The dissolution behavior of additive base metal powder in the wide gap TLP bonded interlayer

Sungwook Kim, Changhee Lee
Division of Materials Science & Engineering, Hanyang University
17 Haengdang-dong, Seongdong-Ku, Seoul 133-791, Korea
Fax: 82-2-2290-0389, e-mail: chlee@hanyang.ac.kr

Ni-base superalloys have been successfully used in gas turbines for buckets and vanes exposed to long periods of service at high temperature. In order to prolong using time, repair and rejuvenation of gas turbine hot parts have been continuously employed. This study focuses on repairing of cracks in the used turbine hot parts using TLP (Transient Liquid Phase) repair bonding process. In the wide gap bonding, longer bonding time is needed and this is a shortcoming of TLP bonding. Base metal powder was added in the insert metal in order to shorten bonding process. The dissolution behavior of added base metal powder under the wide gap interlayer according to the bonding temperature and time was analyzed.

There was no change in the size of the added base metal powder when the bonding temperature was near the liquidus temperature of 1100℃, however, dissolution of base metal powder was occurred before the interlayer got to bonding temperature at 1150℃ and was accelerated at higher temperature of 1180℃. The added base metal powder increased wetting area and decreased liquid volume. The dissolution rate of the mixed insert metal used bond was larger than that of the metal only used bond. The addition of base metal powder was affected on the rate of dissolution.

Key words: Ni base superalloy, Wide gap TLP bonding, Dissolution, Dissolution parameter

1. INTRODUCTION

Transient Liquid Phase (TLP) bonding has excellent advantages concerning the welding problems, where insert metal is melted and solidified isothermally and diffused completely. Because of its high applicability, many studies have been reported concerning bonding process, mechanical properties including creep, microstructure including the distribution of alloying element and precipitation, selection of insert metal, bonding condition and the feasibility of amorphous sheet as insert metal.[1-11]

The most significant limitations to the use of TLP diffusion bonding for the narrow gap of repair were needs for adequate crack surface cleaning and the limits to the size and defects that could be repaired while still producing adequate mechanical properties in the repair joint. The oxides formed in high temperature service cannot be easily removed because the nickel alloys are strengthened by precipitation hardening elements such as aluminum and titanium, which form stable oxides. The cracks are ground out and eroded or worn areas are dressed to remove all surface oxides.[12] These preparing process make a wide gap. There is a problem in the wide gap TLP process, however, long holding time for the homogenization of interlayer. For saving the bonding process time, base metal powder is normally added in the bonding interlayer. Base metal power acts as an additional sink for dissolution of the melting point depressants (B, Si, etc.) from the melted insert metal.

The approach on the dissolution step has been conducted by Y.Nakao[4] using Nernst-Brunner equation[13]. Because of the difficulty in both analysis and experiment, however, study of dissolution has been hardly done. This was treated with only insert metal used and there was no study on dissolution in the base metal powder mixed bonding interlayer. The main purpose of this paper is to study the dissolution of base metal during heating and isothermal state at rapid heating rate in base metal power mixing insert used wide gap.

2. EXPERIMENTAL PROCEDURE

The materials used were a GTD-111 nickel base superalloy as the base metal, AMDRY 780TM paste as the insert metal. Insert metal paste is a nickel base alloy which has 3.2wt% boron-4.5wt% silicon as an additive melting point depressants and has the eutectic temperature at 1040℃. IN738 powder was used as an additive base metal powder, which has similar chemical composition with the base metal and has 75um mean particle size. The chemical compositions of the materials used are given in Table 1.

Table 1 Chemical compositions of base metal and insert materials (wt.%)

Alloy	Cr	Co	Al	B	Ti	Mo	W	C	Nb	Ta	Si	Ni
GTD-111	14	9.5	3.0	0.01	4.9	1.5	3.8	0.1	·	2.8	·	bal.
IN738	16	8.5	3.4	0.01	3.4	1.7	2.6	0.17	0.9	1.7	·	bal.
AMDRY780	·	·	·	3.2	·	·	·	·	·	·	4.5	bal.

A cast bar of the base metal was solution treated at 1150℃ for 4 hours and aged at 845℃ for 24hours followed by air cooling. Coupons with dimensions of 13mm diameter and 3mm thickness were cut from the bar by means of electro discharge machining (EDM). After machining, they were ground with 2000 grit

silicon carbide emery paper to remove the oxide layer produced by EDM process. Powder mixtures were prepared by mixing additive base metal powder and filler powder with weight percentage ratio of 60/40.

