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Effect of interlayer configurations on joint formation in TLP bonding of Ti-6Al-4V to Mg-AZ31

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Abstract. In this research work, the transient liquid phase (TLP) bonding process was utilized to fabricate joints using thin (20μm) nickel and copper foils placed between two bonding surfaces to help facilitate joint formation. Two joint configurations were investigated, first, Ti-6Al-4V/CuNi/Mg-AZ31 and second, Ti-6Al-4V/NiCu/Mg-AZ31. The effect of bonding time on microstructural developments across the joint and the changes in mechanical properties were studied as a function of bonding temperature and pressure. The bonded specimens were examined by metallographic analysis, scanning electron microscopy (SEM), and X-ray diffraction (XRD). In both cases, intermetallic phase of $CuMg_2$ and Mg_3AlNi_2 was observed inside the joint region. The results show that joint shear strengths for the Ti-6Al-4V/CuNi/Mg-AZ31 setup produce joints with shear strength of 57 MPa compared to 27MPa for joints made using the Ti-6Al-4V/NiCu/Mg-AZ31 layer arrangement.

1. Introduction

The Ti-6Al-4V alloy has a high specific strength, good oxidation resistance, and high elastic modulus which makes it an attractive choice for aerospace, marine, and oil and gas industries [1–3]. The magnesium alloy Mg-AZ31 is a light structural alloy, with a high specific strength, good formability, and recently has been found to be suitable for use in the automotive industry [4–6]. However, differences in the physical properties of these alloys (e.g. melting point for Ti-6Al-4V is 1650^{o} C and 680^{o} C for AZ31) make the joining of these dissimilar alloys a great challenge. Transient Liquid Phase Bonding (TLP) process has been used to join various advanced metals and alloys [7–10]. In previous work [11,12] three eutectic forming interlayers based on nickel, copper and aluminum were tested to enhance joint formation between Ti-6Al-4V and Mg-AZ31. It was found that the nickel foil was the most suitable eutectic former and it gave the highest bond shear strength (39 MPa) compared to the copper and aluminum foils. However, the copper foil produced a eutectic liquid at a temperature below the eutectic temperature for Ni-Mg ($T_{E\ Mg\text{-}Cu}$= 485^{o}C and $T_{E\ Mg\text{-}Ni}$= 512^{o}C)[13,14]. Therefore, in order to take advantage of the lower eutectic temperature of Cu and the better joint quality produced using nickel foils a combination of both foils may produce fewer hard intermetallic phases inside the joint region and give better joint shear strengths. In this study, bonds were made between Ti-6Al-4V and Mg-AZ31 using a combination of nickel and copper as eutectic forming interlayers.

2. Materials and experimental work

Commercially available Ti-6Al-4V and Mg-AZ31 alloys were obtained from William Gregor Ltd (London, UK) and from Goodfellow (Cambridge, UK) respectively. The alloys were received in the form of extruded rods with10 mm diameter; the specimens were cut to 5 mm thick sections, ground and polished down to 1000 grit surface finish followed by rinsing and cleaning in an acetone bath. The chemical composition of these alloys obtained by WDS analysis is shown in Table 1. The Ni and Cu foils are cut into a dimension of 10x10 mm square pieces. Prior to diffusion bonding, the Ti-6Al-4V samples were pickled in diluted HCl (20%HCl-80%distilled water) for 3 minutes, the Ni and Cu foils were pickled for 1 minute to remove surface oxides and degreased in acetone solution. Figure 1 show the XRD spectrum for the as received Ni and Cu foils.

Table 1: Chemical composition (wt%) of Ti-6Al-4V and Mg-AZ31 using the WDS analysis.

