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DIFFUSION BRAZING OF A NICKEL BASED SUPERALLOY PART 2 – EFFECT OF SOLIDIFICATION MODE ON THE MECHANCIAL PROPERTIES

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Abstract

Relationship between microstructure and mechanical properties of transient liquid phase (TLP) bonded joints of GTD-111 nickel base superalloy using a Ni-Si-B interlayer was investigated. Shear strength and hardness profile of the joints were discussed with respect to the bond microstructure. In the bonding condition, in which isothermal solidification has not been completely accomplished, eutectic constituent which has the highest hardness in the bond region is the preferential failure source. There is an inverse relation between the eutectic size and shear strength of the joints. At the bonding time of 75 min at 1100°C, when the eutectic products are completely removed, bonds with shear strength of about 68% of that of the base metal are achieved.

Key words: transient liquid phase bonding; nickel-base superalloy; mechanical properties; isothermal solidification

Introduction

Gamma prime (γ′) strengthened nickel-base superalloys are extensively used in hot sections of aero-engine and power generation turbines. They offer excellent high temperature tensile strength, stress rupture life and creep properties, fatigue strength, oxidation and corrosion resistance, and microstructural stability at elevated temperatures.

Two important key microstructural requirements of γ′ strengthened nickel base superalloys joints are the avoidance of undesired intermetallic phase in the middle of the joint and development of a desired γ/γ′ microstructure in the joint region. Production of joints which fulfill the microstructural requirements for high stresses and temperatures can be achieved *via* transient liquid phase (TLP) bonding or so called diffusion brazing

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process [1-7]. In general, it is considered that there are three distinct stages during diffusion brazing, namely: base metal dissolution, isothermal solidification and solid-state homogenization. Combining isothermal solidification with a subsequent solid state homogenization treatment, offers the possibility of producing ideal joints [8].

The aim of this research was to investigate the effect of isothermal solidification on the mechanical properties of the diffusion brazed GTD-111 nickel based superalloy.

Exprimental Procedure

Standard heat treated GTD-111 nickel base superalloy was used as the base metal in this investigation. The chemical composition (in wt.%) of GTD-111 was as follows: Ni-13.5Cr-9.5 Co-4.75Ti-3.3Al-3.8W-1.53Mo-2.7Ta-0.23Fe-0.09C-0.01B. A commercial Ni-4.5Si-3.2B alloy (MBF30), in the form of amorphous foil with 25.4 μm thickness was used as the interlayer. 10mm×5 mm×5 mm coupons were sectioned using an electro-discharge machine. To remove the oxide layer, contact surfaces were ground with 600 grade SiC paper and then ultrasonically cleaned in acetone bath. The interlayer was then inserted between two base metal coupons. Stainless steel fixture was used to fix the coupons in order to hold the sandwich assembly and reduce the metal flow during the TLP operation. Liquidus and solidus temperatures of the interlayer are 1054°C and 894°C, respectively. Bonding was carried out at 1100°C for 30, 45, 60 and 75 min under a vacuum of approximately 10^{-4} torr in a vacuum furnace. Joints with complete isothermally solidified microstructure were homogenized at 1150°C for 240 min in an argon gas atmosphere (%99.999 Ar) using a tunnel furnace.

Bonded specimens were sectioned perpendicularly to the bond. Microstructure of the joints was studied using optical microscope and scanning electron microscope (SEM). For microstructural examinations, specimens were etched using Murakami etchant (10g KOH, 10g $K_3[Fe(CN)_6]$, 100 ml H_2O).

Microhardness test was used to determine the joint region hardness profile. The test was conducted on samples cross sections using a 25 g load on a Buehler microhardness tester. Room temperature shear test was performed employing an Instron tensile machine with a cross-head speed of 2 mm/min. The edge effects were removed by machining before the shear test. The shear fixture used for testing is schematically shown in Fig. 1.

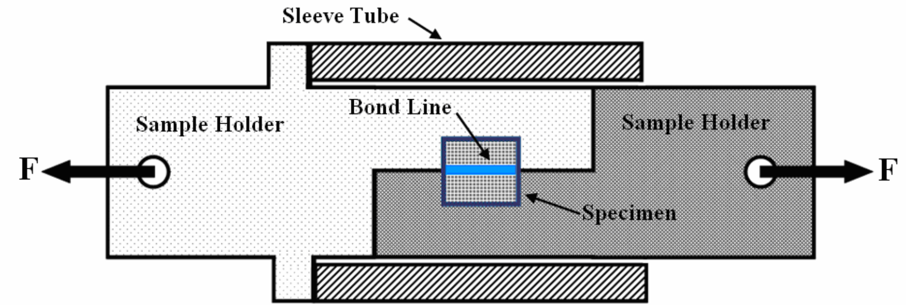
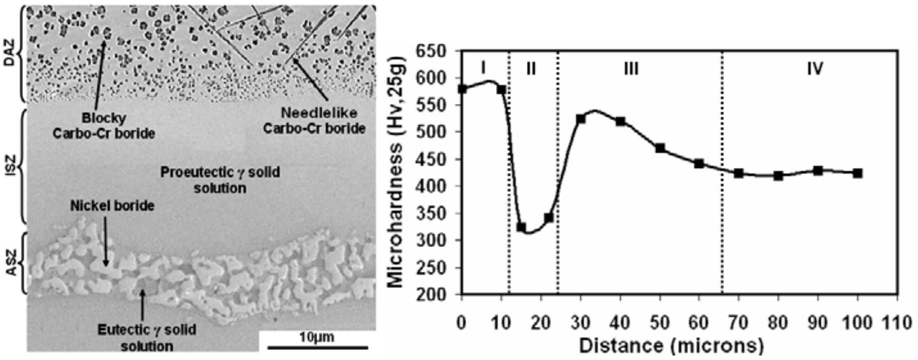