Bonding was conducted using a range of holding times from zero to 600sec at temperature range of 1100-1200℃ in a high frequency heating vacuum furnace. The vacuum pressure was about 2 x 10-5 torr. During the bonding process, a compressive stress of about 1 MPa was used to hold the joint together during bonding. Tungsten wire with 200 μm diameter was employed to initially maintain the desired width of the interlayer. The heating rate was 10℃/sec and cooling of the joint was performed very rapidly by injection of He gas. The heating rate and peak temperature was controlled by a reading thermocouple attached to the specimen.

For the metallurgical investigation, the bonded joints were sectioned, mounted and polished for metallurgical examination under an optical microscope using standard procedure. Metallographic samples for the OLM and SEM observation were etched at room temperature in a solution consisted of 1.2g CuCl2 + 10ml HCl + 10ml ethanol. The mean size of particle in the bonded interlayer was measured by a computer-assisted size analyzer. Micro hardness test distribution was measured at a load of 100g.

3. RESULTS AND DISCUSSION

3.1 Influence of bonding temperature

As is commonly known, the amount of dissolved material depends on the bonding temperature and the chemical composition of both the insert metal and the base metal. Figure 1 shows typical microstructures of bonded interlayer at different bonding temperatures 1100, 1150, 1180℃ without holding for any length of time. There was no change of added base metal powder at bonding temperature of 1100℃, as shown in Figure 1(a). Base metal powders were not fully wetted. There were also so many pores that were caused by insufficient wetting and filling of gap. The melted insert metal was solidified to eutectic phase. The change of microstructure at bonding temperature of 1150℃ was shown in Figure 1(b). Dissolution was started from the surface to the center through the grain boundaries of additive base metal powder. Base metal powders were partially dissolved and the initial base metal powders became smaller ones. Small size particles were observed near the base metal powders. For cases where grain boundary diffusion is much more rapid than lattice diffusion, the following process can be envisioned. During the initial stages of dissolution, the solute from the liquid will rapidly penetrate the grain boundaries. For the remainder of the process, the solute will diffuse into the grains within the powder by lattice diffusion. Figure 1(c) shows the microstructure of bonded interlayer at bonding temperature of 1180℃. Most of base metal powders were almost dissolved. Particles near base metal powders formed to larger size. There were several kinds of phases in the bonded interlayer such as remained base metal powder, eutectic phase, pro-eutectic phase, and blocky type precipitate.
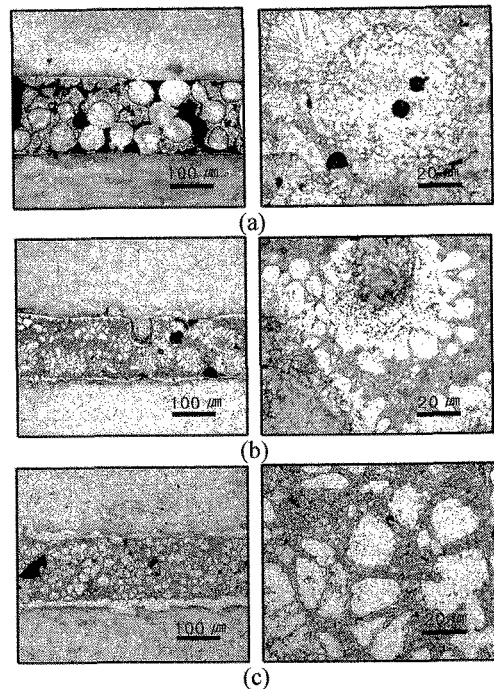

(a)

(b)

(c)

Fig.1 The OLM microstructure of interlayer during TLP bonding process. The holding time is 0sec and bonding temperature is (a) 1100℃ (b) 1150℃ (c) 1180℃.

Figure 2 shows SEM microstructures of the bonded interlayer. EDS mapping (Figure 2(b)) indicated that the area 1 was different from the area 2 in Co content. From this result, it can be expected that the small size particle area 2 is a pro-eutectic phase that is firstly solidified from the liquid and the area 3 is an eutectic phase.
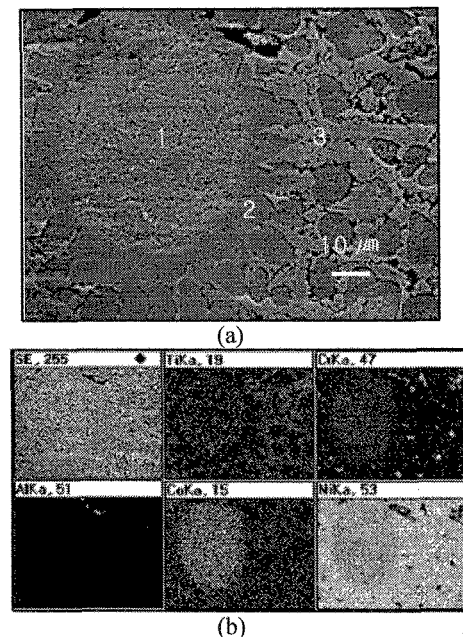

