Journal of Materials Processing Technology 226 (2015) 25–31

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Improved steel/aluminum bonding in bimetallic castings by a compound casting process

Wenming Jiang[a,b,*], Zitian Fan[a], Chi Li[a]

[a] State Key Lab of Materials Processing and Die & Mould Technology, Huazhong University of Science and Technology, Wuhan 430074, PR China
[b] School of Mechanical & Electrical Engineering, Wuhan Institute of Technology, Wuhan 430073, PR China

ARTICLE INFO

Article history:
Received 9 March 2015
Received in revised form 29 June 2015
Accepted 30 June 2015
Available online 7 July 2015

Keywords:
Steel
Aluminum
Bimetallic
Bonding
Compound casting
Surface treatment

ABSTRACT

Different surface treatment methods of steel inserts, including aluminizing, coating surface modifier as well as a combination of coating surface modifier and aluminizing (surface modifier + aluminizing), were introduced into the fabrication of carbon steel and ZL114A aluminum bimetallic castings during compound casting process. The aluminizing method slightly improved the bonding of the bimetallic casting compared with untreated method, and a gap at the interface was observed, leading to a poor bonding. In the case of the coating surface modifier method, the integrity of the interface was greatly increased because of the improvement of the incompatible between steel and aluminum, which indicated a mechanical bonding without a reaction layer, resulting in a limited improvement of the bonding. While the surface modifier + aluminizing method promoted a sound interface together with a metallurgical bonding, and a reaction layer with an irregular tongue-like morphology and an average thickness of approximately 30 μm was formed, which mainly consisted of Fe_2Al_5, $FeAl_3$, Al_8Fe_2Si, and $Al_2Fe_3Si_3$ intermetallic compounds, resulting in a significant improvement of the bonding.

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1. Introduction

There are many methods to fabricate bimetallic materials. Wang et al. (2014) developed a modified direct-chill casting process to prepare an 8090/3003 bimetal slab of aluminum alloys. Hejazi et al. (2009) investigated the effect of copper insert on the microstructure of gray iron produced using a lost foam casting. Zhang et al. (2014) developed an electro polishing + anodizing surface treatment method for improved bonding in the magnesium/aluminum bimetallic castings. Liu et al. (2014a,b) fabricated a clad hollow billet with an internal layer of 3003 and external layer of 4045 using a horizontal continuous casting. Wang et al. (2008) prepared Mg/Al dissimilar materials using a vacuum diffusion bonding. Hajjari et al. (2012) examined the joining of aluminum 413 and pure magnesium using a compound casting process.

However, few literatures reported that steel and aluminum bimetallic castings are obtained by the compound casting process. Liu et al. (2013, 2014a,b) fabricated the Al–7Si/gray iron bimetal composites with a compound casting process as well as the Al/galvanized low-carbon steel samples using a compound casting process associated with high-pressure torsion. Many previous studies with respect to the steel and aluminum bimetallic materials mainly focus on the formation and growth of intermetallic phases between steel and aluminum obtained using an aluminizing method. Bouché et al. (1998) studied the interaction between solid iron and liquid aluminum by immersion tests. Kobayashi and Yakou (2002) investigated the growth mechanism, morphology and mechanical properties of Fe–Al intermetallic compound layers on the surface of carbon steel with an aluminizing method. Bouayad et al. (2003) reported the kinetic interactions between solid iron and molten aluminum using immersion tests. Zhang et al. (2013) investigated the formation and growth mechanism of the intermetallic phase at the Al/Fe interface with the dipping baths of Al–Si and Al–Ge alloys. Moreover, the knowledge about the control of oxide film from the carbon steel as well as the wettability between the steel and aluminum are still incomplete in the fabrication of the steel and aluminum bimetallic castings.

In the present work, the compound casting process was used to produce carbon steel and ZL114A aluminum alloy bimetallic castings. Different surface treatment methods of the steel inserts, including aluminizing, coating surface modifier as well as surface modifier + aluminizing, were performed to improve the bonding of the bimetallic castings. The effects of surface treatment methods on the microstructures, macro-characteristics, and mechanical

* Corresponding author at: State Key Lab of Materials Processing and Die & Mould Technology, Huazhong University of Science and Technology, Wuhan 430074, PR China.
E-mail address: jwenming@163.com (W. Jiang).

http://dx.doi.org/10.1016/j.jmatprotec.2015.06.032
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Table 1
The nominal chemical composition of the ZL114A aluminum alloy (wt%).

Element	Si	Mg	Ti	Fe	Al
Content	6.75	0.63	0.14	0.084	Balance

Table 2
The nominal chemical composition of the carbon steel (wt%).

Element	C	Mn	Si	P	S	Ni	Cr	Fe
Content	0.24	0.65	0.37	0.03	0.02	0.25	0.25	Balance

properties of the steel and aluminum bimetallic castings were investigated.

2. Experimental procedure

2.1. Materials

ZL114A aluminum alloy and structural carbon steel were used to prepare the steel and aluminum bimetallic castings. The carbon steel and ZL114A aluminum alloy were used as a substrate material and a molten aluminum bath, respectively. Chemical compositions of the ZL114A aluminum alloy and carbon steel used are listed in Table 1 and 2, respectively. A 10% ammonium chloride solution was used as a surface modifier of the steel inserts.

