Bond strength and metallurgical analysis of stainless steel-aluminum bimetallic castings with Ni interlayer using thermocol mould

V Raja[1], M Kavitha[2]
{vr.pe@psgtech.ac.in[1], mka.metal@psgtech.ac.in[2]}

[1]Department of Production Engineering, [2]Department of Metallurgical Engineering, PSG College of Technology, Coimbatore 641 004, India

Abstract. Ni interlayered Stainless Steel (SS) – Aluminium (Al) Bimetallic Castings (BmC) were successfully produced via pouring the molten aluminium over thermocol moulds with SS pipe insert. The effect of interlayers on integrity and bond strength of the produced BmC were studied and reported. The optical micrographs and liquid penetrant testing revealed very small micro pores in BmC with Ni. Scanning Electron Microscopy (SEM) images confirmed the above observations and the elemental/point analysis using Energy Dispersive Spectroscopy (EDS) attachment at the interface proved the diffusion of elements from interlayer into the casting. It was observed that Ni showed less reaction layer at the interface. The bond strength of uncoated and Ni interlayered BmC were determined as 10.57 and 20.3 MPa respectively.

Keywords: Thermocol mould; interlayers; reaction layer; bond strength.

1 Introduction

The secret to combining the appealing properties of most common structural elements in one monolithic section is to join dissimilar materials like steel and aluminium [1]. Steel-aluminium BmC is hard to combine due to their distinct properties [2-4]. Stainless steel and aluminium bimetals can also be used in industrial applications [5] such as pipes for transferring hot corrosive fluids, coolants, oil, and gases. However, for effective corrosion resistance and heat transfer without fluid leakage, a robust metallurgical bonding between the stainless pipe and aluminium overlay is necessary [6]. Although there is a lot of literature on utilising different interlayers for steel-aluminum bimetallic joints [7-10], there isn't a lot of material on using interlayers between SS-Al bimetallic joints [11,12].

Table 1: Materials composition (in wt%)

Material	Si	Cu	Mg	Mn	P	S	Ni	Cr	C	Fe	Al
Al	0.03	0.011	0.02	-	-	-	-	-	-	0.1	balance
SS 304	0.49	-	-	1.5	0.03	0.03	8.18	18.48	0.07	balance	-

ICCAP 2021, December 07-08, Chennai, India

DOI 10.4108/eai.7-12-2021.2314611

As a result, the focus of this research is on SS-Al interlayers and comparing their relative properties and bond strength. Ni coating over steel components is done commercially to improve corrosion and wear resistance. The influence of a Ni interlayer on the wettability of the Al layer atop SS is investigated in this paper. Another innovative aspect of this project is the utilisation of low-cost thermocol moulds to produce Al castings over stainless steel pipe inserts. The impacts of the Ni interlayer at the contact, as well as mechanical properties, were next examined and reported.

2. Experimental Procedure

The chemical composition of commercially pure aluminium and SS 304 pipe inserts are given in table1. Production of BmCs was elaborately discussed in the previous work [13]. Size of interlayer coating was fixed as 30 µm thick since it is commercially applied. The produced castings were characterized using CARL ZEISS optical microscope and JEOL 6000 model SEM with EDS attachment. The integrity and bond strength of the produced castings were done using Liquid Penetrant Test (LPT) and Universal Testing Machine (UTM).

3. Results and Discussion

As shown in figure 1a, visual inspection of the casted BmC samples with uncoated or Ni interlayers revealed that the good bonding of the Al casting layer over SS pipe. LPT discovered the minute cracks that were exposed at the surface and subsurface level as shown in figure 1(b) and 1(c). In a BmC sample without an interlayer, the presence of a red ink dye penetrant shows micro holes at the interface that are not visible to the human eye. When comparing the BmC with interlayer to the BmC without interlayer, the absence minute gap at the interface is noticeable. Ni coated BmC reveals some amount of penetrant near the interface after applying the developer, which confirms the presence of micro pores which are less than uncoated specimen. Optical micrograph was used to check the interface integrity and SEM/EDS analysis reported that mechanical interlocking at the interface as shown in figure 2. The mechanism of mechanical interlocking was presented in the previous work [13].

