Development of Temperature–Time and Pressure–Time Diagrams for Diffusion Bonding Ti – AA7075 Aluminium Alloys

N. Sithivinayagam, R. Hariharan, R. Praveen Rackson, V. Pravin Kumar and Rubeshwaren

Abstract--- *Two dissimilar aerospace materials Cp Ti and AA7075 were joined by diffusion bonding. When joining these dissimilar material, go for Trial and error method. From this investigation, developing diffusion bonding windows for Cp Ti – AA7075 of dissimilar materials. The quality of the bond of the joints were tested by microhardness, microstructure analysis and lap shear testing.*

Keywords--- *Diffusion Bonding, Aluminium Alloys, Development of Temperature, Time and Pressure.*

I. INTRODUCTION

Diffusion bonding is a solid-state joining process in which two prepared surfaces are joined at elevated temperature ranging from 0.5 to 0.8 Tm (where Tm is the absolute melting temperature) under pressure. The process has an important influence on the design and manufacture of work pieces, since it is of great advantage to bond similar or dissimilar materials.

One of the most typical application for the Aluminum alloy Al7075 and Commercially pure Titanium (Cp Ti) is in aircraft structural parts due to their properties such as high strength to weight ratio and good corrosion resistance. So, joining Al7075 to Cp Ti is desirable in aerospace industry to have low cost and weight parts. However, due to significant differences in physical properties of these alloys such as melting point and heat conductivity, conventional fusion welding techniques cannot be used. Process parameters such as bonding time and temperature play an important role in bonding process and consequently the joint quality.

AlHazaa et al. joined Al to Ti with Cu as interlayer, but had not gained shear strength in comparison with Sohn et al. works. Lead-free Sn-based alloys are widely used to join dissimilar alloys. In a previous study, Kenevisi and Mousavi Khoie joined Al7075 to Cp Ti using Sn-based alloy as interlayer. Coating the surfaces with Cu prevents the oxide formation on Ti/Al interface and increases the wettability of Sn–Zn alloy. In addition, Bi enhances the wettability of the Sn–Zn eutectic system.

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Table 1: Chemical Composition

Chemical Compositions of the Parent Materials (wt%)

Cp Ti

C	Fe	O	N	H	Ti
0.02	0.10	0.15	0.02	0.0011	Bal

AL 7075

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.4	0.5	1.6	0.3	2.5	0.15	5.5	0.2	Bal

Table 2: Mechanical Properties

Mechanical Properties of the base Metals at Room Temperature

Alloy	Shear strength (MPa)	Ultimate tensile strength (MPa)	Elongation at Break (%)	Hardness HB
Cp-Ti	297	319	23	80
Al 7075	150	220	17	60

