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Structure of the AZ91 alloy pressure castings fabricated of home scrap containing charge

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Abstract

The influence of the AZ91 alloy home scrap addition to the metal charge on both the structure and the selected mechanical properties of pressure castings was examined in this article. Two heats were made using different components, the first with only pure AZ91 alloy ingots in the charge, and the second containing 30 wt % of home scrap. The hot chamber 3 MN machine was used for casting. The structures of the castings and their Brinell hardness were examined for both cases. A strong refinement of crystals was observed in castings made with the contribution of the recycled material. Any significant differences in castings hardness were not observed.

Keywords: Pressure die casting technology; Magnesium alloys; Casting structure; Mechanical properties.

1. Introduction

Production of castings by the high pressure technology, and particularly by means of the hot chamber diecasting machines, is characterised by a relative small output. It results from the fact that this method is used for producing small castings, so that the mass of gating system is often comparable with the mass of the castings themselves. The relative small output means also that the usage of the charge material in the form of pure ingot metal is frequently equal to 50% only. It is obvious that the reduction of the price of castings depends on the degree of home scrap utilization. Therefore the best way of reducing the production costs of magnesium castings is the internal recycling in the foundry. The usage made of home scrap in the foundry can be as follows:

- remelting of home scrap and casting sows of the suitable chemical composition,
- remelting of home scrap in the intermediate furnace and adding the remelt to the liquid magnesium alloy in the holding furnace of the casting machine,
- remelting of home scrap directly in the machine furnace.

From the energetic and economic points of view the most effective is the third option provided that the uncontaminated scrap from the well-known source is used. This solution requires for the smallest changes with respect to the standard production process. It also does not involve large investment. It can be employed by the foundries which have problems with the storage of home scrap generated during the casting process.

A question then arises whether it is possible to produce castings of suitable quality with respect to the surface smoothness, strength, and structure, and whether the long-term consequences of such a solution would not increase the production costs e.g. due to the faster wearing out parts of the casting machine injection system [1].

The home scrap stored in the foundry is often strongly oxidized, what results from the properties of the arising oxide, which is of different structure than the underlying material. Cracking of the magnesium oxide layer induces further corrosion inside the metal, differently from aluminium alloys, where the oxide layer is compact and adhere well to the base material, producing the passivation effect [2]. High chemical reactivity of magnesium and the properties of its oxide demand therefore for specific melting conditions of magnesium alloys, which would protect them against oxidation.

The AZ91 alloy is the most frequently used cast alloy for high pressure die casting. Its popularity results from its excellent casting and technical properties, good machinability, and relatively low price. It is an alloy which in many cases is competitive to the aluminium alloys in the market. This results from the possibility of high pressure die casting by means of hot chamber machines, which – in turn – exhibit higher productivity (number of injections per unit time) than the cold chamber machines.

Aluminium is the most frequently used component of magnesium alloys. This is induced by its positive influence on the mechanical and casting properties of the magnesium-aluminium alloys. Various aluminium percentages enhance the particular properties of the alloy. The increasing aluminium content increases hardness, tensile strength and yield strength. The maximum elongation and the highest tensile strength for magnesium-aluminium alloys is obtained for the aluminium content equal to 5÷6%. The aluminium content in magnesium-based casting alloys can reach 11%.

Aluminium reacts with magnesium thus generating the $Mg_{17}Al_{12}$ compound along grain boundaries, what deteriorates the creep resistance. The $Mg_{17}Al_{12}$ phase precipitates are of lamellar or fibrous appearance and act as corrosion centres, reducing the corrosion resistance of the alloy. It is the aluminium content in the alloy which is decisive for the amount of arising $Mg_{17}Al_{12}$ phase. The volume percentage of the latter can reach even 17% in the AZ91 casting alloy. The corrosion resistance of magnesium alloys can be enhanced by manganese addition. Manganese positively influences also their mechanical properties. Zinc, silicon, and rare earth metals are easily dissolved by liquid magnesium alloys. Their content in the alloy remains practically unchanged for a long period of time. Aluminium and zinc influence positively the casting properties, but silicon is regarded as the contaminant. The cast ability of the alloy is better if zinc content does not exceed 6%. Magnesium pressure castings are characterised by very good surface smoothness and good filling of the die cavity. Their main defect – as in pressure castings made of other materials – is the internal porosity. This is however caused not by the alloy properties, but is specific for the high pressure die casting technology [3, 4, 5].