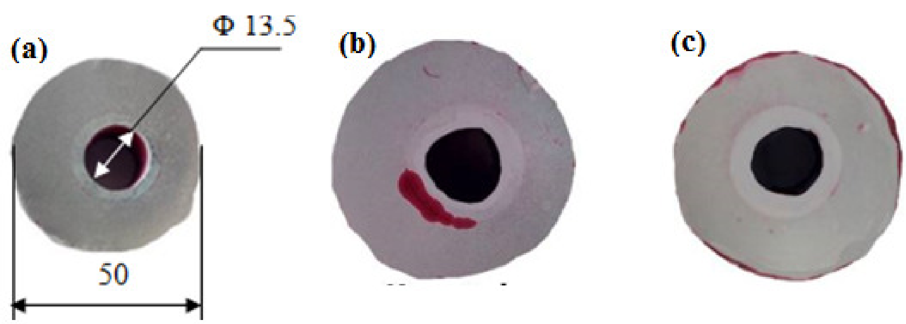


Figure 1 BmC sample (a) Visual inspection, (b) Uncoated, (c) Ni interlayer

At the contact, tiny pores with a diameter of a few micrometers were discovered. Figure 2(b) shows a scanning electron microscope image that confirms the optical microscopy results.

The EDS analysis at the SS side, as revealed in the SEM picture in the right corner, is displayed in figure 2(c). Without any Al diffusion, this supports the presence of Fe, Cr, Ni, and Mn. The elemental mapping illustrated in Fig. 2(d) to (f) revealed that Al and SS have a distinct interface with no inter-diffusion. SS scraps obtained during metallographic sample preparation/polishing may be responsible for a few SS particles embedded in the Al side. Fig. 2(g) shows the EDS analysis at Al side and confirms the commercial purity of Al used for casting. Figure 3 presents the microscopic analysis of Ni interlayer BmC. The dark continuous interlayer of about 30 µm thickness between Al and SS was observed in the micrograph as shown in figure 3 (a). The thickness of the interlayer was confirmed by SEM in Fig. 3(b), with satisfactory adhesion of the Ni interlayer to the SS. At the Al/Ni contact, however, tiny micro holes were discovered. The EDS point analyzer reported that the Ni contact is presented as shown in figure 3(c). This confirms the presence of pure Ni in the interlayer at point 001. The EDS elemental mapping shown from Fig. 3(d) to (f) showed that there is relatively very less diffusion of Ni into Al region. However, Fig. 4 (a) shows the point analysis at point 004 very close to Ni interlayer; having 18% Ni in Al. Fig. 4 (b) shows the point analysis at 002 few micrometers from the interlayer, which confirmed the presence of 100% Al without any Ni. This confirmed the metallurgical bonding between Ni interlayer and Al at the interface without much diffusion of Ni into the Al casting. Since Ni is having good solubility in both Fe and Al, the good integrity at the interface of the pipe and casting was assured with metallurgical bonding.