Alloy	Al	V	Fe	Zn	Ni	Mn	Mg	Ti
Ti-6Al-4V	6.70	4.44	0.17	0.05	0.02	0.02	0.00	Rem.
Mg-AZ31	2.82	0.01	0.00	1.10	0.00	0.13	Rem.	0.00

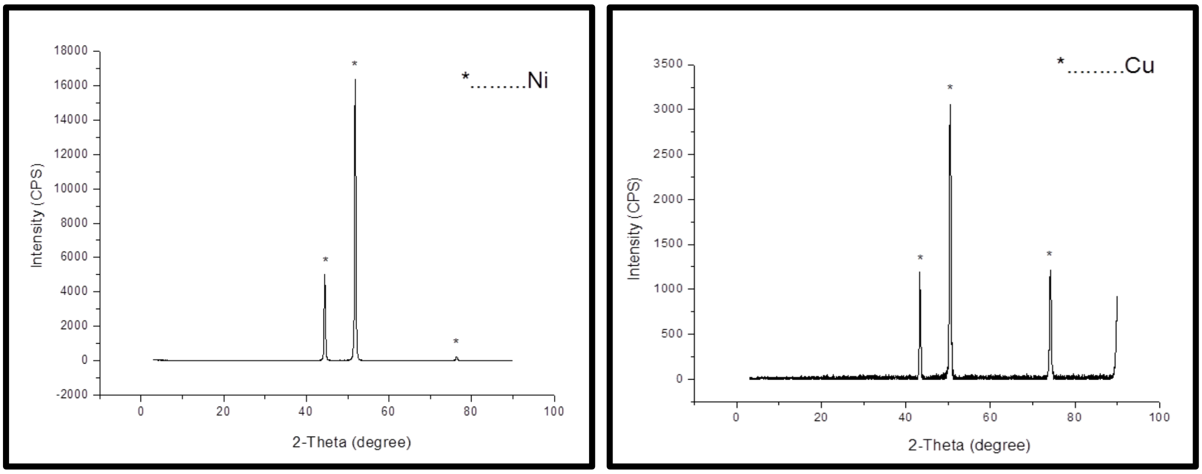

Figure 1. XRD spectra for Ni and Cu foils as received.

TLP bonding was carried out in a vacuum chamber with a pressure of $4X10^{-4}$ Torr (0.053 Pa). Induction heating was used with heating rate of 50 ºC /min. A bonding pressure of 0.35 was applied to provide surface to surface contact and to hold the specimens together. For microstructural characterization the bonded samples were prepared by grinding and then polished using 0.25 micron diamond suspension. SEM micrographs were taken by JEOL JXA 8200 electron microprobe analyzer equipped with wavelength dispersive X-ray spectroscopy (WDS) and energy dispersive X-ray spectroscopy (EDS) for composition analysis. A Vickers micro-hardness test was carried out using a Shimadzu mini-load micro-hardness tester. A micro-hardness profile was established with 600 µm on each side and 50 g of load. The shear strength measurements were carried out using a 25kN load-cell tensile testing machine (Tinius Olsen H25KS) at a cross head-speed of 0.5mm/min. X-ray diffraction

(XRD) of fractured surface was performed to study the phase composition and intermetallic compounds formed inside joint region. A Rigaku Multiflex CuK α radiation source with a step size 0.1° and step time 5 s was used at 40 kW and 20 mA over a 2θ scanning range of 10-90° . Joints were made using interlayer configurations Ti-6Al-4V/CuNi/Mg-AZ31 and Ti-6Al-4V/NiCu/Mg-AZ31.

3. Results and discussion

3.1. Microstructural development

The SEM micrograph of joint interface for Ti-6Al-4V/NiCu/Mg-AZ31 made at 515°C bonding temperature, 0.35 MPa bonding pressure for10 min bonding times is shown in figure 2. At bonding times of less than 10 minutes joints could not be made and were seen to fail between Ni and Ti-6Al-4V interface. This was attributed to the absence of eutectic liquid formation at the Ni/Ti-6Al-4V interface although evidence of liquid formation was seen between Cu and Mg. At 10 minutes bonding time, the Cu-Mg eutectic formed and reacted with the Ni interlayer, then it started to dissociate and formed a small amount of liquid.

