BONDING PHENOMENON IN TRANSIENT LIQUID PHASE BONDING OF NI BASE SUPERALLOY GTD-111

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Abstract

Metallurgical studies on the bonded interlayer of directionally solidified Ni-base superalloy GTD111 joints were carried out during transient liquid phase bonding. The formation mechanism of solid during solidification process was also investigated. Microstructures at the bonded interlayer of joints were characterized with bonding temperature.

In the bonding process held at 1403K, liquid insert metal was eliminated by well known mechanism of isothermal solidification process and formation of the solid from the liquid at the bonded interlayer were achieved by epitaxial growth. In addition, grain boundary formed at bonded interlayer is consistent with those of base metal.

However, in the bonding process held at 1453K, extensive formation of the liquid phase was found to have taken place along dendrite boundaries and grain boundaries adjacent to bonded interlayer. Liquid phases were also observed at grain boundaries far from the bonding interface. This phenomenon results in liquation of grain boundaries. With prolonged holding, liquid phases decreased gradually and changed to isolated granules, but did not disappeared after holding for 7.2ks at 1473K. This isothermal solidification occurs by diffusion of Ti to be result in liquation. In addition, grain boundaries formed at bonded interlayer were corresponded with those of base metal. In the GTD-111 alloy, bonding mechanism differs with bonding temperature.

Key words

Directionally solidified Ni-base superalloy, GTD111, Transient liquid phase bonding, Microstructures Bonding mechanism, Bonding temperature

1. Introduction

Ni base superalloy, GTD111 is used extensively for high temperature rotating in land-based gas turbines[1]. Degradation of engine components may be caused by factors such as thermal cracking and distortion, oxidation, sulphidation, or other forces of corrosion, erosion, fretting and wear, damage from foreign objects ingested into the engine and distortion resulting from creep[2]. Rather than replacing these damaged expensive components at a cost of between 20~50% of the cost a new component. Arc welding, EB welding, brazing and TLP bonding are applied for repair of these components. However, the integrity of the repair has to be such that the mechanical properties of the joint are as close to or equivalent to the directional solidified materials properties

Transient Liquid Phase bonding (TLP Bonding) was chosen for this study as higher strength joints can be achieved compared to welding. This is believed to be because welding of GTD-111 alloy can result in hot cracking and micro fissuring during fusion welding and the formation of polycrystalline in weld metal.[3]

Transient liquid phase bonding has been developed to joint hot cracking susceptible Ni base cast superalloys and called “TLP bonding” or “Activated diffusion bonding”[4]. A liquid film temporarily forms at bonding interlayer during TLP bonding and solidifies isothermally by diffusion of melting point depressant in insert metal. Consequently, the excellent joint quality can be expected. TLP bonding has been applied for many cast superalloys and mechanism of TLP bonding have been also researched. However, The bonding mechanisms for directional solidified Ni base superalloys which content of Ti is high have not established, yet.

In this work, the change of the microstructure in joints of directionally solidified Ni base superalloy, GTD-111 TLP bonded with an insert metal MBF-50 as a function of bonding temperature and holding time were investigated.

2. Materials and experimental procedure

The chemical composition of the base metal and insert metal is presented in Table 1. Directionally solidified Ni base suepralloy, GTD-111 used for gas turbine bucket was employed as base metal. Thin foil of Ni-Cr-Si-B based MBF-50 alloy was used as filler metal. Melting range of MBF-50 is 1338K ~ 1423K.

Specimens to be bonded mechanically grounded up to #1500 silicon carbide paper and then cleaned by degreasing in acetone in an ultrasonic bath. The insert metal was insert into the base metal. The bonding was conducted in a high frequency induction furnace with vacuum of 10^{-4} torr or better. The specimens to be bonded were heated to 1403K and 1453K at a rate of 4K/sec and were held at bonding temperatures for 0 ~ 7.2ks and then were cooled in a furnace. Pressure applied with dead weight to the specimens was about 1.76MPa. Thermocouple percussion welded near bonded interlayer to control temperature.

