APPLICATION OF MELT-SPUN SUPERALLOY RIBBONS

TO SOLID PHASE DIFFUSION WELDING FOR NI-BASE SUPERALLOY

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Abstract

Solid phase diffusion welding using an insert metal having almost the same compositions as the base metal is investigated in order to realize high welding strength for Ni-base superalloys. For the purpose of this study, melt-spun superalloy ribbons, which are noticed due to its dimensions in thickness and fine grain structures, are examined about superplastic property and application as insert metals. Welding is carried out for various welding pressures, times, temperatures, atmospheres, cleaning treatment for welded surface, and heat treatment after welding. Base metal used is René80, and insert metals are ribbons of IN738LC, IN738FC and Ni-20Al-5Cr produced by a twin-roll rapid solidification process. In this investigation, welding strength, evaluated by tensile tests at 980°C using ribbons aged at 1200°C for only 5h, exhibits high strength almost equal to that of the base metal.

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Introduction

Liquid phase diffusion welding using a thin interlayer having a melting point lower than that of base metal is widely used for Ni-base superalloy welding.(1)(2) This process has an advantage of low welding pressure, but is has several disadvantages as outlined below.

(1) A long homogenizing treatment time.

(2) A decrease in the welding strength because of the existence of a heterogeneous layer composed of boride, low melting point elements, etc.

(3) Aggregation of the dispersed oxide because of joint melting in case of an oxide dispersion strength (ODS) alloy.

On the other hand, solid phase diffusion welding using an insert metal having almost the same composition as the base metal eliminates these problems. Here, effects such as less deformation of the base metal and improvement of contact are realized by deformation of the insert metal itself. However in solid phase diffusion welding, higher welding pressure is usually needed and it is hard to fabricate the thin interlayer needed for welding γ' precipitate-hardened Ni-base superalloy.

Therefore, we looked at grain refining and making a thin interlayer by rapid solidification (twin-roll process). If fine grain Ni-base superalloy ribbons are made by rapid solidification, it is expected that they deform with low stress by superplastic deformation and the welding pressure for solid phase diffusion welding can be decreased due to their easy deformability. We found that superalloy ribbons have fine grain structures and superplastic potential.(3)

In this paper, we investigate further the superplastic proprety of the superalloy ribbons and apply them as an insert metal to solid phase diffusion welding for cast γ' precipitate-hardened Ni-base superalloys, in order to realize high welding strength.

Experimental procedure

The welding base metal studied was γ' precipitate-hardened Ni-base superalloy René80, which was cast in 10mm diameter rods, and machined to 8mm in diameter, 10mm in height and 1μm in average roughness on the welding surfaces. The insert metals (ribbons) used were: IN738LC which was expected to have a driving force for diffusion due to the difference in composition; IN738FC which contained less C than IN738LC; and Ni-20Al-5Cr had a composition like that of the main elements of Ni-base superalloy and was expected to increase the volume of the γ' phase in order to improve the strength. Table 1 lists the chemical compositions of alloys used.

Table 1 Chemical compositions of alloys used (wt%).

Alloy	Co	Cr	Mo	W	Al	Ti	Nb+Ta	C	Zr	B
René80	9.51	13.94	3.90	4.06	2.96	5.02	—	0.16	0.04	0.01
IN738LC	8.63	15.99	1.71	2.52	3.32	3.38	0.48	0.1	0.08	0.01
IN738FC	8.20	15.60	1.65	2.59	3.23	3.33	2.65	0.007	0.10	—

Melt-spun ribbons were produced in Ar gas on two Cu-2%Be rolls (150mm in diameter). The two roll surface velocities were 10m/s, roll compression force was 6900N, and initial roll gap was 0mm. The molten metal was ejected through an orifice (1mm in diameter), using an Ar gas flow, after the alloy was melted. Thickness and widths of ribbons were about 50-100μm and 8-15mm, respectively.

