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Microstructural analysis of diffusion bonding on copper stainless steel

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ABSTRACT

Diffusion bonding is one of the solid-state welding processes, were bonded through the diffusion welding method. The bonding was achieved by placing the specimens under a load of pressure 5 MPa nickel layer is used in between the material and the temperate range was taken between 700 and 900° C. The findings suggested distinct diffusion were found in the different parameters. The results indicated the formation of separate diffusion zones at both Cu/Ni and Ni/SS interfaces during the diffusion bonding process. In both interfaces, the thickness required an increased inspection by rising the manufacturing temperature. The microstructure analysis also done on the diffusion boded joints with various parameters.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Newer Trends and Innovation in Mechanical Engineering: Materials Science.

1. Introduction

The joining of materials through fusion welding techniques is difficult if the physical properties such as the fusion temperature and the thermal expansion coefficients of the two materials are very different, so that the fusion on both sides of the welding joints has to be controlled simultaneously. Diffusion bonding is a solid-state bonding process which can join a wide variety of metal and ceramics also can be used in advanced applications of engineering. Through diffusion bonding all materials whose chemical and metallurgical properties are adequate can be bonded. Diffusion bonding provides a novel joint process for identical and dissimilar materials, without gross microscopic distortion and with limited dimensional changes. Through diffusion bonding all materials whose chemical and metallurgical properties are adequate can be bonded. Diffusion bonding provides a novel joining process without gross microscopic distortion and with minimal dimensional adjustments for identical and dissimilar materials. Furthermore, there is virtually no phase transition or microstructural shift during the process. More than one half of the melting temperature is used for joining the metals. From the literature different types of materials were joined cast iron, magnesium, different types of steels by diffusion bonding process [1–4].

By normal fusion methods of joining will create more impurities and cannot be joined perfectly due to different material properties. Because of residual stress in the material linear expansion coefficients caused by the associated mismatch. Furthermore, the difference in the alloying species' intrinsic diffusion coefficient will give more defects in the interlayers. These defects will leads to the reduction in the strength and failure of the component. Some literature documented the development of medium- and nano-cracks in copper/stainless steel bonded with diffusion by Kirkendall impact. In this research, efforts were made to bond stainless steel and copper plates using nickel as an intermediate material. This was achieved in the temperature range of 700–800° C, under compression loading. The findings indicated the clear effect of bonding temperature on the interface of the microstructure and the mechanical properties of the bond [5–7].

2. Experimental work

The Stainless Steel alloy (304) and 50 mm x50 mm × 5 mm Pure Copper metal bar is purchased and these bars are cut into 10 parts of 50 mm × 50 mm × 5 mm lengths. Then, the impurities on the surface of these materials are forced to remove by grinding machine and then precisely dimensioned using cutting machine. These materials are given a mirror polishing for the inter-layer coating to bind strongly to the surface using emery sheet of various grades. This mirror polishing technique helps to fully eliminate the impurities from the surface and thus improves the coating and bonding strength. The schematic diagram for the diffusion bonding is shown in the Fig. 1, the prepared specimens for diffusion boding were shown in the Fig. 2. The experimental setup with the compression machine with a furnace were shown in the Fig. 3. Inert

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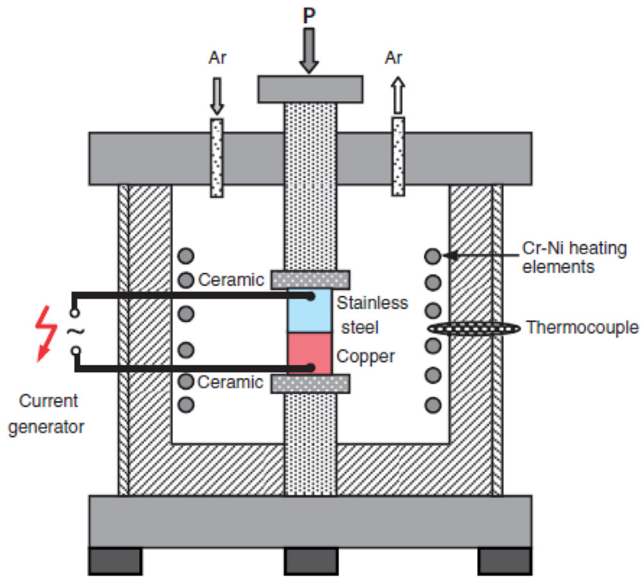

Fig. 1. Schematic illustration of diffusion welding equipment.

