Comparison between conventional and lost foam compound casting of Al/Mg light metals

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The microstructure obtained in conventional and lost foam compound casting of Al/Mg alloy was examined and compared. X-ray diffraction, optical and SEM examinations showed that casting magnesium melt around the aluminium insert, in both methods, is caused formation of an interface consisting three different layers. Layer I, beside aluminium consists of Al_3Mg_2 intermetallic compound, layer II consists of $Al_{12}Mg_{17}$ phase and layer III, in the vicinity of magnesium, is formed of $Al_{12}Mg_{17}+$(Mg) eutectic. The result of Vickers microhardness tests, at the interface zones, showed that the hardness of the middle layer is increased substantially (200–250 HV) in comparison to the hardness of the base metals, namely aluminium and magnesium. Using the LFC method reduced the thickness of interface as a result of both, lowering the temperature and the speed of melt. The mean thicknesses of the interface in the conventional and LFC processes were 600 and 200 μm respectively.

Keywords: Compound casting, Lost foam casting, Interface, Aluminium, Magnesium

Introduction

Compound casting is a process of joining two metals or alloys via direct casting in which one component is in the solid state, as a core, and the other as pouring metal. In such a manner, a diffusion reaction zone between the two metals, and thus a continuous metallic transition, from one metal to the other can be formed.[1–3] This method is used for joining semifinished parts with complex structures, simply by casting a metal onto or around a solid shape.[4] Despite these benefits, the joining process of metals like aluminium and magnesium, by the compound casting process, is associated with many problems and constraints such as formation of oxide layers on the surface and precipitation of undesirable intermetallic compounds.[5–8] Production of a composite bimetal part with the appropriate properties is required to overcome these problems.

Lost foam casting (LFC) has been used as a production process for more than 50 years. In this process the embedded polystyrene pattern in the sand mould is decomposed by molten metal. So, the molten metal replaces the polystyrene pattern and duplicates all features of the pattern.[9] Currently, many casting facilities are dedicated strictly to the lost foam process because of its interesting and numerous advantages such as no mould parting line, no cores, more accurate dimensions, no environmental pollutants, ability to produce complex pieces and also cost reduction.[10–12] An interesting advantage of this process is the possibility of mounting the desired solid part inside the polystyrene pattern (coring) and performing the casting process afterwards. Divandari *et al.*[13,14] used LFC method to study different dissimilar metallic couples, such as aluminium/copper and cast iron/copper, and studied the microstructure and properties of the obtained products. Also Cho *et al.*[15] used the lost foam compound casting (LFCC) in order to join aluminium and steel. Thus, this method can be used for the production of parts with desirable mechanical and physical properties and may lead to spread the application of this process.

Magnesium and aluminium are the first and second engineering light metals respectively and are attractive in vehicle structure applications for improving energy efficiency which reduces the emission of greenhouse gases. In many cases, one of these materials alone does not satisfy the requirements of lightweight constructions, and dissimilar joining between these two metals must be faced.[16] However, many researchers have used the compound casting in order to join different dissimilar and similar metallic couples such as steel/cast iron,[17,18] steel/Cu,[19] steel/Al,[15,20] Cu/Al,[13] Al/Al,[3,20,21] and Mg/Mg,[22] but joining dissimilar light metals such as aluminium and magnesium, by compound casting process, is still a relatively unexplored area. A good contact with satisfactory metallurgical and mechanical properties between Mg/Al, Al/Al and Mg/Mg couples, leads to significant increase in application of these light metals in automotive and aerospace industries which results in lower fuel consumption.[21,23]

In this work, the conventional compound casting (CCC) and LFCC processes for the dissimilar joining of Al/Mg light metals were studied. Bonding conditions including microstructure characteristics and microhardness were examined in order to evaluate

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and compare CCC and LFCC processes for joining these two metals.

Experimental procedure

Commercially pure aluminium and magnesium were used to prepare Al/Mg couples by the compound casting process. Mean chemical compositions of the materials used are listed in Table 1.

In order to fabricate the Al/Mg couples by the compound casting process cylindrical inserts, with 20 mm diameter and 100 mm height, were machined from aluminium ingots. Their surface were ground with the silicon carbide papers up to 1200 grit, then rinsed with acetone and placed within a cylindrical cavity of a CO_2 sand mould with 40 mm diameter and 80 mm height. Schematic of the mould used in the casting process and the prepared Al/Mg couple are illustrated in Fig. 1. Gating system in the CCC and in the LFCC processes were made with wood and polystyrene (EPS with a density of 0·02 g cm^{-3}) patterns respectively.

