Recycling Automotive Magnesium Scrap

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Magnesium die castings have been experiencing tremendous growth in the automotive market for ten years. The European guideline for disposing of old automobiles has had a lasting effect on magnesium recovery and recycling. This article will review the European guideline for automobile disposal and the current technologies used to recycle magnesium scrap from automotive components.

INTRODUCTION

Worldwide, approximately 52 million cars are produced each year. Magnesium has played an ever-greater role in that production since the 1990s, when it was rediscovered by automotive manufacturers, who wanted to create a 3-l car. Due to its low specific gravity, magnesium is used nowadays widely for light automotive parts. Thus, magnesium die castings have been experiencing tremendous growth in recent years.

The European guideline for automobile disposal benefits the recovery of magnesium, as auto makers consider the recycling process in the design and manufacture of new cars. These regulations also improve the logistics of scrap recovery. As the number of scrap collection points for magnesium diminish, the concentrated magnesium scrap flow will be easier to monitor, and, as a result, more magnesium will be recycled.

AUTOMOTIVE MAGNESIUM COMPONENTS

The application of magnesium in the automotive industry is influenced by automotive weight restrictions and reductions. Due to a growing emphasis on comfort and safety features, the average middle-category car has become increasingly heavy in recent years. That increase in weight has led to rising fuel consumption. According to expert assessments, every 100 kilograms of extra weight results in an additional fuel consumption of 0.3 liters.[1]

To minimize the weight increase, individual automotive components such as steering wheels, gear boxes, instrument panels, seat components, rims, rear flaps, and reflectors have been made of magnesium alloys. The next step forward is expected to occur within five years, with the use of creep-resistant magnesium alloys in the power train. In addition, major European automotive manufacturers are researching extensively the application of magnesium in engines.

As more applications are developed for magnesium, its alloys are growing increasingly diversified, posing new recycling challenges. For example, intensive alloy development efforts are under way to improve the creep properties of corrosion resistance and die-castability. Several alloy compositions containing calcium, lithium, scandium, yttrium, zirconium, or rare earth elements (gadolinium, dysprosium, strontium, cerium, neodymium) have been published.[2] The wide spectrum of magnesium alloys, along with the necessity of coating, make recycling extremely difficult.

Magnesium components are coated either for corrosion protection or for decorative purposes. Magnesium parts that are exposed to a corrosive atmosphere require a special preventive measure, such as the application of a chemical conversion coating and/or organic coating. The use of oily, coated magnesium makes recycling of old cars into high-quality die-casting alloy ingots that meet ASTM specifications difficult because severe problems occur: The magnesium melt gets contaminated by impurities, the formation of dross increases, and harmful gases exhaust. The recycling of slag and dross, which are by-products of remelting and refining, is an unsolved problem. To ensure the competitiveness of magnesium, alternative methods of magnesium recycling have to be established.

LEGISLATIVE FRAMES FOR THE AUTOMOBILE INDUSTRY

The aims of the European auto disposal guideline are similar to the environmental goals of the European countries: to protect the soil, water, and air. In addition, the quantities of waste products to be disposed of should be reduced, and where waste disposal is unavoidable, the resulting harm to the environment should be limited.

The recycling guideline will influence the design and production of automobiles in the following ways:

- Vehicle manufacturer's must collaborate with the materials and supply industries to limit the use of hazardous materials in vehicles from the design stage onward,

Table I. Magnesium in Automotive Components

Automotive Parts	Typical Mg-Alloy	Coatings
Gear box	AZ91	Conversion coating
Steering wheel	AM50, AM60	—
Rear flap	AM50	Conversion coating, painting
Seat components	AM50, AM60	—
Rim	ZK60, ZK30	Conversion coated
Instrument panel	AM50, AM60	Painting
Reflector	AZ91	Plating
Valve cover	AZ91	Conversion coating, painting
Engine	CRA*	Conversion coating