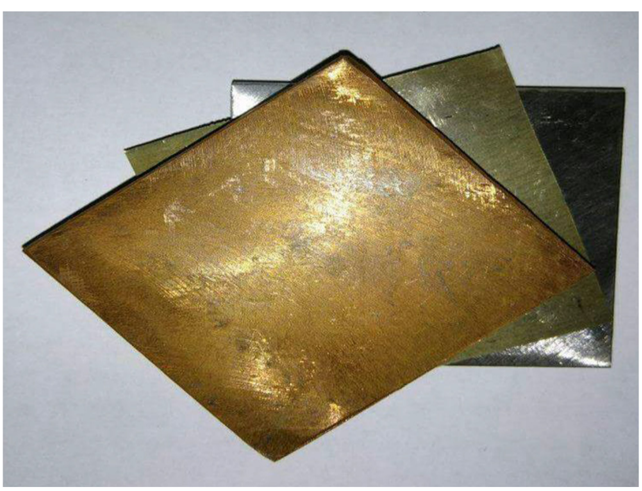

Fig. 2. Prepared work piece material.

atmosphere was maintained throughout the experimentation [8–9].

The prepared specimens were put into the experimental setup, with various parameters the experiments were conducted. The various process parameters such as temperature, holding time, and pressure were analysed for the selected materials based on the literature studies. The materials were heated in the furnace more than half of the melting temperature of the material and the pressure of 5 MPa was applied. Normally the levels of temperature selected within the range of 0.6–0.8 t_m. Table 1 shows the various process parameters selected for the diffusion bonding. Fig. 4 shows the diffusion bonded samples with different parameters in the diffusion bonding machine of max temp 850℃ with constant pressure of 5 MPa and 30 min of holding time. The samples were cooled down to room temperature in the furnace after the experimentation. [10–14].

The diffusion bonded specimens were shown in the Fig. 5. For the testing purpose the specimens were cut into pieces by EDM wire cut. The specimens were prepared for shear test and for microstructure analysis. Specimen's for microstructure analysis were moulded for easy polishing process. The bonded specimen is cut into two pieces of dimensions 20 mm × 50 mm and 30 mm × 50 mm using wire cut EDM machine. The small piece is taken for shear test. It is fixed in the fixtures as shown in the fig and the lapshear test is carried out. Then the other pieces cut in the EDM are first moulded as shown below in the Fig. 6.

The shaped pieces are then then grinded finely to a smooth surface. Such bits are finely grinded the top using 4 types of emery papers.These pieces are etched using reagents for viewing in microscope. Microstructure is improved by Etching. The purpose of etching is to improve the microstructural characteristics, such as grain size and phase characteristics, optically. Changes these micro-structural features selectively, depending on the composition, stress or structure of crystals. The etchants generally used for the following.

For Cu- (10 ml) Potassium Dichromate+ (5 cc) of HCl solution
For SS- Glyceregia (Derivative of Aquaregia).

3. Results and discussion

3.1. Lap Shear Test Results

Generally, the tensile testes are used to find the mechanical properties of any material. It is a process of applying load on both

Fig. 3. Experimental setup.

Table 1
Process parameters.

