

In-line Recycling Technology for AZ91D Magnesium Alloy

Hideaki MIYASHITA*
Yuji MOCHIZUKI***

Tsuyoshi KAWABE*
Koji NATSUHARA***

Masashi SHIMODA**

ABSTRACT

An in-line recycling technology and equipment for recycling scraps generated in the process of die casting AZ91D magnesium alloy parts have been developed. The new technology enables the scraps to be recycled at the same quality as primary alloy and the molten metal to be continuously supplied to the die casting process.

Material and melting costs have been reduced by approximately 20% compared to the use of conventional recycled ingots. The technology has been applied in the manufacture of magnesium head covers and intake manifolds for V6 engines from 2009 year models onwards.

1. Introduction

The achievement of automotive weight savings in order to increase fuel efficiency is an important issue today, in view of global environmental issues and other factors. In Europe and the U.S. in particular, there is an increasing trend towards the use of magnesium alloys as a means of achieving these weight savings. Honda has also, to date, commenced mass production of engine head covers, steering wheels, and V6 engine intake manifolds using a general purpose magnesium alloy, and oil pans and manual transmission cases using a heat-resistant magnesium alloy.

However, magnesium alloys display a high level of activity, and attempting to help ensure burn, oxidation resistance and corrosion resistance increases costs against aluminum alloy parts, a factor that limits the application of magnesium alloys in numerous cases. The reduction of costs is therefore an important issue in enabling increased use of these materials.

In the case of aluminum alloy parts, die casters are able to directly recycle the scraps such as runners, biscuits, warm-up shots, and casting rejects that are produced during casting. However, while some

manufacturers are able to do so in the case of magnesium alloy scraps, the vast majority send the scraps out to specialist recycling companies. The resultant costs for transporting scraps and recycled ingots, recycling, and ingot-forming is one factor that increases the cost of magnesium alloy parts against those of aluminum alloy parts.

2. Development Goals

The aim of the project discussed in this paper was to reduce the manufacturing costs of magnesium alloy parts by enabling in-house recycling of AZ91D magnesium alloy scraps by die casters (Fig. 1) and instituting an in-line recycling process, in order to increase the application of lightweight magnesium alloys. The following specific goals were established:

- (1) Development of a technology enabling scraps to be recycled, including runners and biscuits, to the same quality as primary alloys
- (2) The development of in-line recycling equipment able to continuously supply recycled molten metal to the casting process

* Automobile R&D Center

** Honda Foundry Co., Ltd.

*** Metts corporation

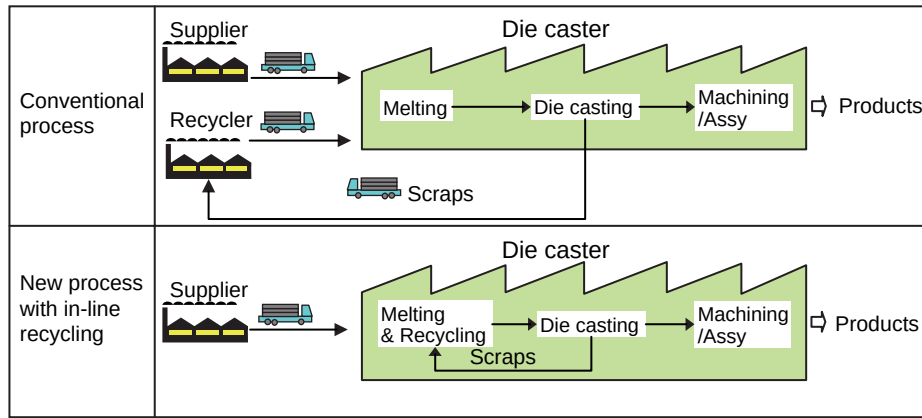


Fig. 1 Comparison of manufacturing process for AZ91D magnesium alloy parts

Table 1 Chemical components of AZ91D and effect of melting

		Chemical component (wt%)						
AZ91D specification (ASTM B93)	Alloy	Al	Zn	Mn	Si	Cu	Fe	Ni
	Product	8.5 -9.5	0.45 -0.9	0.17 -0.40	0.05 Max	0.025 Max	0.004 Max	0.001 max
Scrap	Before melting	8.8	0.80	0.19	0.03	0.003	0.0049	0.0005
	After melting	8.8	0.80	0.18	0.03	0.003	0.0055	0.0005
Primary alloys	Before melting	9.1	0.82	0.23	0.03	0.003	0.0010	0.0005
	After melting	9.0	0.81	0.22	0.03	0.003	0.0015	0.0007

