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Effect of Mould Preheat Temperature on the Solidification Structures of Zn-27Al Alloy

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Abstract— **Gassing and oxidation are the common problems associated with the casting process of Zn-Al alloy which can affect the technological and mechanical properties of the alloy. The rate of cooling is the most important factor in determining the rate of nucleation and therefore, the grain size. At low cooling rate the solidification structures are coarse grained due to predeposition. The aim of this research is to understand the effect of mould preheat temperature on the properties of microstructures of cast Zn-27Al alloy. The ZA-27 alloy were cast at pouring temperatures 700°C while the mould preheat temperatures were 300°C, 350°C and 400°C. The ZA-27 alloy made at three different casting conditions were examined metallographically and analyzed qualitatively using optical and scanning electron microscope. Microstructure refinement, reduction in casting defects and elimination of segregation were controlled with the change of cooling rate. The performed investigations are discussed for the reason of a possible improvement of structural properties of the alloy.**

Index Terms— **Casting, metallic alloys, mould, ZA-27 alloy, mirostructure, phase transformation**

I. INTRODUCTION

The ZA alloys are suitable for casting by a variety of methods including permanent mould and high-pressure die casting. Advantages often associated with the use of the ZA alloys include high mechanical properties, low melting energy consumption, machinability, excellent bearing characteristics and wear resistance. The strength of the zinc-aluminum alloy increases with the aluminum content, so that the 27% aluminum alloys have the highest tensile strength. The zinc-aluminum system has a eutectic at approximately 5% aluminum, so that in the commercial alloys the temperature range over which freezing occurs also increases as the aluminum content increases until, in the case of the 27% aluminum alloy, the freezing range is nearly 109°C. Its freezing range is wide particularly in comparison with its low liquidus temperature (close to 500°C). This naturally makes it prone to solidification micro shrinkage, and casting conditions must then be chosen carefully, in order to secure the internal soundness [6, 7, 12].

The size of grains in a casting is determined by the relation between the rate of growth G and the rate of nucleation N. If the number of nuclei formed is high, a fine grained material will be produced, and if only a few nuclei are formed, a coarse grained material will be produced. The rate of cooling is the most important factor in determining the rate of nucleation and therefore, the grain size [3]. Rapid cooling (chill cast) will result in a large number of nuclei formed and fine grain size, whereas in slow cooling (sand cast or hot mould) only a few nuclei are formed and they will have a chance to grow, depleting the liquid before more nuclei can form. Other factors that increase the rate of nucleation, thus promoting the formation of fine grain are insoluble impurities and stirring the melt during solidification which tends to break up the crystals before they have a chance to grow very large [2-6, 12, 15].

The rate of growth relative to rate of nucleation is greatest at or just under the freezing point. If the liquid is kept accurately at the freezing temperature and the surface is touched by a tiny crystal (seed), the crystal will grow downward into the liquid. If it is withdrawn slowly, a single crystal can be produced [4]. In general, fine-grained materials exhibit better toughness or resistance to shock. They are harder and stronger than coarse-grained material. In industrial casting processes, where a hot liquid is in contact with an originally cool mold, a temperature gradient will exist in the liquid. The outside is at a lower temperature than the center and therefore starts to solidify first. Thus many nuclei are formed at the mold wall and begin to grow in all directions. They soon run into the side of the mold and each other, so that the only unrestricted direction for growth is toward the center. The resulting grains are elongated columnar ones, perpendicular to the surface of the mold. Next to the mold wall where, the cooling rate is fast, the grains are small; while toward the center cooling rate is much slower, the grains are large and elongated [1,9-13].

Zn-Al system offers the advantage of unlimited liquid solubility, without its leading to the formation of deleterious intermetallic compounds. Depending on the aluminum content under consideration, the freezing range can however, vary substantially, and the as cast microstructure can exhibit very distinct features. All the Zn-Al alloys now commercially available are strengthened by copper and magnesium addition. The former induces the occurrence of supplementary phase which do not derive from the binary equilibrium diagram. In this connection, it must be point out that, on top of its hardening and unfortunately enough embrittling effect, Mg helps in increasing the resistance to intergranular corrosion. On the other hand, Cu improves creep and corrosion behaviors [4, 5].

Zinc-aluminum alloys are normally strengthened and hardened with copper and magnesium additions; both are known to form intermetallic compound particles and to affect the solid state reactions. Magnesium is effective in small concentrations and also assures that intergranular corrosion will not take place in atmosphere of high humidity when impurities such as lead, tin and cadmium are accidentally

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high. Copper addition is also made to increase creep strength and to improve corrosion resistance. However the addition of too much copper to zinc aluminum alloys influences the ageing characteristics. The mechanical properties will decrease by a greater extent and undesirable dimensional growth will occur with time. Zinc alloys are susceptible to ageing because all phases are not in equilibrium in the as cast condition [14-16].