*CRA is creep resistance alloy

Table II. Secondary Magnesium Material

Scrap	Characterization	Problems	Recycling Methods
Class 1A	High grade clean scrap without impurities (e.g., scrap castings, biscuits etc.)	—	Flux-free, Recycling with flux
Class 1B	Clean scrap with a high surface in proportion to the weight	—	Recycling with flux
Class 2	Clean scrap with aluminum or steel inserts. No copper or brass impurities	Fe content, Si content	Magnetic separation, if necessary ICF* and/or diluting
Class 3	Clean, dry, and uncontaminated turnings and swarfs	High surface ⇒ melt losses, oxide-content	Compacting, increased flux quantity, event. cover gas
Class 4	Flux-free residues (eg. dross, sludge)	Oxide content, Fe content	Increased flux quantity, if necessary ICF* and/or diluting
Class 5	Painted or coated scrap with/without aluminum or steel inlays. No copper or brass-impurities	Coating/painting ⇒ melt losses, Fe content, Si content, Ni content	Shot blasting, thermal decoating, if necessary ICF* and/or diluting
Class 6	Oily and/or wet turnings and swarfs	Oil and moisture ⇒ melt losses, oxide content	Thermal treatment, chemical treatment, compacting, increased flux quantity, eventually cover gas
Class 7	Unclean and contaminated metal scrap (e.g., post consumer scrap) may contain: Silicon (Al-alloys, shot blasting) Cu-contaminated alloys Iron inserts Ni coating Non-magnesium sweepings	Oil/moisture and coating/painting ⇒ melt losses, oxide-content, Fe-, Si-, Cu and Ni content	Magnetic separation, shot blasting, thermal treatment, chemical treatment, ICF*, diluting, distillation
Class 8	Flux-containing residues from Mg-Recycling	High content of oxides, chlorides, and fluorides (Mg content < 30 %), Fe content	Expensive hydrometallurgical processing; at time not realized

* ICF is intermetallic compound formation.

to prevent their release into the environment, to facilitate recycling, and to avoid the need to dispose of hazardous waste products.

- The design and construction of new vehicles must take into consideration dismantling, recovery, re-utilization, and recycling of old vehicles.
- Vehicle manufacturers must collaborate with the materials and supply industries to use more recycled material and to extend the markets for recycling materials.

European Community member states must also ensure that the materials and components in vehicles brought into circulation after 1 July 2003 contain no lead, mercury, cadmium, or hexavalent chromium. The most important prescription for automobile producers and motor vehicle importers is certainly the obligation to take back old vehicles from their last holders and/or owners without cost. They are also obliged to operate, either themselves or via third parties, only environmentally acceptable recovery methods. As a result, the number of magnesium scrap collection points will be reduced and scrap will be available from fewer, but larger, sources.

Automobile producers, who will have to bear the costs of recovery, will have to seek ways to recover those costs. A first obvious possibility would be to pass on the costs to purchasers of new vehicles by correspondingly increasing the sale price. In view of the keen competition among auto makers, this would not be a realistic option. Another possibility is to recover costs completely or at least in part by offsetting the value of the secondary raw materials in vehicles against the recovery costs.

Magnesium in the form of class 1 and 2 scrap (Table II) is particularly valuable. Depending on the proportion of magnesium in the vehicle, the metal value could cover recovery costs. Scrap from class 3 to 8 should be included in other metal circuits (e.g., aluminium and steel).

Another important point is that the automobile guidelines also specify recycling targets for all old vehicles. Thus, by January 2006 at the latest, the fraction of material recovered for re-use from all old vehicles must be increased to at least 85% of the average vehicle weight per year. Within the same time limit, the fraction re-utilized and recycled must increase to at least 80% of the average vehicle weight per year. For vehicles made before 1 January 1980, the member states can specify lower targets, but these must not be below 75% for recovery for re-use and 70% for re-utilization and recycling. By

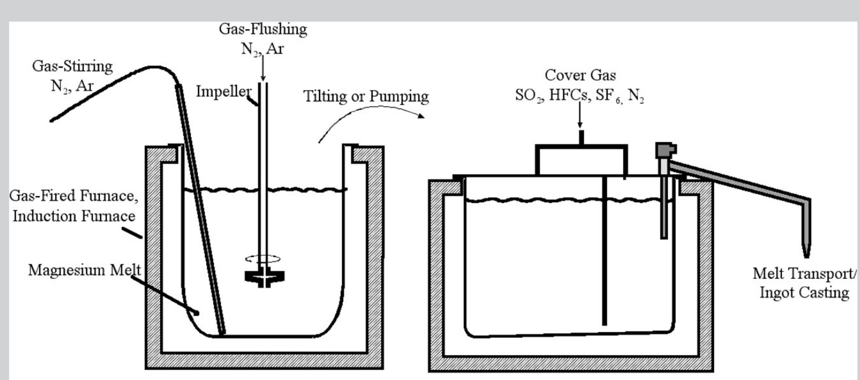

Figure 1. Recycling with flux.