Specimen Number	Temperature (C)	Pressure (MPa)	Holding time (Min)	Remarks
1	750	5	30	Bonded
2	800	5	30	Bonded
3	825	5	30	Bonded
4	850	5	30	Bonded
5	875	5	30	Deformed

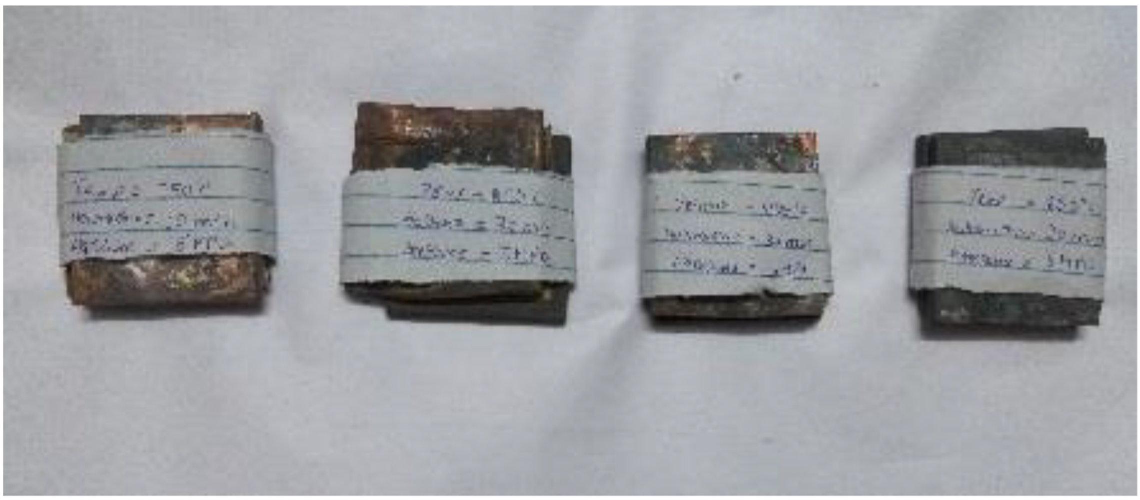

Fig 4. Bonded Specimen at Various Parameter.

Fig. 5. Specimens for shear test.

sides of the specimen till its failure. From this experiment the materials properties were defined as well as the capability of the material during loading. In this work the bonding strength of the material also test by this tensile testing machine. But in this process the load is applied to break the bond between the material. Once we find the shear load that is bonding strength of the specimens. Fig. 7 shows the tensile testing machine the specimens were fixed in the gripper.

Fig. 8 shows the strength results of the specimens and Table 2 shows the specimen strength. The maximum joint strength is 8.38 kN was obtained at specimen bonded at 825° C under the load of 5 MPa for holding time of 30 min.It has been observed from

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Fig. 6. Specimens for Microstructure Analysis.

Fig. 7. Specimen Loaded At Tensile Apparatus Specimen1 Specimen 2 Specimen 3.

above results that the bonding strength increases with temperature increment up to 850° C. With increase in temperature the diffusion rate of atoms increases which helps in formation of intermetallic compound at interlayer. This helps to increase the strength of the specimen.

Initially, Micro hardness readings taken at the bonded region at two different locations. Table 3 shows the hardness of the specimens. Hardness taken from the edge of the copper shows that hardness of the copper decreases when the temperature increases. This is due to the increase in grain size of the copper, which is clearly shown in the microstructure of the specimen. Finally, hardness region taken from the edge of the Stainless Steel 2 mm towards the nickel in three different regions. The bonded SS – Ni region has higher hardness to that of the Cu –Ni region.

3.2. Micro structures of copper and ss alloys with Nickel inter layer

Fig. 9 (a) shows large grains of equi-axed βMatrix with some heat affected spots. Figure (b) shows interlayer zone with the dissolution of Cu in inter layer material (Ni), Cu shows Coagulated heat affected micro structure. Figure (c) shows interface diffusion zone right is the Ni matrix and left side is SS304, SS shows large Equip axed grains and formation of carbide Network of chromium carbide at Ni interface. Fig (d) shows close to the inter layer zone with Precipitated chromium carbide particles and it all shows the equal grains of austenite Of SS304 [15].

Fig. 10 (a) shows large equi-axed grains Cu solid solution with fine precipitate of α impurities in β particles (Cu). Figure (b) shows inter layer zone with Cu diffused to Ni and clear boundary of interlayer material Vanished, Cu or Ni is more diluted. Other side of Ni layer remains same. Figure (c) shows interlayer with SS making a thin diffusion zone but Cu material diffused more into stainless steel. Figure (d) shows equi-axed grains of austenite with Slip bands form during EDM cutting.