Liquid metals, with few exceptions, undergo a contraction in volume due to solidification. This decrease in volume may be as much as 6%. In a properly designed mould, with a provision for liquid supply to the portion that solidifies last, the contraction in volume presents no serious problem. If the entire exterior of the casting should solidify first, the decrease in volume of the interior during solidification will result in a large shrinkage cavity at the mid section [8].The ideal solidification would be that in which the metal first freezes at the bottom of the mould and continues upward to a riser at the top; however heal is dissipated more rapidly from the top of the mould. To minimize the formation of shrinkage cavities abrupt change in thickness and combinations of heavy and light sections should be avoided. If the casting does have heavy sections, they should be designed with riser at the top to supply liquid metal during solidification. Heavy sections should be cut upper most in the mould, and chills may be used in the sand adjacent to the slow cooling pans [6, 9].

The casting temperature has a significant influence on the mechanical properties of cast zinc alloy. Influence of variation of the gradient and solidification rate on the structure of the reinforcing elements has a different character depending if the considered particle is a local heat source with the highest temperature, or if it is a resistance for the heat flow. The measured changes in the temperature gradient and, above all, the gradient change itself as a function of time and location of the investigated area relative to the particle is only caused by differences in thermal properties of components. Variation of derivatives of the temperature may cause variability, which may involve changes in both amplitude and duration of the process [3, 4, 11-13].

Based on the research there are identified two metastable phasesη's and η'E. The dissolution of Cu and Al in the Zn-rich η phase results in a change of the unit cell of the crystal structure, which affect the physical and mechanical properties, in particular the dimensional stability of the alloy [5-7]. Depending on the conditions of the casting process, the material is prepared in a variety of structures, due to solidification of liquid metal. They have impact on the microstructure, grain size, interdendritic distance and thermal conditions [10, 12].

Solidification of the ZA-27 alloy starts with the α' phase dendrites, and then by peritectic reaction of the Zn-β rich phases around the edge of the α' phase. The increase in the cooling rate during solidification reduces the range of occurrence of peritectic reaction in order to enrich the liquid with Zn and stop the solidification of the eutectic β and phase η. The rapid cooling causes - through the β phase transition in eutectoid temperature some irregular particles α and η. Most of the α' phases generally consist of a mixture of Zn-rich phase and Al matrix. These structures are formed by the rapid super cooling of the alloy. The disintegration of the metastable phase is limited by the addition of Cu during the eutectic transformation. After solidification the copper-rich phase forms with the Zn-η the $CuZn_4$ phase in interdendritic areas, most of the remaining copper is dissolved in the η phase [8, 9, 13].

II. Experimental Procedure

A. Casting Condition

Mould used: Permanent mould of cast iron

Alloy used: ZA-27

Furnace used for casting: Pit furnace

Heating system used to preheat the mould: Gas flame

Additives used: Copper 1% and Magnesium 0.02%

Pouring temperatures of the melt: 700°C

Preheat temperature of the mould:

1. 300°C
2. 350°C
3. 400°C

B. Metallography

Metallographic section of a cylindrical shape which had the dimension of 8mm diameter and 10mm height was prepared by lathe machine. Then grinding was done on the surface of the sample. The specimen was polished on a series of emery papers containing successively finer abrasives. The first paper was no.3, then 2, 1, 1/0, 2/0, 3/0 and finally 4/0. The final approximation to a flat scratch-free surface was obtained by the use of a wet rotating wheel covered with a special cloth that was charged with alumina powder of size 0.04µm.

Then etching solution of sodium sulphate and chromic acid in water mixture was used to etch the sample. Then the sample is mounted in the microscope. Various phases were revealed. The microstructures were observed and images were taken. Then the etched and unetched samples were observed in the scanning electron microscope. The backscattered and secondary electron (SE & BSE) images were taken.

