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Thermal Analysis and Microstructure of ZA8 Alloy Solidifying Against Chills

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Abstract Thermal analysis during solidification of ZA8 alloy against copper, hot die steel and stainless steel chills instrumented with thermocouples was carried out in the present work. The investigation showed that the chill material and coating had a significant effect on the cooling curve of the casting. When casting was solidified against chills, the liquidus and eutectic start temperature of the casting remained nearly the same whereas eutectoid transformation occurred at a higher temperature. Cooling rate curve of the casting solidified against coated chill indicated that formation of solid shell and subsequent re-melting in the case of high thermal conductivity coated chill whereas in lower thermal conductivity coated chill, the re-melting of solid shell was absent. It was found that chilling during solidification causes the morphology of dendrites transform to nearly rounded shape with refinement of lamellar eutectic.

Keywords ZA8 alloy · Thermal analysis · Chill material · Microstructure

1 Introduction

Zinc–Aluminum base alloys are used in many industrial applications which offer a broad range of excellent physical and mechanical properties, low melting point, castability, finishing characteristics and ability to cast thin sections [1]. Improved mechanical properties of these alloys can be achieved by controlling the microstructure of the casting. The final microstructure of the casting depends on the cooling behavior of the casting during solidification. Use of chills and/or metal mould is commonly employed in foundry industry to alter the cooling rate of the casting during solidification to obtain desired microstructure. Mojaver and Shahverdi observed that decrease in cooling rate of Zn–27 %Al during end-chill casting results in increase in dendrite arm spacing, percentage porosity and the interdendritic phase area. Investigation on end-chill cast Zn–27 %Al–2 %Cu and Zn–27 %Al–4 %Cu alloys revealed that the density of ε precipitates and amount of eutectoid $\alpha + \eta$ increased with decreasing cooling rates. Further the morphology of ε precipitates varied from semi-plate-like precipitates to fairly spherical precipitates with decreasing cooling rate [2, 3]. Krupinska reported that increase in cooling rate of ZnAl4Cu1 alloy from 0.08 to 0.68 °C/s results in microstructure refinement as well as increase of the alloy hardness by about 24.9 % [4]. Zinc alloy with higher aluminum and copper content commonly known as ZA alloys are die cast and these alloys are identified as ZA8, ZA12, and ZA27 in which the number represents the percentage of aluminum in the alloy. Among these, ZA8 has low melting temperature and can be hot chamber die cast. ZA8 alloy offers high creep resistance and has high strength [1, 5]. The Al–Zn phase diagram along with the composition line of ZA8 (dashed line) is shown in Fig.1. In the present work, effect of chill material on cooling behavior and microstructure of the ZA8 alloy during solidification was investigated.

2 Experimental

ZA8 alloy was used for solidification experiments. Copper, hot die steel (H11) and stainless steel (304) having varying

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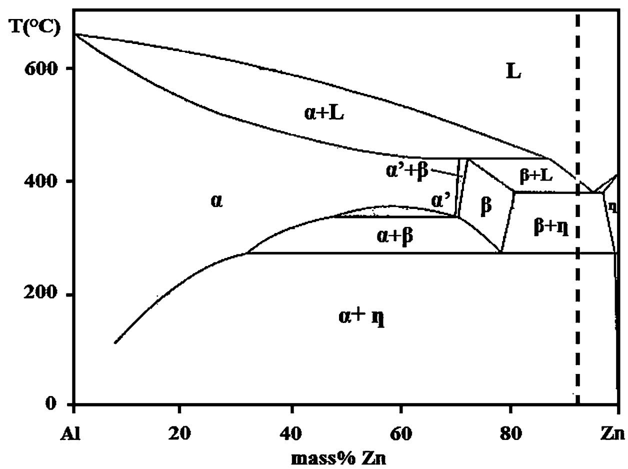

Fig. 1 Al–Zn phase diagram along with the composition line of ZA8 (*dashed line*) [8]

thermal conductivity were used as chill materials to obtain different cooling rates during solidification. Chills were instrumented with mineral insulated K-type thermocouples. The dimensions of chill used are 100 mm length and 25 mm diameter. Two holes of diameter 1 mm were drilled on the cylindrical surface of the chills at distances of 2 and 14 mm from the casting/chill interface to accommodate thermocouples. For coating the chill, it was heated to a temperature of about 150 °C and alumina based coating material was sprayed (6–7 passes) onto the chill surface using a sprayer. The measured coating thickness was about 800 μm for all chills.

