Ultrasonic Bonding of Bare Steel Inserts to A354 Aluminum Alloy in a Sand-Casting Process

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Abstract: We explored the feasibility of using ultrasound-assisted cast-on (UACO) methods for producing bimetal sand castings using as-received bare steel inserts and un-degassed molten A354 alloy. The ultrasound-assisted methods included a direct ultrasound-assisted cast-on (DUACO) method, and an indirect ultrasound-assisted cast-on (IUACO) method. Conventional cast-on (CCO) method was unable to metallurgically bond bare steel inserts to the un-degassed A354 alloy. The IUACO method was capable of producing metallurgical bonding between bare inserts and un-degassed A354 alloy with bonding quality identical to that obtainable using the Cummins process associated with using coated inserts following stringent procedures for insert and molten metal processing. The DUACO method was much effective than the IUACO method in producing high-quality metallurgical bonding between bare steel insert and un-degassed A354 alloy. Push-out test revealed that the shear strength of the bond produced by the DUACO method approached the shear strength of the as-cast A354 alloy. Mechanisms under which defect-free metallurgical bonding were formed were discussed.

Keywords: Aluminum alloy, steel insert, bimetal casting, cast-on method, high-intensity ultrasonic vibration.

1 Introduction

Cast-on method is a cost-effective method for joining iron or steel insert to a lightweight alloy using a casting process [1]. To obtain a high-quality metallurgical bond using the cast-on method, the insert surface has to be absolutely clean and coated with a sacrificial metallic coating, the bond region has to be free from defects such as oxides and porosity, and the molten metal has to be thoroughly degassed and poured under a protection atmosphere [2]. Even with such stringent procedures for insert and molten metal preparation, the bonding is still defective [3]. Methods that do not require the use of such stringent procedures would be of great importance in cost savings in producing bimetal castings of high bonding quality. The aim of this work was to study the feasibility of using UACO methods in bonding bare steel inserts with un-degassed molten A354 alloy in a sand-casting process. The ultrasound-assisted methods included the DUACO method and the IUACO method.

2 Experimental procedure

Fig. 1 is a schematic of the casting configuration. It consisted of a downsprue, a thin runner (6.35×38×203 mm), two thin in-gates (6.35×19×29 mm), a riser (45.7×63.5×244 mm) set on the top of the casting (107×50.8×193 mm), and three inserts. The casting was bottom fed. The middle insert shown in Fig. 1 was not connected to an ultrasonic system. The other two side inserts were each bolted to an ultrasound transducer vibrating at a resonant frequency of 20 kHz. Thus, each side insert was under DUACO conditions while the middle insert was under the IUACO conditions.

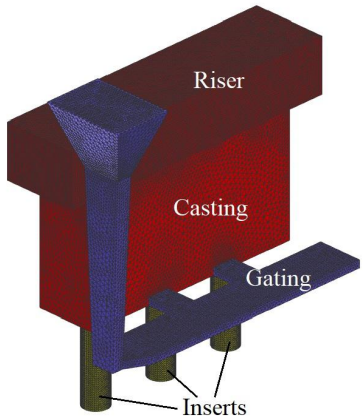

Figure 1. Schematic of the casting configuration.

5 kg of A354 alloy was melted in an electrical resistant furnace, held at 760ºC for 30 min., cooled to a selected pouring temperature and then poured into sand molds. Five disks, about 5 mm thick, were cut near the tip of the insert for the measurement of shear strength using a push-out test carried out on an ATS 10000 tensile tester [4].

3 Result and discussion

There was a large gap between the steel insert and A354 alloy solidified on the insert using the CCO method, indicating that there was no metallurgical bonding between the steel insert and the aluminum casting. Such a result is well known as a bare steel insert is difficult to be bonded to aluminum alloy, especially when the molten alloy is not thoroughly degassed, and the insert is not thoroughly cleansed.

The bonding quality was improved when ultrasonic vibrations were injected into the molten alloy after the alloy was poured over the inserts. However, the bonding quality

varied with the way by which ultrasonic vibrations were injected.

Under the IUACO conditions, the bond on the vertical surface of the insert seems acceptable but a large gap existed on the top surface of the insert. This gap resulted from bubbles that adhered to the top surface of the insert. Ultrasonic vibrations transmitted from the neighboring side inserts were not strong enough to shake those bubbles off the top of the middle insert. Small gaps and isolated pores existed at the vertical insert/aluminum interface but the majority of the vertical surface of the insert was metallurgically bonded to the aluminum alloy. A thin and discontinuous layer of intermetallic phases was formed on the bonding regions of the insert surface. Beyond this layer was the dendritic aluminum structure which contained large branches of aluminum dendrites over 1000 µm long.

Under the DUACO conditions, small and isolated pores still existed at the insert/aluminum interfaces including the top and vertical surfaces of the insert. A thin and continuous layer of intermetallic phases, about 40 µm thick, was formed on bonded regions of the insert surface. Beyond this intermetallic layer was equiaxed aluminum grains of about 100 µm. These grains had less dendritic feature as their secondary dendrite arms were less clearly defined.

Fig. 2 provides experimental data of the push-out test on samples. Data on the Cummins process was taken from literature [2-3].

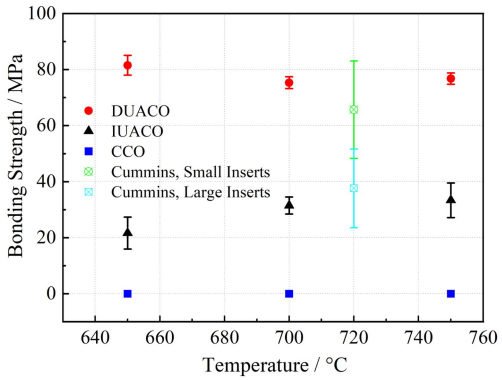

Figure 2. Bonding strength vs. pouring temperature under various conditions.

Without subject to a thorough cleaning and coating procedure, the as-received bare steel insert did not exhibit any significant bonding between the insert and the un-degassed A354 aluminum alloy using the CCO method. The measured bonding strength was between 20 to 40 MPa depending on the pouring temperatures using the IUACO method Such levels of bonding strength were comparable to that obtainable on similar sized inserts in castings made by the Cummins process which has stringent requirements for insert and molten metal preparations. The measured shear strength was about 80 MPa, insensitive to the pouring temperatures, using the DUACO method. Such a bonding strength was comparable to the shear strength of the as-cast A354 alloy. The application of high-intensity ultrasonic vibrations shook off oxides and bubbles that adhered on the surface of the insert and enhanced the steel/aluminum interfacial temperatures, resulted in the formation of a metallurgical bond between the steel insert and the aluminum alloy.

4 Conclusion

High-intensity ultrasonic vibrations are effective in forming a metallurgical bond between a bare steel insert and an un-degassed A354 aluminum alloy. The IUACO method is capable of producing bonding strength comparable to that achievable using the Cummins process. The DUACO method could be used for making a bimetal casting with the bonding strength comparable to that of the shear strength of the A354 alloy.

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