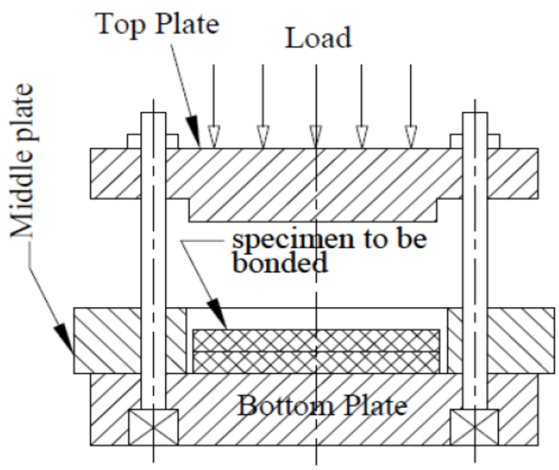

Fig. 1: Arrangement of Diffusion Bonding Specimen

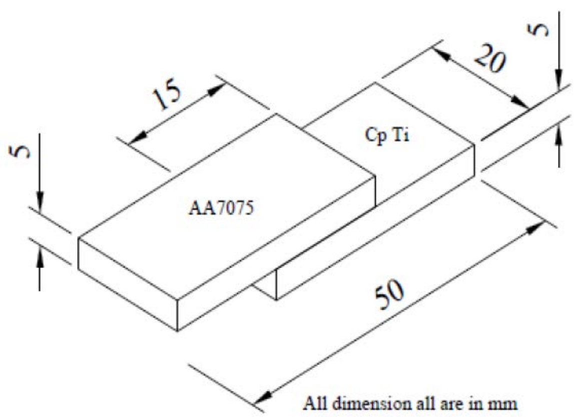

Fig. 2: Lap Shear Test Specimen

II. EXPERIMENTAL WORK

Square shaped specimens (50 mm x 50 mm) were machined from rolled plates of 5 mm thickness Cp Ti and Aluminum (AA7075) alloys. The chemical composition of the base metals used in this investigation is shown in Table 1. The bonding surfaces of samples were ground flat by 200, 400 and 600 grit SiC papers and cleaned in acetone prior to diffusion bonding.

Then the polished and chemically treated specimens were stacked in a die made up of 316L stainless steel and the entire diffusion bonding setup, shown in Fig. 1, was inserted into a vacuum chamber The specimens were heated up to the bonding temperature using induction furnace with a heating rate of 25^0C/min, simultaneously the required pressure was applied. After the completion of bonding, the samples were cooled to room temperature before removal from the chamber.

In this procedure, 35 joints were fabricated using different combinations of bonding temperature, pressure and holding time and they are displayed in Fig. 2.

Microstructure analysis was carried out using a light optical microscope to check the formation of diffusion layer at the interface. As the joints were not large enough for normal lap shear testing, a non-standard test was devised to measure the shear strength of the bonds.

The dimensions of lap shear tensile test specimen are shown in Fig.2 and these specimens were prepared from the Cp Ti / AA 7075 diffusion bonded joints by a line cutting machine (electric spark cutting). Test was carried out in 100 kN capacity servo controlled Universal Testing Machine and the results are presented in Table 3.

Fig. 3: Specimens Were Prepared for Diffusion Bonding

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III. RESULTS AND DISCUSSION

From this work experimental results were presented in Table 3, the following inferences was obtained below :

(1) If the bonding temperature was lower than 400 ^{0}C, there is no bonding was occurred between Cp Ti and AA7075 aluminium alloy and due to the insufficient temperature to cause diffusion of atoms (Fig. 4a).

(2) If the bonding temperature was greater than 450 ^{0}C, then the bonding pressure decreased automatically and this to the melting of CP TI alloy due to higher temperature (Fig. 4b).

(3) If the bonding pressure was lower than 5 MPa, there is no bonding was occurred and this due to less number of contacting points (between surface asperities) through diffusion of atoms generally should occur (Fig. 4c).

(4) If the bonding pressure was greater than 15 MPa, then the plates were deformed plastically causing reduction in thickness and bulging at the outer edges (Fig. 4d).

(5) If the holding time was less than 5 min, then there is no bonding was occurred. These process due to the insufficient time allowed for the diffusion reaction to take place (Fig. 4e).

Lower value parameter (Temp, Pressure & Holding time)	Higher value parameter (Temp, Pressure & Holding time)
1.Temperature, ^{0}C	
*No Bonding at below at Temp. 400 ^{0}C *Due to the insufficient Temperature very less diffusion of atoms were witnessed.	*Above the 500 ^{0}C the aluminium get start melting and deform, *Due to this Bonding Pressure is automatically decreasing.
2.Pressure, MPa	
* No bonding at below at 5MPa Bond pressure. * Due to Less no of mating surface between Cp Ti/AA7075. This causes the Poor bonding .	* Above the 15 MPa Bonding Pressure, Aluminium get start deform and buldging. * Due to this Thickness of Aluminium get reduced.
3.Holding Time, min	
* No bonding at below at 5min Holding time. * Due to insufficient time to No bonding take place in between the Cp Ti/ AA7075	* Holding Time was higher than the 15 min, , Aluminium get start deform and buldging. * Due to this Thickness of Aluminium get reduced.