Cross-sections of the specimens were examined with an optical microscope, SEM, EDX, EPMA and XRD.

Table 1 Chemical compositions of base metal and insert metal used

Materials	Element (wt%)													
	Cr	Co	Ti	Al	Mo	W	Ta	Fe	Mn	Si	C	Cu	B	Ni
GTD111	14	9.5	4.9	3.0	1.5	3.8	2.8	0.5	0.2	0.3	0.1	0.1	0.012	bal
MBF50	19.3	0.01	0.01	0.01	-	-	-	0.05	-	7.19	0.019	-	1.2	bal

3. Results and discussion

3.1 Change of microstructures in bonded interlayer

Fig.1 and Fig.2 show optical microstructures and SEM structures near interface of the joints held for various holding time at 1403K, respectively. A large amount of eutectic is observed at the bonded interlayer of joint held for 0ks. Fig.2 (a) indicate that region correspond to dendrite boundary of base metal dissolved more than dendrite core. This phenomenon occurs because the melting point of dendrite boundary is lower than that of dendrite core. It is confirmed form EDX analysis that eutectic presented in (b) of Fig2 was consisted of Ni-Si compound and Cr boride and phases presented in (c) of Fig.2 were Cr boride. Eutectic width decreases with holding time at 1403K, as shown in Fig.1. After holding for 7.2ks at 1403K, no eutectic was formed. From these results, it is concluded that isothermal solidification proceeds at the bonded interlayer during holding at 1403K.

Fig.3 and Fig.4 show optical microstructures and SEM structures near interface of the joints held for various holding time at 1453K. It is no doubt in comparison with Fig.1 and Fig.2 that the change of microstructures in joints made at 1453K is completely different from the change of those in joints made at 1403K. that is, liquid phases is remained in bonded interlayer and penetrated deep along grain boundary, while holding for 3.6ks at 1453K

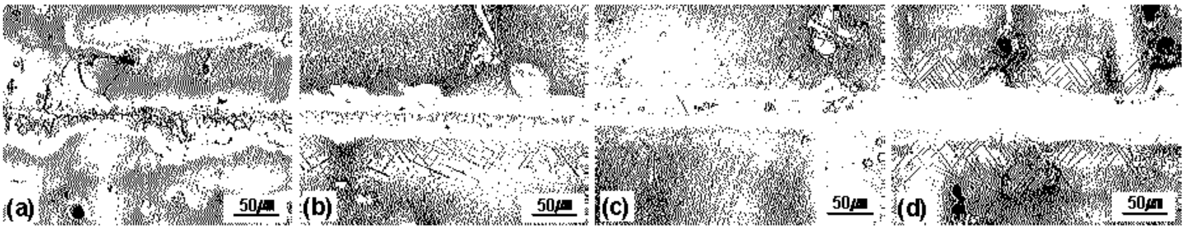

Fig.1 Microstructures in joints bonded at 1403K. (a) 0ks, (b) 1.8ks, (c) 3.6ks, (d) 7.2ks