Cylindrical steel inserts with a 42 mm diameter, 3 mm wall thickness, and 65 mm height were machined from a carbon steel tube, and surfaces of the cylindrical steel inserts were ground with silicon carbide papers up to 1200 grit.

2.2. Casting process

Fig. 1 presents a schematic illustration of the compound casting process. A crucible was first preheated at 300 °C, and a preheated ZL114A aluminum ingot was placed inside the crucible. When the temperature of the molten metal reached 740 °C, the melt was refined using argon gas, and the slag was then skimmed. Afterwards, the molten metal was ready for pouring into a metal mold, and the pouring temperature of the molten metal was 730 °C. The preheating temperature of the metal mold was 300 °C.

The cylindrical steel inserts were treated using different surface treatment methods, such as hot dip aluminizing, coating surface modifier, and surface modifier + aluminizing. Comparative castings obtained without a surface treatment method were poured with a same experimental condition. Processes of the surface treatment methods are shown in the following, respectively.

(a) Hot dip aluminizing: The cylindrical steel inserts were immersed into a molten metal of ZL114A aluminum alloy at 780 °C for 200 s. The coated cylindrical steel inserts were then rapidly placed inside the metal mold for pouring.

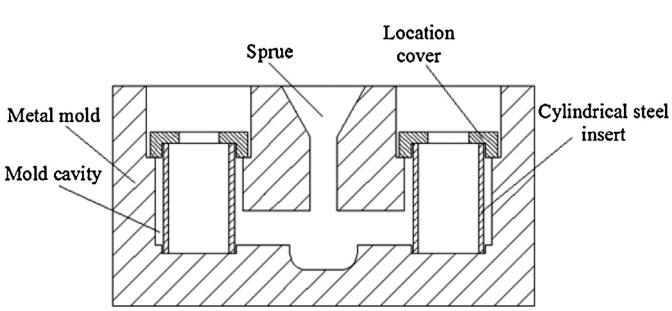

Fig. 1. Schematic illustration of the compound casting process.

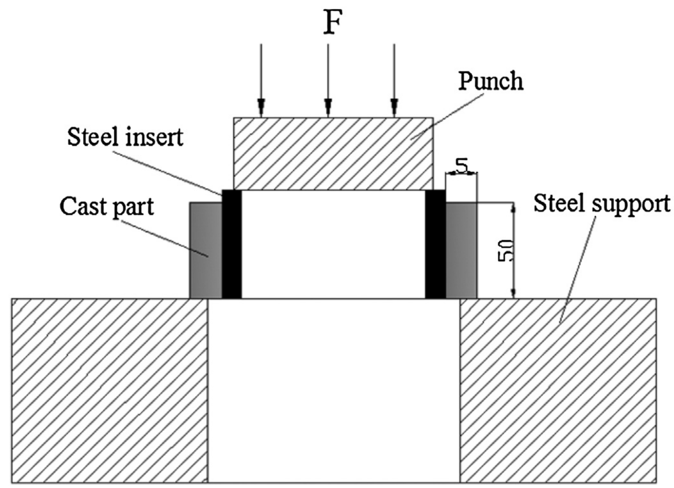

Fig. 2. Schematic sketch of the setup for the push out tests (unit: mm).

(b) Coating surface modifier: The cylindrical steel inserts were immersed into the ammonium chloride solution at 80 °C for 600 s. The coated cylindrical steel inserts were then dried at 120 °C. Afterwards, the cylindrical steel inserts were placed inside the metal mold for pouring.

(c) Surface modifier + aluminizing: The cylindrical steel inserts were first treated using the (b) process, and the hot dip aluminizing process of the cylindrical steel inserts coated by surface modifier was then performed according to the (a) process. The prepared cylindrical steel inserts were rapidly placed inside the metal mold for pouring.

2.3. Microstructural evaluations

In order to investigate interfacial microstructures of the steel and aluminum bimetallic castings obtained by the compound casting process, metallographic samples were cut from the bimetallic castings using an electrical discharge machine. Subsequently, the metallographic cross-sections were prepared by grinding and polishing, and they were then etched using a 0.5% hydrofluoric acid solution. The interfacial microstructures of the metallographic samples were observed using a Me F-3 metallographic microscope or a Quanta 400 scanning electron microscope (SEM). Reaction layers at the interface were identified using an energy dispersive spectrophotometric (EDS) analysis.

The cross-sections of the bimetallic castings were stained red after grinding in order to display gaps at the interface, and a gap ratio at the interface was taken as a ratio of the red length to the perimeter of the interface.

2.4. Mechanical characterizations

Push out tests were performed using a ZwickZ100 universal testing machine in order to determine the bonding strength of the bimetallic castings, as proposed by researchers (Sacerdote-Peronnet et al., 2007; Hajjari et al., 2011; Dezellus et al., 2011). The bimetallic samples were put on a steel supporting surface with a hole of 46 mm diameter and pushed by means of a steel cylinder stub punch at a cross-head displacement rate of 0.5 mm/min to obtain a maximum load. A schematic sketch of the setup for the push out tests is illustrated in Fig. 2. At least three samples were performed to the push out tests in order to minimize errors.

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