the wrought alloys remain unaffected. The size of the casting alloys is reduced, and a simple mechanical separation process, such as screening, can be used to separate them from the wrought fraction. In early laboratory tests, this technique showed great promise by producing cast and wrought fractions of almost 100% purity, but its current state of development is unknown. HVSC has also commercialized a proprietary process for separating wrought and cast aluminum, but it was not possible to obtain specific information about the technique.

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INTRODUCTION

The importance of metal recycling, especially of aluminum as part of the raw material supply, is indisputable because of increasingly stringent environmental regulations. The remelting of recycled aluminum saves almost 95% of the energy required to manufacture pure aluminum from bauxite ore. This, in turn, significantly reduces pollution and greenhouse gas emissions from mining, ore refining, and melting.

There are multiple sources of aluminum scrap, from a variety of industries, available for recycling. In a study performed by Rombach[1], the three biggest markets for aluminum in Europe and North America are the transportation construction, and packaging sectors. Table 1 shows typical applications of aluminum alloys within these three markets. In 2000, the U.S. Aluminum Association reported that the transportation sector accounted for 32.5% of the total aluminum consumed during that year, representing the largest end user of aluminum[2].

Table 1 – Application of aluminum alloys in three market sectors[2].

Market segment	Application	Alloy
Transportation	Engine Castings Wheels Closure Sheet Structural Sheet Extrusion Bumper Extrusions Radiators	38X, 319, 356 A356, 5754 6111, 6016, 6022 5182, 5754, 2036 6082, 6061, 6063 7003, 7129 4XXX, 3003, 1X00
Construction	Painted Sheet Distributor Sheet Extrusions	3105 3003, 5052 6061
Packaging	Beverage Containers Container Rigid Foil Packaging Flexible Foil	3004, 3104, 5182 1X00 8XXX

Due to the short lifespan of aluminum in the transport and packaging industries, these two markets represent the biggest generators of aluminum scrap. Over the next thirty years the anticipated annual growth rate of aluminum in the transportation and packaging industries will continue to rise by 3.1% and 1% respectively[1]. This means that the amount of aluminum used in today's automobile will rise from 115 kg to 170 kg by 2005 and as much as 410 kg in aluminum-intensive vehicles[2]. If these numbers are coupled with the modest increase expected in car production this industry will become the largest producer of aluminum scrap. Since the future surge of aluminum scrap is expected to be in the automotive market, this paper will focus entirely on aluminum scrap from end-of-life vehicles.

AUTOMOTIVE ALUMINUM SCRAP

Aluminum is used in the automotive industry to produce a variety of parts. The distribution of aluminum in a typical car, and the percentage of those parts that are cast or wrought aluminum alloys, are given in Table 2[3]. For recycling purposes, the distinction between cast and wrought aluminum is very important since only pure wrought aluminum scrap can be recycled into a wrought aluminum product again. Currently, the only technique available to reduce the levels of alloying elements when recycling wrought aluminum is dilution. A mixture of cast and wrought scrap can only be recycled into a cast aluminum product. It is clear from Table 2 that the majority of aluminum in the automobile is cast, but this percentage is expected to change dramatically when aluminum car panels, which are mostly wrought alloys, capture a larger percentage of the automotive market by replacing steel which is currently used for these applications. In order for this to occur, the recyclability of wrought alloys needs to increase substantially to meet the increasingly stringent government regulations. This need is being met by advances in the technology for sorting aluminum scrap not only into cast and wrought aluminum alloys, but also into their individual alloy groups. The purpose of this report is to review established and developing technologies for sorting aluminum scrap from end-of-life vehicles.

Table 2 – Distribution of cast and wrought aluminum in automobile.

Area of car	Portion of total aluminum used in car (%)	Cast aluminum alloy (%)	Wrought aluminum alloy (%)
Engine Parts	50	90	10
Chassis	30	90	10
Body	15	20	80
Interior Fittings	5	40	60

SCRAP PREPARATION FOR ALUMINUM SORTING

Collection and Dismantling the End-of-Life Vehicles

End-of-life vehicles enter the recycling path by three different routes: 80% of old automobiles are brought to scrap collection and dismantling yards, 15% go to scrap dealers, and the remaining 5% go directly to the shredders[4]. About 95% of the cars not taken directly to a shredder are dismantled[4]. The main income of a dismantler's business comes from the removal of useable vehicle parts, which are rebuilt or reconditioned and sold to the consumer. The actual components removed depend on their condition and sales potential. Dismantlers across North America are networked through a parts database that is capable of locating any existing part within the network. If the removal is not economical, the part is usually left on the hulk (scrapped body). The more common parts that are removed include the entire front and rear ends, low mileage engines and transmissions, alternators, doors, body panels and glass. It is also mandatory for dismantlers to remove hazardous items, including batteries, fuel, fluids, refrigerants, etc., prior to shredding. The removal of all of these parts represents approximately 50% of the original weight of the vehicle[5].