(a)

(b)

Fig.2 Microstructure of the interlayer on the base metal powder dissolution step, 1150℃, 0 sec. (1: base metal powder, 2: pro-eutectic phase, 3: eutectic phase)

There were many blocky type intermetallic phases along the eutectic phase. The results of EDS show that

the blocky phase is chrome rich precipitates. Intermetallic phases may be formed with the depressant elements such as boron and silicon. Boron forms chromium boride and more borides are formed at higher temperatures. From the chemical composition and shape of the intermetallic phase, it would be Cr_2B.[13] The formation of chromium boride is undesirable as their presence could attribute to a severe reduction in ductility as well as a significant shortening of stress rupture life.

The result of micro-hardness on these phases was shown in Table 2. The micro-hardness of the additive base metal powder was similar with that of base metal and pro-eutectic phase was a lower hardness than the additive base metal powder. The mean hardness value of the eutectic phase is much higher than that of the base metal and the additive base metal powder. It has been reported extensively that this eutectic structure is detrimental to mechanical properties due to its brittleness. This brittle eutectic phase would affect on mechanical properties of the bonded interlayer.

Table 2 Micro Vickers hardness of each phase in bonded interlayer (unit: Hv)

	Base metal	Base metal Powder	Pro-eutectic phase	Eutectic phase
Hardness	474	472	412	554

The tendency of dissolution of additive base metal powder with bonding temperature was plotted as shown in Figure 3. The size of base metal powder decreased rapidly with an increase of temperature. This means that dissolution can largely occur during heating cycle.
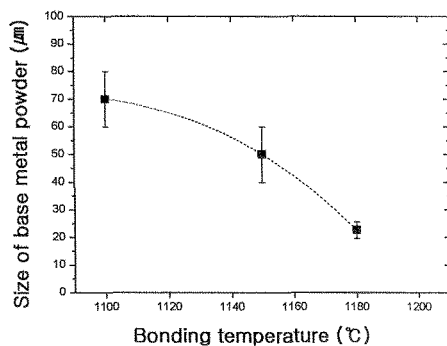

Fig.3 Effect of bonding temperature on the dissolution of base metal powder.

3.2 Influence of holding time

Figure 4 shows microstructures of the bonded interlayer that were produced with a holding time of 60 sec at isothermal temperatures. At the bonding temperature of 1100°C, there is little detectable change in the size of additive base metal powders. Because the bonding temperature was near the liquidus temperature, the additive base metal powder was not dissolved but the surface of base metal powder was changed to darker phase. At the bonding temperature of 1150°C (Figure 4(b)), when holding time was increased to 60sec, the original base metal powders were decomposed to smaller ones. Decomposition of base metal powder start from the surface to the center through the grain

boundaries and dendrite boundaries. Because grain boundary diffusion is much more rapid than lattice diffusion, the solute from the liquid will rapidly penetrate the grain boundaries and dendrite boundaries of base metal powder during the initial stages of dissolution. When holding 60 sec at the boding temperature of 1180°C, isothermal solidification has already preceded as shown in Figure 4(c).
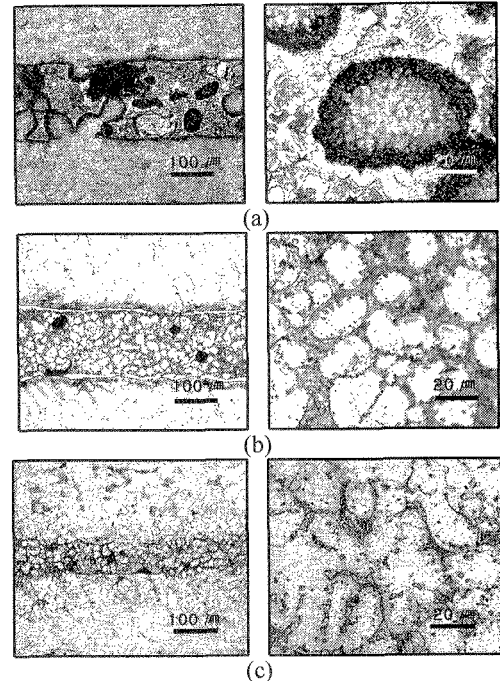

(a)

(b)

(c)

Fig.4 The OLM microstructure of interlayer during TLP bonding process. The holding time is 60sec and bonding temperature is (a) 1100°C (b) 1150°C (c) 1180°C.