The SEM micrograph of joint interface for Ti-6Al-4V/CuNi/Mg-AZ31 made at 515°C bonding temperature, 0.35 MPa bonding pressure for 20 min bonding times is shown in figure 3. At bonding times less than 20 minutes all bonds failed to join, and failure was seen at the Cu foil on both sides between Ni-Cu and Cu/Ti-6Al-4Vinterface. This was attributed to the short bonding time preventing the Ni eutectic liquid from wetting and reacting with the Cu foil.

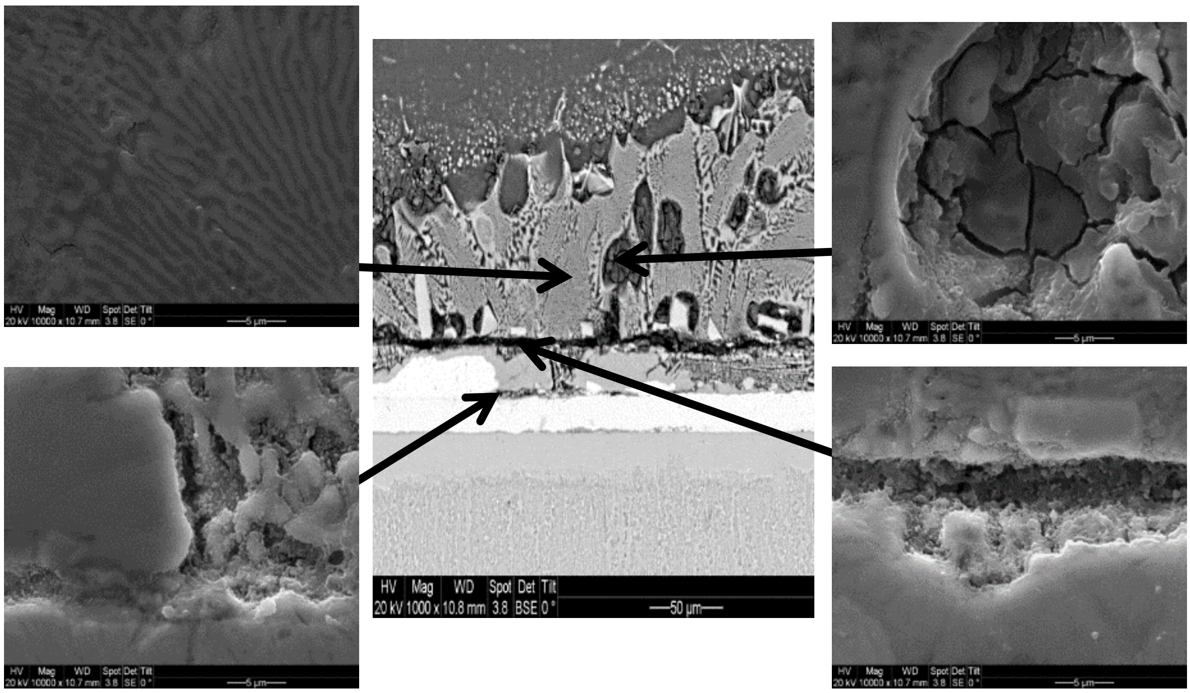

Figure 2. BSE-SEM micrographs of Ti-6Al-4V/NiCu/Mg-AZ31 joint interface after bonding at 515°C and 0.35 MPa for10 min [15].