Processing windows for Temperature –time (T-t)	Processing windows for Pressure–time (P-t)
*Considering Arrhenius formula, welding temperature is the most prime parameter as for as diffusion bonding is concerned [20]	*Above the 500 ^{0}C the aluminium get start melting and deform, *Due to this Bonding Pressure is automatically decreasing.

Table 3: Experimental Results

Joint No.	Bonding Temperature (°C)	Bonding Pressure (MPa)	Holding Time (min)	Bonding (Yes or No)	Shear Strength (MPa)
1	400	5	15	No	-
2	425	5	5	No	-
3	425	5	10	No	-
4	425	5	15	No	-
5	425	5	25	No	-
6	425	10	30	Yes	22
7	425	10	35	Yes	20
8	425	15	20	Yes	18
9	425	15	25	Yes	16
10	425	15	30	Yes	16
11	425	25	35	No	-
12	450	5	30	Yes	22
13	450	5	45	Yes	28
14	450	10	15	Yes	20
15	450	10	30	Yes	23
16	450	10	15	Yes	20
17	450	10	20	Yes	20
17	450	10	30	Yes	22
18	450	15	10	Yes	23
19	450	15	15	Yes	24
20	450	15	20	Yes	26
21	475	5	10	Yes	20
22	475	5	15	Yes	22
23	475	5	20	Yes	24
24	475	10	10	Yes	36
25	475	10	15	Yes	32
26	475	15	10	Yes	12
27	475	15	15	Yes	22
28	500	25	5	Yes	18
29	500	5	15	Yes	18
30	500	5	45	Yes	16
31	500	10	15	Yes	16
32	500	15	10	Yes	14
33	500	15	15	Yes	12
34	525	6.5	10	No	-

IV. DEVELOPING TEMPERATURE– TIME (T–T) DIAGRAM

Temperature– Time (T–t) diagram was constructed, keeping bonding temperature in Y axis and holding time in X axis. At a constant bonding pressure of 5 MPa, the bonding temperature and holding time was varied to find out the processing (working) limits. Similarly, the experiments were conducted to find out the working limits for the bonding pressures of 10 MPa and 15 MPa respectively. These points were used to construct the Temperature–Time (T–t) diagram for the three bonding pressures and they are displayed in Fig. 5a–c.

The selection of diffusion bonding process parameters inside the region in the Temperature–Time (T–t) diagram always yielded good bonding between Cp Ti alloy and AA7075 aluminium alloys. From the Temperature to Time diagram the following inferences can be obtained: The bonding pressure increases, the holding time required to get good bonds decreases, due to irrespective of bonding temperature. However, the bonding pressure does not have significant influence on bonding temperature. The press-bond experiments with aluminium alloys indicates that high temperature, up to 0.881 of the homologous temperature and deformation are highly influential on bond strength.

V. DEVELOPING PRESSURE–TIME (P–T) DIAGRAM

Pressure–Time (P–t) diagram was constructed, keeping bonding pressure in Y axis and holding time in X axis. At a constant bonding temperature of 400 ^{0}C the bonding pressure and holding time was varied to find out processing limits. Similarly the experiments were conducted to find out the working limits for the bonding temperature of 400 ^{0}C and 500^{0}C respectively.

A. Elrefaey, W. Tillmann Infered that the joint could not be bonded at a temperature lower than 800◦C even at holding time of 180 min. However, at 850◦C successful.When the bonding temperature was increased to 850 ^{0}C with out any incremental in diffusion time, bonding could be effected. It is well known that adequate heat, diffusion time and pressure are required for atoms to diffuse in this bonding method.

Diffusion time is dependent operation parameter and is interrelated with temperature, pressure and the type of bonding.

The microstructures of the joints bonded at 475^{0}C and 10min for 5 MPa, 10 MPa, 15 Mpa and 25MPa was shown in Fig. 7.