Since 45% of engine blocks in the automobile are removed at the dismantling yard, nearly half of the aluminum is taken out of the automobile and recycled right away[4]. Moreover, salvaged aluminum wheels are a large source of income for dismantling companies. Overall, about 25% of the aluminum in end-of-life automobiles is removed at collection and dismantling centers, while the remaining 75% is passed onto the shredder. In North America, there are approximately 3000 automotive scrap collection and dismantling yards[6].

In order to prepare the hulk for the shredder, it is transferred to a press for volume reduction. This flattening process not only increases the number of hulks that can be transported on a flat-bed trailer, but also improves the efficiency of the shredder. Once the hulk has been pressed, there is no chance of further dismantling. There are roughly 200 shredders operating in North America[6].

Shredders

The stripped and flattened hulks are sold by the dismantling companies to a shredder plant. A typical shredder uses hammer mills that operate at 2000-6000 HP and are capable of reducing an entire hulk to pieces less than four inches in size in 45 s[6]. The shredder operation is shown in Fig. 1[4].

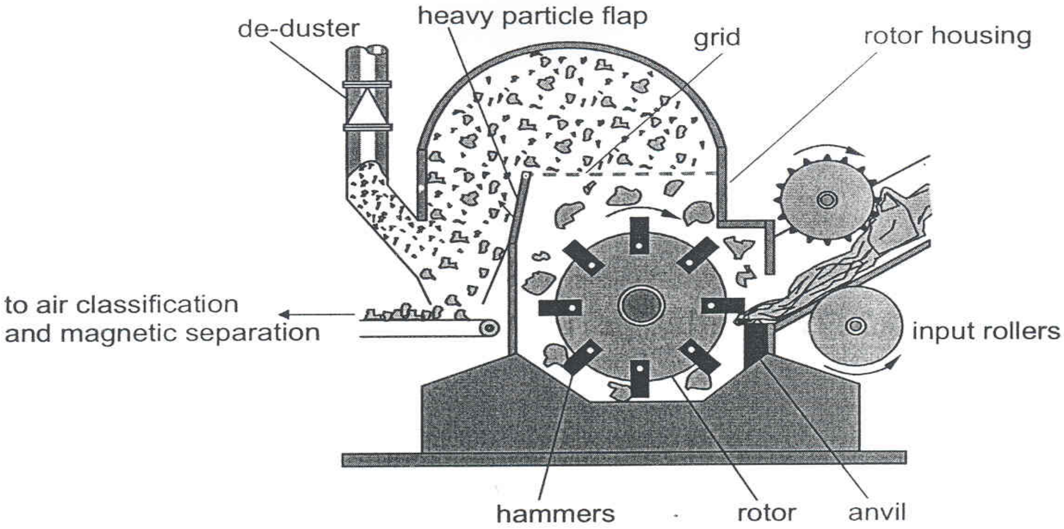

Fig. 1 – Illustration of a typical shredder.

The input rollers further flatten the hulk and feed it into the rotor housing, where flexible hammers shred the car into pieces small enough to fit through the top grid, which typically has four-inch openings. This aids in the separation of single materials and makes the material sorting more efficient. Any components that cannot be shredded to a size smaller than four inches exit the shredder through the heavy particle flap. The de-duster is used to separate out the lighter materials such as dust, fluff, foam, paper, rubber and some wire, while the remaining heavier material is fed onto a conveyor belt and sent to the sorting area of the shredding facility.

CURRENT ALUMINUM SORTING TECHNOLOGIES

There are four main sorting technologies currently used in industry to separate aluminum-based materials from the majority of the shredder scrap. They are magnetic, air, eddy current, and sink-float separation. The first three processes are done in the shredding facility while the last separation method is performed externally in one of the 10 sink-float facilities across North America. All four sorting techniques are discussed in detail in the following sections.

Magnetic Separation

In magnetic separation, a magnetic and a nonmagnetic metal shredder fraction (NMSF) are produced. The most common piece of equipment used for this separation process is called a magnetic drum separator, which is shown in Fig. 2[6]. In this process, a stationary drum with half of its surfaced lined with NdFeB magnets is housed in a rotating cylinder that is set up as a conveyor belt[6]. As the shredded scrap is pushed towards the magnet separator, the ferromagnetic pieces are attracted to the magnet and are removed by the conveyor belt. The non-magnetic material falls into a bin between the two belts and forms the NMSF. Most of the iron and steel pieces are separated out and sold back to the steel mills. This recovered steel represents 72% of the input material[4].