In each experiment, about 0.75 kg of alloy ingot was taken in a preheated fireclay crucible and melted in an electric resistance furnace. The alloy is maintained at temperature of 460 °C for about 20 min. The crucible containing the molten alloy was quickly transferred to the insulated base of the solidification experimental set-up and a twin-bore ceramic beaded K-type thermocouple was inserted into the melt. The instrumented chill was lowered into the crucible such that its bottom surface comes in contact with the liquid melt. Temperature data from both casting and chill were recorded at 0.3 s interval using computerized data acquisition system (NI PXI/PCI-4351). After solidification experiments, the castings were sectioned and the microstructure of specimens at 2 mm from the casting/chill interface location was examined using CARL ZEISS CDIC (Model AXIO Imager) metallurgical microscope.

3 Results and Discussion

Figure 2 represents the cooling behavior of ZA 8 alloy solidified in a fire clay crucible subjected to furnace cooling. It indicates that the liquid metal cools rapidly from pouring temperature to liquidus temperature (A). At liquidus temperature there is a sharp change in slope (AB) and then a plateau is obtained (BC). The temperature thereafter decreases rapidly (CD). It is noted that at the temperature of about 271 °C, there is small change in the slope of the curve (DE). The first derivative of the cooling curve (dT/dt) is also superimposed on Fig. 1. It indicates that the temperature of the sample decreases at a constant cooling rate until it reaches the liquidus temperature. As the alloy cools below the liquidus temperature, solid crystals of β begin to nucleate in the liquid (a). A small peak (aa′) in the cooling rate curve is observed which may be attributed to unstable nucleation of β. Once the crystals of stable β phase nucleate (a′), they give off their latent heat of solidification and the cooling rate of the alloy decreases. When the temperature drops to the eutectic arrest (B), eutectic phase starts to nucleate (b) and the remaining liquid in the alloy will now solidify simultaneously. The latent heat of solidification evolved by the simultaneous crystallization of these two phases arrest the cooling curve at the eutectic temperature until the last liquid alloy is solidified. During this period, the cooling rate of the alloy was almost constant (bc). When the alloy is completely solidified at the solidus temperature (C), the cooling rate increases because there is no further evolution of latent heat and then decreases slowly. At temperature 271 °C, once again, the cooling rate decreases sharply which may be attributed to eutectoid phase transformation of β to $\alpha + \eta$ (d). Once the eutectoid transformation completed (e), cooling rate again increased and decreases slowly.

Figure 3 shows that cooling curves of ZA8 casting solidified under varying degree of chilling. It indicates that the chill material had a significant effect on the cooling behavior of the solidifying casting. The cooling rate of the casting solidified against chills is in the order of SS < HDS < Cu. This is due to difference in thermal conductivities of the chills. Higher the thermal conductivity of