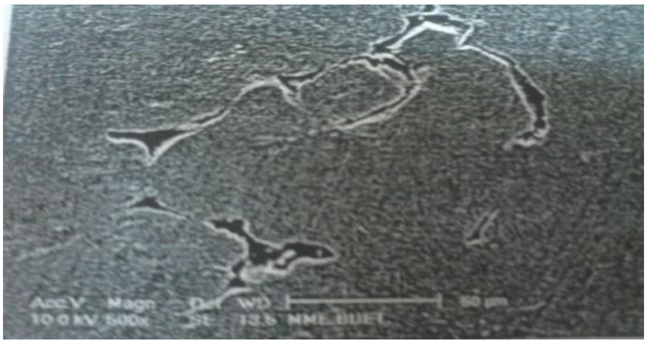

Fig. 1. SE image at mould preheat temperature 300°C, ×500

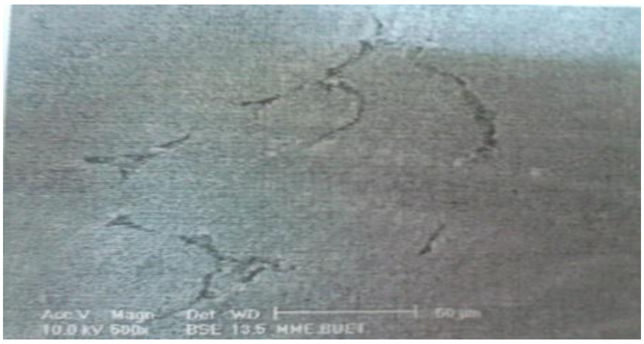

Fig. 2. BSE image at mould preheat temperature 300°C, ×500

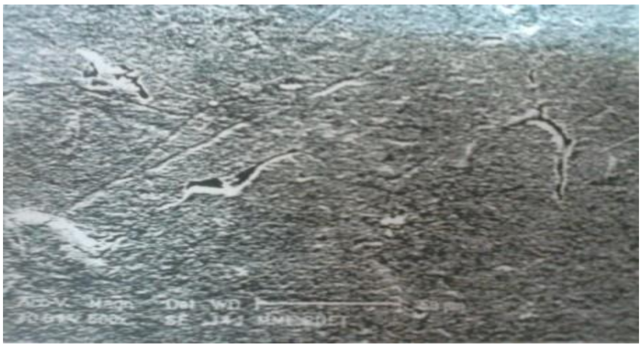

Fig. 3. SE image at mould preheat temperature 350°C, ×500

Fig. 4. BSE image at mould preheat temperature 350°C, ×500

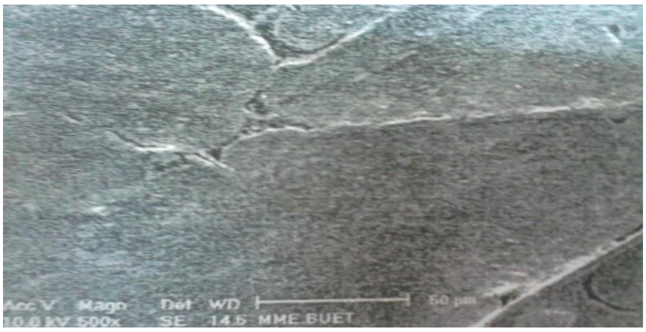

Fig. 5. SE image at mould preheat temperature 400°C, ×500

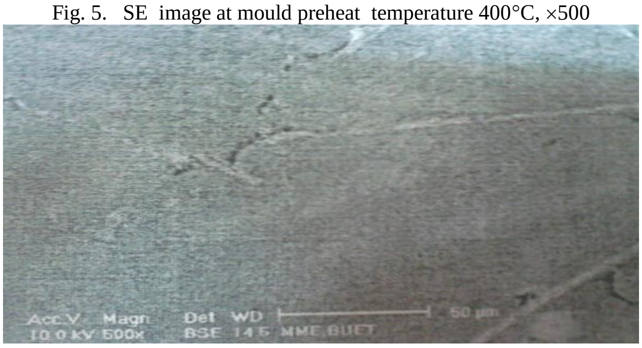

Fig. 6. BSE image at mould preheat temperature 400°C, ×500

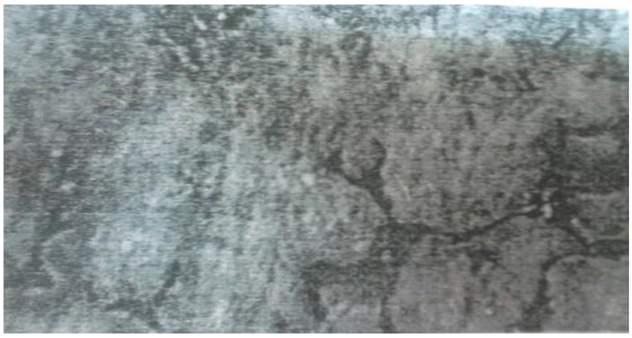

Fig. 7. Optical microscope image at mould preheat temperature 300°C, ×200

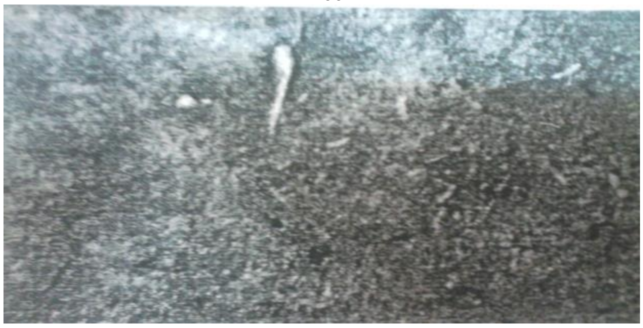

Fig. 8. Optical microscope image at mould preheat temperature 350°C, ×200

Fig. 9. Optical microscope image at mould preheat temperature 400°C, ×200

III. Conclusion

From the present experiment the following conclusions can be drawn

- The dendrites and eutectic regions consist of small, flaky and rod like irregularly shaped intermetallic compound. Otherwise, all the microstructures represent typical cored structure.
- Zn phases as a main phase in this alloy scanning electron microscope investigations shows that, responsible for mechanical properties enhancement, with the possibility to determine the size of the crystallites.
- When the preheat temperature increases the grain becomes coarser. As the mould temperature increases cooling rate decreases, and it gets enough time to grain growth. Sample cast at 300°C shows relatively sound structure than the samples cast at 350°C and 400°C.

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