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Investigation of Bonding Phase Dimension on Shear Strength of Superalloy Brazed by Active Filler Material

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Abstract:

In this study, Nickel-based superalloy in 738 LC was brazed by using (Ni-Ti) and (Ni-Ti-Al) alloys which are active filler alloys under a protective atmosphere (using a high purity 99.999 Argon gas). Five brazing temperatures (1135, 1025, 985, 825, 725 ºC) were chosen based on the solidus temperatures of (Ni-Ti) and (Ni-Al) filler alloys in order to investigate the effects of these temperatures on the performance of the brazed joints. Brazing processes were carried out over a period of time (15min) to ensure that the filler alloys were melted completely. The performance of brazing process was evaluated in terms of bonding strength by the shear test. The results revealed that a maximum value of shear strength (29MPa) was obtained at brazing temperature (985ºC) as compared with other temperatures. It was observed that the highest shear strength was influenced by the formation of (Ni_3Ti) phase. Micro hardness testing appears a gradual increase in hardness towards the centerline of the joint indicating that the composition of the bonded layer consists of a hard intermetallic phase of varying composition at different depth. The samples bonded by (5% Ni 5%Ti 90%Al) at 825ºC revealed the higher value (841.7) HV due to intermetallic and centerline eutectic constituents in the center of brazing seam.

Keywords: Brazing; Active filler alloy; Brazing temperatures; Nickel based superalloy; Shear strength.

1. INTRODUCTION

In the manufacturing industry especially in joining process, brazing is applying to join two materials by using heat and filler metal which has melting point above (450ºC) [1]. For repairing and joining Nickel-based superalloy, a high temperature brazing is very important and commonly used especially in aero engine hot section [2]. The joining of two materials is made by heating up them to the melting point of the filler metal in order to ensure that molten filler flows between the two mating surfaces via capillary action [3]. Inconel 783 LC is a cast-polycrystalline nickel-based superalloy, used in gas turbine blades and other high temperatures applications [4] this alloy had a superior mechanical properties at elevated temperatures beside the high temperature strength that results from the presence of Ni3(Al,Ti) $\bar{\gamma}$ intermetallic FCC phases in γ solid solution matrix this alloy especially used in the hot section of aero engine and gas turbines. In addition, this alloy has an excellent high temperature strength, creep properties, thermo-mechanical fatigue, stress rupture oxidation and corrosion resistance, fatigue strength, and micro-mechanical stability at elevated temperatures [5]. The research focuses on joining of similar material (nickel-based superalloy) by using (Ni-Ti) and (Ni-Ti-Al) active filler metal alloy with different concentration and different temperature at constant time, and studying the effect of temperatures on the shear strength of the joints. The decrease of shearing strength is due to that the base metal is very hard and the creation

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phases which formed by the process are hard, which is intermetallic in natural, these results agreed with many workers.

2. EXPERIMENTAL PROCEDURE

Nickel-based superalloy (first stage gas turbine blade) Inconel 738 LC was used in this study. The samples were prepared by cut the root of the blade by wire cut to the cubic dimension of (10x10x10) cm. The brazing process was carried out in an electrical furnace under a protective atmosphere (highly purity Argon gas (99.999%)) to ensure that the brazed samples are free from undesirable contaminants between the mating materials. The past filler metals were prepared by weighing a suitable amount of metal powder alloy and mixed with a drop of glycerin to form a filler metal paste which is suitable for one joint. Filler alloy types are shown in table (1).

Table 1. Active filler metal alloy specification.