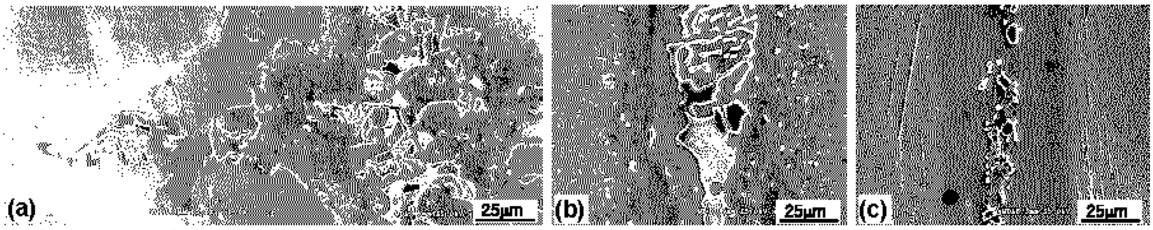

Fig.2 SEM structures in joints bonded at 1403K. (a) and (b) 0ks, (c) 1.8ks

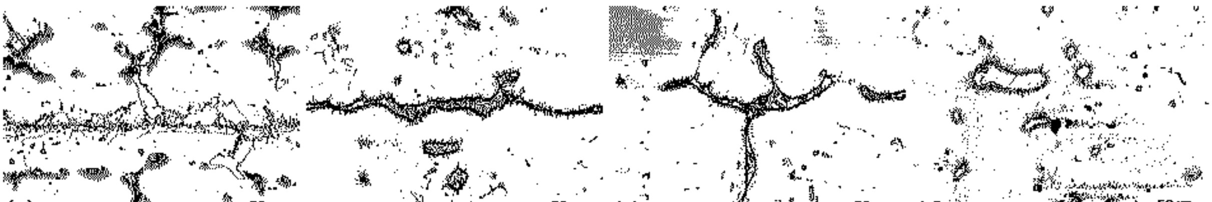

Fig.3 Microstructures in joints bonded at 1453K. (a) 0ks, (b) 1.8ks, (c) 3.6ks, (d) 7.2ks

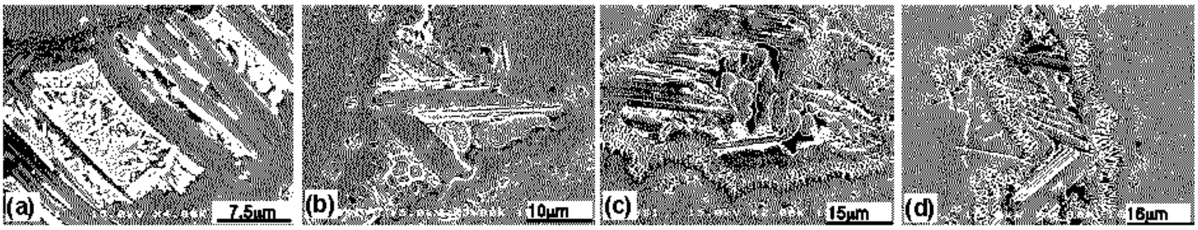

Fig.4 SEM structures in joints bonded at 1453K. (a) bonded interlayer (0ks), (b) grain boundary (0ks) , (c) bonded interlayer (1.8ks), (d) grain boundary (1.8ks)

