[Article ID] 1003- 6326(2001)03- 0405- 04

Microstructures and properties of transient liquid phase diffusion bonded joints of Ni_3Al-base superalloy ①

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[Abstract] An investigation of transient liquid phase (TLP) diffusion bonding of a Ni_3Al-base directionally solidified superalloy, IC6 alloy, was presented. The interlayer alloy employed was Ni-Mo-Cr-B powder alloy. The results show that the microstructure of the TLP diffusion bonded joints is a combination of γ solid solution (or a γ+ γ′ structure) and borides. With the bonding time increasing, the quantity of the borides both in bonding seam and adjacent zones is gradually reduced, and the joint stress-rupture property is improved. The obtained stress-rupture property of the TLP bonded joints is on a level with the transverse property of IC6 base materials.

[Key words] Ni_3Al-base superalloy; TLP diffusion bonding; stress-rupture property
[CLC number] TG 245 **[Document code]** A

1 INTRODUCTION

At present, a great progress has been made for the study on cast Ni_3Al alloys[1]. Ni_3Al alloys have come to show high potential for a variety of structural applications because of their many superior properties, such as yield strength increasing with the temperature. However, an important issue in the development of Ni_3Al alloys for engineering applications is their joining technology. Some studies have shown that crack-free welds can not be obtained for the cast Ni_3Al alloys by fusion welding, and this is attributed to the microsegregation in the base materials[2~6]. Examination of the microstructure in the fusion zone indicates that a distinct microsegregation pattern is developed in the welds and this affects their ordering behavior. Therefore, it is necessary to explore other joining methods and techniques to obtain cast Ni_3Al alloy joints with satisfactory microstructure and properties. The transient liquid phase (TLP) diffusion bonding is one of the most hopeful joining techniques[7].

The alloy used for this study is the Ni_3Al-base cast superalloy IC6, which is developed for aeroengine components in China[8, 9]. Until now, research on joining of Ni_3Al-base superalloys with TLP diffusion bonding has not been reported. However, the TLP diffusion bonding of NiAl-base superalloys has been studied[6, 10~12]. Single crystal bond joints, with properties equivalent to the base metal, have been produced in NiAl single crystals using an activated-diffusion bonding process similar to that used for Ni-base superalloys[13]. In this research, the microstructures and properties of the TLP diffusion bonded joints of IC6 alloy are investigated, and the technical methods to improve the stress-rupture property of the joints at elevated temperature are also discussed.

2 EXPERIMENTAL

The base material used in this study was the Ni_3Al-base directionally solidified superalloy, IC6 alloy, with nominal composition of Ni-(7.5~ 8.5)Al-(13~ 15)Mo-(0.01~ 0.1)B(mass fraction, %). The interlayer alloy was I7P, a Ni-Mo-Cr-B powder (100 μm) alloy. According to the composition design principle of the interlayer alloy used for TLP diffusion bonding, the compositions of I7P are based on those of IC6 alloy, but the element Al was excluded. Besides in order to improve the oxidation resistance and reduce the melting point of the alloy, elements Cr and B with a certain amount were added into I7P. The faying faces of the bonding specimens were mechanically polished to a roughness of 1.6 μm. Before assembling and bonding, all specimens were ultrasonically cleaned in acetone for 5~ 10 min, and then dried by air. The bonding temperature was kept at 1 260 ℃, which was identical with the solution treatment temperature of IC6 alloy. The butt joint specimens with a joint clearance of 0.1 mm were prepared for metallographic examination and property testing. The powder interlayer alloys mixed with a liquid binder were preset on one side of the joint. The bonding experiments were conducted in a two-chamber brazing furnace and the vacuum was better than 2 × 10^{-2} Pa. During bonding process, the interlayer alloys were melted and flew into the clearance to form the joint. The microstructures of the joints TLP dif-

① [Received date] 2000- 07- 24; [Accepted date] 2000- 12- 10

fusion bonded under different conditions were analyzed by optical metallography, electron probe microanalysis and energy-dispersive spectroscopy. Finally, the stress-rupture property of the joints was tested.