Fig.1 Schematic drawing of the shear test fixture

This fixture subjects the sample to a pure shear stress at the bond line. A metal sleeve was placed over the fixture in order to allow no movement of the specimens. For comparison, the shear test was also conducted on the base metal.

Results and Discussion

Fig. 2a shows SEM image of the bonds made at 1100°C for 30min.



a) *b)*

Fig.2 a) SEM microstructure and b) hardness profile of bonds produced at 1100℃ for 30 min

Three distinct microstructural zones may be distinguished in the bond region:

(i) Isothermally solidified zone (ISZ) formed by interdiffusion induced compositional change. The microstructure of this zone consists of proeutectic nickel rich γ solid solution phase and is free from γ′ precipitates.

(ii)Athermally solidified zone (ASZ) formed due to the insufficient time for the completion of isothermal solidification. The microstructure of ASZ consists of microconstituents with eutectic-like morphology, and is made up of two distinct phases. SEM/EDS analysis suggested that the intermetallic phase is a nickel-rich boride and the second phase is a nickel rich γ-solid solution

(iii) Diffusion affected zone (DAZ) consists of second phase particles with two different morphologies: blocky particles and particles with needle-like morphology. EDS compositional analysis of metallic elements suggested that both particles are Cr rich carbo-boride.

Hardness profile across the joint region may be regarded as a quantitative parameter connected with mechanical property of different zones in the joint region. In addition, the hardness profile is a good indicator of bond microstructure and can be used to assess the effect of secondary phase precipitates on mechanical properties. Also, it can be used to assess the degree of homogenization. Fig. 2b shows the hardness profile of this bond indicating four distinct zones.

Region I corresponds to ASZ. According to the microstructure of ASZ, the peak hardness in this zone is due to the fact that the eutectic type structure contains hard brittle nickel boride.

Region II corresponds to ISZ which has lower hardness relative to the base metal. Interdiffusion of alloying elements between the joint region and the base metal determines the hardness of ISZ. Low hardness of ISZ can be attributed to insufficient diffusion of alloying elements such as solid solution strengthening elements (e.g. Co) and γ′ forming elements, Al and Ti.

Region III corresponds to DAZ. The hardness peak which is observed in this region can be related to carbo-boride precipitates.

Region IV corresponds to the base metal.

Joint microstructure depends on elemental interdiffusion between the base metal and the joint region, which, in turn, is governed by bonding time keeping the constant temperature. The average ASZ size was measured using SEM micrographs and plotted against bonding time (Fig. 3).

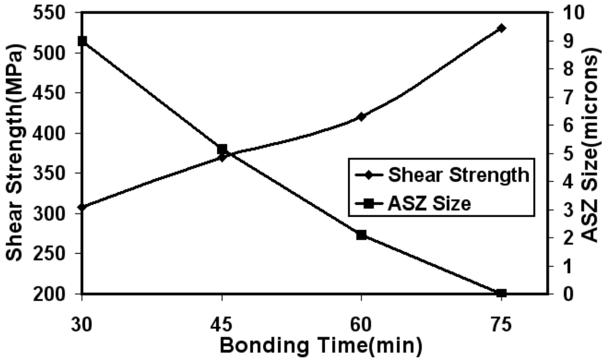
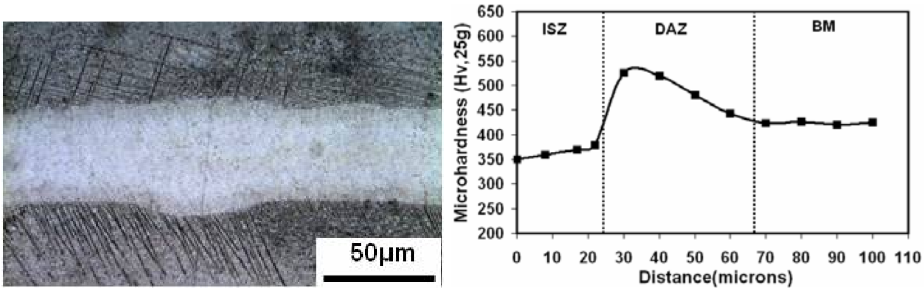


Fig.3 Relation between shear strength and ASZ size with bonding time

As can be seen, ASZ width decreases with increasing the bonding time. Effect of bonding time on the shear strength of TLP joints is also shown in Fig.3. It can be seen that increasing the bonding time increases the joint shear strength. The shear strength of bonds produced at 1100°C for 30 min shows the lowest value. It is known that the joint strength and fracture of TLP joints mainly depend on the bond microstructure. As can be seen from Fig. 3 there is an inverse relation between joint shear strength and ASZ size. When bonding time is increased up to 45 min, the joint shear strength increases to 370 MPa. With further increase in bonding time up to 60 min, the joint shear strength increases to 420 MPa. This can be related to the decrease in the ASZ size. Therefore, it can be deduced that in bonding condition in which isothermal solidification is not completed, the extent of eutectic constituent (ASZ) is the controlling factor of the joint strength.