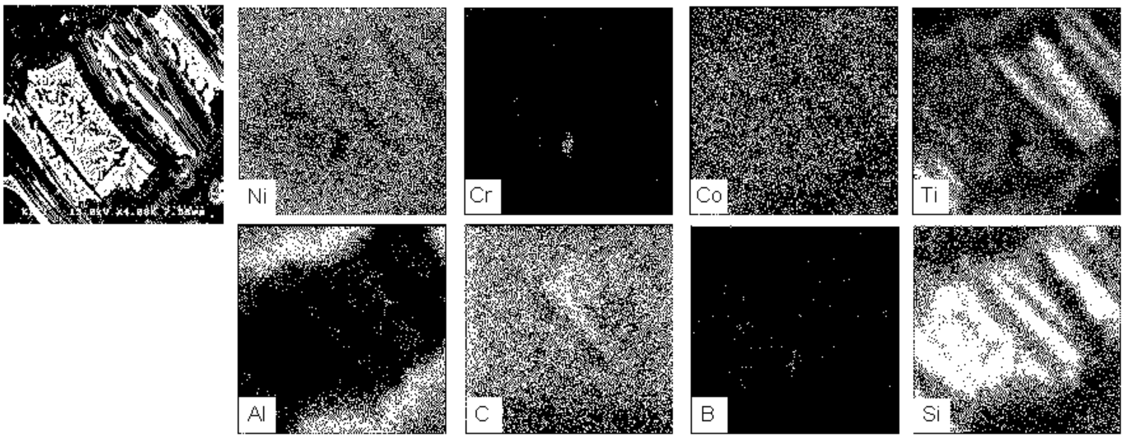

Fig.5 EPMA element mapping in bonded interlayer of joint bonded at 1453K for 0ks

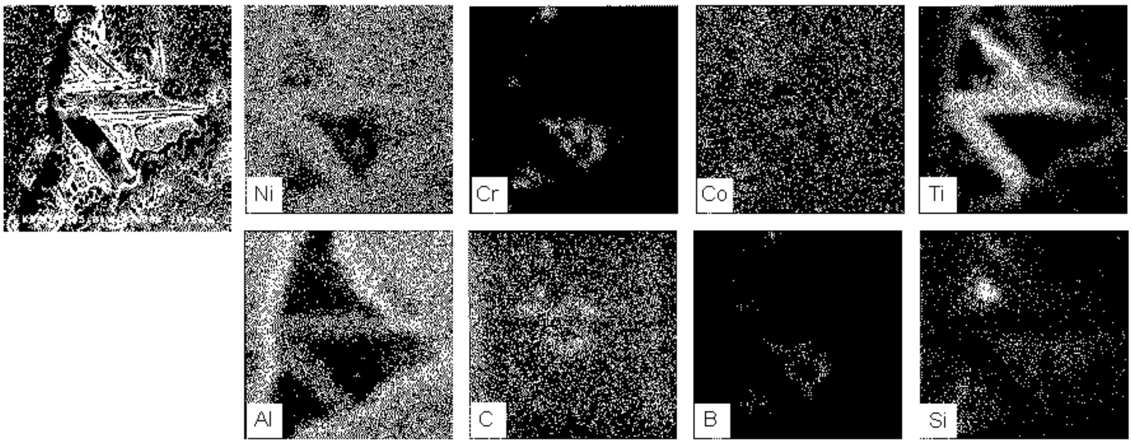

Fig.6 EPMA element mapping in grain boundary adjacent to interface of joint bonded at 1453K for 0ks

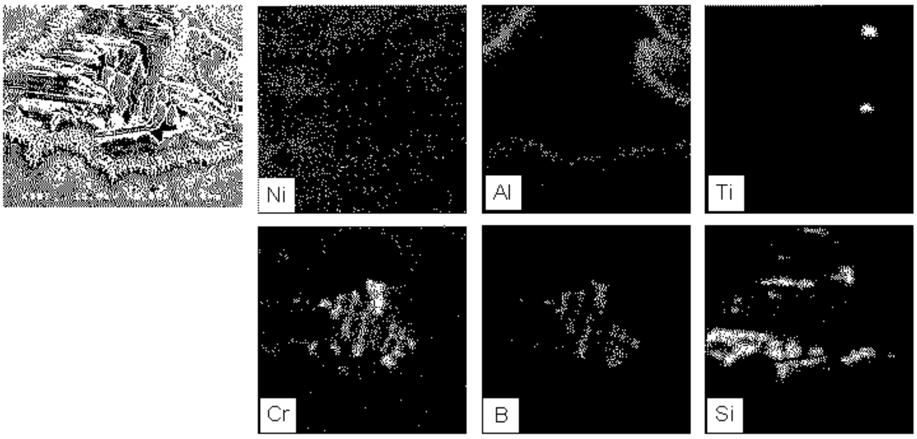

Fig.7 EPMA element mapping in bonded interlayer of joint bonded at 1453K for 1.8ks

Fig.4(a) and (b) indicate microstructure in bonded interlayer and grain boundary of joints held for 0ks, respectively, and (c) and (d) indicate microstructures of joints held for 1.8ks. Microstructures in the grain boundary are quite similar to those in the bonded interlayer. Fig.5 and Fig.6 show SEM structures and results analyzed by EPMA for microstructure indicated in Fig.4(a) and (b), respectively. Both microstructures mixed equally with Cr boride, Ni-Si compound, η phase($Ni_3(TiAl)$), γ' and matrix. Fig.7 shows results analyzed by EPMA for microstructure in the bonded interlayer of joint held for 1.8ks(Fig.4(c)). This result is identical with above results. Solidification process of liquid insert metal during holding at 1453K seems to be different isothermal solidification of typical TLP bonding.

