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Microstructure and Mechanical Property Analysis of Transient Liquid Phase Bonded IN718 Joint

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Abstract

The need to join dissimilar alloys is likely to increase especially in the aerospace and automotive manufacturing industry where an increase in power to weight ratio and fuel efficiency is important factors for the success of this industry. Transient Liquid Phase (TLP) diffusion bonding is a joining process which offers an alternative bonding method for metallic materials which cannot be bonded together by conventional fusion welding techniques. It has generally been observed that besides other experimental parameters (e.g. bonding temperature, pressure and hold time) which influence TLP bonding behavior, the interlayer material plays a vital role in bond formation, joint microstructure and mechanical properties. Transient liquid phase (TLP) bonding is a comparatively new bonding process that joins materials using an interlayer. TLP process is the joining process between two IN718 super alloys and to the metallographic and mechanical analysis. The joining process was implemented at 1050ºC for bonding time 1 hour. The specimen was observed under optical microscope to analyze the microstructure of the bonded sample. Three different contrastive zones are contemplated in the specimen (1) base metal, (2) diffusion affected zone, (3) bonded zone. On heating, interlayer melts and it diffuse in to substrate material, inducing isothermal solidification and melt at high temperature. The process was found joining of IN718 Ni based super alloy. TLP bonding is also use to joining the process in ceramics. The Vickers hardness test was used measure the hardness of the IN-718. The two heat-treated and non-heat treated sample was examined in hardness test. It shown that various zones are derived in the specimen like base metal, diffusion zone and bonded zone. The bonded zone is much higher than the heat-treated sample as compare to non-heat treated.

Keywords: Transient liquid phase (TLP) Bonding; IN718 Ni based Super Alloy; Aerospace and Automotive Manufacturing Industry.

1. INTRODUCTION

Transient liquid phase (TLP) bonding is a widely used capillary joining process. It is a joining process, which applied for bonding many metallic and ceramic systems, which cannot be bonded by conventional fusion welding techniques.TLP bonding is derived from high temperature flux-less vacuum brazing. TLP bonding, the combination of interlayer material and thermal exposure employed are such that significant diffusion takes place during bonding. TLP bonding is eminently suited to the joining of components intended for demanding elevated temperature service. The bonding process characteristically lies between diffusion bonding & brazing, for this reason it is commonly called diffusion brazing. The kinetics of the process is controlled by solid state in to material. This process applied to many materials. The transient liquid phase process will apply those process which solid-state diffusion to drive the interlayer to solidification.

1.1 Transient Liquid Phase Bonding Process

The TLP bonding process involve the following steps [1], which include Setting up the bond, Heating at specified bonding temperature to produce a liquid in the bond region, Holding the bonding temperature until the liquid has isothermally solidified and Homogenizing the bond at a suitable heat-treating temperature.

1.2 Transient Liquid Phase Bonding Kinetics

The kinetics of transient liquid phase bonding is generally divided into following stages [1], which include Melting of interlayer material, Substrate dissolution, Isothermal solidification and Solid state homogenization

1.2.1 Melting of Interlayer Material

In transient liquid phase bonding, the substrate is heated 50 °C above the melting point of the interlayer material. During the heating small amount of interlayer material diffuses into base material and decreases the melting point of the base material near the bond zone.

1.2.2 Substrate Dissolution

In Fig.1.2 shows the Partial dissolution of the substrate material adjusts the composition of the liquid to that of the liquids (C_l). If the composition of the solid immediately adjacent to the liquid is brought to that of the solidus (C_S) at Tb, then the net result will be established at the solid/liquid interface. Once local equilibrium is achieved, dissolution desists. It does not require long-range diffusion in the solid and consequently, the activation energy for dissolution is usually very low, as compared to that for interstitial diffusion. Thus, only a few minutes holding at TB is required to complete the dissolution step. Many materials are joined by TLP bonding having microstructure to achieve mechanical properties

