Investigation on interface of Al/Cu couples in compound casting

G. R. Zare, M. Divandari* and H. Arabi

The joining of Al and Cu commercially pure metals using the compound casting process has been investigated where an aluminium melt is cast onto a solid cylindrical copper insert. The microstructure of the interface between copper core and surrounding aluminium was characterised by optical microscopy, scanning electron microscopy, energy dispersive X-ray spectroscopy and Vickers hardness tests. Results showed that five separate reaction layers are formed in the reaction interface of core and surrounding Al. These layers included Cu_9Al_4, AlCu and Al_2Cu intermetallic compounds; a eutectic layer; and a eutectic α-Al dendritic structure layer. Owing to the presence of hard and brittle intermetallic compounds within reaction layers, microhardness profile showed a peak of 300 HV where both parent metals have hardness $<$50 HV. Microhardness profile also showed that hardness decreases from the copper to the aluminium side.

Keywords: Compound casting, Al/Cu couples, Interface structure, Intermetallics

Introduction

Various techniques can be used for joining two dissimilar metals. Physical and mechanical properties of constituent metals, such as structural properties, corrosion resistance, wear resistance, thermal conductivity and expansion, should be considered in the selection of two metals.[1] The production of Al/Cu couples would have its specific technical and economic impact, since it would enable the creation of engineering solutions combining copper's improved mechanical, thermal and electrical properties with aluminium's low specific weight and cost[2] and also its limitation and weakness in an aqueous environment.[3]

In recent years, many investigators have studied different processes for fabricating Al/Cu couples, such as friction welding,[4–6] friction stir welding,[7–9] diffusion bonding,[10–12] cold rolling[13–15] and explosive welding.[16] Details of the difficulties, in the production methods, are given in the papers mentioned above; but in summary, long process time, high operating cost and specific requirements, for the shape of the substrate, may render these solid state joining processes as not easy for practical and industrial applications. Compound casting process, however, can potentially provide an economical way to produce this bimetal without limitation in geometry and dimension, which have been under great attention in the past three decades.

Compound casting is defined as a process in which two metallic materials, i.e. one in the solid state and the other as a liquid, are brought into contact with each other in such a manner that a diffusion reaction zone forms between the two materials and thus a continuous metallic transition occurs from one metal to the other. Compound casting might, for example, be deployed to join a wrought alloy part with cast components of complex shape simply by casting a liquid metal onto or around the solid component.[17,18] In recent years, Al/Al,[17,19] Al/Mg,[20,21] Mg/Mg,[22] cast iron/mild steel[23] and Al/Fe[24] couples have been subject of investigations, but bonding of Al/Cu couples by this method has not yet been thoroughly studied. Recently, Divandari and Vahid Golpayegani[25] have inserted copper wire in polystyrene pattern, and cast A356 Al alloy onto, and studied the reaction of molten aluminium alloy and copper wires with various diameters to investigate which types of phases and compounds may form during the reaction of the inserted wire with the molten alloy. They reported that a concentration of Cu rich phases and other phases such as $AlCu_3$, AlCu, Al_2Cu and Si particles and Fe containing intermetallic was found in the interface of the Cu wire and the matrix.

In the present study, the formation of various phases in the interface of commercially pure Al and Cu insert, produced via compound casting process, is studied, and the possible mechanism of their formation at the interface is discussed.

Experimental

Commercially pure aluminium and copper were used to produce Al/Cu couples using the compound casting process. Their chemical compositions are given in Table 1. In order to fabricate the Al/Cu couples by this process, cylindrical inserts with 5·12 mm diameter were used. Their surfaces were ground with silicon carbide papers up to 1500 grid, then rinsed with acetic acid and placed within a cylindrical cavity of a CO_2 sand mould. Inserts were placed in a position in such a way that from

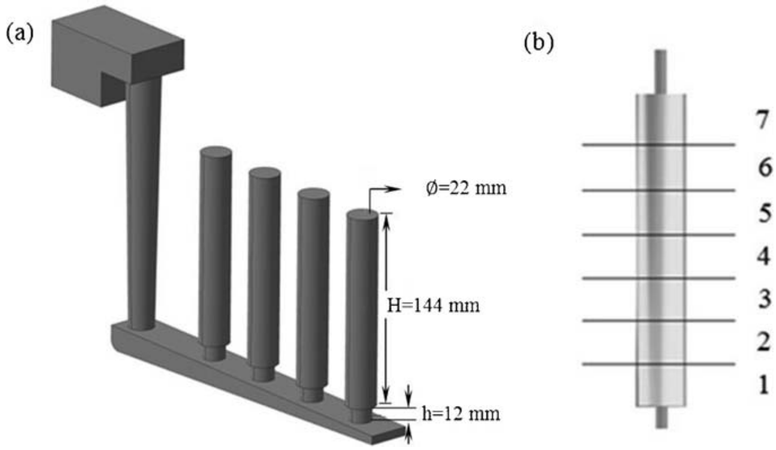
Iran University of Science and Technology, Tehran, Iran