3.2 Bonding mechanism

It was found from the change of microstructure with bonding temperature examined above that TPL bonding process differs with bonding temperature. With this in mind, mechanism of bonding process at each bonding temperature was examined further.

Fig.8 shows the relation between eutectic width and the square root of holding time at 1403K. Where the eutectic width was determined by dividing the total area of eutectic by the measured length, 4.5mm. and total area of the eutectic in the bonded interlayer was examined using area analyzer. There are good linear correlations between reduced eutectic width and square root of holding time. From this result, it is confirmed that the isothermal solidification process at 1403K id controlled by the diffusion process of depressant element such as boron and silicon into base metal.

Fig.9 shows relation grain boundary of base metal and grain boundary formed at bonded interlayer of joint held at 1403K for 3.6ks and its schematic diagram. Numbers of the grain boundary at the bonded interlayer corresponded to numbers of it at both mating base metals.

Fig.10 shows indexing of the EBSP pattern obtained from regions indicated as A, B and C in Fig. 3. Table 2 shows results that analyzed crystallographic orientations of TD(transverse direction), LD(longitudinal direction) and ND(normal direction) at each position from EBSP pattern. The crystallographic orientations of B position in bonded interlayer have the deviation of 1.0 ° - 1.4° from orientation of base metal. Since this deviation seems to be in an error range, it might be inferred from these data that there is not a difference between the orientation of bonded interlayer and that of base metal. From these results, it is clear that solids epitaxially grow inward liquid insert metal from both mating surface of the base metals during isothermal solidification.

To examine bout mechanism of binding process at bonding temperature of 1453K is as follows. Fig.11 shows microstructures and results analyzed by EPMA of joints made under condition of 1473K x 0ks. (b) is observed in bonded interlayer and (c) and (d) is observed in grain boundary and dendrite boundary which is away 1.5mm from interface, respectively. These results revealed that phases in bonded interlayer and grain boundary contain boron and carbon, but phases in dendrite boundary contain only carbon. The appearance of boron in grain boundary far away from interface indicated that liquid insert metal reacted with phases in grain boundary. It is impossible that this phenomenon occur by diffusion of boron at condition of 1473K x 0ks.

It is quite likely that this phenomenon occur by liquation of grain boundary. Liquation temperatures of grain boundary of GTD-111 in the range of 1423K to 1433K have been given from experiment. While heating and holding at a bonding temperature of 1453K above liquation temperature, insert metal melts and liquation occurs also in grain boundary and both liquids is mixed. Liquids are remained because melting point of liquid phases formed is lower than bonding temperature, although born diffused into base metal and matrix. However liquid phases disappeared when holding time increases over 7.2ks. This isothermal solidification occurs by diffusion of Ti to be result in liquation.

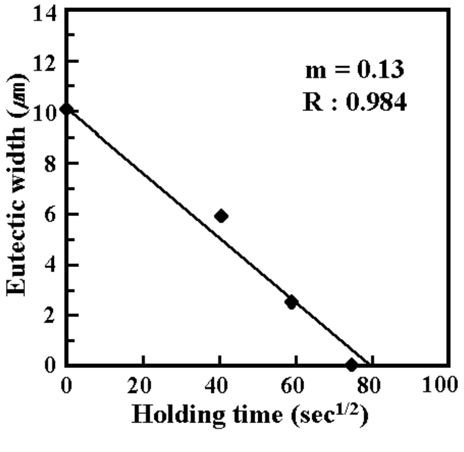

Fig.8 The relation between eutectic width and the square root of holding time at 1403K.