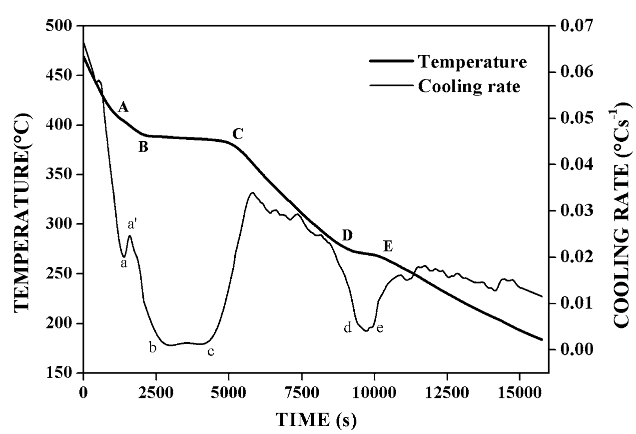

Fig. 2 Cooling curve of ZA8 alloy solidified in a crucible

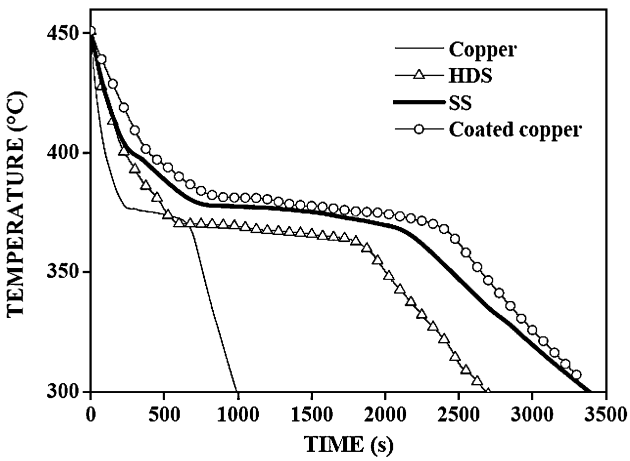

Fig. 3 Cooling curve of ZA-8 casting solidified under different conditions

chill, faster is the heat transfer from the casting resulting in increased cooling rate of casting. Further, local solidification time (time required to cool from the liquidus temperature to the solidus temperature) of the casting decreases as the cooling rate of casting increases. The average cooling rates of 0.04, 0.11, 0.17 and 0.41 °C s^{-1} were obtained for the casting solidified in a crucible and against SS, HDS and copper chill respectively. The corresponding local solidification times were 3968, 1907, 1088 and 602 s. The coating of the chill material results in decreased cooling rate of casting and increase in local solidification time. The presence of coating offers additional thermal resistance (L_c/k_c) and decreases the heat transfer from the casting to the chill.

The cooling rates of the casting against temperature of the casting are plotted. Three valleys designated as p, q and r are observed (Fig. 4) which indicates the start of nucleation of β dendrites (liquidus temperature), start of eutectic transformation and start of eutectoid transformation respectively. All these transformations occur early and duration of these transformations is short when the casting was solidified against chills. Further, it is observed that casting solidified against high thermal conductivity chill (copper chill), the occurrence of valley 'p' is not significant indicating stable nucleation of β dendrites. The use of chill did not have a significant effect on the liquidus and eutectic temperatures of the casting but eutectoid temperature of the casting changed. It is observed that eutectoid transformation temperature of casting increased from 271 °C to around 330 °C and decreased the time of eutectoid transformation. The possible reason could be that β phase formed in the short interval during chilling may not be stable up to a temperature of 271 °C and starts to decompose at higher temperature.

The cooling rate curves of casting solidified against coated chills show different behavior at the initial stage