Fig. 11 (a) shows Cu extreme side with effects of stress which causes the deformation of Cu grains it also shows formation of laminar α grains, it contains the intender marking. Figure (b) shows the diffusion of Cu towards the diffusion zone with the formation of more α phases, but inter layer source diffusion of Cu into Ni zone but SS shows clear diffusion zone without any diffusion to interlayer. Figure (c) shows interface of the interlayer diffusion zone Cu side shows diffusion of Cu atoms but not continuous, on other hand, left side shows Austenite with formation of chromium carbide network at grain boundary of austenite. Figure (d) it shows equi-axed austenite grains with carbide Precipitated into grain boundaries.

4. Conclusion

In this work the properties of diffusion bonded specimens made with copper/ stainless steel and interlayer of Nikal sheets were analysed through microstructural and mechanical properties.

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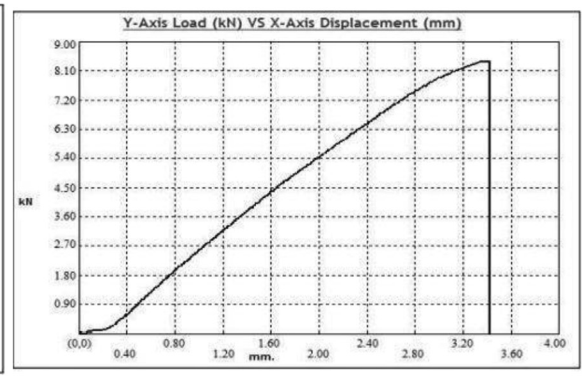
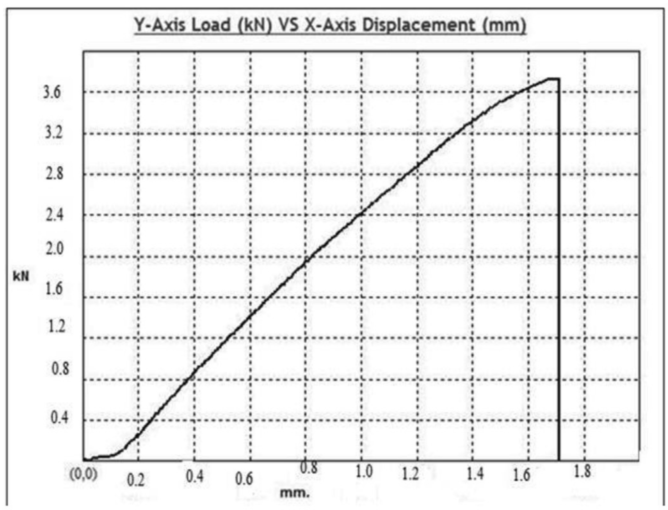
Specimen1



Specimen 2



Specimen 3

Fig. 8. Shear strength results.