3 RESULTS AND DISCUSSION

3.1 Microstructures of diffusion bonded joints

Figs. 1~3 show respectively the microstructures of the joints TLP diffusion bonded at 1260 ℃ for 4 h, 24 h and 36 h. The analysis results by EDS and EPMA indicate that the joints bonded at 1260 ℃ for 4 h (as shown in Fig. 1) mainly consist of γ-solid solution and dendritic borides. There exist four zones adjacent to the bonding seam because of the diffusion and penetration of Cr, B from I7P into the base material and the diffusion of Al from the base material to the bonding seam. From the bonding seam to the base material, the four zones are the dark transition zone "*A*", the light transition zone "*B*", the zone rich in bar-like and needle-like phases "*C*", and the base material. *A* zone is composed of a γ+ γ′ two-phase structure based on γ phase. In *B* zone, there are a few boride bars and needles in the γ+ γ′ matrix. In the next zone (*C* zone), the eduction of Ni, Mo borides is relatively more concentrated. The compositions of bar-like phases are similar to those of the dendritic phases, and it can be determined that they are Mo_2NiB_2 phases according to the Mo-B phase diagram and the analysis of Ref. [8]. The B content in the needle-like phases is lower, and they may be $(Mo, Ni)_2B$. The eduction of borides consumes a great quantity of Mo, Ni, which makes Al relatively rich in the adjacent zone, thus resulting in the formation of γ′ integument around the borides (as shown in Fig. 1(c)). The base material is composed of γ+ γ′ structure based on γ′ phase. In this zone, the content of γ phase is lower, and there exits some local inhomogeneous eduction of γ phase.

Prolonging the bonding time to 24 h, it can be seen from Fig. 2 that the element *B* diffuses further to the base material, resulting in the decomposition of the dendritic borides in the bonding seam. The amount of the borides is gradually reduced, and they distribute discontinuously. Moreover, compared with the joint bonded at 1260 ℃ for 4 h, Al content is increased by 1.5% in the bonding seam matrix, while Cr content was decreased by 2.7%. The bonding seam of the joint bonded at 1260 ℃ for 24 h is composed of a fine homogenous γ+ γ′ two-phase structure but based on γ (as shown Fig. 2b). In the zones adjacent to bonding seam, there are still some boride bars and needles, but the total content of them is reduced obviously, and they distribute more dispersively. There is seldom γ′ integument around the borides. When prolonging bonding time up to 36 h. It can be seen from Fig. 3 that the phase structure in the bonding seam and the zone adjacent to the bonding seam changes slightly. However, compared with the joints bonded at 1260 ℃ for 24 h, Al content of the bonding seam is increased from 3.9% to 4.4%, while Cr content is decreased from 3.75% to 2.83% because of the further diffusion of the elements. As a result, the γ′ phase content in the bonding seam is increased to some extent, but it is not completely equal to that in the base material.

3.2 Stress-rupture property of joints

Table 1 gives the stress-rupture test results. It can be seen that:

1) The stress-rupture property of the joints bonded with the interlayer alloy I7P at 1260 ℃ for 36 h