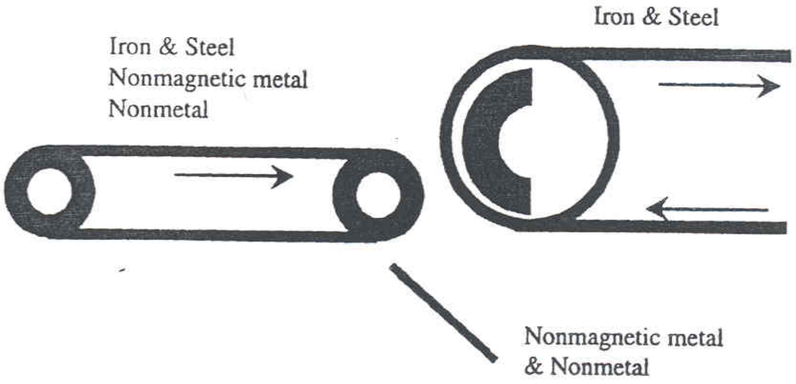

Fig. 2 – Magnet separator.

Air Separation

Once magnetic separation has isolated the NMSF, multiple air-separation steps are performed to better concentrate the NMSF into recyclable components. A suction nozzle above the conveyor belt is used to remove the light non-metals such as plastics, rubbers, foams and fibers from the heavier metallic fraction. Other common air separation methods are an elutriator, in which the pieces are dropped through an upward flow of air, and an air knife, in which pieces are dropped through static air. Both of these methods are used to remove the low-density materials. The materials removed amount to approximately 22% of the input feed and are better known as shredder residue[4]. The majority of the shredder residue is used as a daily landfill cover[2].

Wolf[4] indicated that 81.5% of the initial aluminum content in the pressed hulk remains in the NMSF. Nearly 18% of the aluminum from the pressed hulk is lost in the shredder residue. In most European shredding facilities, the air separation step is performed prior to the magnetic separator.

Eddy Current Separation

In North America, Eddy Current Separation (ECS) is the third and final sorting step used by the shredding facility to further concentrate the metal portion of the NMSF. ECS works by exposing the material to an external magnetic field that repels the nonmagnetic electrically conductive metallic particles. When this type of particle enters a magnetic field, a counter-acting current is produced inside the particles to protect and repel them away from the magnetic field. The overall effect is the generation of a forward thrust (F) and torque (T) on the particles resulting in their ejection from the stream of non-metallic materials[6]. Figure 1 illustrates the force and the movement acting on a non-magnetic metallic particle in the magnetic field of a standard eddy-current rotor[6].

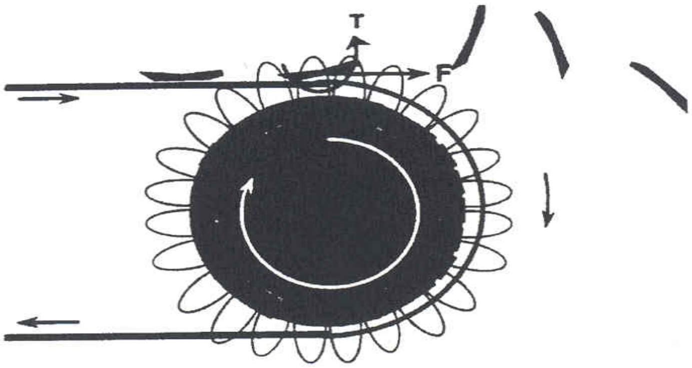

Fig. 3 – Non-magnetic metallic particle in the magnetic field of eddy current rotor[6].

The rotor is lined axially with alternating rows of north and south poles of NdFeB magnets that produce the magnetic field[6]. It is inserted into a nonmetallic outer shell, which acts as a conveyor head pulley, bringing in the mixed metal and nonmetal materials[6]. Varying the speed of the rotor causes the magnetic field to change with time.

The drawback of ECS is that, since the separation is based on the generation of a magnetic repulsion force with in the material, some shapes, especially foils and wires, cannot be sorted effectively since they do not generate eddy currents.

Gesing et al.[6] reported that the end product of ECS is a 30-95 wt % metallic NMSF. Analysis of this fraction in North America shows an estimated composition of 70% aluminum (30-40% of this is wrought alloys), 10% zinc, 7% copper, 8% brass, 4% stainless steel, and 1% lead[6]. Due to the relatively high aluminum content in the metallic portion of NMSF, some shredder facilities have recently started producing a low-grade aluminum product for direct sale to secondary aluminum smelters. This has enabled the facilities to completely eliminate the sink-float process, generating savings in both processing and transportation costs. In order to improve the concentration of aluminum before the material is sold, the metallic fraction is either passed through a secondary ECS machine or floated in a sink-float separation bed of fluidized dry sand particles.

