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Diffusion brazing of IN738 to SiC ceramic with Ag-Cu-Ti powder: Effect of bonding time on metallurgical and mechanical properties

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ABSTRACT

Diffusion brazing of SiC ceramic to IN738 using an Ag-Cu-Ti powder-mixture as an interlayer was carried out for the first time. The impact of the bonding time (30 and 45 min) on metallurgical features and shear strength of the joints was assessed. The results revealed that raising the bonding time resulted in expanding of the brazing layer from 46.98 μm to 55.31 μm. Besides, increasing the bonding time also enhanced the shear strength of the SiC/Ag-Cu-Ti/IN738 joints.

Introduction

Dissimilar welding of various alloys like Al to Mg [1], Al to Cu [2], and ceramic to metal [5] are widely used in many industries; such as aerospace, nuclear and electronic industries. Recently, various joining processes of dissimilar alloys have received remarkable attention. Amongst different joining processes, the diffusing brazing (welding) can be considered as an important process that has a marvelous potential in joining all the materials [4]. Indeed, the joining of different materials with the use of conventional welding methods like fusion welding is extremely formidable and extremely prone to hot cracking owing to the discrepancy in their metallurgical and chemical properties [5,6]. Recently, the vast majority of researchers have focused on the diffusing brazing of ceramics and metals. In comparison to other fusion-based methods, diffusion brazing is desirable/ideal for materials that are difficult to weld by applying a reaction-assisted diffusion mechanism in joining. Xia et al [7] investigated the brazing technique for bonding the Ti_3SiC_2 ceramic to TC4 alloy using a Ni interlayer. They have explored the impact of interlayer thickness on metallurgical features. Shi et al. [9] employed the mixture of Zr and IN625 powders to braze the SiC at a temperature of 1400 °C. Wang et al. [10] investigated the use of AgCu filler for brazing Inconel 600 alloy and ZrB2-SiC ceramics. Based on the existing literature, the diffusion brazing of IN738 to SiC via the use of Ag-Cu-Ti interlayer is yet to be elucidated in detail. This study will be providing the first time information on the diffusion brazed SiC/Ag-Cu-Ti/IN738 joints. The choice of this filler/interlayer is chosen for this study because it can establish good wettability with the SiC ceramic while maintaining good metallurgy with the IN738 alloy. The feasibility of diffusion brazing of SiC ceramic to IN738 Ni-base superalloy as a function of bonding time using Ag-Cu-Ti active powders as an interlayer was assessed.

Experimental setup

The base materials used in this research's investigation were IN738 superalloy (from MAPNA Group) and SiC ceramic (Brazekaran Company) with dimensions of 10 × 10 × 6 mm. Note that Ag-Cu-Ti powder-mixture was located as an interlayer between the SiC ceramic and IN738 in this study (see Fig. 1a). With the help of PVC slabs, the thickness of the interlayer was fixed at 25 μm. Fig. 1b displays the FESEM images of the Ag-Cu-Ti interlayer. To remove any dirt before the diffusing bonding process, the parts were ground (with the use of a 1000-grit SiC paper),

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polished, and cleaned ultrasonically in acetone solution for 15 min. Diffusion brazing was carried out at different bonding times (30 and 45 Min) at a fixed brazing temperature (900 °C) and a constant bonding pressure (2 MPa) under the vacuum of 3×10^{-3} pa. Fig. 1c exhibits the diffusion brazing apparatus used in this study. A schematic illustration of the SiC/Ag-Cu-Ti/IN738 arrangement is given in Fig. 1d. In order to carry out the microstructural examination of the SiC/Ag-Cu-Ti/IN738 joints, field emission scanning electron microscopy (FE-SEM) equipped with energy-dispersive X-ray spectroscopy (EDS) was employed to clarify the phases formed at the interface of joints. Afterward, the polished surfaces of the SiC/Ag-Cu-Ti/IN738 joints were electro-etched with 10 % aqueous oxalic acid for the 20 s at 15 V. The phases present in the joint were identified via the use of X-ray diffraction (XRD). The shear strength of the joints was obtained using an INSTRON 5500R tensile testing machine at a loading rate of 1 mm/min. The average of three shear tests was reported as the actual tensile result in this paper.