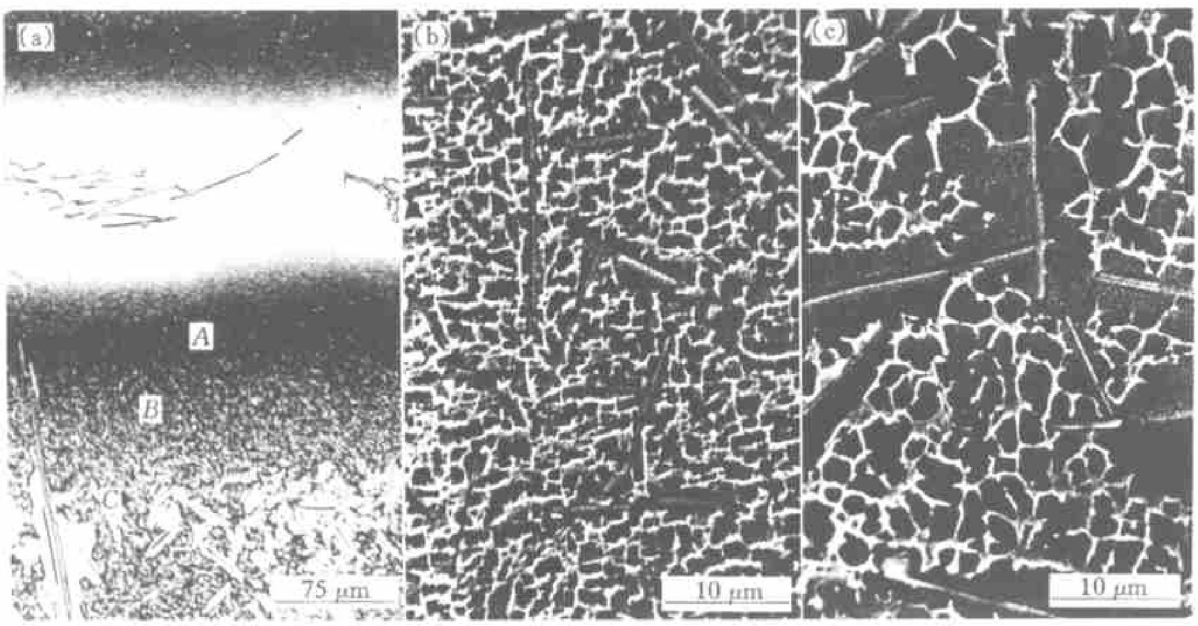

Fig. 1 Microstructures of joint diffusion bonded at 1260 ℃ for 4 h
(a) —Joint; (b) —*B* zone; (c) —*C* zone

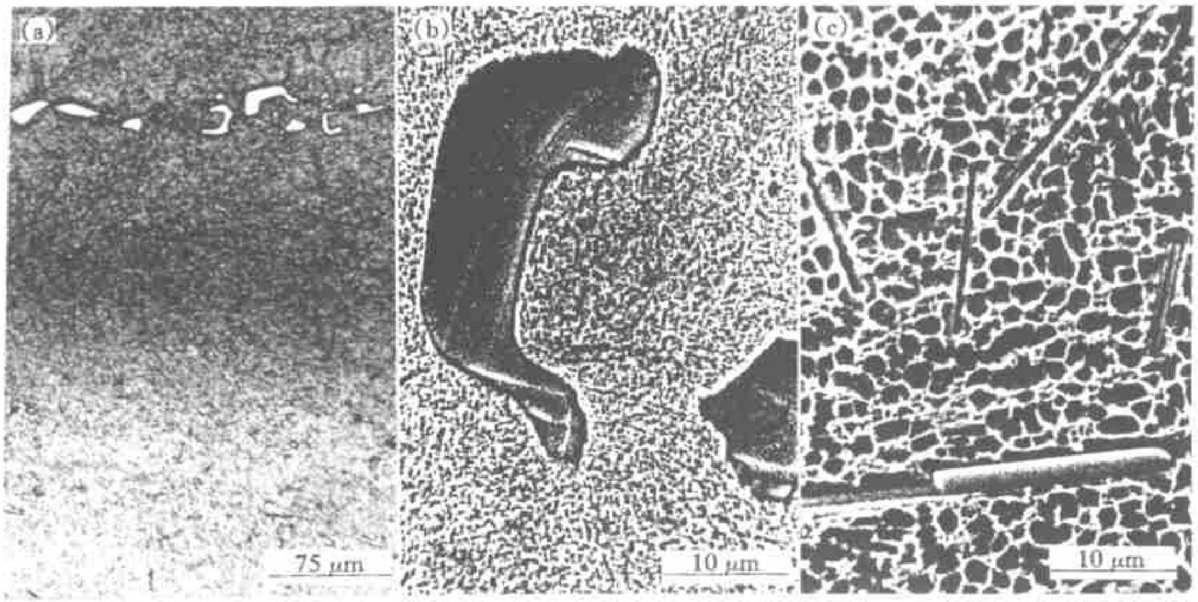

Fig. 2 Microstructures of joint diffusion bonded at 1 260 ℃ for 24 h
(a) —Joint; (b) —Bonding seam; (c) —Needle-like phases