Gesing and Wolanski[2] have reported that HVSC has developed a practice whereby ECS machines are used to separate out the different types of metal. The theory behind this technique is that, since different metals have different eddy current or electrical conductivity measurements, some metals will be thrown farther than others. By placing collection bins at a given distance from the ECS machine, there are considerably fewer contaminant metals included with the recovered aluminum. The current status of this new technology is unknown, but it is most likely in the research or pilot-plant scale of development.

The fluidized bed sink-float technology is relatively new and in its limited use has the potential to become a worldwide tool for sorting non-ferrous metals from the metallic portion of the NMSF. The main advantage of this technology is that it is a dry method for separating different metals from the scrap stream by simply changing the flow of air and thus, the density of the sand. This allows for individual metals to be floated out of the scrap without transferring the entire scrap stream to another media chamber. In order to implement this process on a commercial scale, a number of issues need to be addressed and resolved. This technology has a low-density selectivity because of the high velocity of air, which tends to create bubbles and convection currents within the bed, required for fluidization of high-density sand. Also, tubular pieces tend to fill up with sand and sink rather than float to the surface. Finally, the material entering the fluidized bed must be completely dry and free of lubricants.

Because of the problems associated with separating aluminum from the metallic portion of the NMSF, the majority of it is still sold to wet sink-float plants for more complete material separation.

Sink-Float Separation

North America has roughly 10 high-capacity sink-float plants in operation that handle the entire NMSF output from all 200 shredding facilities[6]. In these sink-float plants, both water and water-based slurries are used to generate a bath with a known specific gravity (SG) so that materials with different densities can be separated. The densities of common materials found in NMSF are given in Table 3[7].

The primary difference between North American and European sink-float plants is that the North American plants use a three-step separation process with media SG of 1, 2.5, and 3.5[6] while the Europeans use a two-step separation with media SG of 2.0 and 3.0[4]. In order to create a desirable slurry, ferrosilicon powder or magnetite is often used. The typical North American operation will be discussed in more detail.

Table 3 – Density values of common automotive materials.

Material	Density (g/cm^3)
Foam plastics	0.01-0.6
Wood	0.4-0.8
Natural rubber	0.83-0.91
Polypropylene	0.90
H.D. polyethylene	0.96
Polystyrene	1.0-1.1
Polyvinyl chloride	1.40
Magnesium and alloys	1.74-1.88
Hollow aluminum	2.2-2.5
Aluminum and alloys	2.6-2.9
Zinc and alloys	5.2-7.2
Stainless steels	7.5-7.7
Brass and bronze	5.2-7.2
Copper and alloys	7.5-9.0
Lead and alloys	10.7-11.3

The metallic portion of the NMSF is first screened into two different fractions; coarse and fine. The very fine material is removed from the process entirely. It has been reported[4] that some of this fine material is sold to Southeast Asia where it is separated by hand. The coarse fraction is sent onto the first floatation stage, in which pure water (SG = 1) is used as the separation media. During this stage, most of the non-metallic materials, such as low-density plastics, foam, and wood, are floated out and removed. The sink portion of the first stage is then transferred to the second media slurry with a SG of 2.5. Here, high-density plastics, magnesium and hollow aluminum alloys are removed by floatation. The floated fraction is then rinsed to remove the media and fed to an ECS, where the metallic materials (magnesium and hollow aluminum) are separated from the non-metals. Separation of the two metals can be achieved by colour sorting, which will be discussed in a later section. In the third stage, all the remaining aluminum alloys and insulated wire are floated, washed, and transported to an ECS system to differentiate between metals and non-metals. The end result is an almost pure aluminum fraction consisting of cast and wrought alloys. The sink portion of this last stage consists of heavier metals, such as brass, zinc, copper and lead.

Most of the aluminum alloys in the metallic portion of the NMSF can be adequately separated from the scrap stream using current sink-float practices. However, this technology is not sensitive enough to separate hollow aluminum materials from magnesium alloys, cast from wrought aluminum alloys, or aluminum alloys into their individual alloy groups. Three other disadvantages of the sink-float process are:

1. The process is very cost intensive, requiring large capital investments for the separation vessels and the closed-loop water treatment system necessary for maintaining constant slurry densities and avoiding the discharge of dirty water to the environment.

2. The media used to produce the correct specific gravity within the floatation tanks may contaminate the scrap, necessitating additional cleaning steps to produce a high quality end product.

