Effects of the pouring temperature on the formation of the bonding zone between AZ91 and AlSi17 in the compound casting process

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Abstract. The compound casting process was used to join AZ91 magnesium alloy to AlSi17 aluminium alloy. Liquid AZ91 was poured onto a solid AlSi17 insert placed in a steel mould heated to 370 °C. The experimental results showed that the temperature of the AZ91 melt affected the formation of the bonding zone between the two alloys. A continuous bonding zone was formed by applying a pouring temperature of 650 °C. The use of higher temperatures, i.e. 680 °C and 700 °C, did not lead to the formation of a continuous metallurgical transition zone at the AZ91/AlSi17 interface. The bonding zone was analysed using an optical microscope and a scanning electron microscope equipped with an energy dispersive X-ray (EDS) detector. The structural constituents of the bonding zone near the AlSi17 alloy were: an Al₃Mg₂ intermetallic phase, primary Si particles surrounded by a rim of an Mg₂Si intermetallic phase and fine Mg₂Si particles. The area of the bonding zone that was adjacent to the AZ91 alloy had a eutectic structure composed of an Mg₁₇Al₁₂ intermetallic phase and a solid solution of Al and Si in Mg.

1 Introduction

Compound casting is an economical manufacturing process employed to produce bimetal parts. It involves casting one type of metal or alloy, in a molten state, directly onto another metal or alloy, which is solid. The diffusion process that takes part during casting contributes to the formation of a continuous metallurgical bonding zone between the two metal materials. In recent years, much research has been conducted to use compound casting to join dissimilar metal materials, for instance, cast steel to chromium cast iron [1], steel to cast iron [2-4], steel to Al [5], Al to Cu [6], Al alloy to Al [7], Mg alloy to Mg alloy [8] and Al to Mg [9,10].

Because of the increasing needs of the automotive industry for lightweight metal alloys and composites, the fabrication of Mg/Al bimetals seems to be a promising solution. These materials have unique properties, which make them suitable for specific applications. Mg/Al compound materials can be produced by twin-roll casting [11], hot rolling [12, 13], extrusion [14], explosive cladding [15] and, as mentioned above, by compound casting. The compound casting technique has proved to be well-suited for fabricating Mg/Al items with intricate shapes.

This paper analyses the application of the compound casting method to join AZ91 magnesium cast alloy to AlSi17 aluminium cast alloy. It focuses on the influence of the pouring temperature on the formation of the bonding zone between the two alloys. It also discusses the microstructure of the AZ91/AlSi17 interface.

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2 Experiment procedure
Molten AZ91 magnesium alloy and solid AlSi17 aluminium alloy were used in the compound casting process. The AlSi17 was in the form of cylindrical inserts with a diameter of 30 mm and a thickness of 5 mm cut from an ingot. The inserts were ground using up to 800 grit SiC paper and then cleaned with ethanol. The casting process began by placing an AlSi17 insert at the bottom of a steel mould and both were heated up to 370 °C. In the meantime, AZ91 was melted in pure argon up to 650 °C, 680 °C or 700 °C and then cast onto the AlSi17 insert under normal atmospheric conditions.

After the casting process was completed, the AZ91/AlSi17 bimetal specimens were cut and prepared for metallographic observations using a STRUERS automatic polishing machine. Polishing was performed with colloidal silica. The microstructure of the bonding zone was observed by means of a Nikon ECLIPSE MA 200 optical microscope and a JEOL JSM-5400 scanning electron microscope. The chemical composition of the interfacial area was studied using an X-ray energy dispersive spectrometer (EDS). The phase composition of the bonding zone was determined on the basis of the EDS quantitative results and the phase diagrams for Mg-Al [17] and Mg-Al-Si [18].

3 Results and discussion
The analysis was conducted for AZ91/AlSi17 specimens produced at three different temperatures. From the results it is clear that a pouring temperature of 650 °C led to the formation of a continuous, uniform and defect-free bonding zone at the AZ91/AlSi17 interface (see figure 1).

![Figure 1. Optical micrograph of the bonding zone for the AZ91/AlSi17 bimetal specimens fabricated by compound casting at a pouring temperature of 650 °C and a mould temperature of 370 °C.](image)

Figure 2 presents an SEM image of the bonding zone with the corresponding EDS line scan results. The elemental distribution indicates that the zone is rich in Mg, Al and Si. Higher concentrations of Al and Si and a lower concentration of Mg were observed on the AlSi17 side. The interfacial reaction between the molten AZ91 and the solid AlSi17 insert occurring during the compound casting process led to the formation of a transition layer between the two materials, which had a multiphase structure.
Figure 2. SEM image of the bonding zone and the corresponding EDS line scan results.