3. Technological Issues

As Table 1 shows, the specifications regarding alloy composition and the quantities of Fe, Ni, and Cu in the finished product are strict for AZ91D in order to help ensure corrosion resistance⁽¹⁾. To enable the nature of the changes occurring in the components of AZ91D during the melting and casting processes to be determined, scraps from a diecast product and a primary alloy were dissolved and cast into 200 mm-long plate-shaped test pieces measuring 55 x 20 mm. Following cooling, the microstructures of these test pieces were compared, enabling the agenda for scrap material recycling to be determined. The melting temperature and the holding time until casting for the test pieces were average figures drawn from melting and casting conditions.

Table 1 shows the composition of the materials before and after melting. For both the scraps and primary alloy, no change is observed in Ni and Cu content, but Fe content increases in both cases. The Fe content of the scraps before melting is 49 ppm, close to the upper limit in product standards. Following melting, Fe content increases to 55 ppm, exceeding the maximum established in product standards. The solubility limit of the Fe

	After remelting of primary alloys	After remelting of scraps
Fe (ppm)	15	55
Organization		
Composition analysis (EPMA)		
Corrosion resistance (after 24 hr salt spray test)		

Fig. 2 Comparison of organization and corrosion resistance after remelting of AZ91D scraps and primary alloys

increased from less than 1 ppm to more than 30 ppm at 650°C⁽²⁾. Given this, the increase in the Fe content can be attributed to the fact that the Fe from the crucible is eluted into the molten metal in the melting and holding processes.

The test pieces were cut through the middle and abraded to enable study of their microstructures and corrosion resistance. The results are shown in Fig. 2. When depositions between which no differences could be observed using optical microscopy were subjected to electron probe micro-analysis (EPMA), they were determined to be Al_6Mn in the primary alloy, while they were $\text{Al}_8(\text{Mn}, \text{Fe})_5$ in the scraps, in which Fe content had increased. A decline in corrosion resistance was determined. $\text{Al}_8(\text{Mn}, \text{Fe})_5$ has a higher potential difference with the magnesium mother phase than Al_6Mn , and it was conjectured that the deposition of this intermetallic compound due to the increase in Fe content had caused corrosion resistance to decline⁽³⁾.

In addition, the vacuum fusion extraction absolute pressure reading method was used to study the gas content of the test pieces, and they were also cut through the middle to enable evaluation of the ratio of their surface area occupied by inclusions. The results showed that gas content and inclusions had both increased in the scrap material. These included gases trapped during casting and surface oxide films, and it was therefore considered that casting quality and product strength might decline if the material was recast without their removal.

Based on the tests discussed above, the following agenda was set for the recycling of AZ91D magnesium alloy scraps:

- Reduction of Fe content
- Removal of gases and inclusions

In order to enable these objectives to be met, the project decided on the development of in-line recycling equipment, which would enable continuous supply of recycled molten metal to the casting process at the same quality as primary alloy, and without any change to casting conditions such as cycle time.

4. Development of Recycling Technology

4.1. Reduction of Fe Content

Figure 3 shows the behavior of Al-Mn-Fe intermetallic compounds in a molten Mg-9%Al alloy, as reported by Holta, et al⁽⁴⁾. L indicates the liquid phase, and $\text{L} + \text{Al}_8(\text{Mn}, \text{Fe})_5$ indicates that the intermetallic compound $\text{Al}_8(\text{Mn}, \text{Fe})_5$ is deposited in the liquid phase. The range of deposition of $\text{Al}_8(\text{Mn}, \text{Fe})_5$ expands with increasing Fe content in the molten metal. This correlates with the test results discussed in Chapter 3, that numerous deposits of $\text{Al}_8(\text{Mn}, \text{Fe})_5$ were observed in the test piece in which Fe content had increased. Even if the Fe content is constant, an increase in the Mn content or a reduction of the temperature of the molten metal results in the