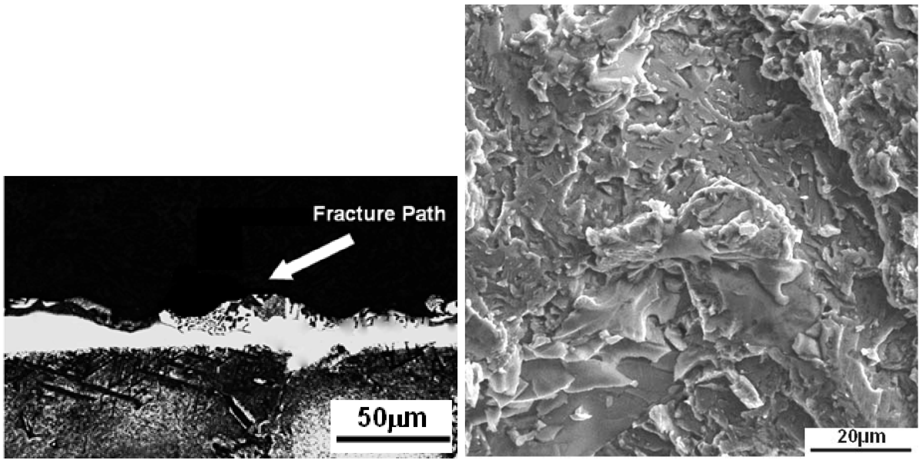
Isothermal solidification, which prevents the formation of centerline eutectic constituent, is completed at the bonding time of 75 min at 1100°C (Fig. 4).



a) *b)*

Fig.4 a) SEM microstructure and b) hardness profile of bonds produced at 1100°C for 75 min

Fig. 4a shows the microstructure of an isothermally solidified bond produced at 1100°C for 75 min. This figure indicates that ASZ is completely removed and the bond region is free from the hard brittle nickel boride intermetallic phase. Fig. 4b shows the hardness profile across the joint region of bonds at 1100°C for 75 min. As can be seen the peak in the hardness profile observed in DAZ of bonds made at 30 min is still observable after the completion of isothermal solidification. Low hardness of joint centerline is due to the insufficient formation of γ′ within the joint, leaving a relatively soft bond region. As can be seen from Fig. 4a, joint centerline is almost γ′ free.



a) *b)*

Fig.5 a) SEM micrograph of fracture path and b) SEM micrograph showing fracture surface of bonds at 1100°C for 30min

Microstructural examination of fracture surface of TLP bonds produced at 1100°C for 30 min shows crack propagation through the centerline eutectic (Fig.5a). High hardness of eutectic products (see Fig.2b) coupled with the fact that nickel boride phase forms interlinked network provide a metallurgical notch which significantly decreases the load carrying capacity of the joint. The fractography of fracture surfaces verified this fact (Fig.5b). This figure shows semi-cleavage/intergranular fracture surface of non-isothermally solidified joint. These modes of fracture are called low energy fracture modes which confirm low shear strength of this bond. Therefore, it is necessary to eliminate the eutectic products in order to improve the strength of joints.

At the bonding time of 75 min at 1100°C, in which the eutectic products are completely removed, bonds with shear strength of about 68% of that of the base metal (780 MPa) were achieved. It can be deduced that in bonding condition with the complete isothermal solidification, the amount of γ' precipitates in the bond region is the dominant factor for the shear strength. Therefore, it seems that precipitates in DAZ have less detrimental effect on the joint shear strength due to their non-continuously distributed fashion along the joint/base metal interface. However, the high chromium content of DAZ precipitates, can lead to a significant depletion of chromium around this region, which may result in a decrease in the corrosion resistance [9]. Considering lack of sufficient gamma prime precipitation in ISZ and the presence of the large amount precipitates in DAZ, there is a need to design a proper post bond heat treatment to homogenize the bond.

Conclusion

Microstructure and mechanical properties of TLP bonded GTD-111 nickel base superalloy were investigated. Based on the result of the present study the following conclusions can be drawn:

(1) In bonding condition in which isothermal solidification is not completely accomplished, eutectic type structure of ASZ which has the highest hardness in the bond region is the preferential failure source.

(2) There is an inverse relation between the eutectic size and shear strength.

(3)With completion of isothermal solidification, the extent of γ' formation in the bond region is the controlling factor for the joint shear strength.

(4) Considering lack of sufficient gamma prime precipitation in ISZ and the presence of the large amount precipitates in DAZ, there is a need to design a proper post-bond heat treatment to homogenize the bond.

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