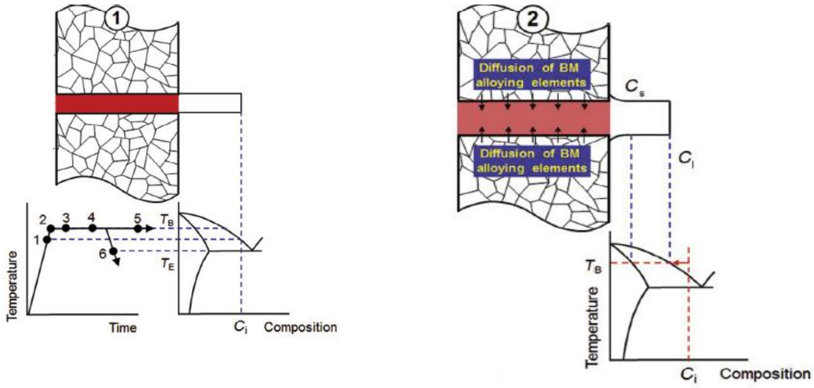

Fig.1.2 Dissolution stage in TLP bonding [3]

1.2.3 Isothermal Solidification

Fig.1.3 shows that the isothermal solidification of TLP bonding. After completion dissolution process, the liquid interlayer reached at maximum width & the melting point B starts to diffuse in to solid substrates. In this TLP, bonding process local equilibrium is maintained at solid/liquid interface throughout the solidification. The composition of Liquid and Solid remain fixed at CL& CS respectively. Thus, it continuous to diffuse during holding time and it will be removed entirely. Isothermal solidification is requiring long-range order in solid phase and in case of general, it is much slower than the substrate dissolution. However, there is no kinetic restriction at the interface. The important characteristics are that; it exists a temperature at which minimum solidification time occurs.

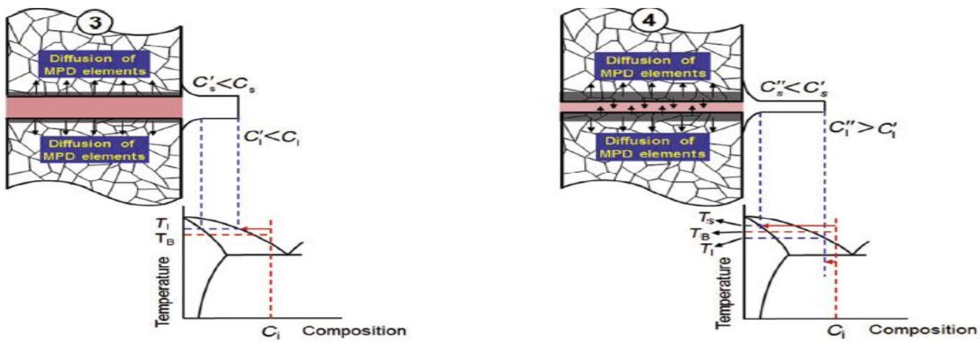

Fig.1.3 (a) Isothermal solidification (b) Complete isothermal solidification[3]

1.2.4 Solid State Homogenization

In solid-state homogenization which shows in Fig.1.4, Transient liquid phase bonding continued to in the order of homogenize the bond. The centerline of the bond line is must be reduced to below at room temperature solubility. Solid-state homogenization stage requires long range to diffuse of melting point in the substrates. It depends upon time at temperature. If the difference between CS& CL is large, solid state homogenization of TLP bonding can be protracted even it high. A solid-state diffusion process controls it, which is similar to other homogenization process. Therefore, the homogenization requires maximum time. TLP process assume that these are sequential &cannot be parallel. Fig.1.4 shows the solid-state homogenization.