A microstructure analysis indicates that change in grain morphology is more obvious for Cp Ti with the increasing Bonding Pressure than for AA7075 alloy. Equiaxed and more homogeneous grains are seen in these specimens due to absence of HAZ (heat affected zone) who exist in the fusion welding methods. Grain growth in the bonded materials can be attributed to recrystallization and to the enveloping of small grains by bigger ones. The tendency for grain growth after recrystallization is related to grain boundary energy. In order to obtain a lower level of energy, total grain boundary per unit volume needs decreasing and this, in turn, requires the growth of grains. However, it is well known that grain growth is not desirable. From the results, it is apparent that shear strength of the bonds depends on bonding temperature, bonding pressure and holding time. However, shear strength cannot be used to evaluate the extent of bonding because the specimens may have different tempered conditions.

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But it was reported [16] that the actual shear strength requirements of the bonds for aircraft structures are generally in the order of 10–20 MPa. Hence, in this investigation, the shear strength of the bonds was evaluated by conducting lap shear tensile strength. From the shear strength values, it could be inferred that all the bonds satisfy the

VI. MICRO HARDNESS PROFILE

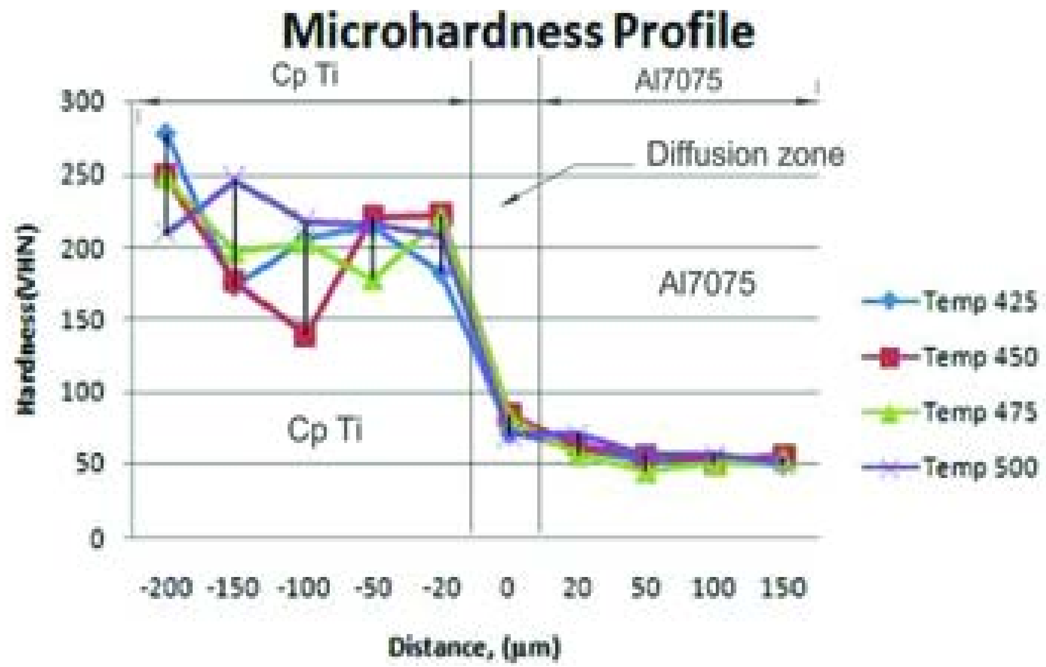


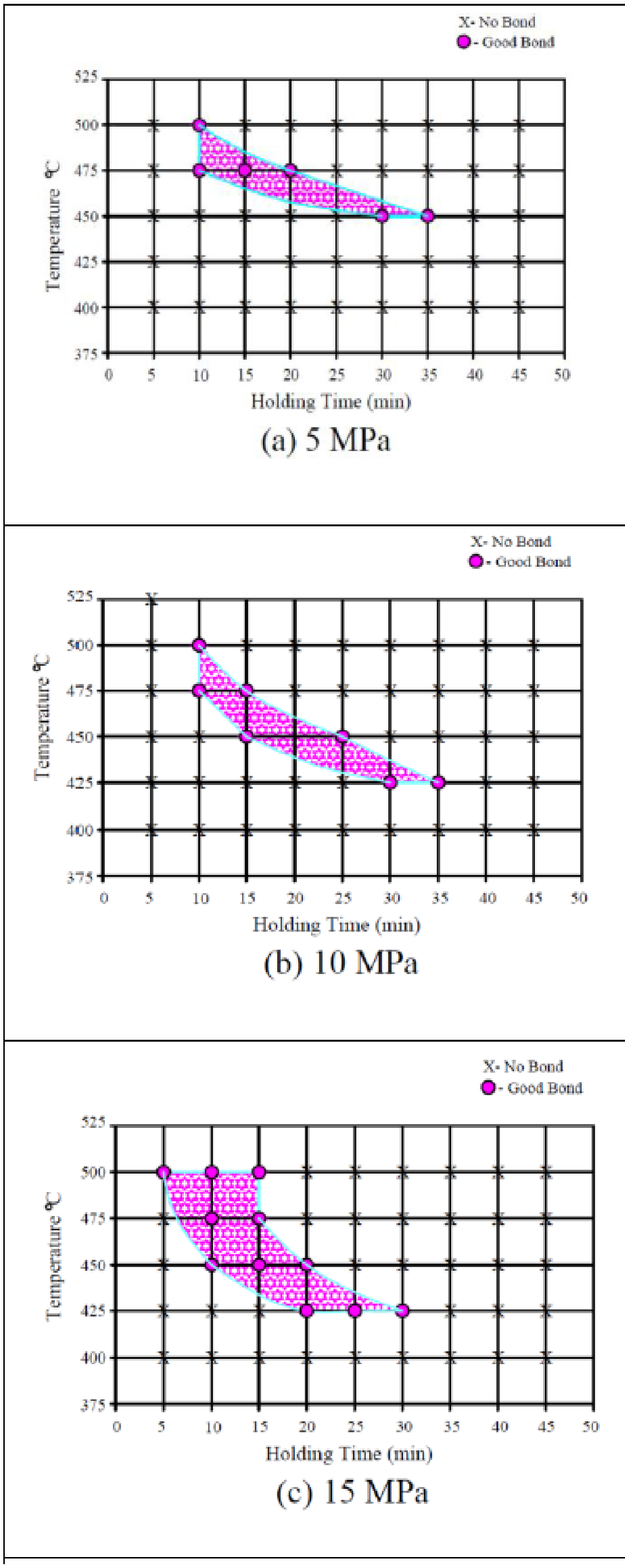
Fig. 8: Microhardness Profile

Fig. 3 shows the hardness test results obtained from joints as a function of bonding Temperature. The hardness value at joint interface taken from the 425 ^{0}C bonded sample is the lower value. This was due to the insufficient temperature to cause diffusion of atoms in the joint region. As bonding Temperature increases, the hardness values of the joint interface increase too.

This increase in the hardness values is due to formation of the intermetallics at the joint center. On the other hand, the hardness at a distance of 20 µm from the joint center in Al7075 side for bond made at 450 ^{0}C is higher than the values of 425 and 475 ^{0}C bonded joints.

This is due to the fact that the width of the joint region was reduced with increasing Temperature. As can be seen in the hardness profiles, the hardness at a distance of 50 µm from the joint center in Al alloy side of a 15 min bond was measured to be 83.1 VHN which belongs to Al matrix.

Moreover, the hardness of 271 VHN was recorded at a 50 µm distance inside the Ti alloy which can be attributed to the Ti matrix. Therefore, it can be concluded that eutectic phases and intermetallic compounds were formed at this distance range.