Results and discussion

The FESEM cross-sectional backscattered (BSE) and secondary (SE) images of the SiC/IN738 brazed joint via Ag-Cu-Ti mixed powders as interlayer under the brazing conditions of 30 and 45 min is illustrated in Fig. 2a and b, respectively. It is remarkably obvious that SiC and IN738 are soundly bonded regardless of the bonding time. No visible defect like void or porosity is formed at the brazed interface, which confirms that Ag-Cu-Ti filler alloy wets the SiC ceramic and IN738 alloy to aid the bonding between them. Furthermore, a uniform brazing layer is observed adjacent to the SiC ceramic, irrespective of the holding time (see red arrows in Fig. 2a). However, the thickness of the brazing layer in the sample generated with 45 min bonding time gradually increased from 46.98 μm to 55.31 μm. Indeed, it can be inferred that the prolonged brazing time causes a larger amount of Cu, Ag, and Ti to dissolve at the interfacial SiC/IN738 [12]. The presence of the Ag-rich (light grey) and Cu-rich (dark grey) phases at the interfacial SiC/IN738 zones was another finding during the diffusion brazing of the SiC/IN738 joint. The area fraction of the Cu-rich regions increased with the increase in the bonding time from 30 to 45 min around the IN738 side (see Fig. 2) due to better interatomic diffusion. The good wettability of the Ag-Cu-Ti facilitated good bonding with the SiC ceramic side and also maintained a good diffusion-induced metallurgical bonding with the IN738 alloy. The EDS results revealed that the weight percentage (wt%) of the elements in the Ag-rich and Cu-rich phases in the sample fabricated at 30 min bonding time (points A and B) were 91.64% Ag, 4.96% Cu, 1.28 Ni, 2.11% Ti and 3.11% Ag, 96.66% Cu, 0.03 Ni, 0.09% Ti, respectively. Whereas considering EDS results of the points D and E in the sample fabricated at 45 min bonding time the weight percentage of the elements in the Ag-rich and Cu-rich phases were 93.82% Ag, 5.93% Cu, 0.11% Ni, 0.13% Ti, and 6.88% Ag, 92.93% Cu, 0.06% Ni, 0.1% Ti. This result reveals that there is a somewhat increase in the wt% of elements such as Ag and Cu owing to the increase in the bonding time. An increase in the bonding time is expected to have facilitated more elemental diffusion to support the EDS results presented in Fig. 2.

Although it should be pointed out that the amount of Cu-rich phase near the SiC ceramic and IN738 for the sample produced at 45 min was less than that of the sample produced at 30 min, which can be connected to a higher solubility limit of Cu with time increment. Thus, it can be deduced that the accumulation of the Cu-rich phase adjacent to SiC ceramic and IN738 mainly depends on the bonding time during the diffusion brazing. Moreover, results demonstrated that a rise in the holding time resulted in the formation of an uneven and wavy-like interface adjacent to the IN738, while the interface of the other specimen (generated at lower holding time) is approximately even and straight, as represented in the Fig. 2a and b, that can be stemmed from the fact that a longer bonding time during the process can simplify and in fact facilitate the dissolution and diffusion of elements (see green arrows in Fig. 2a) [8]. The EDS composition analysis of points C (in Fig. 2a) and F (in Fig. 2b) showed that point C is composed of 3.31% Ag, 20.05% Cu, 32.16% Ni, 44.48% Ti, and point F is composed of 2.56% Ag, 25.13% Cu, 34.45% Ni, 37.86% Ti. There is a slight difference in the wt% of the identified elements due to the disparity in the bonding/holding time of the joints. This is owing to the thermal-activated elemental diffusion. The EDS mapping of the diffusion-brazed IN738 side confirms the occurrence of elemental diffusion in the joint (see Fig. 3). Elements like Al, Cu, and Ag have relatively palpable diffusion degrees in the joint while the diffusion of Ni (from the IN738 side) into the interfacial/brazed zone of the joint is not pronounced owing to the high melting point of Ni. Meanwhile, the XRD results of the samples subjected to 30 min and 45 min holding times are presented in Fig. 4. The increase in the bonding/holding time did not significantly influence the phases (SiC, Ag3Si, TiC, Ag, and Cu) formed at the diffusion-brazed region of the joints but the peaks of phases were significantly affected. The prolonged holding/bonding time is considered to have aided better diffusion of Ag and Si elements in the joint to form the Ag3Si phase having a more pronounced XRD peak in Fig. 4b compared to Fig. 4a.