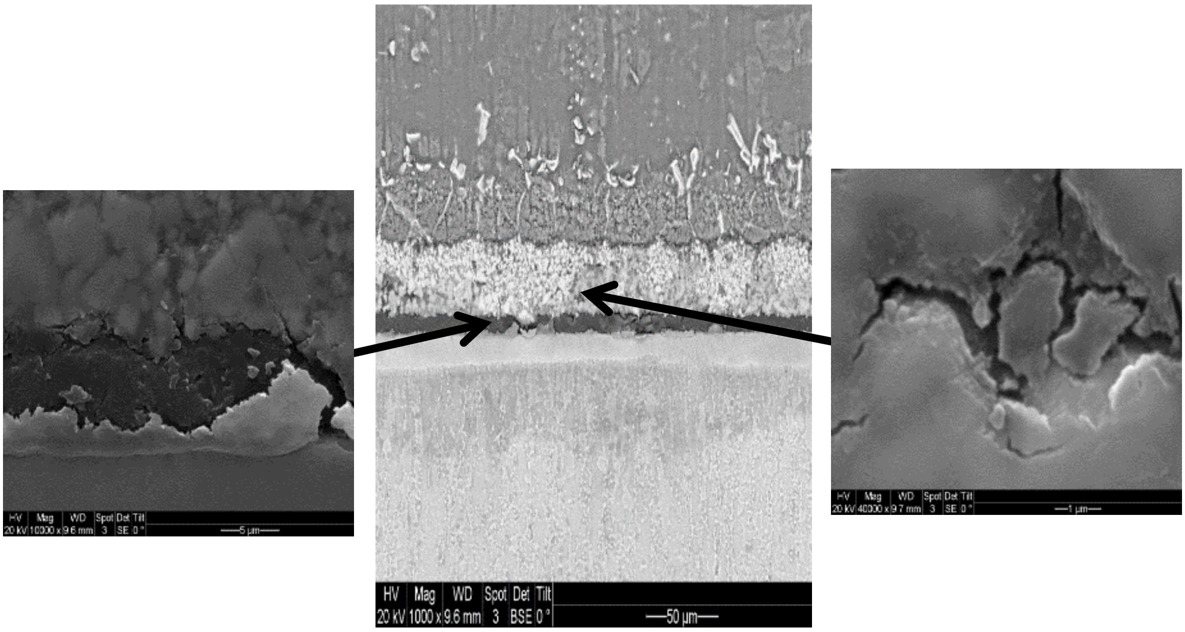

Figure 3. BSE-SEM micrographs of Ti-6Al-4V/CuNi/Mg-AZ31 joint interface after bonding at 515ºC and 0.35 MPa for20 min [15].

3.2. Mechanical properties of the joint

Micro-hardness profiles for joint interface as a function of time are shown in figure 4. This profile can give a good indication on the nature of phases and intermetallics formed inside joint region. For the Ti-6Al-4V/NiCu/Mg-AZ31 configuration, as the bonding times increased from 10 to 20 minutes, at bonding time of 10 minutes a smooth transition between the two parent alloys was noticed from 250 VHN to 60 VHN. Comparing the two interlayer configurations at the same bonding time and pressure, it was observed that the Ti-6Al-4V/CuNi/Mg-AZ31 configuration resulted in higher hardness profile on both sides of joint interface towards Ti-6Al-4V and Mg-AZ31. The maximum hardness observed was at the joint center and a value of 308 VHN was recorded. After 200 µm inside Mg-AZ31 the micro-hardness profiles for the 10 minutes Ti-6Al-4V/NiCu/Mg-AZ31 and 20 minutes Ti-6Al-4V/CuNi/Mg-AZ31 measured the same value with an average of 56 VHN.

For joints produced using Ti-6Al-4V/NiCu/Mg-AZ31 setup; the bond shear strength was 27 MPa. However, increasing the bonding time to 20 minutes resulted in a decrease in shear strength to 18 MPa. This decrease in shear strength was attributed to the change in Cu-Mg eutectic concentration before complete reaction with Ni was possible. For a longer bonding time, a higher volume of Cu-Mg eutectic formed leaving less eutectic available to wet the Ni/Ti-6Al-4V interface. However, for Ti-6Al-4V/CuNi/Mg-AZ31 even the bond time less than 20 minutes failed to achieve a joint, the 20 minutes resulted in higher shear strength of 57 MPa which is twice the strength obtained for joints made using the Ti-6Al-4V/NiCu/Mg-AZ31 setup.