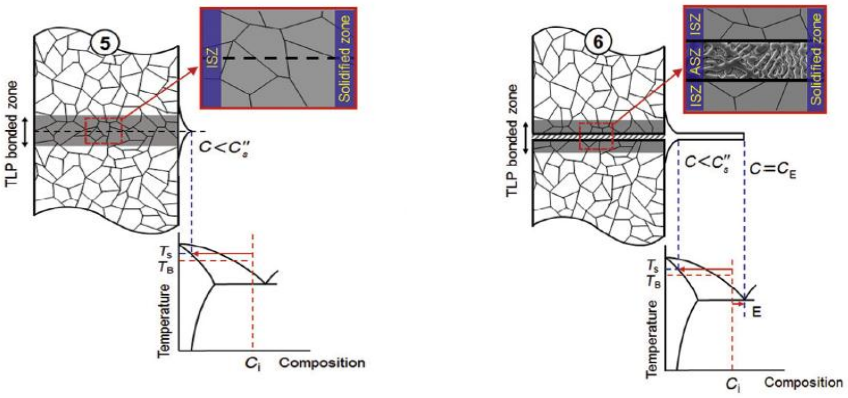

Fig.1.4 (a) Solid state homogenization (b) final stage [3]

2. LITERATURE REVIEW

In this section, brief history of TLP bonding and some previous investigations are discussed. The influence of different process parameter on the microstructure and mechanical properties of the bond are highlighted. Also some variant of TLP bonding is discussed. *Pouranvari et al.* [2] performed an experiment to obtain a relationship between microstructure and strength characteristics relationship during transient liquid phase (TLP) bonding of cast IN718 nickel based super alloy. Based on the LMP, explore the bonding temperature. It was found direct relationship between LMP & ISZ. *Shamsabadi et al*. [3] performed and experiment to study the effects of temperature and time on the microstructure of the transient liquid phase (TLP) joints of IN-738 by using electron microscope like SEM, TEM. TLP bonding was conducted in an electrical furnace under a vacuum at 1150 °C for 1–120 min. specimen was more effective with no pressure applied. *M. Pouranvari et al*. [4] performed an experiment to observe the effect of bonding temperature on microstructural development during TLP bonded GTD-111 nickel based super alloy using Ni-Si-B interlayer. DAZ function is affected bonding temperature at 1100 ºC. AZ was observed while at1180 ºC base metal precipitates. *M. Pouranvari et al*. [5] performed experiment on solidification and solid state precipitation phenomena during transient liquid phase(TLP) bonding of wrought IN718 nickel base super alloy using Ni based ternary alloy. The bonding was carried out at 1000℃ for 10 min in vacuum furnace. Hardness test was conducted and it was found that the hardness of diffusion-affected zone was more as compared to the isothermal solidification zone due to the diffusion of boride precipitate into the DAZ. *Pouranvari et al.* [6] established that the transient liquid phase bonding of wrought IN718 using standard heat treatment cycles. The supper alloy use with liquids temperature of about 999℃ was founded in TLP bonding process . Hardness test was carried out after heat treatment process and it was found that the hardness of the ISZ was lower than the BM due to decrease the solid solution. *Ekrami at el*. [7] performed an experiment to study the effect of transient liquid phase diffusion bonding on microstructure and properties of a nickel base super alloy Rene 80. Ni based interlayer was bonded at 1100 ºC under vacuum pressure at its relative time. *Binesh et al.* [8] performed TLP bonding on IN738LC super alloy are carried out causing rapidly solidified Ni based foil. The effect of bonding temperature 1130-1170°C at 5-120 min. It shown in microstructure that the joint region and its mechanical properties. The solidification occurred during cooling from bonding temperature is formation of gamma solid, ternary, binary, joints brazed at 1130.1150,1170°C. *Khakian at el.* [9] performed TLP bonding IN718 and also IN738 is carried out at low bonding temperature isothermal solidification occurs. The interlayer used in Ni based alloy. The bonding was carried out at temperatures of 1080C, 1120C, 1150C and 1180C for different bonding times. As a result, shear strength increases with increase its time. *Maleki et al*. [10] studied the effect of gap size on transient liquid phase bonded IN738LC alloy using powdered AMS 4777 as the filler metal. As a result, it was in lower concentrations these elements may be in larger gap sizes. *Liu et al.* [11] performed an experiment to study the effect of transient liquid phase bonding on the ductility of nickel base super alloy in a stress rupture test. In stress rupture, testing it was observed that despite having approximately equal strength, the elongation and reduction of area of the TLP joints are lower than those of matrix samples are The solid solution strengthening of boron coming from the amorphous interlayer and the sub grain boundaries formed in the bonding zone contribute to the reduction of ductility of the TLP joints.