The quality of castings achieved by the high pressure die casting is affected by many parameters and factors, among which the most important are: metal temperature, die temperature, the quality of applied layers of die and plunger lubricants, injection pressure, plunger (metal) velocity, die venting system arrangement, the shape of casting, and the quality of liquid alloy [6, 7, 8].

2. Methods and results of investigation

Comparative examinations of pressure diecasting of AZ91 alloy coming either from pure ingot metal or from metal containing 30 wt % of home scrap have been carried out. The purpose of examination has been the metallographic assessment of the changes in the internal structure of cast items, as well as the comparative assessment of their quality and the degree of wear of the shot-end parts determined for basic alloy and for the alloy with the increased oxide content in the molten material due to the home scrap addition.

Castings have been produced by means of hot chamber die casting machine of 3 MN clamping force equipped with the resistance furnace of 80 kW power rating, used for both melting and holding of molten metal. The metal temperature during the filling of the die has been maintained at the level of 630°C, while the die temperature has been 200 °C. The protective atmosphere, consisting of dry air and 0.5% of SO_2, has been established over the liquid metal surface during melting and filling operations to protect the alloy against oxidation. During the second part of experiment, home scrap in the form of slightly oxidized metal taken from gating systems directly after casting, cooling, and shakeout operations has been charged into the machine furnace in the amount of 30 wt % of liquid charge.

Two hundreds of door handles has been pressure cast of each alternative of AZ91 alloy charge. The following parameters of the casting process have been applied: the velocity of the 1st stage – 0.15 m/s, the velocity of the 2nd stage – 2.5 m/s, position of velocity change – 30 mm, time of pressure intensification – 1.5 s, cooling time – 7.5 s, cycle duration – 30 s. After being ejected, the shots with gating systems have been cooled in the air to the ambient temperature. Then the randomly selected items have been taken for the structure and hardness examination.

Spectrometric examinations have been done, three for each inspected composition, to determine the chemical composition of ingot metal, of castings achieved from the remelt of 100% pure ingots, and of castings obtained from the charge containing 70% of pure ingots and 30% of home scrap. Three randomly selected castings produced of each alternative charge composition have been examined with respect to their surface quality, and their hardness has been measured. Then the metallographic microsections have been prepared and the microstructure has been qualitatively assessed. The microstructure has been revealed by etching with 3% solution of nitric acid in ethyl alcohol (Nital).

There has been carried out also the assessment of wear of the shot-end components (gooseneck, plunger, gooseneck nosepiece, and nozzle) after some longer period of casting with use of the home scrap containing charge. The lifetime of these elements has been compared with the data obtained for the production of casting with use of pure AZ91 alloy ingots.

Chemical compositions of a pure ingot, of a casting made of pure ingot remelt (casting I), of a casting made of metal containing 30% of home scrap (casting II), and – for a purpose of comparison – of a standardized AZ91 alloy are presented in Table 1.

Table 1. Chemical composition of AZ91 alloy

	Element content in %						
	Al	Cu	Fe	Mn	Ni	Si	Zn
Standard	8.5	0.000		0.17	0.000	0.00	0.45
	9.5	0.025		0.40	0.001	0.05	0.90
Ingot	8.8	0.006	0.003	0.20	0.001	0.04	0.60
Casting I	8.69	0.001	0.0019	0.152	0.0012	0.023	0.70
Casting II	8.64	0.002	0.0022	0.144	0.0012	0.030	0.62

A comparison of chemical compositions of castings, ingots used for remelting, and the data given by the Standard reveals that the content of basic elements, i.e. Al and Zn, meets the demands of the Standard. The iron and nickel contents has gone over the limit. This minor exceeding of the standard values is rather insignificant and does not influence the structure. The results indicate that the recycling of the home scrap by its remelting in the die casting machine furnace is a cheap and appropriate way of its utilization.

The microstructure of castings is shown in Figures 1-3 at 200× magnification.