The correlation between shear strength and bonding time of the SiC/Ag-Cu-Ti/IN738 joints is demonstrated in Fig. 5a. It is noticeably clear that bonding time had a pivotal role on the shear strength of the SiC/IN738 joints. As a consequence, increasing the bonding time from 30 min to 45 min slightly increased the mechanical properties of the joints from 21.61 MPa to 29.88 MPa. Indeed, rising bonding time from 30 min to 45 min led to the formation of a wider brazing layer, as mentioned in the previous section. Additionally, the increase in the shear strength could be linked to a better interatomic diffusion as bonding time is increased [1–3]. These attributes (improved diffusion and brazing layer) are considered to have provided a better loadbearing resistance in the joint subjected to 45 min bonding time.

Similarly, the prolonged bonding time is adjudged to have facilitated better wetting and diffusion-induced bonding between the SiC and the IN738 alloy to produce SiC/Ag-Cu-Ti/IN738 joint with a better shear strength To clarify the fracture mechanism of the joints after the shear strength test, the fracture surfaces of the joints produced at various bonding time are analyzed by SEM. As can be seen, when the bonding

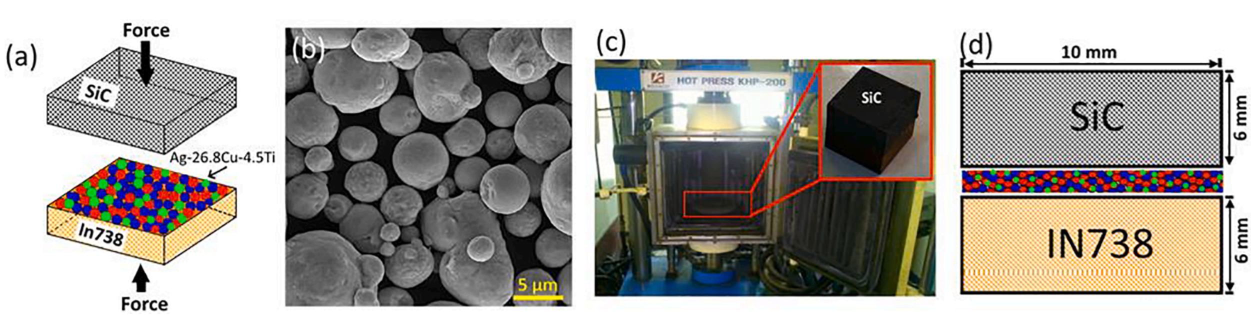

Fig. 1. (a) Schematic illustration of diffusion bonding of IN738/Ag-Cu-Ti/SiC, (b) FESEM image of Ag-Cu-Ti powder as interlayer, (c) The hot press vacuum furnace for diffusion bonding, (d) Schematic illustration of SiC, IN738 and Ag-Cu-Ti arrangement.