deposition of $\text{Al}_8(\text{Mn}, \text{Fe})_5$ or $\text{Al}_6(\text{Mn}, \text{Fe})$. This indicates that control of the Mn content and the temperature of the molten metal could be used to promote the deposition and settling of Al-Mn-Fe intermetallic compounds artificially, thus enabling the Fe content of the alloy to be reduced. Obtaining a Mn content of 0.18% or more when the molten metal temperature is 660°C and of 0.22% or more when the molten metal temperature is 670°C would enable the deposition and settling of the intermetallic compound $\text{Al}_8(\text{Mn}, \text{Fe})_5$, as well as the consequent reduction of the Fe content of the alloy when the Fe content exceeded 40 ppm, the upper limit for alloy standards.

The addition of Al-Mn, as used when primary alloys are cast, is available as a method of obtaining high Mn content. However, given that a rapid increase in Mn content was necessary in the in-line recycling method, it was decided that the Mn content would be increased by adding a primary alloy containing an appropriate quantity of Mn at a fixed ratio.

In order to control the elution of Fe from the crucible and obtain the necessary Mn content, it was desirable to

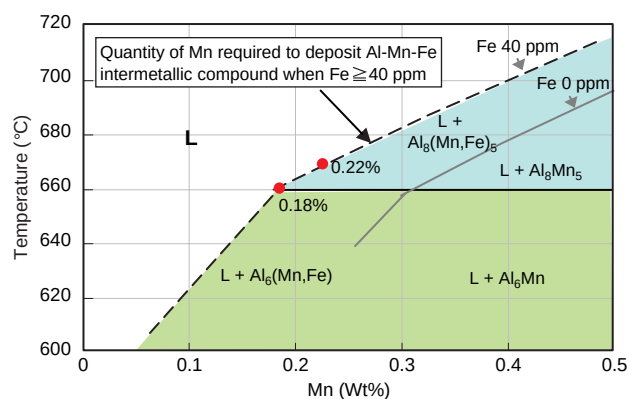


Fig. 3 Composition of Mg-9%Al-Fe-Mn alloy

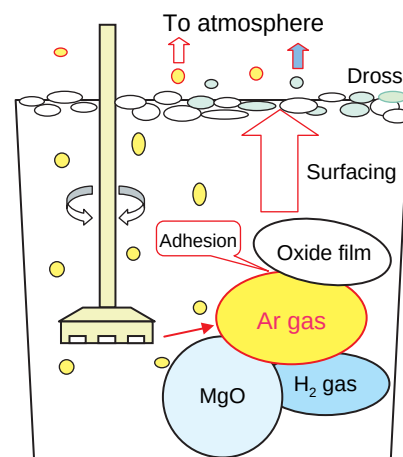


Fig. 4 Concept of reduction of gas/oxide in smelting process

reduce the temperature of the molten metal. However, a temperature of 660°C or more was needed to enabling the alloy to be melted without leaving any residue of the intermetallic compounds (Al_6Mn and $\text{Al}_6(\text{Mn}, \text{Fe})$) formed by the Mn.

It was decided that promotion of the deposition and settling of the intermetallic compound of Mn, $\text{Al}_8(\text{Mn}, \text{Fe})_5$, by means of controlling the Mn content and the temperature of the molten metal, would be employed as a method of reducing the quantity of Fe in the alloy.

4.2. Reduction and Removal of Gases and Inclusions

The addition of flux to the alloy is one method of removing gases and inclusions from AZ91D alloy scraps, but a considerable amount of time is required for settling following the addition of the flux, making this method unsuitable for in-line recycling. The method shown in Fig. 4⁽⁵⁾, which does not involve the use of flux, was therefore selected. A metal treatment unit with two-way rotation is used, enabling separation and flotation of gases, inclusions, and oxide films in the molten metal by means of argon gas bubbling. The unit turns argon gas into fine bubbles, and a shaft and disk for dispersion of the argon gas bubbles rotate in the opposite direction every few seconds. This controls the drawing in of dross on the surface of the molten metal and the stirring up of sludge that has settled on the bottom of the crucible, and distributes argon gas uniformly throughout the molten metal. This results in a short settling time following treatment, making this method suitable for in-line recycling.