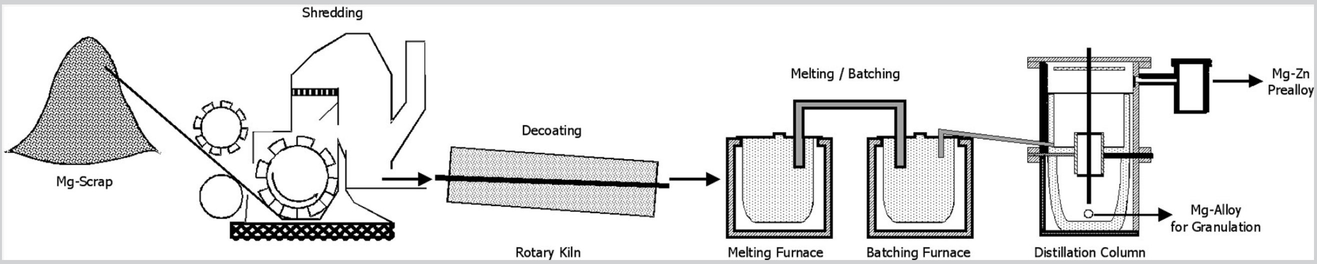

Figure 2. A recycling concept for contaminated Mg-scrap.

1 January 2015 at the latest, the re-use and recovery from all old vehicles must increase to at least 95% of average vehicle weight per year and, by the same deadline, the re-utilization and recycling must amount to 85% of average vehicle weight per year.

The most important aspect of the new law is certainly the obligation to take back old vehicles from their last holders without cost. Depending on the market price for the recoverable secondary raw materials, old vehicles have a negative value. Because of the new guideline, environmentally acceptable recycling processes are necessary. If more magnesium components are used in future cars, the research and development of recovery methods will be necessary.

ECOLOGICAL AND ECONOMICAL ASPECTS

Over the last few decades, public awareness of the impact of industrial production on the environment has grown. Resource conservation refers not only to the magnesium production feedstock, but to the energy consumption during primary metal production as well. A kilogram of magnesium produced from raw materials requires the equivalent of 35 kWh, whereas a kilogram of refined-recycled metal would consume less than 3 kWh. The full potential of utilizing magnesium in the automotive industry only becomes apparent when the environmental impacts over the lifetime of the car, as well as recycling at the end of product life, are taken into account. For recycling to be the most ecologically efficient and sensible method to get rid of waste, the cost of manufacturing secondary raw materials must be lower than the fee required for alternative waste disposal.

The recent increase of Russian and Chinese primary material supplies in western markets has affected scrap recycling. The price of primary magnesium fell to $1,500/t, making the economical recycling of clean, sorted scrap possible. But, in general, magnesium is valuable. Depending on the proportion of magnesium in the vehicle, the metal value could cover recovery costs. The European magnesium recycling industry in 2001 had a recycling capacity of 31,500 t, and that amount is expected to increase in 2002 to 41,500 t.

SCRAP CATEGORIES AND RECYCLING SCENARIOS

Due to the intensified use of magnesium automotive components, the magnesium die-casting industry is expanding rapidly. Unfortunately, in typical magnesium die-casting operations, only around 50% of the metal input becomes a finished product. The remaining 50% is handled by the foundry or by an external recycler. Casting return material can contain biscuits, sprues, runners, flash, overflows, dross, sludge, scrap parts, and uncoated rejects from the finishing process.[3]

As the magnesium content in automobiles increases, the recycling rate for old automotive scrap is likely to increase. Designers of vehicles plan for the easy dismantling and recovery of automotive components, according to their material. Nevertheless, the recovery potential of the magnesium fraction in old cars is rather low due to the use of coatings.

The different categories of secondary magnesium material are listed in Table II along with problems and possible recycling methods. The value of those materials depends on their quality and condition. Sorting the magnesium scrap correctly is crucial for producing a product that meets specifications. As magnesium and aluminium closely resemble each other, a load of magnesium scrap may contain aluminium scrap as well. The magnesium-finishing industry, in addition to magnesium recyclers and die casters, could benefit from a knowledge of sorted separation.

Currently, only class 1A and 1B material can be recycled easily into high-purity alloys. More complex handling is required for class 2 material, depending on the level of contamination, and for all class 5 and higher material. Because additional process steps are required, the cost of secondary magnesium material class 2 and higher generally determines the economical attractiveness of recycling. The cost of the material may exceed the value of magnesium recovered.

Different methods for remelting secondary magnesium material are known.[4] In the conventional method of recycling, scrap is melted in a crucible furnace and a refining flux is distributed. To ensure a chloride- and fluoride-free product, a fluxless method of recycling was developed.