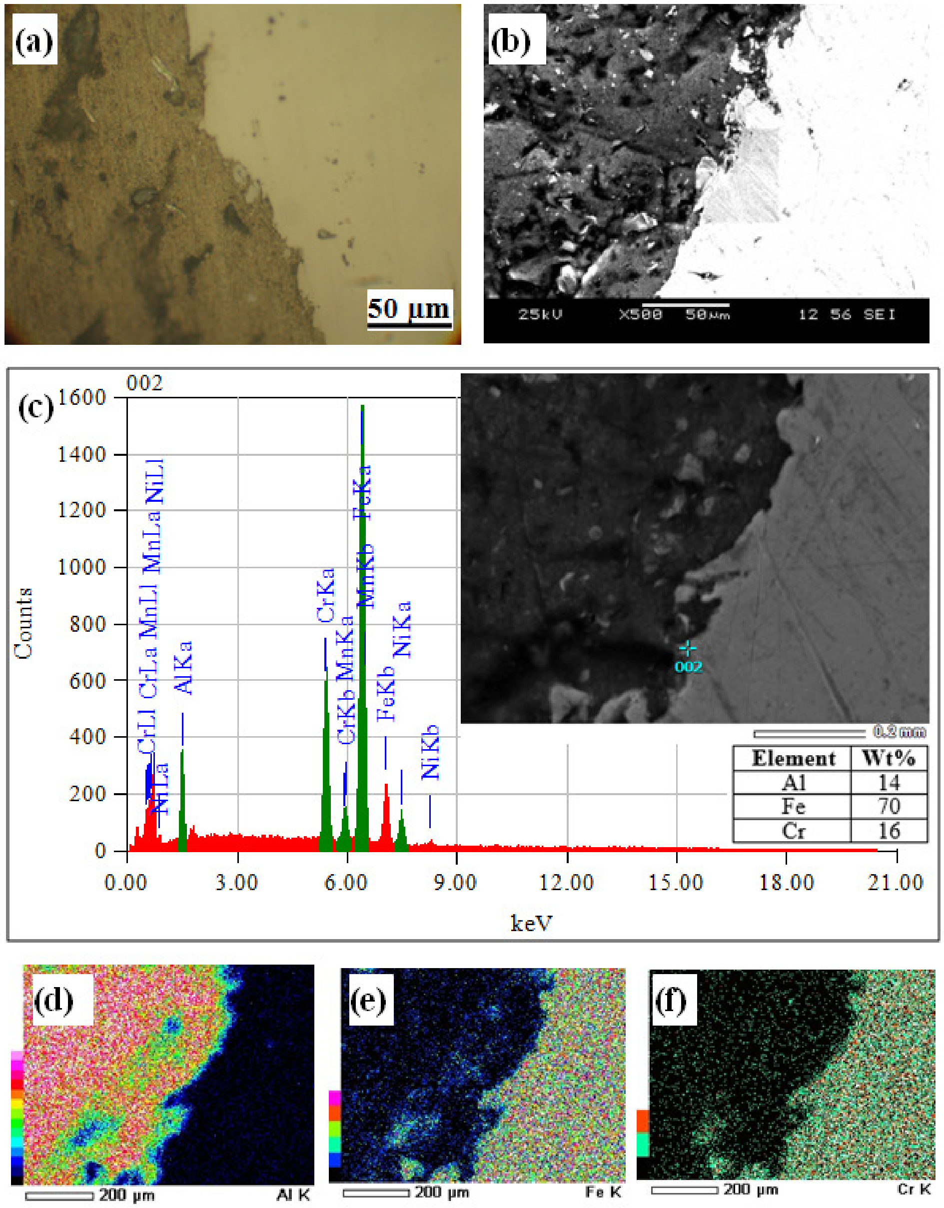
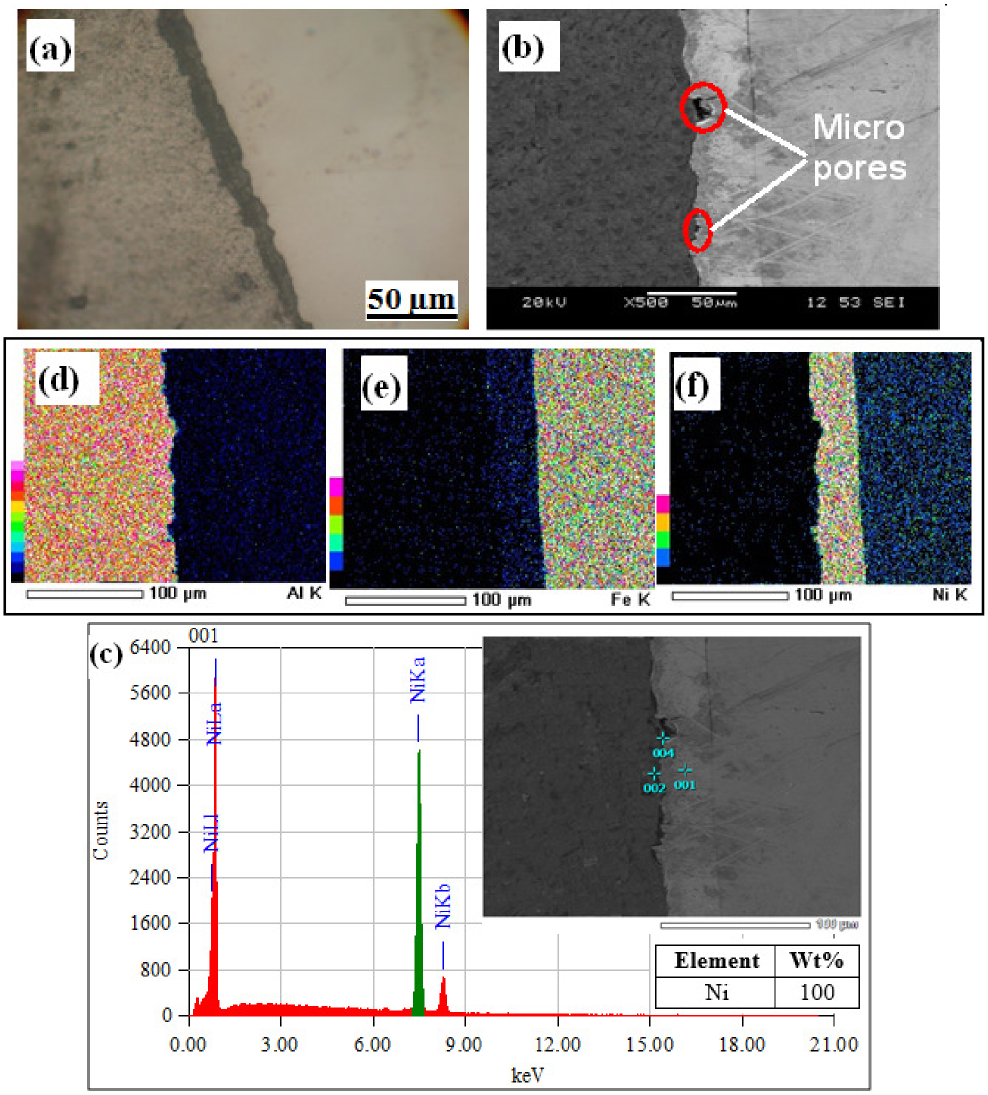
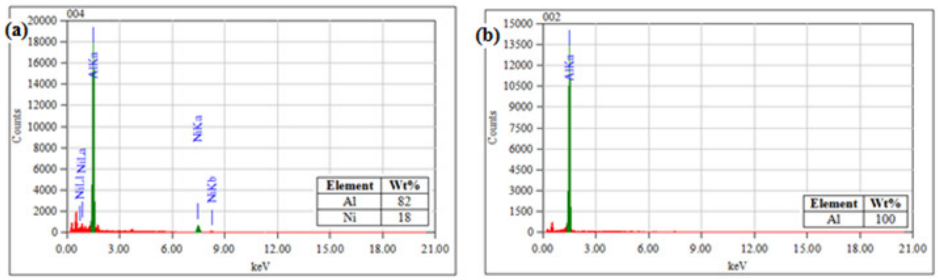