4.3. Development of Equipment for In-line Recycling Use

In order to realize in-line recycling, it was necessary to reduce the Fe content of the alloy and remove the gases and inclusions quickly and continuously, without changing casting conditions such as cycle time. In order to enable this, an in-line recycling furnace for melting, smelting, and settling the alloy was developed by dividing the crucible into three sections. Control of the temperature of the molten metal in the first section has been enabled by optimization of the temperature and the positioning of the

Table 2 Mn and Fe content in AZ91D after in-line recycling

Material		Mn (%)	Fe (ppm)
Before recycling	Primary alloy	0.234	10
	Scrap	0.204	36
After recycling	50% scrap/primary alloy	0.217	20

burner. The scraps, to which primary alloy has been added in order to adjust their Mn content, are introduced to the first section, where they are melted in order to promote deposition and settling of $\text{Al}_8(\text{Mn}, \text{Fe})_5$ and reduce their Fe content. The metal treatment unit with two-way rotation is positioned in the second section. The speed of rotation of the disk, the period for counter-rotation, and the flow rate of the argon gas have been optimized, enabling separation and flotation of the gases and inclusions in the molten metal by means of uniform dispersion of argon gas. The sludge that has been stirred up in the process of treatment of the molten metal is then allowed to settle in the third section, after which the recycled molten metal is supplied to the casting process.

This three-section recycling furnace is connected to the melting and dosing furnace contiguous to the die-casting machine by a siphon tube, enabling the realization of in-line recycling (Fig. 5).

4.4. Recycled Molten Metal and Product Quality

In order to help prevent foreign matter or extraneous material from adhering to or being mixed with the scraps for recycling, only runners, biscuits, warm-up shots, and parts rejected during the casting process are used, and the mixing ratio is determined by the quantity of scraps produced and the quantity of Mn in primary alloy required to reduce the Fe content of the scraps.

Table 2 and Fig. 6 show the results of an evaluation of the quality of the recycled molten metal using a 50% mix of scraps from the casting of a head cover. The recycling processing has reduced the Fe content, and the quantities of gases and inclusions have also been reduced to a level equivalent to or below those of primary alloy. Figure 7 shows the external appearance of the part cast by supplying this recycled molten metal to the melting and dosing furnace contiguous to the die-casting machine. The external quality of the part cast using the recycled alloy is equivalent to that of a part cast using primary alloy. Figure 8 shows the results of a strength test of a test piece cut from the part. The average strength of the test piece is the same as that of a primary alloy test piece, but the range of $\pm 3\sigma$ variation is approximately 26% lower in the case of the recycled alloy, indicating that the stability of its quality is equivalent to or greater than that of primary alloy.

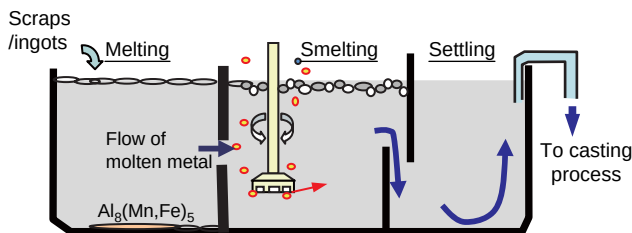


Fig. 5 Process of manufacture of AZ91D magnesium alloy parts with in-line recycling furnace divided into three rooms