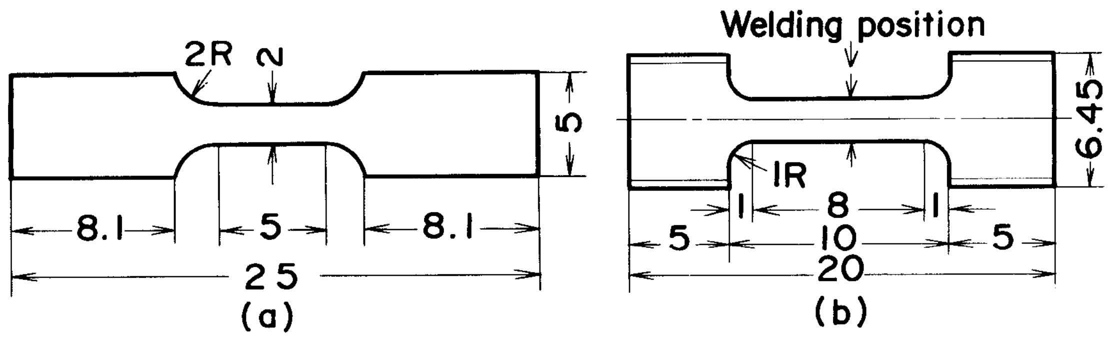


Figure 1 Dimensions of tensile specimens:
(a) for ribbons, (b) for welding strength.

Superplasticity of the ribbons was evaluated by tensile tests carried out at various strain rates at 1100°C in 10^{-3}Pa vacuum atmosphere. In this test, the strain rate was fixed by controlling the crosshead speed correspondingly to elongation of the ribbon through the test. The dimensions of a tensile specimen for the ribbon are shown in Figure 1(a).

Solid phase diffusion welding was performed in 10^{-3}Pa vacuum atmosphere using a tungsten mesh heater. Heat treatment after welding was conducted by aging at 1200°C for 5-10h followed by air cooling(A.C.) in Ar gas, and then 1100°C for 1h followed by furnace cooling (F.C.) in the welding furnace. Welding strength was estimated by tensile tests at a 1.7μm/s in tensile rate. (Initial strain rate was 3.3×10^{-4}/s.) The dimensions of a tensile specimen for welding strength are shown in Figure 1(b).

Results and discussion

Superplasticity of melt-spun superalloy ribbons

Figure 2 shows relationships between peak flow stress or elongation and strain rate for IN738LC and Ni-20Al-5Cr ribbons in tensile tests at 1100°C. The peak flow stress decreased monotonously with decereasing strain rate, and the minimum peak flow stress for IN738LC was 16MPa. The maximum