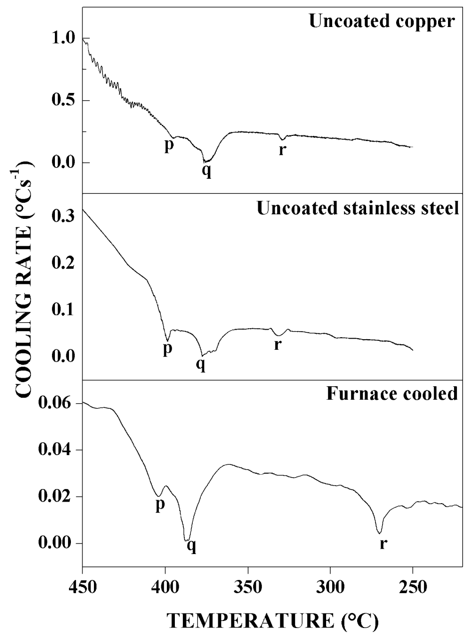

Fig. 4 Cooling rate curve of ZA-8 casting solidified under different conditions

compared to uncoated chills (Fig. 5). In the case of casting solidified against coated copper chill at 430 °C, there is a small peak and the cooling rate is constant up to a temperature of 405 °C (region mn) and is followed by sudden decrease in the cooling rate. In the case of coated SS chill, the region of constant cooling rate was not observed. In earlier experiments authors observed that heat flux transients at casting/chill interfacial analysis showed a double peak during solidification of casting against coated chills. Further, it was observed in the HTC curve, the second peak

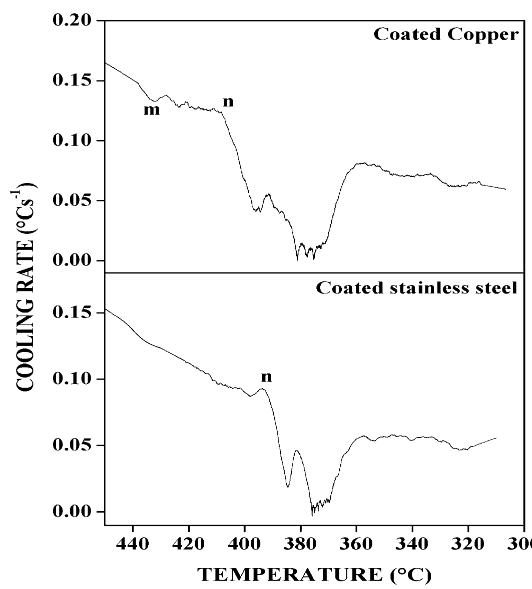

Fig. 5 Cooling rate curve of ZA-8 casting solidified against coated chills

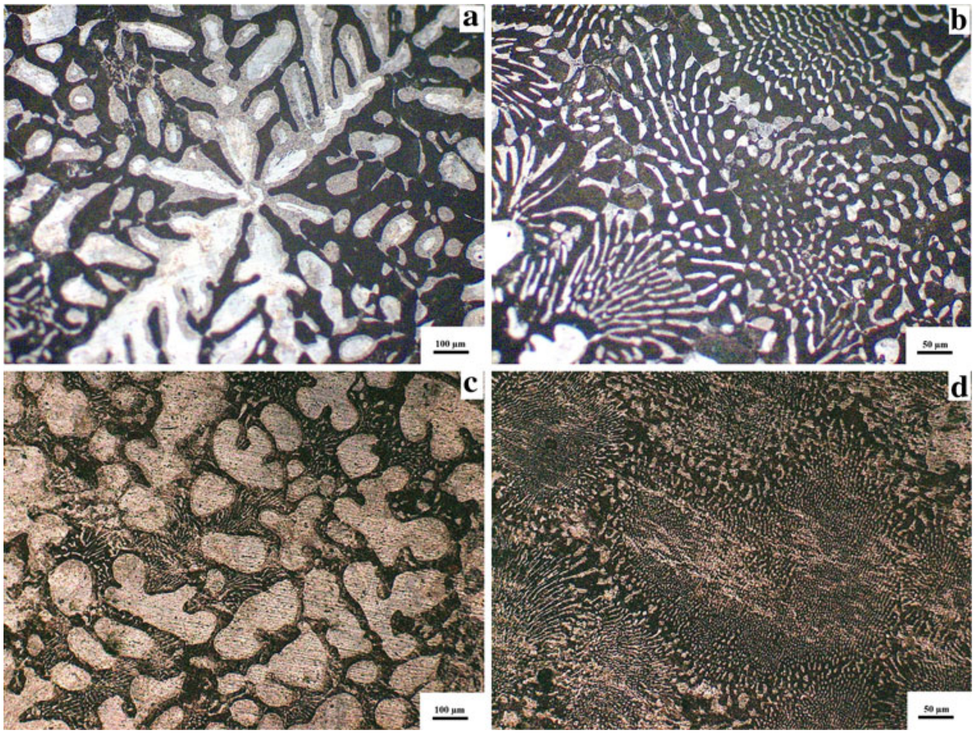

Fig. 6 Microstructure of ZA8 alloy solidified in fireclay crucible (**a**, **b**) and copper chill (**c**, **d**)