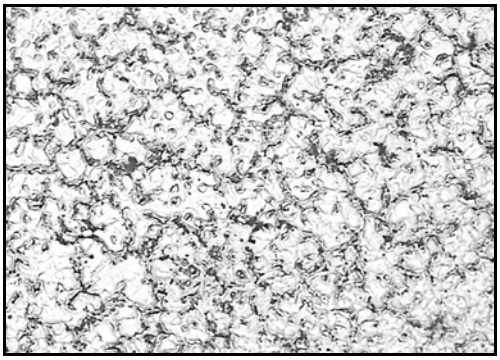

Fig. 1. Microstructure of AZ91 alloy ingot

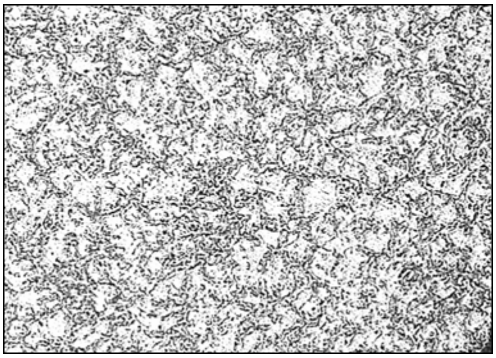

Fig. 2. Microstructure of a pressure casting made of remelted AZ91 alloy ingot

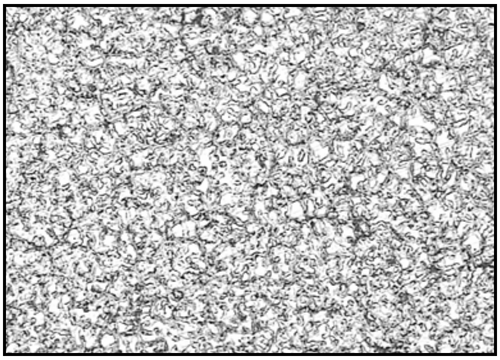

Fig. 3. Microstructure of a pressure casting made of metal containing 30% of AZ91alloy home scrap

Figures 4 and 5 show microstructures of pressure castings made of AZ91 alloy, either remelted from pure ingots or produced with 30% addition of home scrap, at 1000× magnification.

Fig. 4. Microstructure of a pressure casting made of remelted AZ91 alloy ingot

Fig. 5. Microstructure of a pressure casting made of metal containing 30% of AZ91alloy home scrap

The results of hardness measurements are presented in Table 2.

Table 2. Brinell hardness of pressure castings

Alloy	Hardness HB	
	Pure ingots	30% recycled + ingots
AZ91	70.1	72.2
	70.4	71.8
	69.8	73.0

3. Conclusions

Large grains of primary phase (bright areas) and the $Mg_{17}Al_{12}$ phase placed along the grain boundaries (dark areas) can be seen in the microstructure of AZ91 alloy ingot. The pressure casting made of remelted AZ91 alloy ingots shows a distinct refinement of structure caused by the rapid cooling of metal in the metal die. Simultaneously the content of $Mg_{17}Al_{12}$ phase is increased due to the significant deviation from the equilibrium state during the metal crystallization. The presence of home scrap in the charge has resulted in further strong refining of structure in comparison with both the ingot structure and the casting achieved of pure ingot material. One can also see a great increase in $Mg_{17}Al_{12}$ phase fraction. The $Mg_{17}Al_{12}$ phase precipitates arising along grain boundaries are smaller for the case when recycled material has been used, however they are considerably more densely arranged. A comparison of microstructures of the examined castings at a high magnification confirms that the precipitates of $Mg_{17}Al_{12}$ phase are smaller in the castings produced with use of the home scrap. It can result from the nucleation-promoting influence of very fine magnesium oxide particles present in the liquid alloy. Such a result can suggest the modifying influence of home scrap on the $Mg_{17}Al_{12}$ phase crystallization. The microstructural examinations have also revealed that the casting made of charge containing home scrap are characterised by more even distribution of internal porosity. Moreover, the hardness of castings produced of metal containing 30% of home scrap has slightly increased.

Examination of wear out of the shot-end elements in the high-pressure hot chamber die casting machine has shown lower wear of these parts, i.e. of gooseneck, plunger, gooseneck injector, and nozzle. A gooseneck along with a plunger has endured 100,000 injections of metal prepared with the use of home scrap, what makes twice the lifetime of a gooseneck working in a metal remelted from pure AZ91 ingots. It is probably the result of even distribution of very fine magnesium oxides. The investigations with respect to this problem should be continued, and if they are confirmed, this would be an indication that this way of casting should be applied for AZ91 alloy, and maybe also for other magnesium alloys.

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