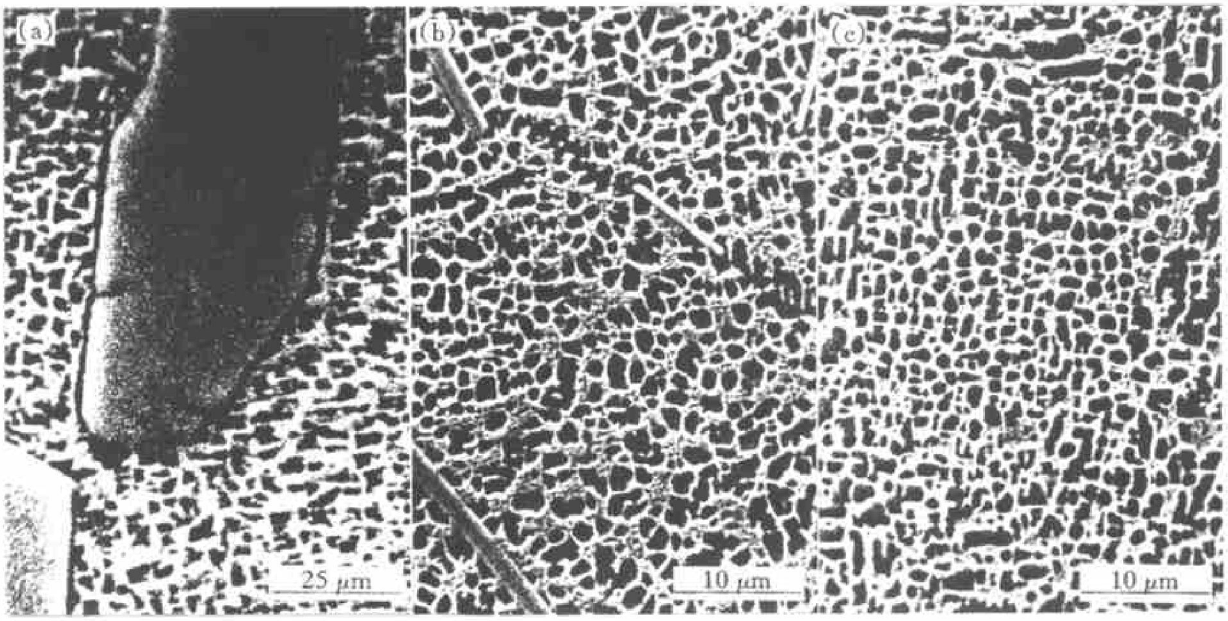

Fig. 3 Microstructures of joint diffusion bonded at 1 260 ℃ for 36 h
(a) —Bonding seam; (b) —Needle-like phases; (c) —Base material

reaches the transverse property level of the base material (980 ℃/100 MPa/100 h), but it is much lower than the longitudinal stress-rupture property of the base material (980 ℃/200 MPa/100 h). When the joints solidify isothermally, the crystal grains grow epitaxially from each faying face. In addition, because there are grain boundaries on the faying faces and there is a difference between the grain orientations of two faying faces, the obtained joints are of the polycrystalline structure containing the grain boundaries. Therefore, it is difficult to obtain the joint stress-rupture property reaching the longitudinal property level of the base material.

2) Increasing the bonding time can markedly improve the joint stress-rupture property. For example, the life time under 980 ℃/100 MPa of the TLP diffusion bonded joint at 1 260 ℃ for 24 h is very short (only about 1 h), while for the joint bonded at the same temperature but for 36 h, its life time under 980 ℃/100 MPa reaches 213 h. This is because that, for a long holding time at the bonding temperature, on one hand, the joint microstructure and composition are more homogeneous, the amount of the brittle phases is gradually reduced, and they show a more scattered distribution; on the other hand, the strengthening element Al of the base material diffuses into the bonding seam, so the bonding seam is strengthened. The structure of the bonding seam changes from $\gamma + \gamma'$ structure based on γ phase to that based on γ' phase.

Table 1 Stress-rupture properties of TLP diffusion bonded joints of IC6 alloy

Specimen number	Bonding condition	Stress-rupture property			Failure location
		Temperature/ ℃	Stress/ MPa	Life time/ h	
0-11	1 260 ℃, 24 h	1 100	50	11.17	Joint
0-12	1 260 ℃, 24 h	980	100	1.08	Joint
0-19	1 260 ℃, 36 h	980	140	39.50	Joint
0-20	1 260 ℃, 36 h	980	100	62.58	Joint
0-21	1 260 ℃, 36 h	980	100	213.00	Joint

4 CONCLUSIONS

1) The main phases in IC6 joints TLP diffusion bonded with I7P interlayer alloy are γ-solid solution (or a γ+ γ′ structure) and borides. In the zones adjacent to the bonding seam, there exist the bar-like and needle-like borides.

2) With the bonding time increasing, the quantity of the borides both in the bonding seam and the zones adjacent to the bonding seam is gradually reduced, and the joint stress-rupture property is improved. However, it is difficult to obtain the joint structure and composition completely identical to those of the base material.

3) The IC6 joints bonded at 1 260 ℃ for 36 h with I7P interlayer alloy possess good stress-rupture property which is on the level with the transverse property of the base material at 980 ℃.

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(Edited by YANG Bing)