PRODUCTION, PROCESS PARAMETERS OPTIMIZATION AND CHARACTERIZATION OF ALUMINIUM-STAINLESS STEEL BIMETALLIC CASTINGS

ABSTRACT

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ABSTRACT

Ability to join the ferrous and non-ferrous materials initiate a new era of materials age to produce functionally graded lightweight components with enhanced/ combination of properties for heat transfer, defence, aerospace, and automotive applications. Bimetals are the dissimilar metal/alloy combinations casted in a single or two stages to produce a metallurgically bonded monolithic part with two/more distinct properties. Bond quality of bimetallic castings depends on the process parameters employed during casting and solidification process. In this research, Aluminium- stainless steel bimetallic pipe castings were produced by lost foam compound casting method, where decomposable thermocol moulds were used. Molten pure aluminium was poured over SS 304 stainless steel pipe (18 mm ID X 30 mm height) to get a bimetallic pipe (50 mm OD X 30 mm height) for hot chemical transfer applications. The produced castings were machined and polished for further characterization and testing using Optical Microscopy, Scanning Electron Microscopy with Energy Dispersive Spectroscopy, liquid penetrant testing and shear punch test. The influence of important process parameters like Pouring Temperature (PT), Insert Temperature (IT), Insert Thickness (ITC), surface roughness (Ra) and interlayer/bond coatings over the pipe were correlated with the resultant bond strength of the produced castings. Hybrid optimization techniques consists of Response Surface Methodology (RSM) and Genetic Algorithm (GA) were used to optimize these process parameters to get the maximum bond strength in the produced BmCs.

Initially, twenty seven experiments were planned as per the Box-Behnken design of experiments method accounting the pouring temperature (670°C to 730°C), insert preheat temperature (100°C to 400°C), insert thickness (1 mm to 3 mm), and surface roughness (0.3 µm to 0.9 µm) with the above mentioned maximum and minimum values as inputs. According to the above mentioned experimental runs, shear punch test was

carried out to evaluate the peak loads before fracture to determine the bond strength of the BmCs. Maximum bond strength of 17.04 MPa was observed when the processing conditions were 705°C pouring temperature, 400°C insert temperature, 1 mm insert thickness and 0.6 µm surface roughness. The response surface regression values for the all individual parameters and their second order interactions were found to be significant, since the obtained P values were ≤ 0.05, i.e., within the 95% confidence limit. The response surface 2D model showed concentric type of responses for PT and Ra with maximum bond strength around medium levels of input parameters, while elliptical type of responses was observed for other interactions. An inverted parabolic 3D contour plots were obtained for Ra & PT and PT & IT interactions, while curved surfaces for other parameters interactions. A second order non-linear equation developed from RSM was used for predicting the maximum possible bond strength as 18.02 MPa for the processing conditions PT: 705°C, IT: 400°C, ITC: 1 mm and Ra: 0.6 µm. Genetic algorithm optimization tool was used to determine the forbidden levels of all the process parameters to achieve a maximum bond strength of 19.20 MPa for the conditions PT: 711°C, IT: 395°C, ITC: 1.5 mm and Ra: 0.55 µm. An experimental validation was done for the above processing conditions and actual bond strength of 19.13 MPa was achieved. Next chapter dealt with the introduction of interlayers at the interface of Al and SS to improve its bond strength.

The next set of Al-SS BmCs were produced with different interlayer coatings (Ag, Cd, Cr, Cu, Ni, Zn, and brass) electroplated over SS pipe (18 mm ID X 30 mm height) before the casting process to increase the wettability of molten Al over the pipe so that there may be reaction layer formation between Al, interlayer and SS pipe which ultimately may increase the bond strength. The important process parameters considered for achieving maximum bond strength in Al-SS BmCs with interlayers were PT, IT, and ITC with their levels 670°C to 730°C, 100°C to 400°C and 1 mm to 3 mm respectively. Wettability test showed hydrophilic nature of Zn and Cu interlayers with < 90° contact angle. Silver interlayered Al-SS BmC showed reduced interlayer thickness with reaction layer consisting of Al-Ag solid solution at Ag and Al interface. In the Cd interlayered Al- SS BmC thickness of the interlayer reduced may be due to the evaporation of low melting point Cd during pouring of molten aluminium. In chromium interlayered Al-SS bimetallic castings, a good metallurgical bonding was observed due to the solid solution formation of chromium with aluminium and iron respectively. Copper, Nickel, and Zinc interlayered Al-SS BmCs showed increase in interlayer thickness due to Al_xCu, Al_xNi, and Fe_xZn intermetallics along with solid solutions. Shear punch test results showed a maximum bond strength of about 18.37 MPa for Zn interlayered BmC while 3.49 MPa was observed for Ni interlayered BmC. The maximum bond strength was observed in Zn interlayered BmC may be due to the formation of solid solutions like Al-rich (α), Zn-rich (η) and Fe-rich (γ) and homogeneous distribution of intermetallics between Al, Zn, and Fe. However, brittleness of Al_xNi intermetallics in Nickel interlayered BmC might have led to the reduced bond strength leading to interface failure at the lower levels of load due to the presence of porosity which might have acted as stress raisers for easy crack initiation and propagation.

From the above results obtained, Al-SS BmCs with Zn interlayer were taken for further studies to optimize the process parameters to get enhanced bond strength. Another set of fifteen experiments were planned using Box-Behnken design of experiments with PT (670-730°C), IT (100-400°C) and ITC (1-3 mm) as input parameters. The maximum bond strength of 25.33 MPa was observed for the processing conditions PT: 705°C, IT: 250°C and ITC: 2 mm. All response surface 2D models developed between different parameters showed elliptical type of responses corresponding to the variation in effect of parameters for the processing conditions. A second order non-linear equation developed from RSM for Zn interlayered BmC predicted the maximum possible bond strength as 26.75 MPa for the processing conditions PT: 705°C, IT: 250°C and ITC: 2 mm. Genetic algorithm determined the maximum bond strength as 26.87 MPa for the conditions PT: 707°C, IT: 277°C, and ITC: 1.86 mm. Confirmation tests were done by keeping the pouring temperature 707°C, insert temperature 277°C, and insert thickness 1.86 mm and the result showed that 26.80 MPa bond strength. It was observed that the use of interlayer/bond coats improved the bond strength by promoting interdiffusion to form reaction layer at the interface. Further characterization was done on Zn interlayered BmC's to understand the mechanism and characteristics of bonding.

Spiral morphology was observed in the Zn interlayered BmC at 730°C pouring temperature (high pouring temperature and high insert temperature). Aluminium rich and iron rich solid solutions along with Fe_4Al_{13} intermetallics were found at the interface. These mixtures of phases disintegrated the solid solution of iron into particles leading to the peeling off stainless steel layer. Hence, the spiral-like morphology might have formed due to the presence of Zn rich intermediate liquid phase in the interface region while casting. The formation of the Al-rich and Fe-rich solid solutions as reaction layer between Al and SS without the micro gap around 705°C may contribute to the significant increase in bond strength of produced BmC with different insert temperatures and insert thickness. Further characterizations were done using X-ray diffractometer, which confirmed the presence of more amounts of Al-rich solid solution (83%) along with Zn-rich solid solution and intermetallics. Reaction layer thickness of 30 µm observed at the interface might have attributed to the increased bond strength of produced BmC at 705°C pouring temperature. Hence, Al-SS BmCs with a maximum bond strength around 27 MPa were successfully produced using the lost foam compound casting process, which can be used for transition joints, liquid sodium transfer, pipes for syngas coolers, and pipes for urea production.