Investigation of Al/Steel Bimetal Composite Fabrication by Vacuum Assisted Solid Mould Investment Casting

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Bimetal composites are a group of promising engineering materials with high developing and service potential. Especially in many fields they can be a powerful low cost alternative to metal–ceramic composites. The most commonly encountered type of these composites is steel reinforced aluminium matrix composites which stand out with high wear and abrasion resistance. Significant fabrication processes of metal/metal composites are based on liquid metal techniques. In this study, Al/steel composite specimens were produced by using vacuum assisted solid mould investment casting technique. A7075 wrought aluminium alloy were infiltrated into steel preforms, which were produced with 304 stainless steel and H13 hot-work tool steel turnings, in the plaster based solid investment casting moulds. Microstructure observations, HV microhardness measurements, scanning electron microscopy and energy dispersive X-ray spectroscopy analysis were carried out for characterization.

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1. Introduction

Metal–matrix composites (MMCs) are used for structural applications where high strength, stability and high wear resistance is required. Because of the increasing demand for lightweight, energy efficient materials in fields like automotive and aerospace, the availability of low cost reinforcements and economic processing of light weight composites become necessary [1, 2].

However metal–metal composites have not been studied as much as metal–ceramic composites, metallic reinforcements have great potential with providing cost advantage compared to ceramic reinforcements [3].

Up to present there are several liquid state techniques which have been used to processing of metal–metal composites. For instance, Bhagat [4] fabricated aluminium matrix composites reinforced with stainless steel wires by powder metallurgy (PM) techniques.

Baron et al. [3] investigated two types of sintered metal preforms (steel and stainless steel) reinforced aluminium composites prepared by varying squeeze casting conditions. Also Colin et al. [5] used stainless steel fibre preforms for aluminium matrix composite production with squeeze casting. Stir casting technique has been studied by Mandal et al. [6]. In this technique aluminium melt is stirred to form a vortex and coated plain steel fibres added to centre of the vortex, then the melt was poured into metal moulds.

Lee et al. [7] used periodic cellular steel wire-woven preforms to produce Al/steel composites. In this process, woven preforms were placed in a preheated steel mould and melted aluminium was poured into this mould. Very similar to this method, Agarwala et al. [8] produced Al/steel composite ingots with using regularly placed mild steel wires.

In our work, stainless steel and hot-work tool steel turnings were used to prepare pressed preforms and vacuum assisted solid mould investment casting technique was carried out to liquid aluminium alloy infiltration into these preforms. Vacuum assisted solid mould investment casting technique is known for MMCs fabrication. It has been successfully employed with ceramic preforms [9]. Also, it could be a new and alternative approach to Al/steel composite production.

2. Experimental details

304 stainless steel and hot-work tool steel H13 turnings, which were used as reinforcement, were provided from a local machining workshop. The chemical compositions of steel turnings are given in Table I. Shortened turnings were filled into a cylindrical steel mould with 20 mm in diameter and 40 mm in height and 125 MPa pressure was applied by using a mechanical press to fabricate a steel preform. A photograph of steel preforms is shown in Fig. 1.

Fig. 1. Photograph of steel preforms.

The solid investment casting mould, which was used for vacuum infiltration, was prepared with a cylindrical

TABLE I

Chemical composition of steel turnings (wt%).

Steel	C	Si	Mn	Cr	Ni	Mo	V	Fe
304	0.08	1.00	2.00	18.0	8.0	–	–	Bal.
H13	0.50	0.20	0.25	4.50	–	3.0	0.15	Bal.

wax pattern with 21 in diameter and 50 mm in height. The wax pattern was fastened to a rubber flask base and a stainless steel perforated flask was placed on the base. Holes of the perforated flask were covered with an adhesive band. Plaster bonded (plaster/silica) commercial investment powder were mixed with water in the ratio of 0.40, then the flask was filled with the slurry under vibration. After 2 h holding, the flask was placed into an electrical furnace for dewaxing and burnout process. According to a certain burnout regime the mould was heated up to 700 °C gradually. The steel preform was placed into mould just ten minutes before the casting; in this way preheating of the preform was provided without excessive oxidation. The flash mould was taken out from the furnace at 700 °C and was placed into the vacuum casting machine. 10^{-5} Pa pressure was applied during the casting process. A7075 alloy was melted at 830 °C in an electric resistance furnace using a clay/graphite crucible, and then was cast into the mould as shown in Fig. 2. Chemical composition of the A7075 alloy is given in Table II. After solidification, the mould was dipped into the water for decomposition and the cast part was taken out.