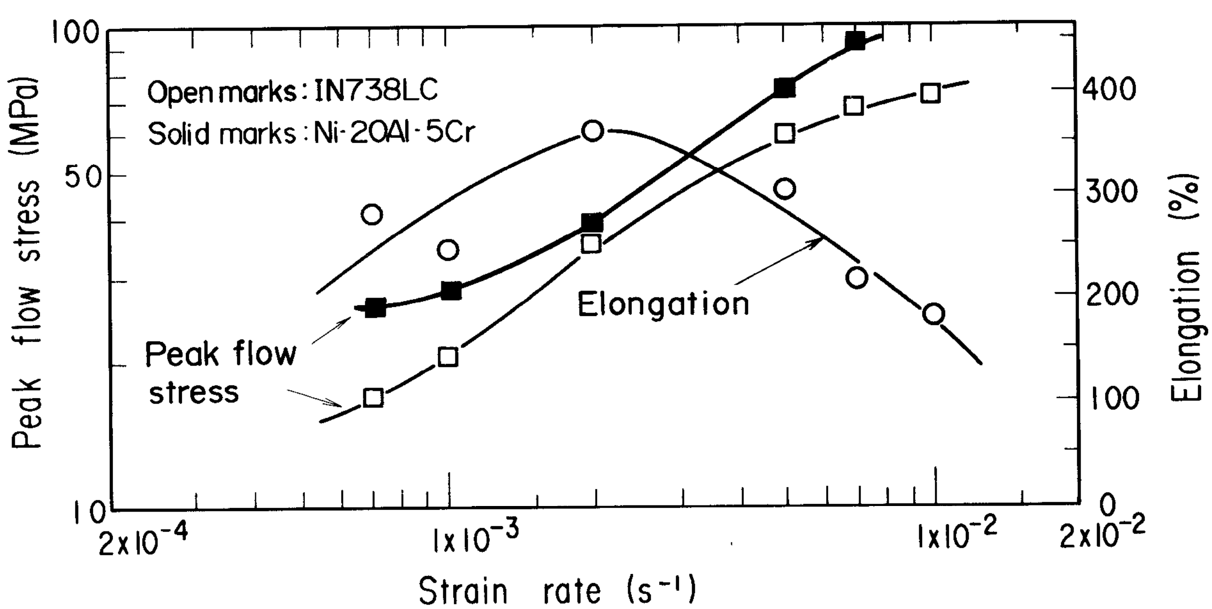


Figure 2 Relationships between peak flow stress or elongation and strain rate for IN738LC and Ni-20Al-5Cr ribbons at 1100°C.

elongation value of the IN738LC ribbon, which was only about 100μm thick, was larger than 360% which was the limit of the test machine used. The maximum m value of IN738LC evaluated from the slope of the peak flow stress curve was 0.73. The Ni-20Al-5Cr ribbons indicated characteristics similar to the IN738LC ribbons, though only peak flow stress is plotted in Figure 2. From these results, the ribbons in this study were considered to exhibit superplasticity.

At a high temperature, deformation stress of ribbons tended to decrease with increasing temperature. On the other hand, it is generally difficult for single phase alloys to exhibit superplasticity, because fine grains of single phase alloys are easily coarsened by aging at high temperature. Ni-base superalloy is usually a single phase at a higher temperatures than 1200°C because of dissolution of the γ' phase. Then in this study, welding were carried out at 1050-1150°C, considering the low deformation stress and ductility of ribbons.

<u>Solid phase diffusion welding for Ni-base superalloy</u>

Solid phase diffusion welding was carried out using Renē80 base metal with and without IN738LC ribbons while changing the welding pressure, time, and temperature. Standard welding conditions were set as 49MPa for pressure, 3.6ks for time and 1100°C for temperature. Figure 3(4) shows the effects of welding pressure, time, and temperature on welding strength at room temperature with and without IN738LC ribbons. The welding strength using ribbons was higher than that without ribbons under all conditions. This meant that the ribbons contributed were considered to the improvement of welding strength. These effects of ribbons were considered to be caused by easier deformability with small grains. The base metal was hardly deformed during welding because cast Renē80 had large grains and high strength at 1050-1150°C. For example, 0.2% yield stress at 1100°C of the base metal was 126 MPa, when the initial strain rate was $2x10^{-4}/s$. On the other hand, the fine grained ribbon, which showed superplasticity in the casting direction, exhibited about a 20% reduction in thickness after welding. As a result, an active green surface appeared on the ribbons, and