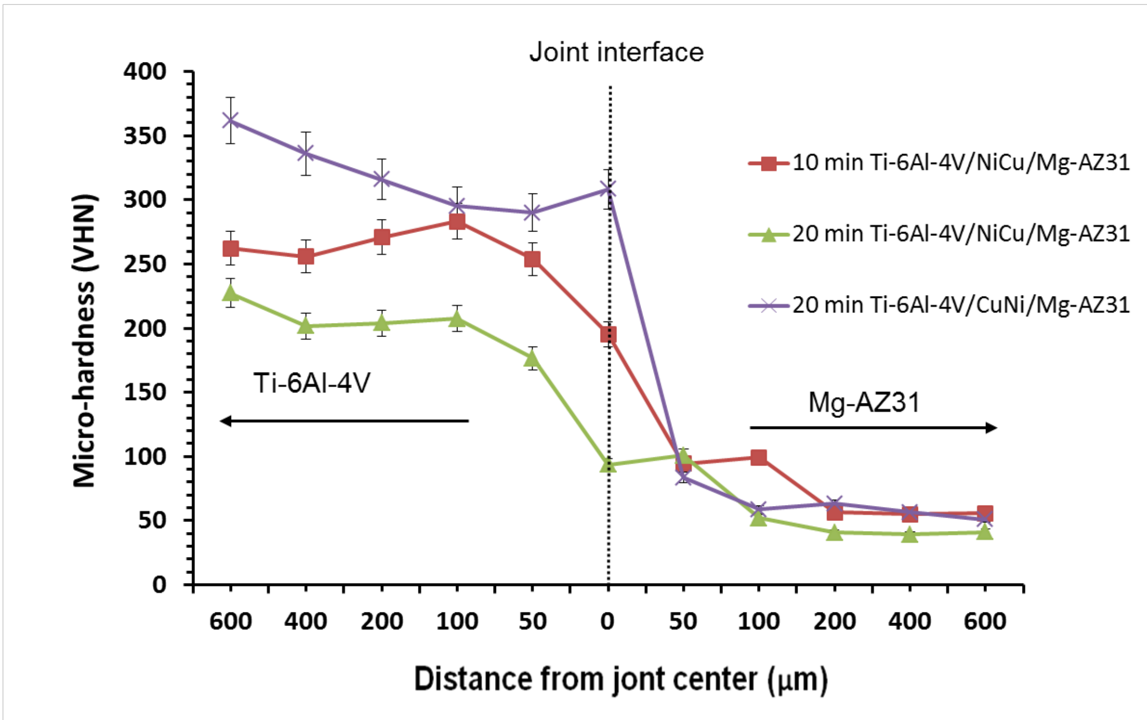

Figure 4. Micro-hardness profile for joint made at 515ºC, 0.35 MPa for different bonding times.

3.3. Fracture surface and XRD spectra

The SEM micrograph and XRD spectra achieved from Mg-AZ31 fractured surface are shown in figures 5. The complexity of the system made difficult to identify the phases formed and the intermetallics inside joint region where 7 elements are reacting with each other to form the bonds. However, the application of XRD spectra with WDS and EDS allowed the prediction of phases formed. In the Ti-6Al-4V/NiCu/Mg-AZ31 configuration, at bonding time of 10 minutes 5 major compounds were detected on the fractured surface, only two was common with the fractured surface obtained for 20 minutes which are Mg and Mg_3AlNi_2. Mixed failure mode of brittle and ductile was observed. Those two observations suggested that the fracture path propagated between the reactions layers and contained both Cu and Ni. However, $CuMg_2$ was not detected at 20 minutes bonding time which suggested the decrease in Cu eutectic towards the formation of Ni eutectic as the bonding time progress. For the Ti-6Al-4V/CuNi/Mg-AZ31 setup, the formation of $CuMg_2$ and Mg_3AlNi_2 intermetallics was observed. Furthermore AlTi was detected at the Mg-AZ31 fracture surface, this suggested that the diffusion of Ti towards the joint interface and the fracture propagated close to Ti-6Al-4V interface. However, only ductile fracture mode was observed in the Ti-6Al-4V/CuNi/Mg-AZ31 set up.