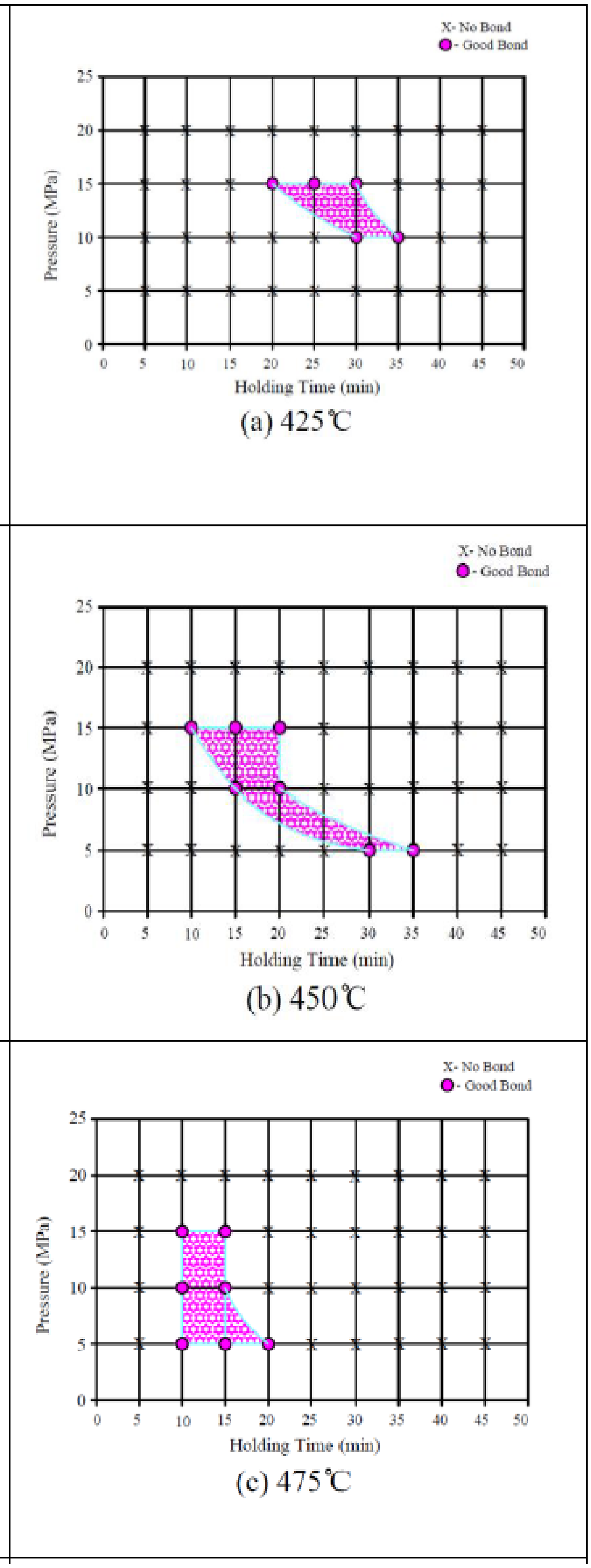
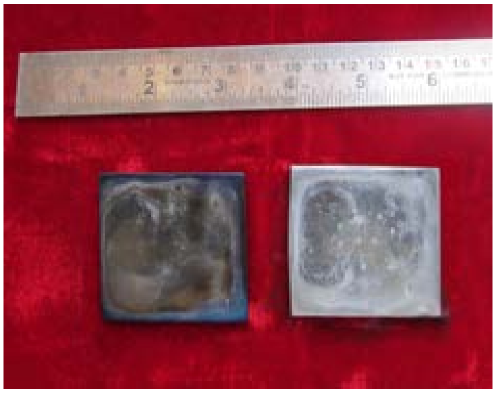