3. The technology is shape dependant since dense materials that are hollow or boat-shaped will float.

The problems associated with the traditional sink-float process have spurred the development of a completely dry, automated process that produces high quality individual metal fractions of both cast and wrought aluminum alloys. In order for this to be achieved, the metals must not only be sorted into their primary constituent but also into their specific alloy group and alloy form (cast or wrought). This will make recycling the metal easier, and allow production of a high-quality product for direct resale back into the market. Over the last decade, a number of new sorting technologies, which focus on the chemical composition of individual pieces for more complete and accurate separation, have emerged on both a commercial and a pilot scale. These technologies include colour sorting and laser and X-ray induced breakdown spectroscopy. A new technique for separating cast and wrought aluminum alloys has also emerged during this time, and it is called the hot-crush technique.

NEW ALUMINUM SORTING TECHNOLOGIES

Colour Sorting

Colour sorting is one of the first automated sorting processes to be used industrially, and it was developed by the Huron Valley Steel Corporation (HVSC), which is the world's largest non-ferrous scrap sorter. Over the past decade, HVSC has used this technique to sort zinc, copper, brass and stainless steel. Colour sorting is based on computer image analysis in which the colour of each metallic piece is detected. Pieces, the colour of which lies within a specified range, are automatically directed out of the feed material. In order for this to work properly, a singling mechanism is used to produce a chain-like profile of scrap particles before the image detector. HVSC's colour sorter has proven to be very accurate, producing metal purities over 98%[6] which is possible because this sorting method is independent of particle size and shape[6]. The technological advancement of computers over the last decade has greatly increased the speed of real time image analysis.

Recently, HVSC has used its colour sorting technology to accurately separate the light metal fraction obtained from the second media stage of the sink-float industry. In a paper by Gesing and Wolanski[2], they reported that an efficiency greater than 99% was possible when separating magnesium alloys from hollow aluminum products. It is believed that this technique is now being used at full scale at HVSC to produce pure metal fractions of magnesium and hollow aluminum.

Due to the advancement of industrial colour sorters over the last few years, the ability to effectively sort different metals with slight colour variations has improved dramatically. This has enabled Alcoa to develop a method of grouping wrought aluminum alloys by family[8]. In this recently patented process, the aluminum scrap is coloured by selective etching in different solutions, since the colour of the scrap after etching depends on the concentration of particular alloying agents. For example, aluminum with a high silicon and manganese content will turn the scrap gray while zinc and copper combine to turn the scrap dark. When the scrap stream is etched in a mild caustic or sulphuric acid solution[9], the 2XXX, 3XXX and 7XXX series alloys can be separated out. A second etching step uses a mixture of copper sulfate and hydrochloric acid[9] that enables the colour sorter to identify the 5XXX and 6XXX series alloys. Because of the degree of discolouration caused by either of the two etchants, the aluminum scrap can be separated into their individual families. However, colour sorters cannot be used to separate individual alloys within a family. This is because there is no association between separate alloys and a specific colour. For example, an alloy with high zinc and low copper contents has a similar colour as an alloy with high copper and low zinc concentration.

The advantage of this new sorting method is that the two processes involved, color sorting and metal etching, are well understood and have been practiced industrially for a number of years. Although no technical issues need to be resolved in order for this technique to be commercialized, some small hurdles still prevent this method from being 100% effective. Factors such as heat treating, surface roughness, and material transfer time from the etching solution to the rinsing station, can all have minor effects on the resulting colour. Casting alloys have also proven to be much harder to separate into individual families since segregation during cooling can cause considerable compositional differences within the material. Waste effluents produced during the process require treatment before disposal which is an environmental concern. Although these issues are currently being addressed, the major concern is still the market potential for scrap with a wide compositional range within each alloy family. In most cases, customers demand compositional limits that are much tighter than the average specification of a particular alloy family. Therefore, the scrap that has been sorted into the aluminum alloy families still needs to be further refined into the individual alloys in order to meet tighter material compositional specifications.

Laser Induced Breakdown Spectroscopy (LIBS)

To achieve the highest quality aluminum scrap possible, a sorting system that separates both cast and wrought aluminum into specific alloys was required. Such a system must be able to determine the actual chemical composition of each piece of scrap in an efficient and economical manner. This lead to the development of Laser-Induced Breakdown Spectroscopy (LIBS) for accurately sorting aluminum scrap into individual alloys.