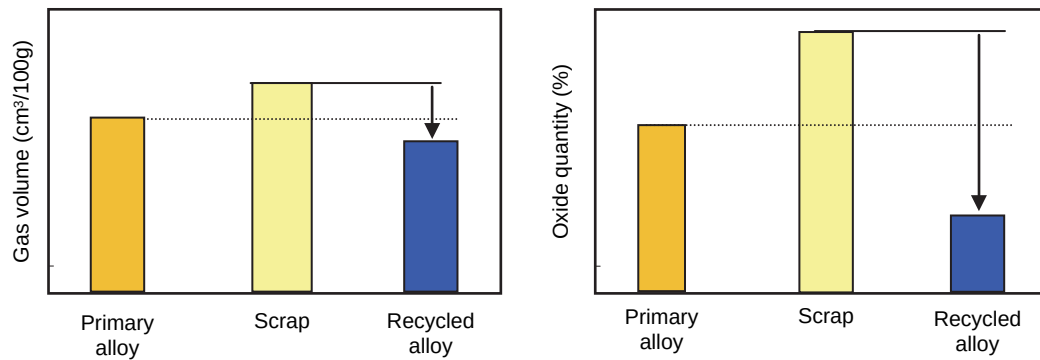


Fig. 6 Comparison of gas volume/oxide quantity after AZ91D in-line recycling

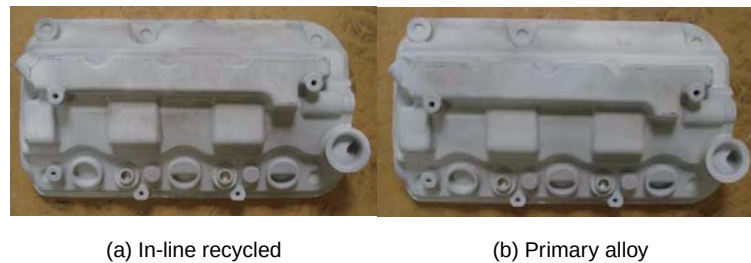


Fig. 7 Comparison of appearance of AZ91D magnesium front head cover for V6 engine

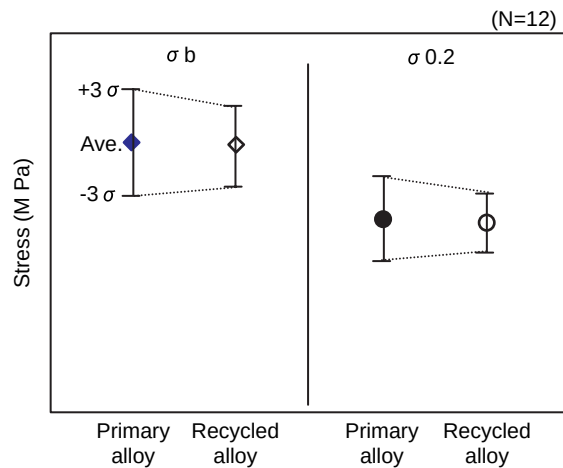


Fig. 8 Comparison of intensity of stress in test pieces taken from AZ91D magnesium front head covers

5. Conclusion

A technology for recycling AZ91D magnesium alloy scraps and an in-line recycling furnace based on this technology have been developed. The new method produces recycled alloy of an equivalent quality to primary alloy, but the cost of producing and melting the material is approximately 20% lower than the cost when using conventional recycled ingots. In addition, doing

away with the requirement for forming the recycled molten metal into ingots, re-melting and transporting the material, has reduced the CO₂ released during production by approximately 36%. The new technology has been applied in the production of V6 engine head covers and intake manifolds from 2009 year models onwards.

The details of the new technology are as follows:

- (1) Reduction of the Fe content of recycled magnesium alloy through control of Mn content and the temperature of the molten metal, and the removal of gases and inclusions through the use of a metal treatment unit with two-way rotation, have enabled AZ91D magnesium alloy scraps to be recycled at the same quality as primary alloy.
- (2) The division of the crucible into three sections and the optimization of the temperature and position of the burner and the processing conditions for the molten metal have enabled the development of an in-line recycling technology able to rapidly and continuously supply recycled molten metal to the casting process, with no modification of casting conditions.

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■ Author ■



Hideaki MIYASHITA



Tsuyoshi KAWABE



Masashi SHIMODA



Yuji MOCHIZUKI



Koji NATSUHARA