*Corresponding author, email divandari@iust.ac.ir

Published by Maney on behalf of the Institute
Received 9 July 2012; accepted 27 July 2012
DOI 10.1179/1743284712Y.0000000096

Materials Science and Technology mst10315.3d 20/8/12 15:43:51
The Charlesworth Group, Wakefield +44(0)1924 369598 - Rev 7.51n/W (Jan 20 2003)

ONLINE COLOUR ONLY



1 Schematic sketches of *a* pattern used for casting process and section's dimension (mm) and *b* number and position of samples taken

each end, top and bottom sides, 40 mm of their lengths was protruded into the mould. The molten aluminium was cast around the copper inserts at 700°C under normal atmospheric conditions. A schematic sketch of the pattern, used in the casting process, is illustrated in Fig. 1.

In order to study the interfacial microstructure of the Al/Cu couples, each cast bars were cut in seven parts perpendicular to the axis of cylinder (Fig. 1*b*). After grinding and polishing, the samples were etched by a 0·5%HF and then were examined using a MEIJI Techno optical microscope equipped with a Moticam 2000 camera and a VEGAII XMU Tescan scanning electron microscope equipped with an energy dispersive X-ray spectroscopy (EDS). Microhardness test of the reaction compounds formed in the interface of Al/Cu was conducted using an MX9660a hardness tester with a testing load of 50 g and a holding time of 20 s.

Results and discussion

Microstructure and morphology of reaction area

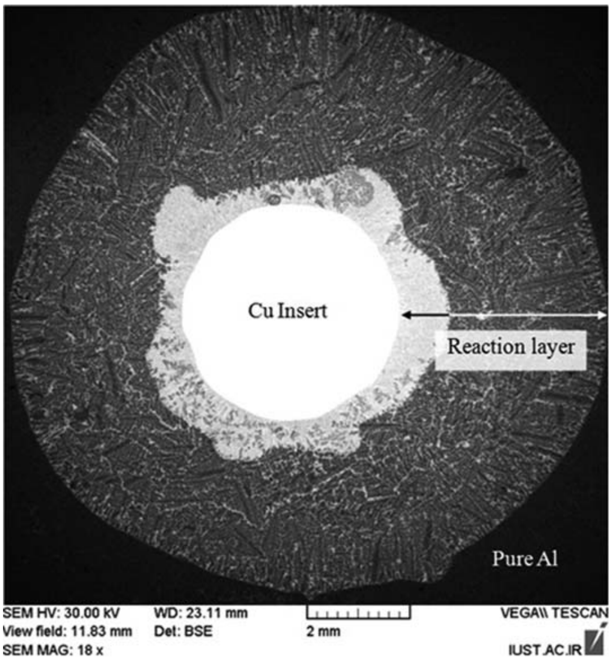
The aluminium melt, after pouring into the mould, starts rising up in the mould cavity and surrounding the copper insert. If the heat content of the liquid Al is enough, then melting the surface layers of the insert and forming a solution of aluminium and copper liquid can be expected. The formation of this solution is partially via diffusion of aluminium and copper atoms in each other in the liquid state and/or via mechanical mixing, possibly as a result of convection inside the melt. Copper concentration gradually decreases towards the aluminium base metal, and because of this concentration gradient between the copper insert and the aluminium base metal, a reaction area including various phases can be formed between these two metals (Fig. 2). The continuous metallic transition from insert to pure Al is shown in Fig. 3*a* and *b*.

Figure 4 shows the optical microscopy image of reaction phases near the insert. It can be seen that three compound sublayers with different thickness have been formed between the copper and the eutectic (lamellar) phase. Energy dispersive X-ray spectroscopy was performed to identify the chemical composition of these layers.

The labelled sublayers in Fig. 5 and the related EDS results are demonstrated in Fig. 6. The suggested composition for each sublayer and the existence area of phases in the equilibrium phase diagram are summarised in Table 2. As can be seen, the sequence of intermetallics is Cu_9Al_4, AlCu and Al_2Cu from Cu towards Al respectively. Moreover, thick layers of eutectic phase and eutectic+α-Al dendritic structure are formed beside the above mentioned phases (Figs. 2 and 3).

Table 1 Chemical compositions of materials used in present study/wt-%

Cu	Sb	Zn	Ag	Fe	Si	Al	Material
0·04	…	0·01	…	0·12	0·12	99·71	Al
99·99	0·009	…	0·002	…	…	…	Cu



2 Image (SEM) of reaction interface between Al melt and Cu insert

Materials Science and Technology mst10315.3d 20/8/12 15:43:52
The Charlesworth Group, Wakefield +44(0)1924 369598 - Rev 7.51n/W (Jan 20 2003)