Figure 2 Uncoated BmC characterization (a) Optical micrograph (b) SEM (c) EDS at 001 (d) (e) (f) Elemental mapping



Element	Wt%
Ni	100

Figure 3 Ni interlayer BmC characterization (a) Optical micrograph (b) SEM (c) EDS at 001 (d) (e) (f) Elemental mapping



Element	Wt%
Al	82
Ni	18

Element	Wt%
Al	100

Figure 4 EDS analysis report for points at (a) 004 (b) 002

Fig. 5 shows the result of shear punch test. Load against displacement is shown for uncoated and Ni interlayer BmC. It is observed that BmC with Ni interlayer showed higher peak loads of about 6.58 kN when compared to uncoated BmC. The bond strengths of uncoated and Ni interlayer BmC calculated using the formula reported in work [8] and found as 10.57 MPa and 20.3 MPa respectively. The minimum bond strength requirement for bimetal components is 20 MPa. Hence, Ni interlayer BmC may be used in applications like hot corrosive fluid transfer, light weight structures and sacrificing working layer. Due to the addition of Ni it has been observed that the increase in bond strength over uncoated BmC. Formation of reaction layer might be the reason for increased bond strength. Moreover, the plastic deformation is quit high in Ni interlayer BmC.

Deformation started at 4.5kN and went upto 6.58 kN for the deformation range from 1.2mm to 2 mm. Though the thickness of Ni interlayer was 30 µm, the bond strength was relatively less due to micro gaps formation as indicated in the fig.3 (a).