3. EXPERIMENTAL SETUP

3.1 TLP Set up

An experimental setup was designed in Fig.3.1, shows the bonding set up of TLP of IN718. TLP bonding set up is consisting of following parts. (a)Impedance power source provide the high temperature; (b)Copper wire connection;(c) Spring loaded nut and bolt mechanism, which provides the pressure for the bonding process; (d) Graphite; (e) Thermocouple, which connected to the sample to observe the bonding temperature; (f) Argon gas; (g) Measuring scale- uses to measure the displacement of the spring so that applied force can be calculated.

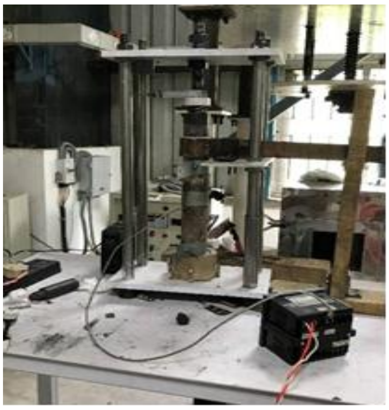

Fig. 3.1 TLP Set Up

3.2 Working process

The power supplied from the power source, which is shown in Fig.3.2. Because cupper is good conductor of heat and electricity, so use the wire to the heater. The two cylindrical graphite is used and its surface must be cleaned and finished. Then placed two Inconel sample in between the two graphite electrode. The interlayer of the material is sandwiched between the IN718 sample. As the graphite is highly oxidation, so to prevent this we used a sleeve like material over the whole graphite. The thermocouple is used to cover the applied system. Argon gas is applied. Fig .3.2 shows that the controller and impedance power source. Then slowly rotate the nut on the sample so that pressure will have applied. And the measuring scale is used to measure the force which applied after rotate the nut. Connected the thermocouple wire with the Inconel sample. And on the other hand of the wires must connected to the temperature source, and noted the desired bonding temperature. It can be measured by the help of F=KX, where k is spring load, x-displacement. When applied heat from the power source examined that the temperature increases slowly up to 1050 ºC and it’s taken so many time. Due to heat generated in copper wire it used the decent cooling fan to prevent heating.

Fig.3.2 (a) Controller (b) Impedance Power Source (c) Transformer

3.3 Sample Preparation

IN718 which is nickel (Ni) based super alloy sample are used for this experiment. At first cut the sample by wire cut electric discharge machine with any dimension but the surface of the sample is must be plane for this experiment. The two work pieces taken in proper same dimension which is placed in them. The surface of the sample cleaned and voids free and no light can have passed between the sample during operation. Then it cleaned with acetone to remove the unwanted material and we used the layer on the sample and sand witched with other sample. It is very important that when we bonded the sample by interlayer in between the sample which melts by bonding process.

3.4 Microstructural Analysis

The steps are preparation of metallographic specimen for microstructural analysis is as follows:

1**. Mounting**

Place the sample face down on the small piston inside the press, and lower the piston into the cylinder by opening slightly the valve on the front of the press. Approximately three tablespoons of Bakelite are poured over the sample, and the top of the press gently screwed into place. The cylindrical heater is plugged in and turned on and place the heater on the mold. By using the lever, we pushed up on it. When Bakelite's heated it starts to cover the whole area of the sample with no voids and any crack. Left for few minutes so that it accurately bonded with the sample. By the help of lever, apply the pressure some time when it going to be bonded. At last removed the heater and place the cooler to cool it sometime.