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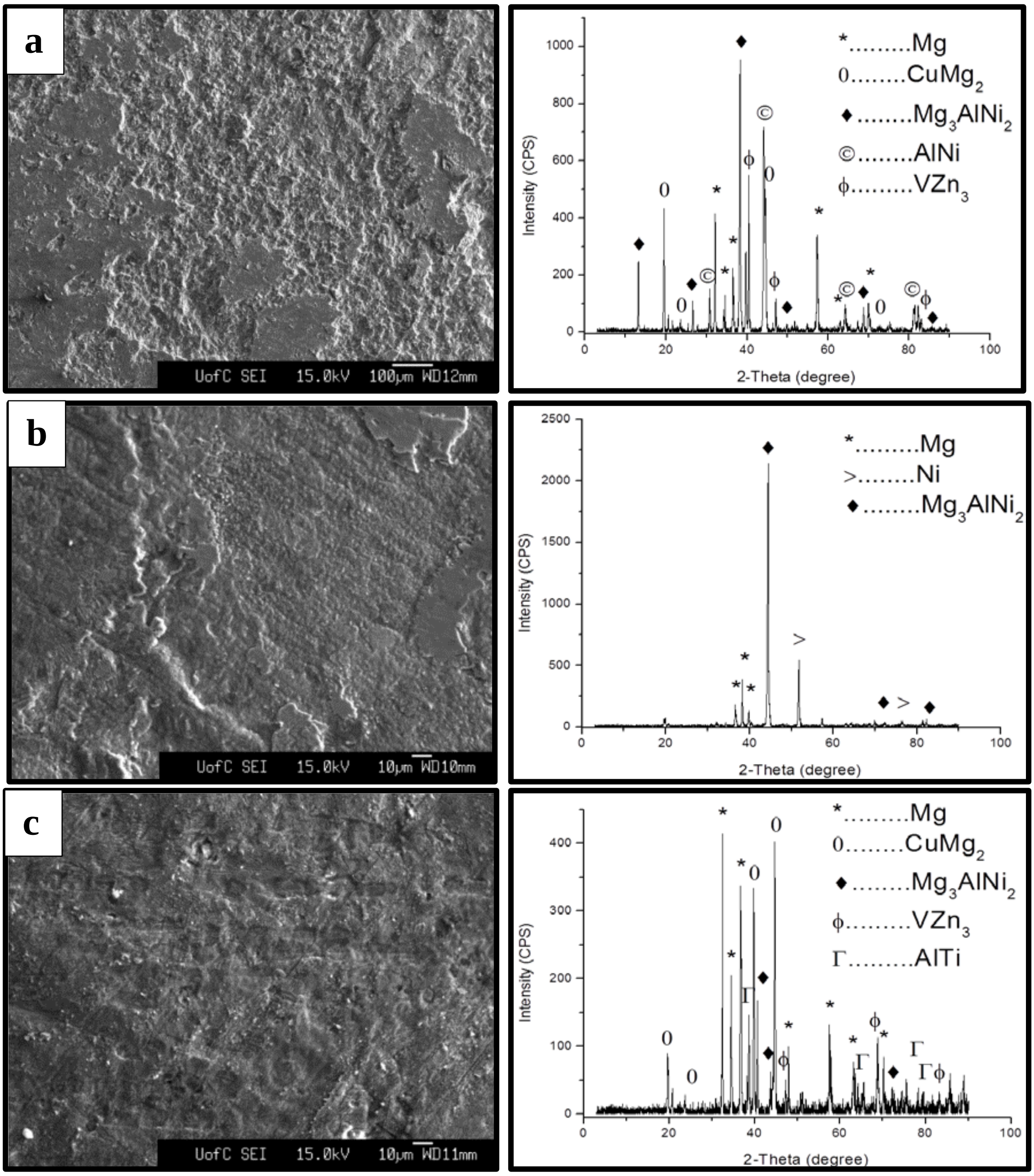

Figure 5. SEM micrograph and XRD spectra for Mg-AZ31 fractured surface for bond made 515ºC, 0.35 MPa, and 20 minutes for a) Ti-6Al-4V/NiCu/Mg-AZ31 at 10 minutes b)Ti-6Al-4V/NiCu/Mg-AZ31 at 20 minutes c) Ti-6Al-4V/CuNi/Mg-AZ31 20 minutes.