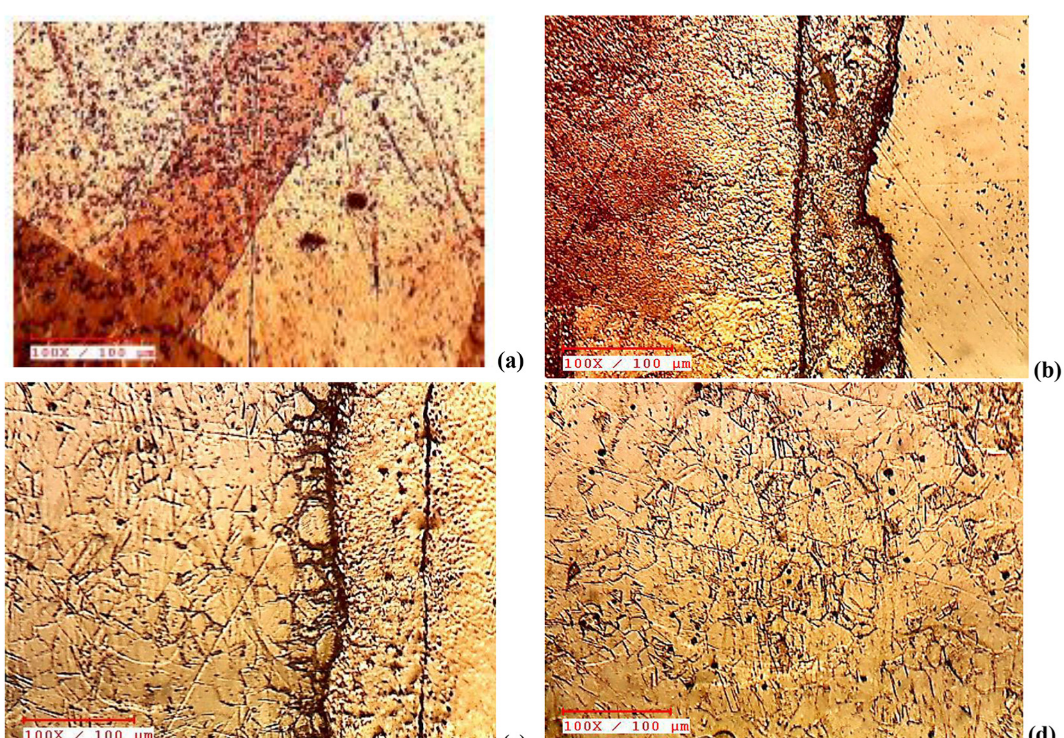


Fig. 9. Micro structure at 800C.

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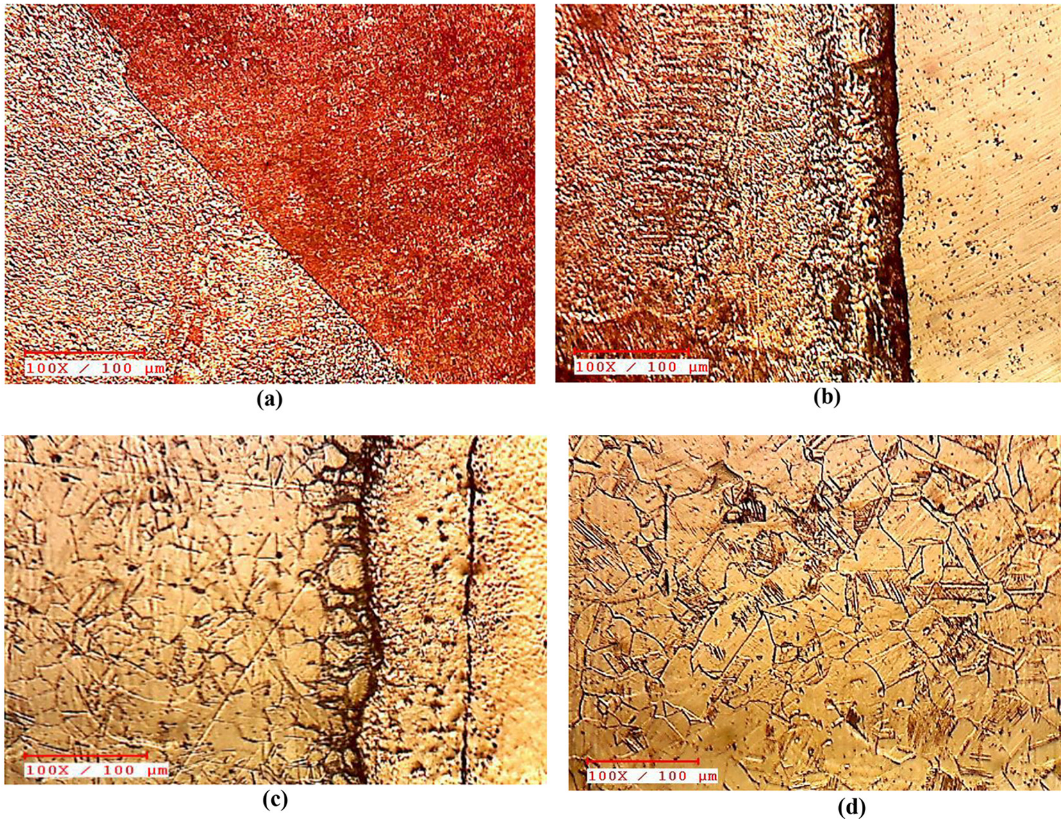

Fig. 10. Micro structure at 825C.