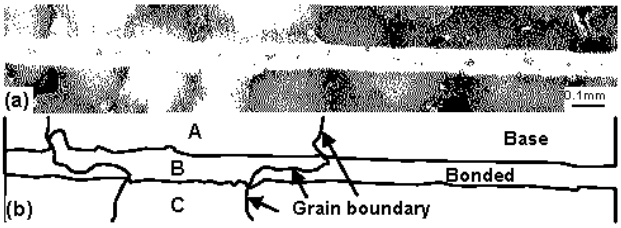

Fig.9 grain boundary feature formed at bonded Interlayer of joint held at 1403K for 3.6ks and its schematic diagram.

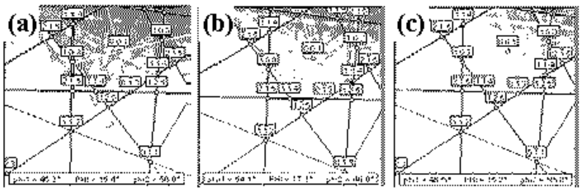

Fig.10 The EBSP pattern obtained from regions indicated as A, B and C in Fig. 3.

Table 2 Crystallographic orientations analyzed from EBSP pattern

	ND	LD	TD
A	92.6°	59.4°	3.3°
B	92.5°	59.4°	3.1°
C	93.4°	57.8°	2.3°

TD(transverse direction), LD(longitudinal direction) and ND(normal direction)

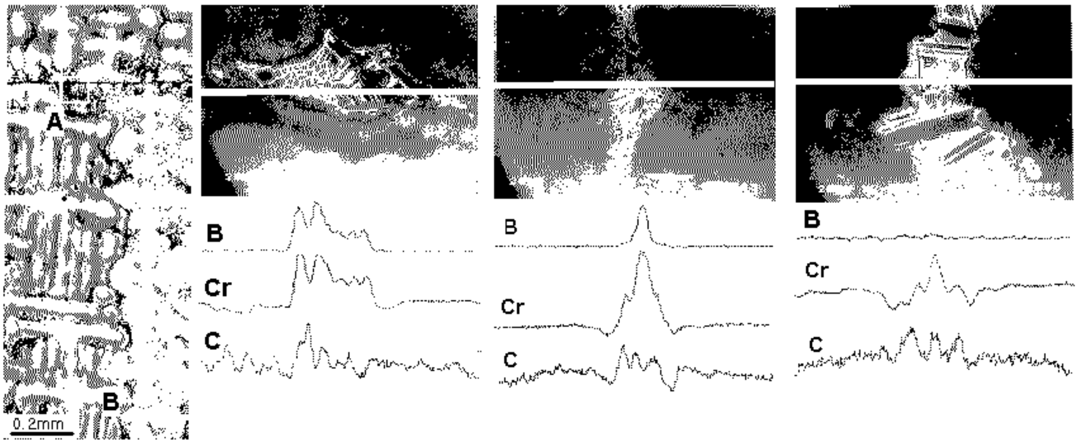

Fig.11 Optical microstructure of joint bonded with condition of 1453K x0ks and EPMA line analysis for phases in boded interlayer (b), grain boundary(c) and dendrite boundary(d) away far from interface.

4. Conclusion

The results of this investigation are now summarized

1. In the bonding process held at 1403K, liquid insert metal was eliminated by well known mechanism of isothermal solidification process and formation of the solid from the liquid at the bonded interlayer were achieved by epitaxial growth. In addition, grain boundary formed at bonded interlayer is consistent with those of base metal.
2. In the bonding process held at 1453K, extensive formation of the liquid phase was found to have taken place along dendrite boundaries and grain boundaries adjacent to bonded interlayer. Liquid phases were also observed at grain boundaries far from the bonding interface. This phenomenon results in liquation of grain boundaries. With prolonged holding, liquid phases decreased gradually and changed to isolated granules, but did not completely disappeared after holding for 7.2ks at 1473K. This isothermal solidification occurs by diffusion of Ti to be result in liquation. In addition, grain boundaries formed at bonded interlayer were corresponded with those of base metal.
3. In TLP bonding process of the directionally solidified Ni base superalloy, GTD-111 alloy, isothermal solidification mechanism differs with bonding temperature

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