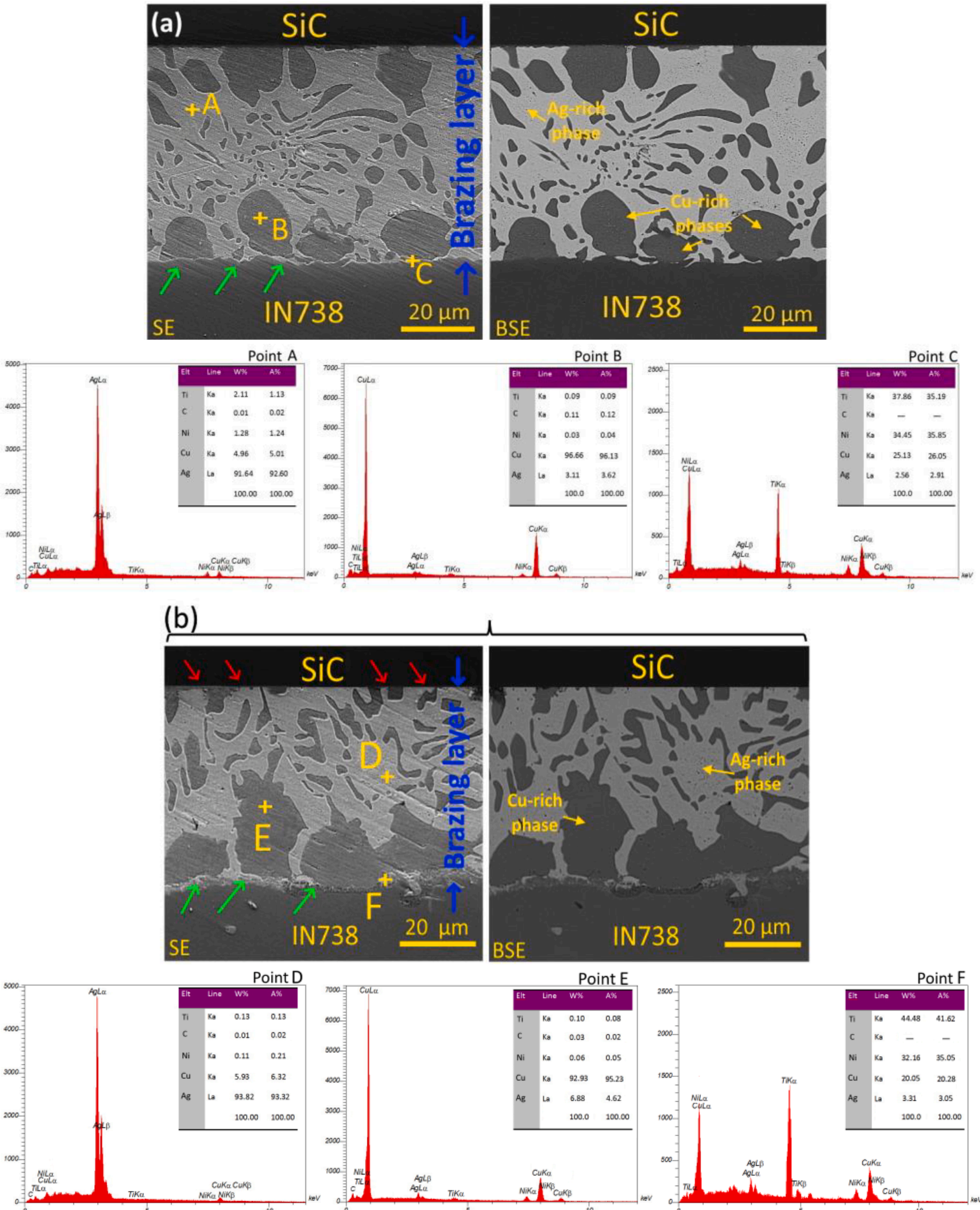

Fig. 2. FESEM illustrations and EDS analyses of SiC/Ag-Cu-Ti/IN738 joint as a function of bonding time, (a) 30 min and (b) 45 min.

time increased from 30 min to 45 min, the amount of Cu-rich phases decreased at the SiC side (see Fig. 5). The fracture modes were brittle regardless of the bonding time, and micro-cracks were found in the sample bonded at 30 min time.

Conclusions

For the first time, diffusion brazing of SiC ceramic to IN738 using an Ag-Cu-Ti powder as an interlayer was carried out. Longer bonding time during diffusion brazing caused a larger brazing layer. By increasing the bonding time from 30 to 45 min, an uneven and wavy-like interface was formed adjacent to the IN738 that can be ascribed to the dissolution and