Fig. 4: Temperature-Time Diagram

Fig. 5 Pressure-Time Diagram



a) Temperature <400^{0}C

b) Temperature >500^{0}C

a) Pressure < 5MPa

b) Pressure >15MPa

a) Holding time < 5min

b) Holding Time > 15MPa

Fig. 6: Bonds Fabricated Using Lower and Upper Limits of Process Parameters

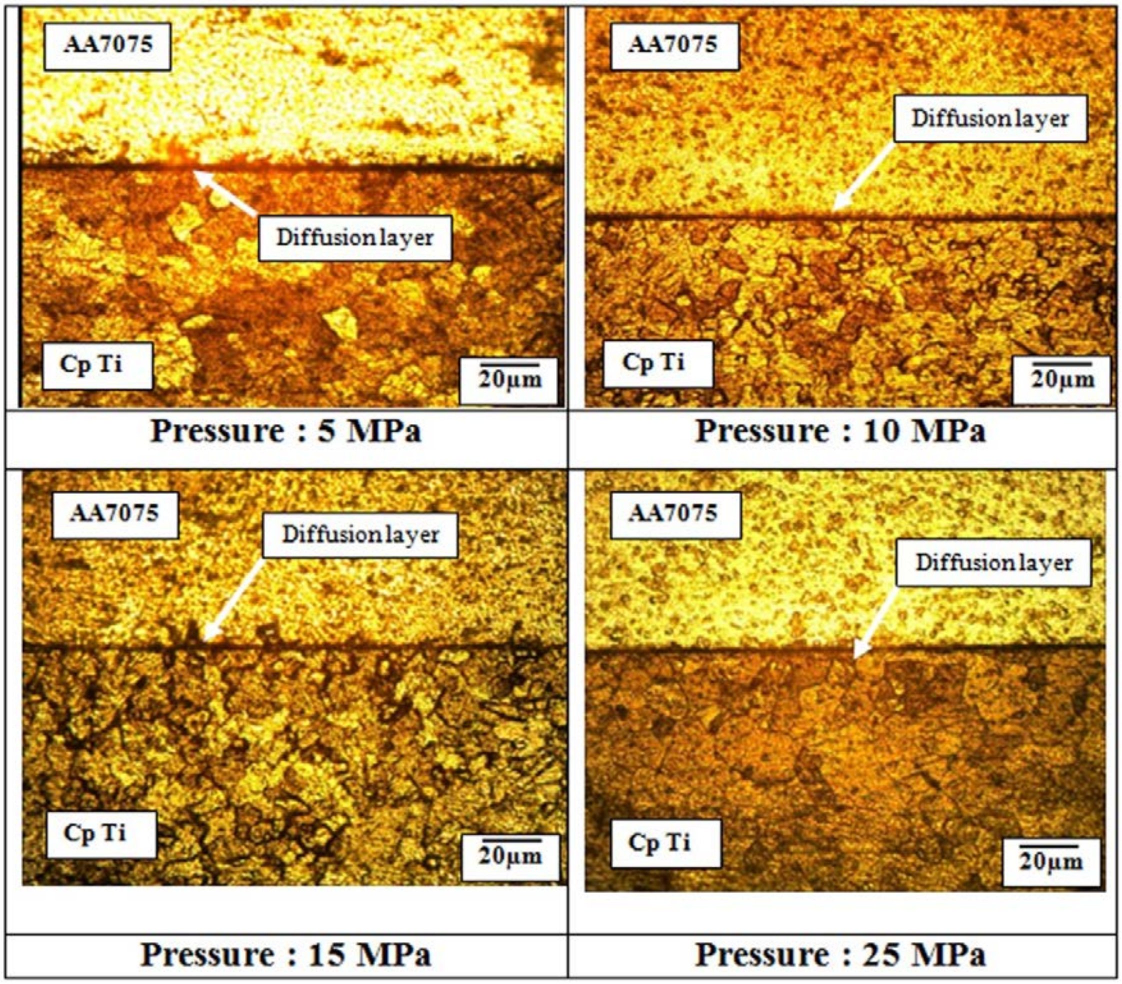


Fig. 7: Optical Micrograph of the Specimen Bonded at 475^0 C

VII. CONCLUSIONS

In this investigation, will act as reference maps to the design engineers and welding engineers for selecting appropriate diffusion bonding process parameters to join Cp Ti – AA7075 aluminium alloy without trial experiments. A bonding temperature of 475 ^{0}C, bonding pressure of 10 MPa and holding time of 15 min yielded highest shear strength due to the formation of optimum thick diffusion layer at the interface of Cp Ti – AA7075 aluminium alloy.

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