RECYCLING METHODS

Recycling with flux is the most common technology for magnesium remelting. Figure 1 illustrates a discontinuous melting process in which a gas or inductively heated crucible furnace and an electric blanked holding furnace form a unit, which is completed by a melt transport or an ingot casting machine. After the crucible is charged, the magnesium scrap is melted. Oxidation is prevented with a flux addition. Generally, three different types of flux are used to prevent oxidation in the melt and for refining. The use of a CaF_2-poor flux ensures better prevention of oxidation. The separate addition of a CaF_2-rich flux enables the exact control of the refining process.[5] A smaller logistic expense is incurred, however, with a combined flux for prevention of oxidation and refining. Above 650°C, the melt is stirred with nitrogen or argon to homogenize the chemical and thermal distribution. After reaching a specific temperature, which depends on the alloy and flux used, nonmetallic impurities and hydrogen are removed with an impeller treatment. Before casting or transporting the melt to die-casting machines, an end control of the chemical composition and the oxide content is made.

In contrast to recycling with flux, remelting in the salt-free process is continuous in a single aggregate.[5] This gas-fired crucible furnace consists, in most cases, of three chambers for melting, refining, and settling. The scrap is charged through a paddle to prevent admittance of oxygen into the covered furnace. To free the scrap from any moisture, it must be preheated at temperatures above 100°C. The process steps—melting, stirring with nitrogen or argon, and settling—are similar to the flux process.

Because of the limited metallurgical possibilities (e.g., the restricted admittance to the melt and the renunciation of flux), only the remelting of scrap class 1A is practicable. In addition to melting, magnesium scrap may be recycled by grinding it into powder for iron and steel desulfurization applications. This method is limited to specific types of clean scrap; drosses and other contaminated scrap are not used because they can introduce impurities into the finished product.

To maximize the metal recovery, magnesium die castings with paint finishing should be cleaned completely to remove all organic residues before remelting. The organic coating on magnesium automotive parts consists of paint and lacquer, which represents 3–7% of the overall magnesium component weight. Among fluidized bed decoaters and belt decoaters, the rotary kiln is the most used decoating technology for shredded paint-finished magnesium scrap. After melting the treated magnesium scrap conventionally, the contaminated magnesium melt can be refined by distillation. The products of such a refining unit are a Mg-Zn-prealloy and a magnesium alloy, which may be used for iron and steel desulfurization. In Figure 2, the innovative recycling method is shown.

REFINING OF CONTAMINATED MAGNESIUM MELT

Due to the high content of impurities causing intensified corrosion, the wider use of recycled magnesium alloy scrap as structural material is impossible. Above all, iron, silicon, copper, and nickel reduce the corrosion resistance of magnesium alloys dramatically. The many methods known for refining magnesium include fluxing, sedimentation, and filtration. There are several standardized fluxes for the refining of magnesium, predominantly based on chlorides and fluorides.

The current techniques for pyrometallurgical refining of contaminated magnesium differ not only in their applicability, but also in their effectiveness.[6] For successful pyrometallurgical refining with additives, the refining reagent must be able to form intermetallic compounds with the impurities of the contaminated magnesium melt. The probability of intermetallic compound formation depends on the electronegativity, on the ionization potentials, and on the ionic radii of the interacting components.

Processes are available for eliminating metallic contamination with the aid of manganese, zinc, cobalt, beryllium, boron, titanium, or zirconium additives. Manganese chloride ($MnCl_2$) and boron additives have been found to be effective for iron reduction in magnesium. Another reagent used in removing iron impurities from magnesium is beryllium chloride ($BeCl_2$), which is an effective refining additive with low residual levels of beryllium in the magnesium alloy. Despite the excellent refining ability, beryllium chloride is not a desirable choice because of its toxicity. Silicon can be removed by adding zinc chloride or cobalt chloride. In these processes, complex iron and silicon compounds precipitate. Refining magnesium by adding titanium or titanium chlorides removes iron and silicon from the metal effectively. However, the use of titanium is preferable in view of its low solubility in magnesium. Given the strong interactions in the Mg-Ni and Mg-Cu systems, the removal of copper and nickel from magnesium with the aid of additives is practically impossible. At the present, the recycling and refining of magnesium is restricted to melting processes. Thus, it is absolutely necessary to have uncontaminated clean scrap, and the melting has to occur under a flux or inhibitive gas to control melt surface burning. Distillation seems to be a remarkable alternative for using all types of scrap for recycling. Purification of magnesium by vacuum distillation is documented in several patents.[7] The aim of these methods is the production of highly purified magnesium from industrially refined magnesium for the manufacture of semiconductor devices.

These vacuum purifying apparatus have a rather low productivity and work discontinuously. Distillation under standard pressure needs less equipment and the distillation can occur in a continuous way. Furthermore, the risk of reoxidizing the evolved gas through air ingress to the furnace and condenser is reduced. A further method involves the refining of magnesium from the melt by fractional crystallization on a cooled rotating body.

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