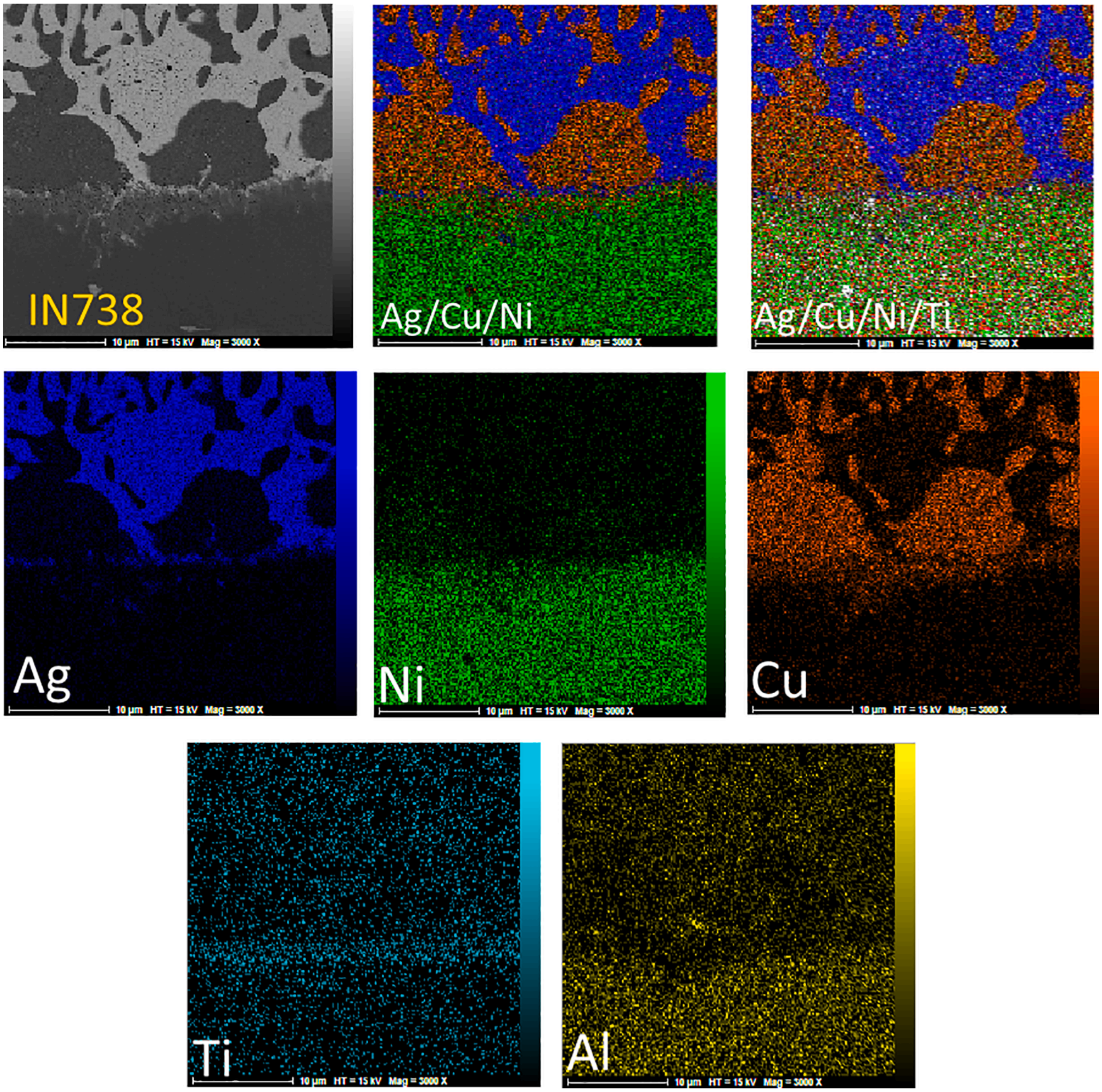

Fig. 3. EDS Map analysis of the SiC/Ag-Cu-Ti/IN738 joint.

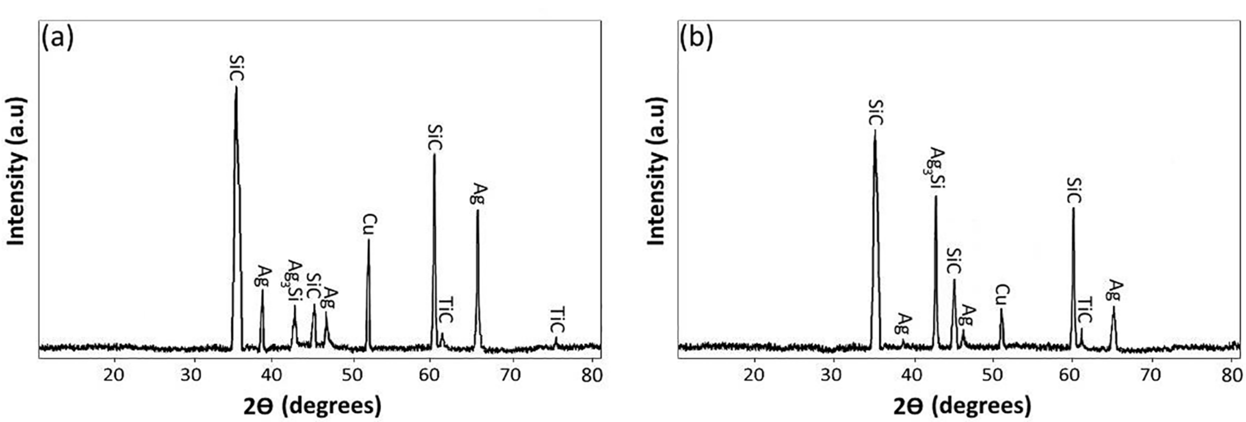

Fig. 4. XRD patterns of the SiC/Ag-Cu-Ti/IN738 joint with bonding time of (a) 30 min and (b) 45 min.