Filler Type	Filler Composition Wt. %	Alloying Content Wt. %			Filler Condition	Brazing Temperature ^{o}C
		Ni	Ti	Al		
F1	65Ni35Ti	65	35	-	Paste	1135
F2	35Ni65Ti	35	65	-	Paste	1025
F3	28Ni72Ti	28	72	-	Paste	985
F4-a	5Ni5Ti90Al	5	5	90	Paste	825
F4-b	5Ni5Ti90Al	5	5	90	Paste	725

3- RESULTS and DISCUSSION

The microstructure analysis was achieved in order to investigate the phases which were formed during the brazing process. In this study we used SEM to study the microstructure of the joints. A typical brazing joint consists of three zones: (1) substrate zone, (2) diffusion zone, and (3) bonding zone: A thermally solidified zone or (ADZ), it was formed due to residual liquid solidifies in the joint during the cooling of the sample to the room temperature. The solidification of this zone seems to be like:

1. A seam matrix as in case of a joint which bonded by F3 as shown in figure (1c).
2. As a dark blocky shaped discontinuous morphology which is formed from supersaturated phases, as well as gradually pushed to the center area of the brazed joint to form phases rich with filler elements embedded in the matrix, we can observe the variation in the distribution of these blocky phases through the microstructure as a random distribution across the microstructure of bond, as in case of joints bonded by F1, F2 and F5, as shown in figures (1a), (1b), and (1e).
3. For the samples bonded by F4, there were intermetallic and centerline eutectic constituents in the center of the brazing seam.

The results of the shear were (10.5), (7.33), (29), (17), and (23) MPa for the samples bonded by F1, F2, F3, F4a, and F4b respectively as shown in figure (2). The best result was achieved by the sample bonded by 28%Ni 72Ti(F3), it was equal about (29) MPa, as a result of the strong bond between the base metal and filler alloy, as compared with the other joints. The reaction layers that crossed in the center of the brazing area were became splashes and irregular for samples bonded by F1 and F2. This suggests that the continuous reaction layer played an important role to increase the shear strength of the brazed joint as in case of joint bonded by F3. It can be clearly observed that the formation of the reaction layer occurred continuously in close proximity to the in 738 LC side zone compared to the center zone of the brazing area.

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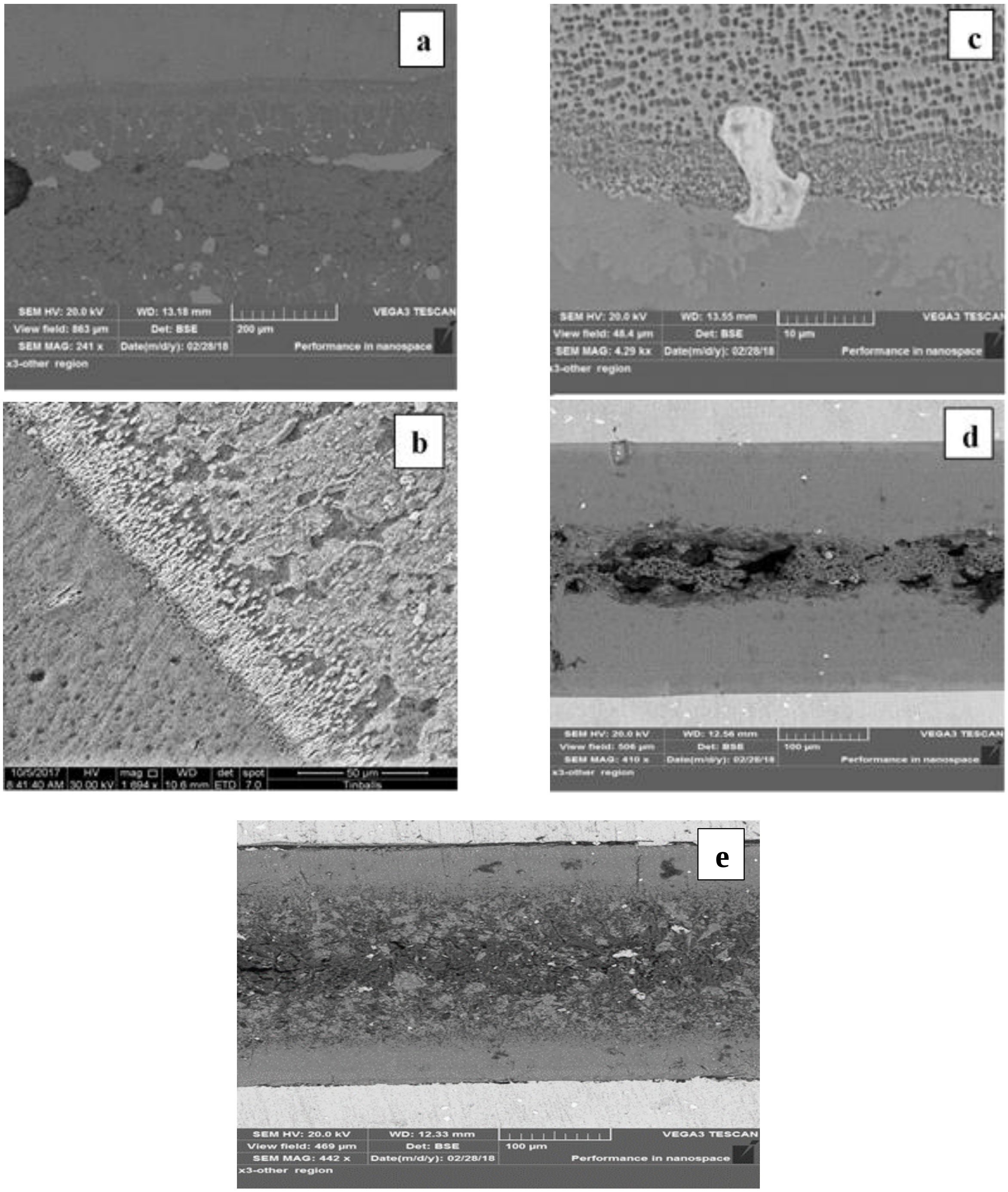