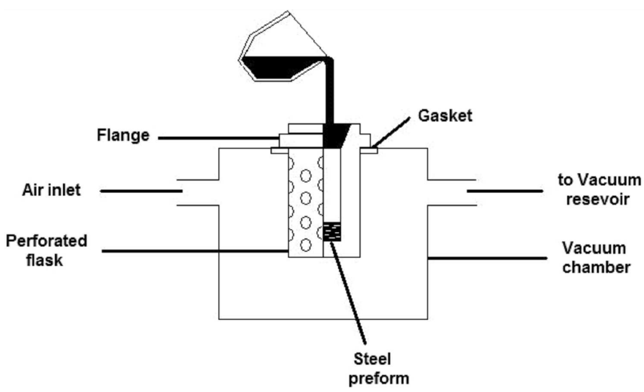

Fig. 2. Schematic illustration of casting process.

TABLE II

Chemical composition of A7075 aluminium casting alloy (wt%).

Al	Zn	Mg	Cu	Fe	Si	Ti	Mn	Cr
Bal.	5.10–6.10	2.10–2.90	1.20–2.00	0.50	0.40	0.20	0.30	0.18–0.28

After casting, T6 heat treatment process was carried out. First, specimens were heated up to 460 °C and held 2 h for solution treatment then quenched in water and held 6 h at 190 °C for artificial ageing. After that specimens were sectioned and metallographic samples for analysis were prepared.

3. Results and discussion

In experimental work, Al/steel bimetal composite specimens were successfully produced by vacuum assisted solid mould investment casting process. High specific A7075 wrought aluminium alloy was preferred as matrix and 304 stainless steel and H13 hot-work tool steel turnings were used as reinforcement materials.

A7075 is an age hardenable alloy and T6 heat treatment was applied to increase matrix hardness and reduce the difference in hardness between matrix and reinforcement. This is very important for smooth metallographic preparing of sectioned specimens. In case of big difference between matrix and reinforcement hardness, naturally their grinding and polishing behaviours are not the same so microstructure observations with enough quality for characterization cannot be possible.

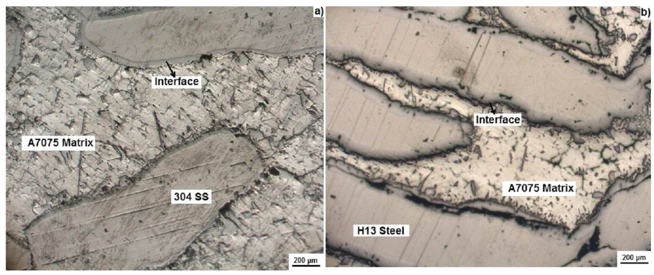

Fig. 3. Light microscope micrographs of (a) A7075/304 and (b) A7075/H13 composites.

In Fig. 3 light metal microscope images of the specimens are given and also scanning electron microscopy (SEM) microstructures are shown in Fig. 4.

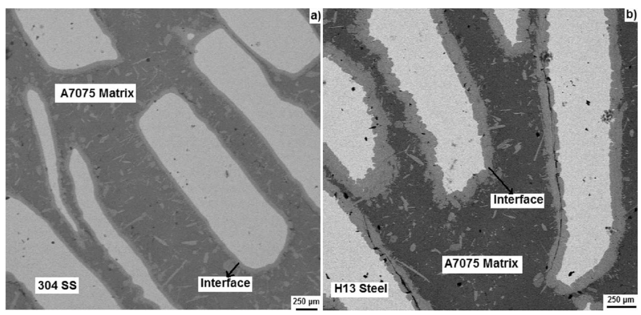

Fig. 4. SEM micrographs of (a) A7075/304 and (b) A7075/H13 composites.

As seen in both images, liquid aluminium alloy was almost fully filled the spaces in steel preforms, surround the turnings and formed bimetal composite structure. The major role in this occurrence belongs to vacuum assistant filling. In the SEM images which are given in Fig. 4 light-coloured island like structures are steel turnings and dark-coloured regions are aluminium matrix. Besides, narrow light grey surrounding zone can be observed around steel structures and these are interface between matrix and reinforcement. This zone shows that bonding between matrix and reinforcement is not only mechanical, but also metallurgical bonding occurs.

TABLE III

Results of EDS analysis in Fig. 5.

	Elements (wt%)			
Locations	Al	Fe	Cr	Ni
Region 1	29.022	54.260	12.144	4.604
Region 2	30.14	59.389	6.492	3.979

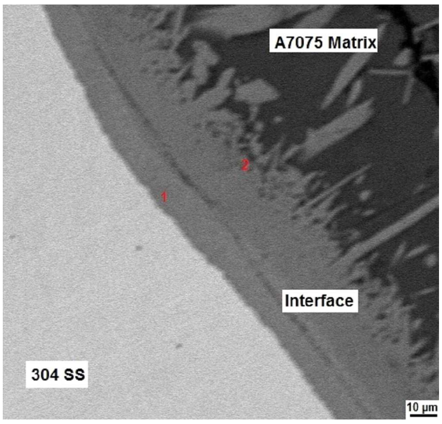

Fig. 5. EDS analysis regions in A7075/304 microstructure.