is lower for high thermal conductivity chill and higher for low conductivity chill as compared to the first peak [6]. It indicates that when the casting solidified against high thermal conductivity chill, thin solid shell forms at the early stage which corresponds to near constant cooling rate between 410 and 430 °C. Further, the coating peels off from the chill results in sudden decrease in cooling rate. Since the solid shell formed may be very thin, it is possible that it may be re-melted and further cooling behavior is the same as uncoated chill. In the case of casting solidified against low thermal conductivity chill, only a sudden decrease in cooling rate at 400 °C was observed. It indicates absence of formation of solid shell and subsequent remelting at the early stage of solidification.

Metallographic studies were carried out to assess the effect of chill materials on the fineness of the microstructure near the interface. Figure 6a shows the microstructure of ZA8 alloy solidified in a fire clay crucible. The microstructure consisted of primary dendrites in a eutectic matrix. The increase in thermal diffusivity of the chill material resulted in higher heat extraction from casting resulting in decreased average secondary dendrite arm spacing. It was found that with an increase in thermal diffusivity of the chill material and cooling rate of the casting, the morphology of dendrites changes to near rounded shape (Fig. 6a, c) with significant refinement of lamellar eutectic (Fig. 6b, d). This may be due to chill surface acting as sites for nucleation of more β phase. Further, Ares and Schvezov observed that the change in cooling rate during directional solidification of ZA alloys result in temperature gradients in the liquid phase and liquidus interface velocity are significantly changed which control the microstructure of the casting [7].

The present study indicates that chilling of ZA8 alloy had a significant effect on the solidification path and formation of microstructure during solidification. The change in microstructure has a significant effect on the mechanical properties of the casting. Thus a proper control over the cooling rate during solidification of ZA8 alloy by judicious selection of chill and mold materials would yield better mechanical properties.

4 Conclusions

Based on the results and discussion the following conclusions were drawn.

1. Chill material had a significant effect on the cooling curve of the casting and cooling rate of the casting increases with increase in the heat diffusivity of chill material.
2. The start of nucleation of β dendrites, start of eutectic transformation and start of eutectoid transformation occured early and duration of these transformations were shorter when the casting was solidified against chills.

3. Casting solidified against high thermal conductivity chill involved stable nucleation of β dendrites.
4. The liquidus and eutectic temperature of the casting remained the same whereas eutectoid transformation temperature was higher when casting was solidified against chills.
5. Chilling during solidification causes the morphology of dendrites transform to nearly rounded shape with refinement of lamellar eutectic.

References

1. Alloy Data. NADCA Product Specification Standards for Die Castings, Section 3 (2003).
2. Mojaver R, and Shahverdi H R, *Wear* **268** (2010) 605.
3. Mojaver R, and Shahverdi H R, *Wear* **271** (2011) 2899.
4. Krupinska B, Dobrzanski L A, Rdzawski Z M, and Labisz K, *Mater Sci Eng* **43** (2010) 13.
5. ZA8 Hot chamber die casting guidelines. Eastern alloys, inc. http://www.eazall.com/casehistories.aspx. Accessed 22 Nov 2011.
6. Ramesh G, and Prabhu K N, *Int J Cast Met Res* **25** (2012) 160.
7. Ares A E, and Schvezov C E, *Metall Mater Trans A* **38** (2007) 1485.
8. Zhu Y, *Mat Trans* **45** (2004) 3083.