Figure 1. SEM image of microstructure for sample bonded by
a) F1 (241x), **b)** F2(4.29kx), **c)** F3(1684x), **d)** F4 (410x) and **e)** F5(442x).

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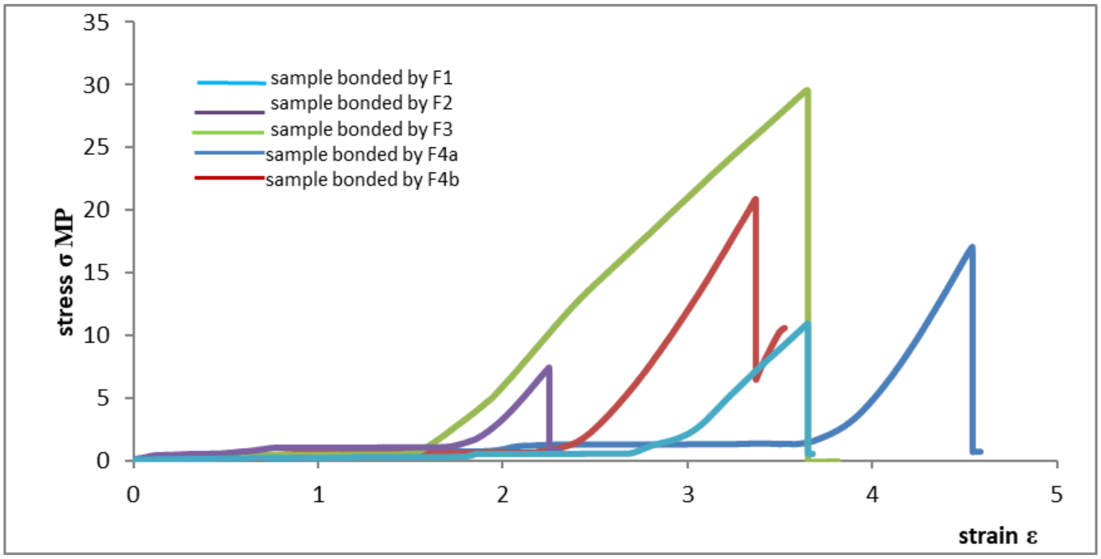

Figure 2. Stress-strain curves during shear test on tensile machine for samples bonded by F1, F2, F3, F4a, and F4b.