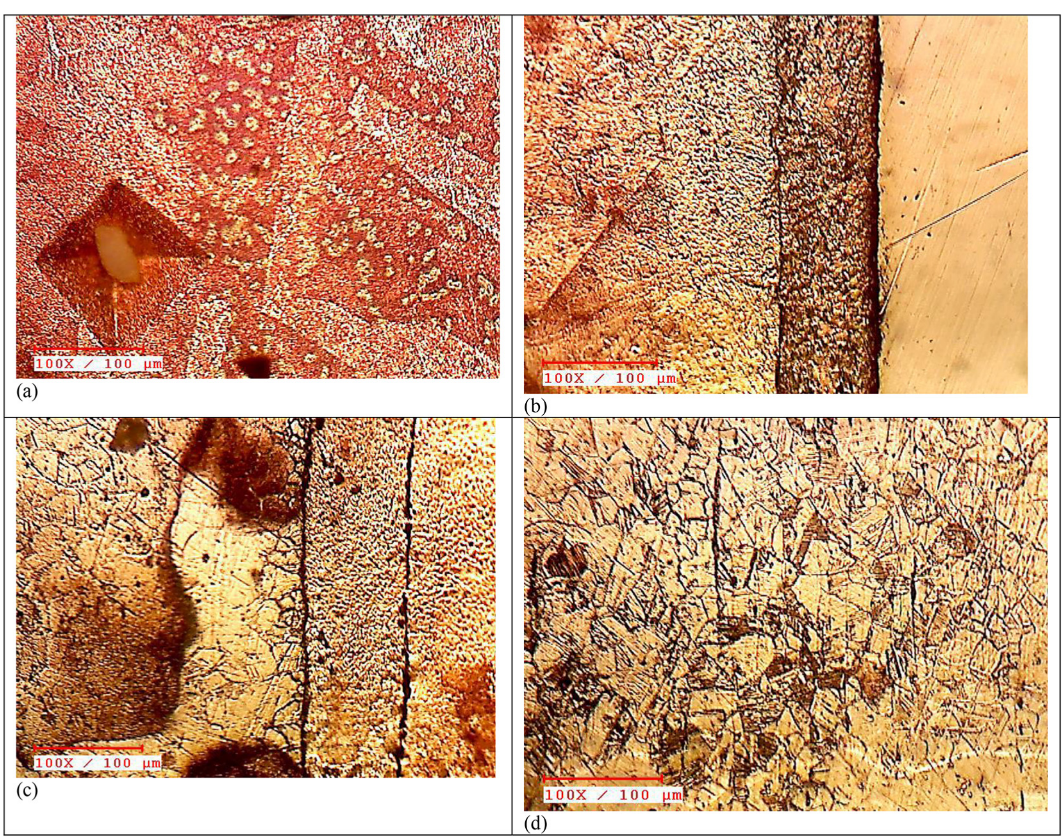

Fig. 11. Micro structure at 875C.

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Table 2
Overall results of lap shear test.

Specimen No	Temperature ℃	Pressure (Mpa)	Breaking Load (KN)
1	800	5	3.75
2	825	5	8.38
4	850	5	4.54

Table 3
Hardness results.