Higher magnification SEM images were used to energy dispersive X-ray spectroscopy (EDS) analysis of the interfaces. Two regions were selected for spot analysis; number 1 is near the steel reinforcement, number 2 is near the aluminium matrix. Figure 5 shows EDS analysis regions on the A7075/304 microstructure and Table III gives elemental results of this analysis. Similar to these, Fig. 6 and Table IV are presented for microstructure of A7075/H13.

TABLE IV

Results of EDS analysis in Fig. 6.

	Elements (wt%)		
Locations	Al	Fe	Cr
Region 1	29.014	68.177	2.809
Region 2	34.769	63.070	2.161

According to the analysis results, interface between A7075 and 304 includes Al, Fe, Cr and Ni elements. Cr and Ni amounts significantly decrease through the aluminium matrix from stainless steel reinforcement. Because of high Al and Fe amounts it can be said that

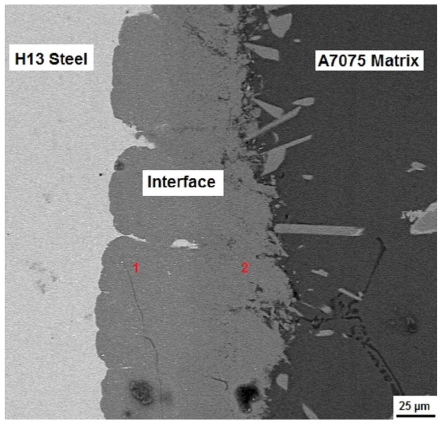

Fig. 6. EDS analysis regions in A7075/H13 microstructure.

interface contains large proportion of Al–Fe intermetallic. In the A7075/H13 specimen, interface consists of Al, Fe and Cr elements. Similarly to the other composite group, Cr amount decreases through the matrix and Al–Fe amounts are higher in both regions.

Microhardnesses' (HV 0.2 kg) of phases were measured and hardness transition curves are given in Fig. 7.

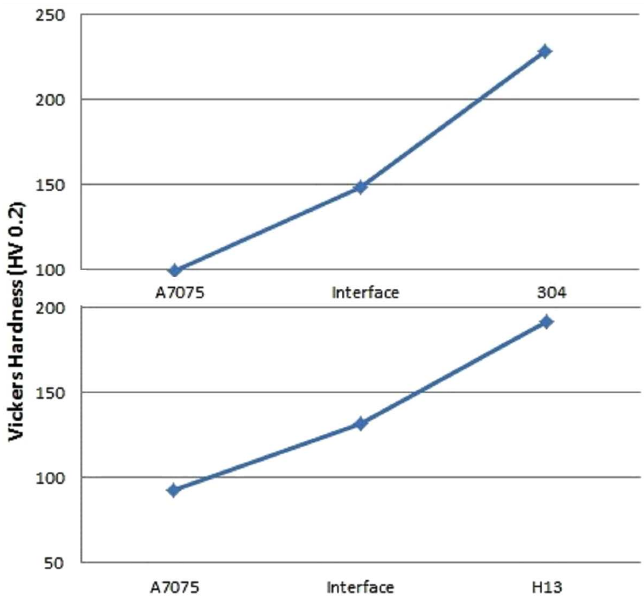

Fig. 7. Vickers hardness measurements of bimetal composite specimens.

Matrix, interface and reinforcement microhardness values of the A7075/304 specimen are 99.6 HV (0.2), 148.1 HV (0.2) and 228.9 HV (0.2), respectively. Also for the A7075/H13 specimen, microhardness values of matrix, interface and reinforcement are 93 HV (0.2), 132 HV (0.2) and 192 HV (0.2), respectively. Although normally hardness of the H13 tool steel must be higher than 304 austenitic stainless steel, in the microhardness measurements the opposite of this occurred. The reason of this may be due to the difference in Cr amount of these steels. Cr amount of the 304 stainless steel is quite higher than H13 hot-work tool-steel. At the time of pre-heating and during casting till to solidification, chromium-oxide (CrO_2) surface layer of the 304 stainless steel should be thickened and this can cause microhardness increase. Moreover, both of the alloys were exposed to higher temperatures. This condition leads to increase of grain size in H13 hot-work tool-steel. So, hardness values of the H13 hot work tool steel decreased. Existing of chromium-oxide (CrO_2) surface layer on the 304 stainless steel hinder the increase of grain size in 304 stainless steel. Also interfaces were affected by this situation. Interface microhardness of the A7075/304 is higher than A7075/H13 due to compositional difference.

4. Conclusion

Bimetal composites which are fabricated with liquid-solid techniques are strong candidates to be successful engineering materials. In this study, Al/steel composites were produced by infiltration technique. Al/steel composites are preferable for lightweight applications which also require high wear resistance. In comparison of metal–metal composites and metal–ceramic composites, metal–metal composites are advantageous in terms of cost. To highlight this cost advantage, waste steel machining turnings were used as reinforcement material. Instead of ceramic powders, fibres or whiskers which are expensive and difficult to supply, various kinds of steel turnings in various shapes can be obtainable in low cost easily. Studies will continue with different matrix alloys and reinforcement materials and further advanced characterizations.

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