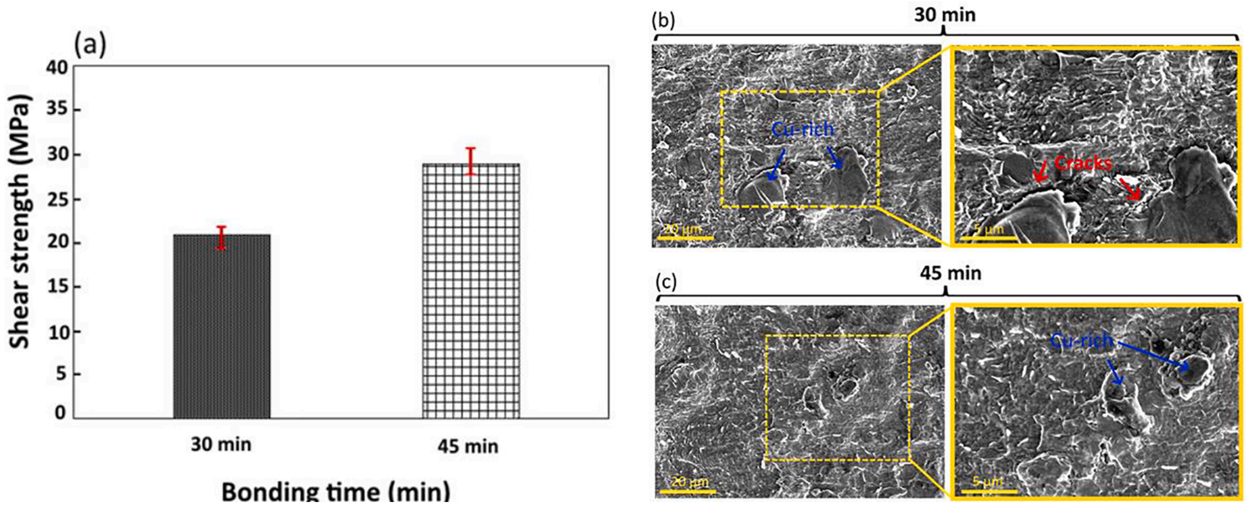

Fig. 5. (a) Influence of bonding time on the SiC/Ag-Cu-Ti/IN738 joints, (a) shear strength, (b) and (c) FESEM images of fracture surfaces for sample produced with 30 min and 45 min, respectively.

diffusion of elements at higher bonding time. Enhancing the bonding time also increased the shear strength of the SiC/Ag-Cu-Ti/IN738 joints by 27%.

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] Paidar M, Mehrez S, Babaei B, Memon S, Ojo OO, Lankarani HM. Mater Lett 2021; 301:129764.
[2] M. Paidar, S. Memon, V. Olegovich Samusenkov, B. Babaei, O.O. Ojo, Materials Letters, 285, 2021, 129160.
[3] Ba J, Li H, Ren B, Qi B, Zheng X, Ning R, et al. Ceram Int 2019;45:8054–7.
[4] Song Y, Liu D, Hub S, Song X, Lei Y, Cao J. Ceram Int 2019;45:8962–70.
[5] M. Paidar M.M. Ravikumar O.O. Ojo S. Mehrez V. Mohanavel M. Ravichandran 297 2021 129919 10.1016/j.matlet.2021.129919.
[6] Paidar M, Ashraff Ali KS, Ojo OO, Mohanavel V, Vairamuthu J, Ravichandran M. J Manuf Processes 2021;61:383–95.
[7] Xia YH, Wang Y, Yang ZW, Wang DP. Ceram Int 2018;44:11869–77.
[8] Ghaderi S, Karimzadeh F, Ashrafi A, Hosseini SH. J Manuf Processes 2020;60: 213–26.
[9] Shi H, Peng H, Chai Y, Li N, Wen Y, Bai D, et al. J Eur Ceram Soc 2021;41:6238–47.
[10] Wang G, Cai Y, Wang W, Gui K, Zhu D, Tan C, et al. J Manuf Processes 2019;41: 29–35.