The LIBS technology was first developed by the Los Alamos National Laboratory in the early 1980s for use in a wide variety of applications[10,11,12]. However, it was not until the early 1990s that this technique was implemented for the analysis of solid metal pieces in a joint project with Metallgesellschaft. The results of this project showed the effectiveness of this technique to accurately determine the elemental composition of metallic scrap[13,14,15]. However, the focus of the project was on the identification of the matrix element and not on the complete spectral analysis of all elements in the scrap. In 1993, Alcan Aluminum, in cooperation with Los Alamos

National Laboratory, undertook a project on the full quantitative analysis of aluminum alloys using LIBS. During this joint venture, several published papers showed that the LIBS technique was more than adequate in determining the full chemical analysis of aluminum alloys[16,17]. In 1996 this project was stopped at the pilot-plant stage, and Alcan focused entirely on primary aluminum production. It was not until the mid 1990s that HVSC combined its experience in colour sorting with LIBS technology to focus on the sorting of metal shred particles. As of 2000, this project was in the pilot-plant scale of development at HVSC and was focused on the sorting of solid aluminum scrap[6]. The basic principle of this aluminum alloy sorter is shown in Fig. 4[6].

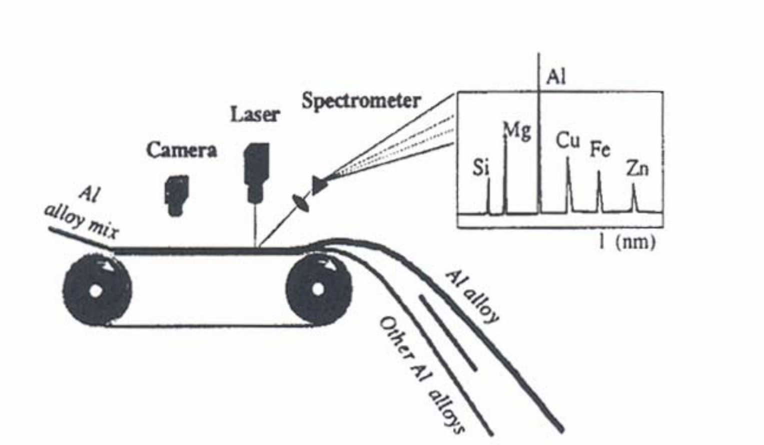

Fig. 4 – Laser induced breakdown spectroscopy for Al alloy sorting.

In the LIBS process a sensor first detects the presence of a particle which is then bombarded with a pulse. The pulse laser illuminates the surface of the metal producing an atomic emission, and the chemical information about the material can be obtained by a spectral detector. Using an optical fiber, a polychromator and a photodiode detector, which are all connected to a computer system, the resulting emission can be transferred to a sorting signal. The sorting signal then activates a mechanical device that forces the identified piece to be placed in a particular sorting bin. Thus, complete separation of the scrap particles into specific alloys (i.e. A359, A356, 6060, 6081, etc.) is achieved. It is anticipated that the first industrial alloy sorter will be capable of analyzing and separating 100 million pounds of aluminum scrap pieces per year[6].

This method is advantageous because not only is it a non-contact technique for analyzing the elemental composition of single pieces of aluminum scrap, but it also has the capability of sorting cast and wrought alloys without using aqueous solutions. By incorporating techniques previously patented by HVSC for high-speed, high-volume handling and computer processing of large amounts of data, this process has become economically viable for commercial purposes.

While it has many advantages, LIBS does have its limitations. The biggest draw-back is that the surface of the aluminum scrap must be free of paints, lubricants or adhesives, since the pulse laser can only penetrate to a depth of thirty angstroms or less on the surface of the aluminum. Alcan had clearly showed that the effectiveness of the LIBS technology was drastically reduced by too much variation in the coating thickness[17]. Since colour sorting can separate bare from painted scrap, HVSC[6] has recommended that it be used prior to LIBS sorting.

There are currently a number of processes used in industry for decoating aluminum scrap. In all de-lacquering processes, aluminum shredder scrap is cleaned by hot air in either a rotary kiln, a packed bed or a fluidized-sand bed. The superior heat transfer obtained using the fluidized-sand bed produces the cleanest, least oxidized metal in the shortest time. By first sorting the aluminum scrap with the colour sorter, it is expected that there will be a significant reduction in the cost of the thermal decoating process since only painted scrap would be processed before moving onto the alloy sorter. An illustration of this process is shown in Fig. 5[6].