2. Grinding

Two types of grinding is required for desired sample optimized in microscope. Paper polishing and cloth polishing by using grinding machine then the sample is proceeding for the examine in microscope.

3. Etching

Chemical etching is method to generate contrast between microstructural features and specimen surface. The etchant was used for Inconel 718 was glyceregia. In the process of etching, the specimen dipped with etchant at some time and suddenly washed in water so that to avoid burning on it. Then the specimen dried by dryer. This process will continue till we get the microstructure of the desired sample.

4. Micro Hardness Measurement

Micro Vickers hardness test requires a micro-sized indenter to measure the hardness. The testing procedure of micro Vickers hardness is similar to that of macro Vickers hardness. Hardness test is done using micro Vickers hardness test machine. In this process diamond like indenter which penetrate on the work sample at load 100-200kg for 1 minutes. The two dimension we measure in this hardness test i.e. d1 and d2. The machine auto genetically measures the hardness and the values are noted down. As there are three zone, base metal, bonded zone, diffusion affected zone. Resulted that the base metal has same hardness while in case of bonded zone the heat treated and non-heat treated zone are different hardness.as shown in graph Fig.4.3.

4. RESULT AND DISCUSSION

The microstructure of the alloy IN-718 shows that the grain boundaries as shown in the Fig.4.1. The bonding temperature is observed at 1050ºC for one hour, but in case of heat treatment it is cleared observed at 760ºC for 10 hours. It was also found that the grain boundaries are largely affected in the whole region of the sample and properly grained in base metal and diffusion affected zone. In microstructure analysis concerning that the grain size, phases present, chemical homogeneity, elongated structure formed by plastic deformation.

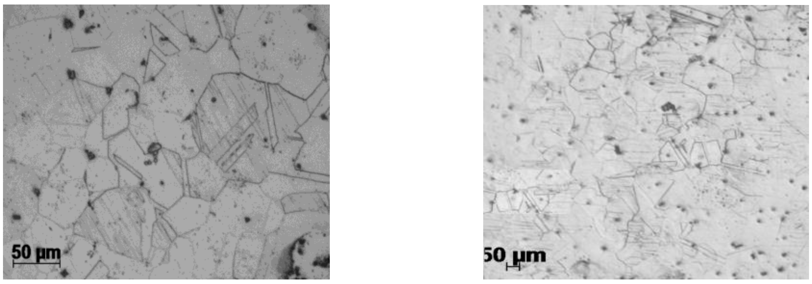

Fig.4.1 Microstructure of Base Metal of IN718

The grains are affected near the base metal and diffusion zone and also bonded zone. After etching the grains are clearly visible. There are so many phases present in microstructure of metal of IN718. In Fig.4.2. shows that there are three zones are obtained, these are base metal, diffusion affected zone and bonded zone. The dark black color region is bonded zone in which boron and silicon is present. And from this region the grains are affected toward the diffusion zone and also base metal.