Magnesium ingots were melted in a steel crucible placed in an electrical resistance furnace under the Foseco MAGREX 36 covering flux to protect magnesium melt from oxidation. The molten magnesium was cast around the aluminium inserts at 700°C under normal atmospheric conditions.

After the casting, specimens were cut from the bottom, middle and top parts of the samples, perpendicular to the cylindrical insert, using an electrical discharge machine (Fig. 2). Then the middle parts polished with 1 µm diamond paste. Owing to nature of dissimilar metals bond, specimens were etched by 1 vol.-%HNO_3 in alcohol solution on the magnesium side and 1 vol.-%HF in distilled water solution on the aluminium side. Specimens were examined using a JEOL JSM-7000F scanning electron microscope (SEM) equipped with the energy dispersive X-ray (EDS) detector. The phase constitutions on the fracture surfaces of the specimens were also identified by using a Rigaku RINT-RAPID X-ray diffractometer. In addition, a Buehler hardness tester with a testing load of 50 g and a holding time of 20 s was used to determine the Vickers microhardness profile across the joint interface.

Results and discussion

Figure 3 shows SEM images from samples prepared by casting magnesium melt around the aluminium insert, using CCC process and LFCC process.

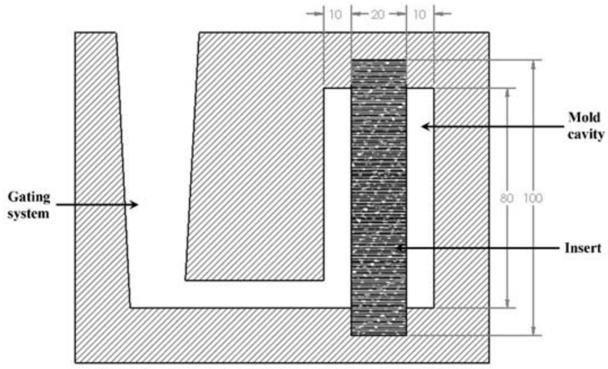
As can be seen in Fig. 3, a relatively uniform interface has been formed due to contact between magnesium melt and the aluminium insert that consist of three different reaction layers. These are a layer at the aluminium side (layer I), a middle layer (layer II) and the layer at the magnesium side (layer III). Also Fig. 3 shows that the thickness of reaction layer, in the case of LFC, is about one-third of the conventional casting method. Therefore, the reaction layer thickness reduces from 600 µm in CCC to 200 µm in LFCC.

X-ray diffraction pattern of the constitutive phases, on the fracture surface of the Al/Mg joint, (Fig. 4) confirms the formation of two Mg phases, Al_3Mg_2 and $Al_{12}Mg_{17}$ intermetallic compounds, within the interface microstructure.

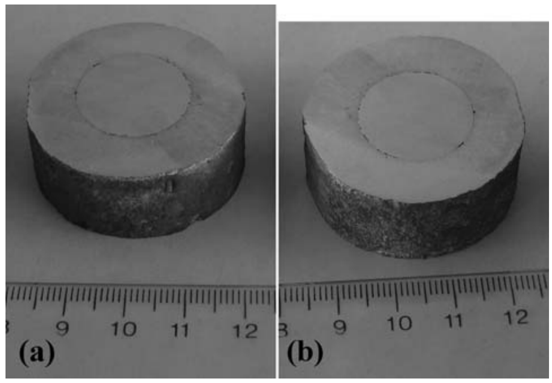
In order to study the interfacial microstructure of the Al/Mg couples in the compound casting process, the reaction layers were examined using EDS, line scan and X-ray map analysis. Figures 5 and 6 show a typical EDS map of the elements Al, Mg and O in the CCC and LFCC cast samples respectively.

Figure 7 shows line scans of the elements Al and Mg in the samples produced by CCC and LFCC. As shown in these figures, the magnesium content gradually decreases across interface from its base toward aluminium insert and it is exactly vice versa for aluminium.

It is noteworthy that across the interface, the curve corresponding to magnesium (upper line) is almost above the curve corresponding to aluminium (lower line) except in a small region of the interface close to aluminium (layer I). This indicates that compounds



1 Schematic of mould used for casting process



a sample prepared by conventional casting; *b* sample prepared by LFC

2 Cross-section of Al/Mg joint in compound casting process

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Table 1 Mean chemical compositions of commercial metals, used in this study/wt-%

	Al	Mg	Zn	Sn	Mn	Cu	Fe	Si
Commercially pure aluminium	99·548	0·027	0	0·076	0·009	0·002	0·0171	0·131
Commercially pure magnesium	0	99·847	0·093	0	0·017	0·012	0·002	0·029

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