Specimen 1	Location	Hardness HV
	Bonded Region	96.98
	From Cu edge – 2 mm	78.4, 77.9, 78.6
	From SS edge – 2 mm	227.4, 210, 198.4
Specimen 2	Bonded Region	94.4, 93
	From Cu edge – 2 mm	65.5, 67.8 , 73.2
	From SS edge – 2 mm	201, 197.6, 193.2
Specimen 3	Bonded Region	96, 98.4
	From Cu edge – 2 mm	78.4, 77.9, 78.6
	From SS edge – 2 mm	227.4, 210, 198.4
Specimen 4	Bonded Region	83.4, 82.7
	From Cu edge – 2 mm	75.9, 73.2, 67.8
	From SS edge – 2 mm	199.1, 201, 204.5

1. Micro-structure viewed by optical microscope indicates the greater diffusional distance of Cupronickel in copper than that of Cupronickel in stainless steel.
2. The maximum bond strength (shear strength) of 8.45 kN have been obtained at diffusion bonded joints processed at temperature 825℃ for 30 min under the load of 5 MPa with Cupronickel interlayer, good coalescence were obtained with the parameter.
3. The increase in temperature during the diffusion bonding have not much impact on the hardness at the joints.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] G. Mahendran, V. Balasubramanian, T. Senthilvelan, Influences of diffusion bonding process parameters on bond characteristics of Mg– Cu dissimilar joints, Trans. Nonferrous Metall. Soc. China 20 (2010) 997–1005.
[2] M. Cetin, Diffusion welding/bonding of ferritic to pearlitic ductile irons. Proc. IME B, J. Engng Manufact., 2011, 225(4), 543–548.
[3] H. Kejanli, M. Tas¸kin, S. Kolukisa, P. Topuz, Transient liquid phase (tlp) diffusion bonding of Ti45Ni49Cu6 P/M components using Cu interlayer. Int. J. Adv. Manuf. Technol., 2009, 44, 695–699.
[4] O. Yilmaz, H. Celik, Electrical and thermal properties of the interface at diffusion bonded and soldered 304 stainless steel and copper bimetal. J. Mater. Process Technol., 2003, 141, 67–76.
[5] S. Kundu, S. Chatterjee, Interfacial microstructure and mechanical properties of diffusion-bonded titanium–stainless steel joints using a nickel interlayer, Mater. Sci. Engg A 425 (2006) 107–113.
[6] M. Ghosh, K. Bhanumurthy, G.B. Kale, J. Krishnan, S. Chatterjee, Diffusion bonding of titanium to 304 stainless steel, J. Nucl. Mater. 322 (2003) 235–241.
[7] H. Arik, M. Aydin, A. Kurt, M. Türker, Weldability of Al4C3–Al composites via diffusion welding technique. Mater. Des., 2005, 26, 555–560.
[8] D.H. Mesa, A. Toro, A. Sinatora, A.P. Tschiptschin, The effect of testing temperature on corrosion–erosion resistance of martensitic stainless steels, Wear 255 (2003) 139–145.
[9] R.M. Davison, ASM Handbook, Vol. 13. Corrosion; 1992. p. 547.
[10] J.A. Penso, Y.M. Lattarulo, A.J. Seijas, J. Torres, D. Howden, C.L. Tsai, Understanding failure mechanisms to improve reliability of coke drums, ASME Pressure Vessel Pip. Div Publicat 395 (1999) 243–253.
[11] M.C. Tsai, C.S. Chiou, J.S. Du, J.R. Yang, Phase transformation in AISI 410 stainless steel, Mater. Sci. Eng. A 332 (2002) 1–10.
[12] A. Durgutlu, B. Gulenc, F. Findik, Examination of copper/stainless steel joints formed by explosive welding, Mater. Des. 26 (2005) 497–507.
[13] T. Mori, S. Kurimoto, Press-formability of stainless steel and aluminum clad sheet, J. Mater. Proc. Tech. 56 (1996) 242–253.
[14] A. Khodadad Motarjemi, M. Kocak, V. Ventzke, Mechanical and fracture characterization of a bi-material steel plate, Int. J. Press. Vess. Pip. 79 (2002) 181–191.
[15] M.A. Anjos, R. Vilar, Y.Y. Qiu, Lase cladding of ASTM S3 1254 stainless steel on a plain carbon steel substrate, Surf. Coat. Tech. 92 (1997) 142–149.

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