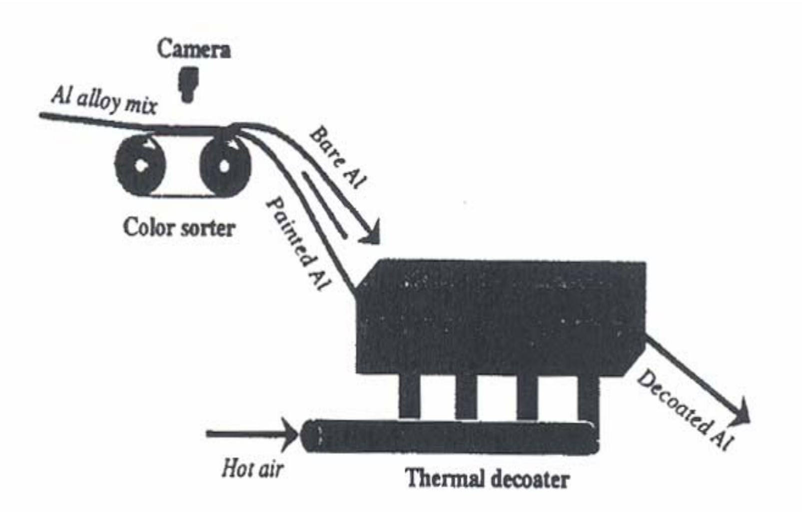

Fig. 5 – Painted Al separation and decoating.

The thermal decoating of the scrap causes a secondary problem by producing a slightly thicker layer of oxide on the surface of the aluminum. Once again because of the poor penetration depth of a single pulse laser, the majority of the analysis would concentrate on the oxide film and not the bulk material. However, in a paper by Gesing and Rosenfeld[17], results show that additional pulse lasers can be used to successfully remove the oxide layer prior to analysis. In order to achieve this, the cleaning and analysis pulse lasers need to be delivered to the same target area on a moving particle. This represents another unique problem in commercializing this process.

X-rays can also be used instead of a laser to illuminate the surface of the scrap. X-ray fluorescence (XRF) has been used for alloy identification, and a number of commercial devices, both portable and hand-held, are already available. It was not until the late 1980s that this technique was considered a viable option for the automated sorting of metallic scrap[18]. Extensive laboratory and pilot-plant investigations demonstrated the effectiveness of this process and lead to the development of an X-ray radiometric sorter for separating non-ferrous metallic scrap. In the early 1990s, the X-ray radiometric sorter was applied to the separation of aluminum alloys into different groups and grades on a pilot-plant scale. Since the characteristic radiation of aluminum ($K\alpha\beta$ - 1.5 KeV) is so low that it is easily absorbed by air and cannot be detected without working in a vacuum, the alloys were only sorted according to their heavier metal alloying additions (Fe, Cu, Zn, Pb, etc.). By determining the content and quantity (spectral ratios) of the major impurity elements, an estimate of the particular aluminum alloy system could be made. Although results show that this technique is unable to accurately determine the specific type of aluminum alloy, it does offer another method for sorting the aluminum into the major alloy families[19]. X-ray radiometric sorters can also separate cast from wrought aluminum alloys because of the large difference in impurity elements between the two groups. Similar to the LIBS, X-ray radiometric sorters are sensitive to surface pollutants (i.e., coatings) and require the scrap to be processed in a decoater.

Mtsensk Aluminum Works currently uses X-ray radiometric sorters in an automated system to process lump-by-lump separation of cast and wrought aluminum alloys[19], but detailed information about the process was unavailable.

SEPARATION OF CAST AND WROUGHT ALUMINUM

To improve the efficiency of separating aluminum scrap into individual alloys, the initial division of cast and wrought aluminum alloys is very important. These two alloys are very different in a number of aspects including surface texture, particle shape and chemical composition. While cast and wrought aluminum alloys contain the same alloying elements, the concentrations are much higher in cast alloys. The maximum concentration of alloying elements in wrought aluminum is approximately 5 wt % while some cast alloys can reach up to 15 wt %. In order to directly remelt wrought aluminum alloys without extensive chemical refining, cast aluminum cannot be incorporated with wrought alloys. Due to the physical differences between the two alloy groups, hand sorting, which is very labour intensive, has been the only method available to separate cast from wrought alloys. This has lead to the development of a number of techniques for fully automating this separation.

The process that has received the most attention is the hot-crush technique[20,21], which is also known as thermomechanical separation. Developed by the U.S. Bureau of Mines in the mid 1980s, this process takes advantage of the low eutectic temperature in all casting alloys. By heating the cast alloys above the eutectic temperature (520-560ºC), they become brittle due to intergranular melting at regions of eutectic composition[21], and this is accompanied by a significant decrease in the mechanical properties of the cast alloys (tensile, impact, shear, strength, etc.). By subjecting the hot cast alloys to a mechanical separation process, such as a hammer mill, the size of the cast scrap can be easily reduced. On the other hand, wrought alloys do not experience the same embitterment until above 600ºC and will maintain their mechanical properties and hold their shape during the hot-crushing separation. The difference in size between cast and wrought aluminum alloys after the hot-crush technique can be seen in Fig. 6. A screening or a rotary trommel can be used to separate the cast from the wrought alloys following crushing. In preliminary laboratory tests the separation efficiency was 100% and 98% for cast and wrought alloys, respectively[21]. However, this method is only economical when used in combination with the decoating process since the energy costs associated with heating the scrap are extremely high. Also, the reduction in size does not allow further sorting of the cast material into individual alloy families.