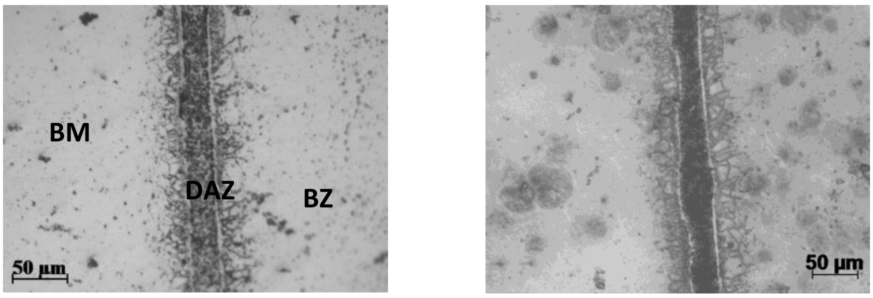

Fig. 4.2 microstructures of TLP bonded IN718

In hardness test, the hardness of the IN718 sample and got resulted that the base metal, diffusion zone, and bonded zone, which have different hardness. In Hardness, the heat treated sample and non-heat treated zone which shown in Fig.4.3and Fig.4.4 respectively. In heat treated graph Fig.4.3 shows that bonded zone is low as compare to the base metal and diffusion affected zone. But in some cases the diffusion affected zone nearly same. On the other hand, in Fig.4.4 the non-heat treated hardness graph shows that the bonded zone is lower as compare to heat treated zone. And the diffusion affected zone is same. But the base metal is slightly different. It observed that when sample heated the hardness zone is high but in which sample is not heat treated the hardness is low. But in which the diffusion-affected zone is nearly same in both HT & NHT. In bonded zone the heat-treated line is greater as compare to non-heat treated zone.

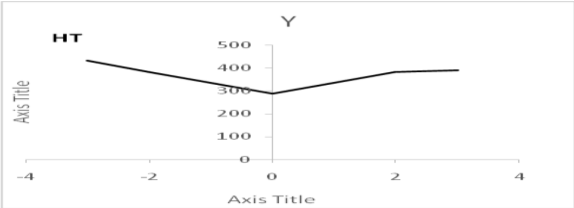

Fig.4.3 Heat Treated Hardness Graph

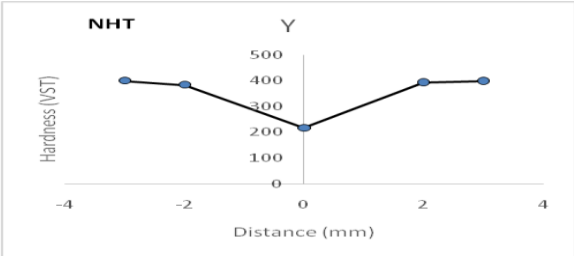

Fig.4.4 Non Heat Treated Hardness Graph

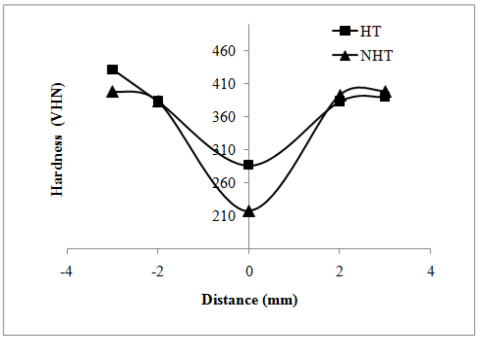

Fig.4.5 Vickers Hardness Graph

In Fig.4.5 the graph shows that the center point is 0. from o to 1 and -1 shows the bonded zone, from 1 to 2 and -1 to -2 shows the diffusion affected zone. Then 2 to 3 and -2 to -3 shows the base metal accurately. The graph is plotted the three zones like BM, BZ, DAZ to measure the hardness between them. During the bonding in hardness, the bonded zone is less than the diffusion zone and base metal due to the lack of the insufficient diffusion of alloy. The hardness which is very less than the bonded zone is non heat treated zone because of the diffusion of the alloy in it. Finally, it concluded that the in hardness graph, heat-treated line is larger than the non-heat treated and the diffusion zone is nearly same as compare to the base metal.

5. CONCLUSION

The TLP bonding of the IN718 was done successfully and the bond obtained was almost homogenous and uniform. As a result, the TLP bonding setup was designed successfully and the bonding of the IN718 super alloy was performed. The microstructural analysis of bonding sample was inspected and three zones are recognized. Those are bonded zone, diffusion zone, base metal. The bonded specimen was heat-treated and the hardness test of both heat-treated and non-heat treated specimen was carried out. A graph was plotted to compare the hardness of heat-treated and non-heat treated specimen which showed that there was a significant rise in the hardness of the heat treated bond zone This rise in the hardness can be attributed to the increase in diffusion of the alloying elements from the base metal to the bonded zone.

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