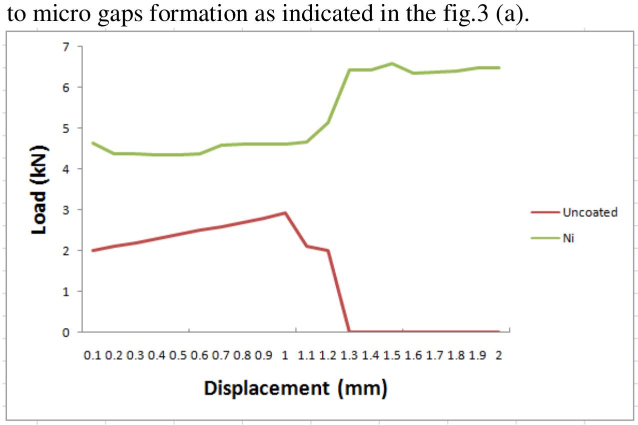


Figure 5 Results of shear punch test

4. Conclusion

The thermocol moulding process was used to successfully make BmC with Ni interlayer and without coating. Reaction layer was observed during casting of Ni interlayer coated stainless steel is used. The bond strength of the interlayer BmC was found to be related to the thickness of the reaction layer. When compared to uncoated BmC, the Ni interlayer improved the bond strength by 9.73 MPa. The interlayer thickness may also change in order to improve bond strength.

References

[1] Springer H, Szczepaniak A, Raabe D. On the role of zinc on the formation and growth of intermetallic phases during interdiffusion between steel and aluminium alloys. Acta Materialia. 2015 Sep 1;96:203-11.

[2] Springer H, Kostka A, Payton EJ, Raabe D, Kaysser-Pyzalla A, Eggeler G. On the formation and growth of intermetallic phases during interdiffusion between low-carbon steel and aluminum alloys. Acta Materialia. 2011 Feb 1;59(4):1586-600.

[3] Jia L, Shichun J, Yan S, Cong N, Genzhe H. Effects of zinc on the laser welding of an aluminum alloy and galvanized steel. Journal of Materials Processing Technology. 2015 Oct 1;224:49-59.

[4] Jiang W, Fan Z, Li C. Improved steel/aluminum bonding in bimetallic castings by a compound casting process. Journal of Materials Processing Technology. 2015 Dec 1;226:25-31.

[5] Kimura M, Suzuki K, Kusaka M, Kaizu K. Effect of friction welding condition on joining phenomena, tensile strength, and bend ductility of friction welded joint between pure aluminium and AISI 304 stainless steel. Journal of Manufacturing Processes. 2017 Jan 1;25:116-25.

[6] Bouayad A, Gerometta C, Belkebir A, Ambari A. Kinetic interactions between solid iron and molten aluminium. Materials Science and Engineering: A. 2003 Dec 20;363(1-2):53-61.

[7] Jiang W, Fan Z, Li G, Li C. Effects of zinc coating on interfacial microstructures and mechanical properties of aluminum/steel bimetallic composites. Journal of Alloys and Compounds. 2016 Sep 5;678:249-57.

[8] Salimi, M., Malekan, M., Nami, B., &Hoseiny, H. (2017). Microstructure characteristics and mechanical properties of the interface layer of coated steel insert-aluminum bimetals. Journal of Materials Research, 32(4), 874-882.

[9] Jiang W, Li G, Wu Y, Liu X, Fan Z. Effect of heat treatment on bonding strength of aluminum/steel bimetal produced by a compound casting. Journal of Materials Processing Technology. 2018 Aug 1;258:239-50.

[10] Ma H, Qin G, Wang L, Meng X, Chen L. Effects of preheat treatment on microstructure evolution and properties of brazed-fusion welded joint of aluminum alloy to steel. Materials & Design. 2016 Jan 15;90:330-9.

[11] Yazdipour A, Heidarzadeh A. Effect of friction stir welding on microstructure and mechanical properties of dissimilar Al 5083-H321 and 316L stainless steel alloy joints. Journal of Alloys and Compounds. 2016 Sep 25;680:595-603.

[12] Habibnia M, Shakeri M, Nourouzi S, Givi MB. Microstructural and mechanical properties of friction stir welded 5050 Al alloy and 304 stainless steel plates. The International Journal of Advanced Manufacturing Technology. 2015 Feb 1;76(5-8):819-29.

[13] Raja V, Kavitha M, Chokkalingam B, Ashraya TS. Effect of Interlayers on Mechanical Properties of Aluminium Casting over Stainless Steel Pipe for Heat Exchanger Applications. Transactions of the Indian Institute of Metals. 2020 Mar 17:1-6.