HVSC has reportedly developed a proprietary process for separating two forms of a wrought product, each with purities greater than 95%, and a cast alloy product with a concentration between 80-90%[2]. However, more detailed information about the process was not available.

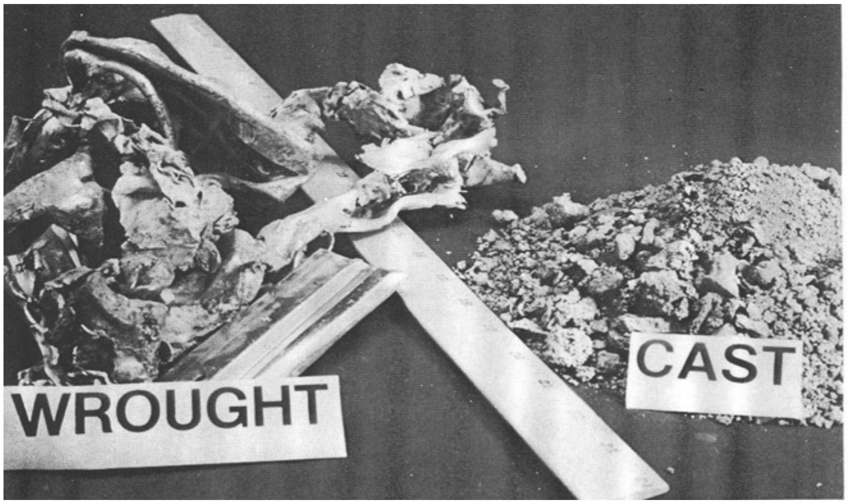

Fig. 6 – Wrought and cast alloy after hot-crush technique.

CONCLUSIONS

The following conclusions have been made from a survey of the available literature:

1. The current infrastructure for sorting aluminum from automotive scrap in North America is well developed, and there are currently 6000 scrap collection and dismantling yards, 200 scrap shredders and 10 sink-float plants in operation.

2. Nearly half of the aluminum contained in an average automobile is removed in the dismantling yard, mostly in the form of the engine block. The other half is passed onto the shredder. The concentration of aluminum in the shredder scrap is between 2.5 and 5.0 wt %.

3. After shredding, three sorting techniques are used to increase the concentration of aluminum in the material to 70 wt %. They are magnetic, air, and eddy current separation.

4. Most of the aluminum is then passed onto a sink-float operation where the aluminum is exposed to a three-step sink-float separation in liquids of specific gravity (SG) of 1, 2.5 and 3.5. The aluminum is floated in both the 2.5 and 3.5 SG steps and separated from the non-metallics by an eddy current separator, resulting in two mixtures of magnesium and hollow aluminum, and aluminum alloys, respectively. Hand or colour sorting is used to sort the aluminum from the mixed magnesium-aluminum fraction. The sorted aluminum is then sold to a melting operation for the production of cast alloys.

5. Over the last decade, several new technologies have emerged to further separate the aluminum scrap into individual alloy families or alloys of both cast and wrought aluminum. These techniques include colour sorting, laser and X-ray induced breakdown spectroscopy, and the hot-crush technique.

6. A commercial process for separating magnesium and hollow aluminum using colour sorting has already been established and has achieved impressive results in producing two pure metal fractions. This process is currently in the pilot-plant scale of development for further

separating wrought aluminum scrap into individual alloy families using the etching process patented by Alcoa. However, this technique does not have the ability to sort cast alloys or wrought aluminum into specific alloys.

7. Laser and X-ray induced breakdown spectroscopy are the only sorting techniques available to sort both cast and wrought alloys into individual alloys. This is completed by analysing the chemical composition of each individual piece of scrap. HVSC is currently proceeding with a pilot-scale development of the laser induced breakdown spectroscopy technology. The only drawback to this technique is that the initial aluminum scrap must be decoated before being analyzed. However, several industrial decoating processes already exist and have been used extensively in the recycling of aluminum can stock.

8. The hot-crush technique is the most popular method for sorting cast from wrought aluminum alloys. By heating both materials between 520-560ºC, the size of the casting alloys can be reduced dramatically by using a simple mechanical separation technique. Screening can then effectively separate the two forms of aluminum alloys. The U.S. Bureau of Mines developed this method, but information regarding its current status was not available.

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