The main conclusion is the bonded phases created by using filler metal (Ni-Ti) and (Ni-Ti-Al) will produce an intermetallic bonding phases with mechanical properties closed to that bonding phases that produced when the base metal is ceramic material. The decrease of shearing strength is due to that the base metal is very hard and the creation phases which formed by brazing process also hard, which is intermetallic in natural, this results were agree with many workers as in Fadhel A. Hashim study when he used active brazing to joining ceramic to ceramic joints, the maximum shear strength were 22.125 MPa [6].

The degree of homogeneity for joint microstructure as well as the mechanical properties were attempted by using the micro hardness testing. This test is achieved by using (1Kg) for (15) second according to ASTM E384, and by measuring the different zone of the sample (Substrate, Diffusion zone, Brazing interlayer zone).

Figure (3) describe the micro hardness profile as a function of location point from both sides of the brazed joint. The Vickers micro hardness test results were shown in the figure (3a and 3b) and table (2) for different filler alloy at different temperatures for the same period time (15) min. We can observe from the results, a peak around 841.7 HV is obtained at the centerline of brazing joint for sample bonded by (5Ni5Ti90Al) (wt.%) F4-a, this high value of hardness resulted from the high inter-metallic compound. According to Ni-Ti phase diagrams, Ni and Ti could react to form NiTi, Ni_3Ti, and $NiTi_2$, intermetallic compounds, and the Ni3Ti intermetallic phase shows the best mechanical properties.

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Table 2. Micro hardness results for the bonded samples.

Sample Bonded by Filler	Micro-Hardness HV				
	Base Metal	Bond Zone	Interlayer	Bond Zone	Base Metal
F1	395.2	441.7	520.0	410.9	341.7
F2	405.0	417.4	509.6	420.8	353.5
F3	396.0	406.1	511.6	457.3	415.4
F4-a	409.3	520.0	841.7	510.9	391.7.0
F4-b	405.5	579.6	337.4	570.8	353.5

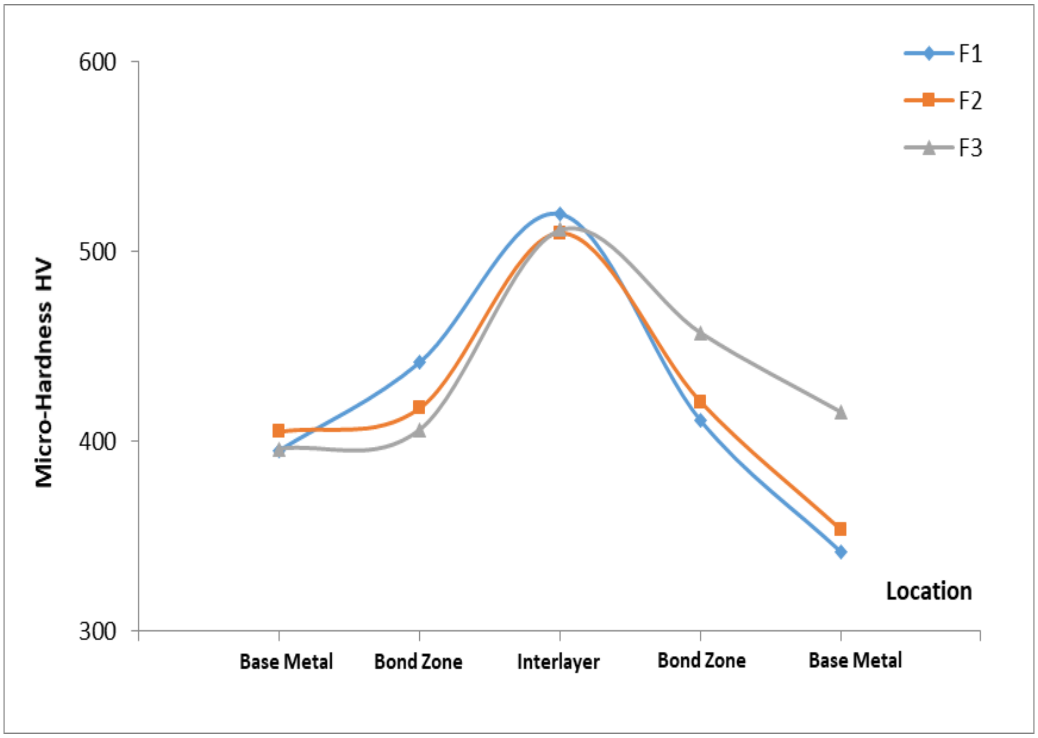

Figure 3. Vickers Micro-Hardness profile across joint-line of IN 738LC brazed by F1, F2, F3.