4. Conclusion

In this study the TLP bonding process was used to join Ti-6Al-4V to Mg-AZ31 using double foil of Ni and Cu. The results showed that different configurations resulted in different minimum bonding times to achieve a joint. When the joint configuration was Ti-6Al-4V/NiCu/Mg-AZ31, a bonding time of 10 minutes was sufficient to achieve a joint. However for the Ti-6Al-4V/CuNi/Mg-AZ31configuration it required 20 minutes to achieve a suitable joint. The maximum shear strength obtained was 57 MPa for the Ti-6Al-4V/CuNi/Mg-AZ31 bonds made at 515ºC, 0.35 MPa and 20 minutes. The formation of Mg and Mg_3AlNi_2 were detected at all joints and the fracture mode was mixed brittle-ductile for the Ti-6Al-4V/NiCu/Mg-AZ31 joints and ductile for the Ti-6Al-4V/CuNi/Mg-AZ31 joints.

5. Acknowledgment

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6. References

[1] Schutz R W and Watkins H B 1998 Recent developments in titanium alloy application in the energy industry *Materials Science and Engineering: A* 243 305–15

[2] Gurrapa I 2003 Characterization of titanium alloy Ti-6Al-4V for chemical, marine and industrial applications *Materials Characterization* 51 131– 139

[3] Lütjering G and Williams J C 2007 *Titanium* (Springer Berlin Heidelberg)

[4] Friedrich H E and Mordike B L 2006 *Magnesium Technology Metallurgy, Design Data, and Applications* (Springer Berlin Heidelberg)

[5] Mordike B L and Ebert T 2001 Magnesium Properties, applications, potential *Materials science and engineering A* 302 37–45

[6] Kulekci M K 2007 Magnesium and its alloys applications in automotive industry *The International Journal of Advanced Manufacturing Technology* 39 851–65

[7] Gale W and Butts D 2004 Overview Transient liquid phase bonding *Science and technology of welding and joining* 9 283–300

[8] Sun D, Liu W and Gu X 2004 Transient liquid phase bonding of magnesium alloy (Mg-3Al-1Zn) using copper interlayer *Materials Science and Technology* 20 1595–8

[9] Sun D, Gu X and Liu W 2005 Transient liquid phase bonding of magnesium alloy (Mg-3Al-1Zn) using aluminum interlayer *Materials science and engineering A* 391 29–33

[10] Cooke K O, Khan T I and Oliver G D 2012 Transient liquid phase diffusion bonding Al-6061 using nano-dispersed Ni coatings *Materials & Design* 33 469–75

[11] Atieh A M, Elbatanouny M and Khan T I 2012 Diffusion Bonding of Ti 6Al 4V and AZ31 Using Ni Foil *Proceeding of Materials Science & Technology 2012 Conference & Exhibition, (JASM XIV)* (Pittsburgh, Pennsylvania, USA: MS&T Partner Societies, 2012)

[12] Atieh A M and Khan T I 2013 Transient liquid phase bonding of Ti-6Al-4V and Mg-AZ31 using eutectic forming interlayers *Proceeding of the 24th Canadian Congress of Applied Mechanics (CANCAM)* (Saskatoon, Saskatchewan, Canada)

[13] Y. Z and A. C Y 1993 Thermodynamic Calculation of the Mg-Cu Phase Diagram *Z. Metallkd.* 84 662–7

[14] Okamoto H 2007 Mg-Ni (Magnesium-Nickel) Supplemental Literature Review: Section III *Journal of Phase Equilibria and Diffusion* 28 303–303

[15] Atieh A M and Khan T I 2013 Transient liquid phase (TLP) bonding of Mg-AZ31 and Ti-6Al-4V using Ni and Cu sandwich foils *Journal of Science and Technology of Welding and Joining, submitted paper*