Figure 3 shows details of the microstructure of the bonding zone on the AZ91 side. In the area adjacent to the AZ91 substrate, there is a two-phase mixture with a lighter phase (marked 1) and a darker phase (marked 2). Below, we can see large light dendrites (marked 3). The results of the EDS quantitative analysis conducted at three points (see figure 3) are provided in Table 1. With reference to the Mg-Al phase diagram and the results of the quantitative analysis it can be concluded that the two-phase mixture is a eutectic composed of an Mg$_{17}$Al$_{12}$ intermetallic phase and a solid solution of Al and Si in Mg. The chemical composition of the large light dendrites correspond to that of an Mg$_{17}$Al$_{12}$ intermetallic phase.

Figure 3. SEM image of the bonding zone on the AZ91 side.
Table 1. Results of the EDS analysis corresponding to the points shown in figure 3.

| Point | Mg (at. %) | Al (at. %) | Si (at. %) |
|-------|------------|------------|------------|
| 1     | 64.47      | 35.27      | 0.26       |
| 2     | 84.46      | 15.13      | 0.41       |
| 3     | 61.39      | 38.61      | -          |

Figure 4 shows the microstructure of the central area of the bonding zone. On the AZ91 side in the upper part of the image, there are dendrites of an Mg$_{17}$Al$_{12}$ phase and a two-phase eutectic. Below the eutectic, we can see grey fine-grained particles, distributed irregularly throughout the light matrix and a large light particle surrounded by the grey phase. The EDS analysis at point 1 (99.91 at. % Si and 0.09 at. % Al) indicates that the large light particle is a primary silicon crystal. The composition of the grey area near the primary silicon (analysis at point 2: 64.54 at. % Mg, 33.44 at. % Si and 2.02 at. % Al) and the grey particles irregularly distributed throughout the light matrix (analysis at a grey particle: 63.52 at. % Mg, 34.30 at. % Si, 2.18 at. % Al) correspond to that composition of the of an Mg$_2$Si intermetallic phase. It is evident that silicon reacted with magnesium, which gave rise to the formation of the Mg$_2$Si intermetallic phase. The composition of the light matrix (analysis at point 3: 60.34 at. % Al, 39.66 at. % Mg) is similar to that of an Al$_3$Mg$_2$ intermetallic phase.

![Figure 4. SEM image of the central area of the bonding zone.](image)

Figure 5 shows an SEM image of the bonding zone on the AlSi17 side. A light primary Si particle can be seen in the area adjacent to the AlSi17 alloy. The Si particle is surrounded by a rim of an Mg$_2$Si intermetallic phase, like the Si particles found in the central area of the bonding zone. Fine particles of the Mg$_2$Si phase in the Al$_3$Mg$_2$ phase matrix were also observed in the area adjacent to the AlSi17 alloy. The analysis of the microstructure revealed that there were small white particles distributed irregularly over the entire AZ91/AlSi17 interface (see figures 3, 4 and 5). The EDS results indicated that the particles were rich in Al, Ni, Mg and Fe (analysis at a light particle: 64.95 at. % Al, 17.36 at. % Ni, 10.18 at. % Mg and 7.5 at. % Fe).
When higher pouring temperatures were used, i.e. 680 °C and 700 °C, the bonding zone that formed between the AZ91 and the AlSi17 was not continuous. Local discontinuities at the AZ91/AlSi17 interface were reported, as shown in figure 6.

Below the discontinuities we can observe a change in the microstructure of the AlSi17 alloy. This suggests that at the beginning of the casting process there was a direct contact between the AZ91 and AlSi17 alloys, which enabled a reaction between them and the formation of the bonding zone, but then the continuity at the reactive interface was lost.

4 Conclusions
The results show that the AZ91 alloy was successfully joined to the AlSi17 alloy by compound casting. When the pouring temperature was 650 °C, a continuous bonding zone with a thickness of 200 μm formed at the AZ91/AlSi17 interface. At higher pouring temperatures, i.e. 680 °C and 700 °C, local discontinuities in the bonding zone were observed. The bonding zone adjacent to the AlSi17
alloy was composed of Si primary particles surrounded by a rim of Mg$_2$Si, Mg$_3$Si and Al$_3$Mg$_2$ intermetallic phases. The area of the bonding zone adjacent to the AZ91 alloy had a eutectic structure composed of an Mg$_{17}$Al$_{12}$ intermetallic phase and a solid solution of Al and Si in Mg.

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