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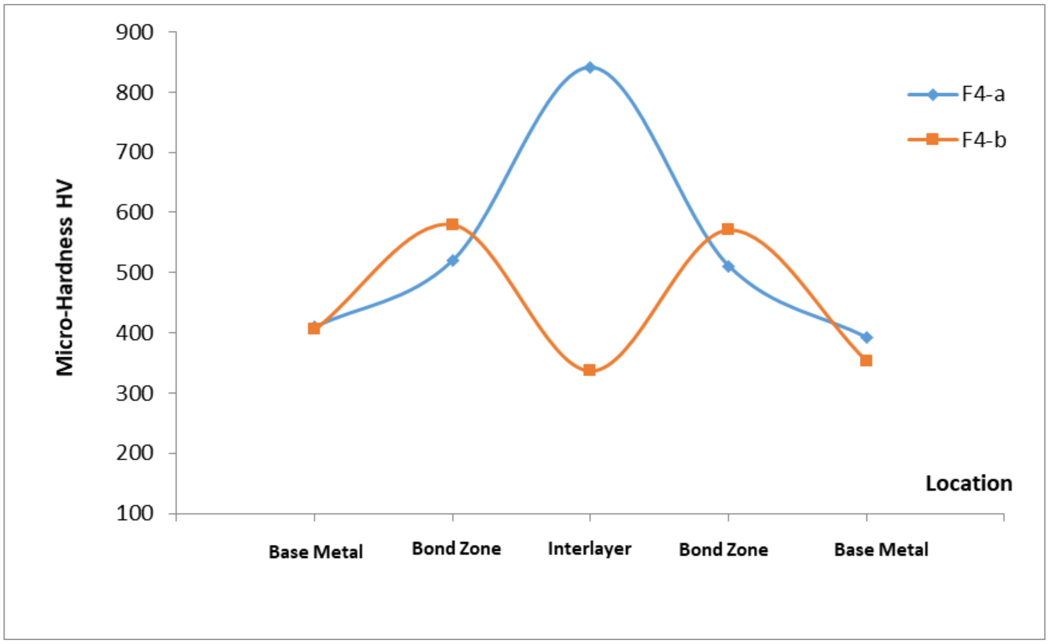

Figure 4. Vickers Micro-Hardness profile across joint-line of IN 738LC brazed by F4-a and F4-b.

4. CONCLUSION

1. For all samples typical brazing consist of three zones: substrate, diffusion zone, and bonding zone.
2. Sample bonded by F3 (28% Ni 72% Ti) at 985 ºC showed a good metallurgical bond and continuous connection as compared with other samples.
3. Formation of reaction layers that crossing the centerline of the brazing area was influenced by the diffusion of some elements from Inconel 738 LC and molten filler alloys (Ni-Ti) and (Ni-Ti-Al) during the brazing process, as well as influenced on the bonding strength of the brazing joints.
4. The main conclusion is the bonded phases created by using filler metal (Ni-Ti) and (Ni-Ti-Al) will produce an intermetallic bonding phase with mechanical properties closed to that bonding phases which produced when the base metal is a ceramic material.
5. All samples showed a gradual increase in micro hardness towards the centerline of the brazing area indicating that the composition of bonded layers consists of a hard intermetallic phases of different composition at different depth. For sample bonded by F4-a (5% Ni 5%Ti 90% Al) the higher value of micro hardness (841.7) HV is results from intermetallic and centerline eutectic constituents in the centerline of brazing joint.
6. The highest shear strength of (23) MPa was obtained at brazing temperature 985ºC for sample bonded by F3 (28%Ni72%Ti).

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