Figure 5 shows the relation between the remained base metal powder and the square root of the bonding time. The slope at the bonding temperature of 1100°C did not change by holding time. Base metal powders were dissolved linearly with holding time at bonding temperatures 1150°C and 1180°C. At the bonding temperature of 1180°C, the additive base metal powder was almost diminished within 30sec.
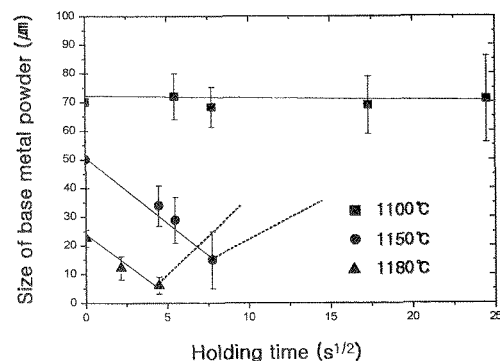

Fig.5 Effects of holding time on the dissolution of base metal powder.

3.3 Influence of additive base metal

In case of only insert metal used for bonding, a theoretical treatment of dissolution of the base metal was done by Y.Nakao, et al.[4] Their treatment was based on Nernst-Brunner's equation.[12] From the mass balance, the Nakao's dissolution parameter, P is

$$P = Kt = h[\ln\{Xs(X+ph)/ph(Xs-X)\}]$$

Where X is dissolution width of base metal after t sec, Xs is a saturated dissolution width, K is a dissolution rate constant, p is the density ratio of liquid over solid, 2h is initial width of liquid. This equation assumed that the total amount of solute in the liquid is always constant.

Figure 6(a) shows the relation between dissolution parameter and holding time at various bonding temperatures for the insert metal only used bond interlayer. Because the diffusion rate is higher at high bonding temperature, the dissolution rate parameter, K is increased with bonding temperature. When base metal powder is added, Figure 6(b) shows the relation between dissolution parameter and holding time at various bonding temperatures. The dissolution rate parameter, K was 0.8 um/sec at 1100℃, 2.4 um/sec at 1150℃ and 5.6 um/sec at 1200℃. The dissolution rate parameter of mixed insert metal used bond interlayer is larger than the insert metal only used bond interlayer. The addition of base metal powder affected on the rate of dissolution by increasing of solid/liquid interface area.
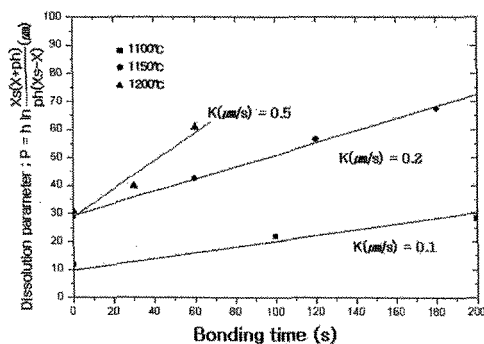
(a)
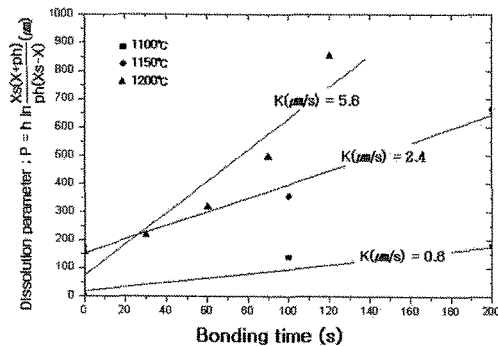
(b)

Fig.6 Relation between dissolution parameter P
and holding time t at various bonding temperature
(a) Insert metal only used (b) Mixed insert metal used

4. CONCLUSIONS

Wide gap TLP bonding with mixed insert metal was investigated to analyze the effect of various bonding temperature, time on the dissolution of added base metal powder.

1. There was no change of added base metal powder at the bonding temperature of 1100℃, because the bonding temperature was near the liquidus temperature, the additive base metal powder was not dissolved.

2. Dissolution was started from the surface to the center through the grain boundaries of additive base metal powder at the bonding temperature over 1150℃. Base metal powders were partially dissolved and the initial base metal powders became smaller ones.

3. The addition of base metal powder affected on the rate of dissolution by increasing of solid/liquid interface area.

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