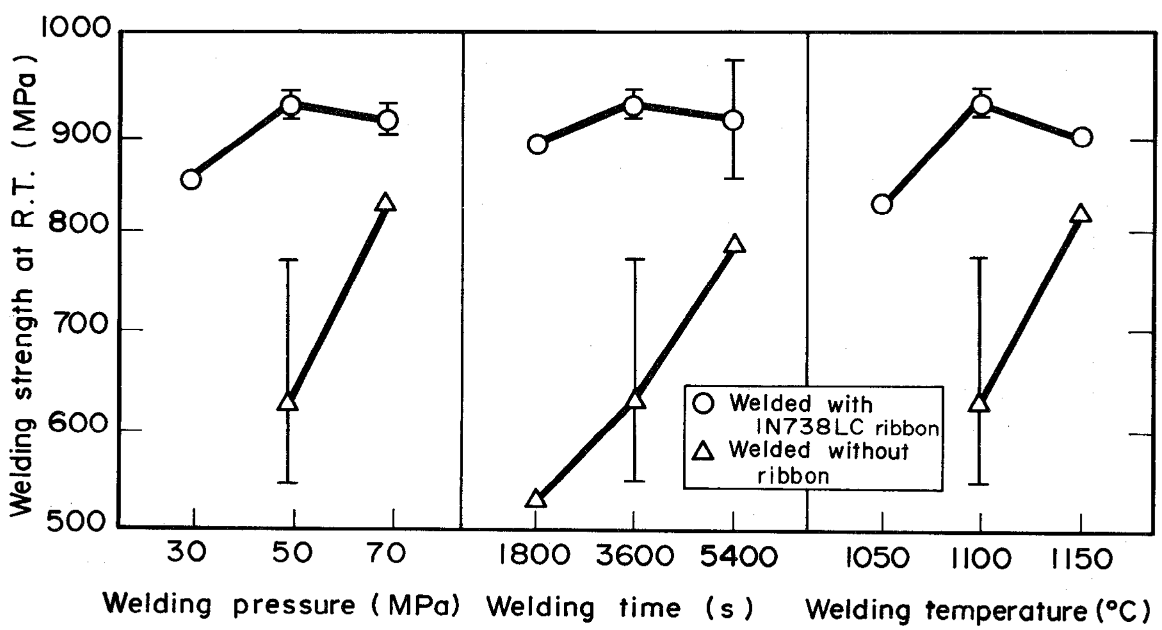


Figure 3 Effects of welding pressure, time, and temperature on welding strength at room temperature of joints with or without IN738LC ribbons.

the joint was securely welded. However, the fractured positions of the joints in Figure 3 were all at the welded interface.

Figure 4 shows the results of electron probe microanalyzer (EPMA) analysis of the welded interface using the IN738LC ribbon under the standard welding conditions. Peaks of C and O were observed at the welded interface which suggested that carbides and oxides caused the decrease in welding strength. The O source for oxides at the welded interface was considered to be the welding atmosphere and an oxide film covered the welded surfaces before welding. An oxide film, about 10-20nm in thickness, was detected by Auger electron spectroscopy (AES) analysis sputtered in the depth direction by Ar ion.

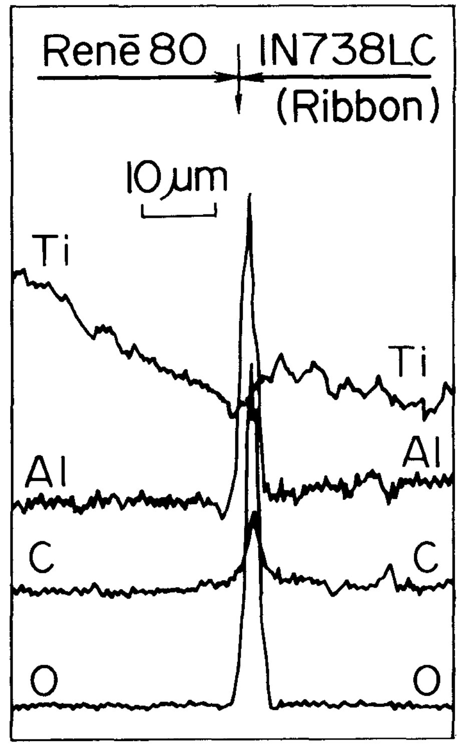


Figure 4 Results of EPMA analysis of the welded interface of the joint using the IN738LC ribbon.

Next, effects of aging at 1200°C on the welding strength were investigated. The following welding was performed at the standard welding conditions, which provided the highest welding sterngth in Figure 3. Figure 5 shows the relationships between welding strength (a) at room temperature, or (b) at 980°C and aging time at 1200°C. At room temperature, joints using Ni-20Al-5Cr ribbons exhibited the highest welding strength, and these fractured at the base metals. However, they had low welding strength and fractured in the insert metals at 980°C.

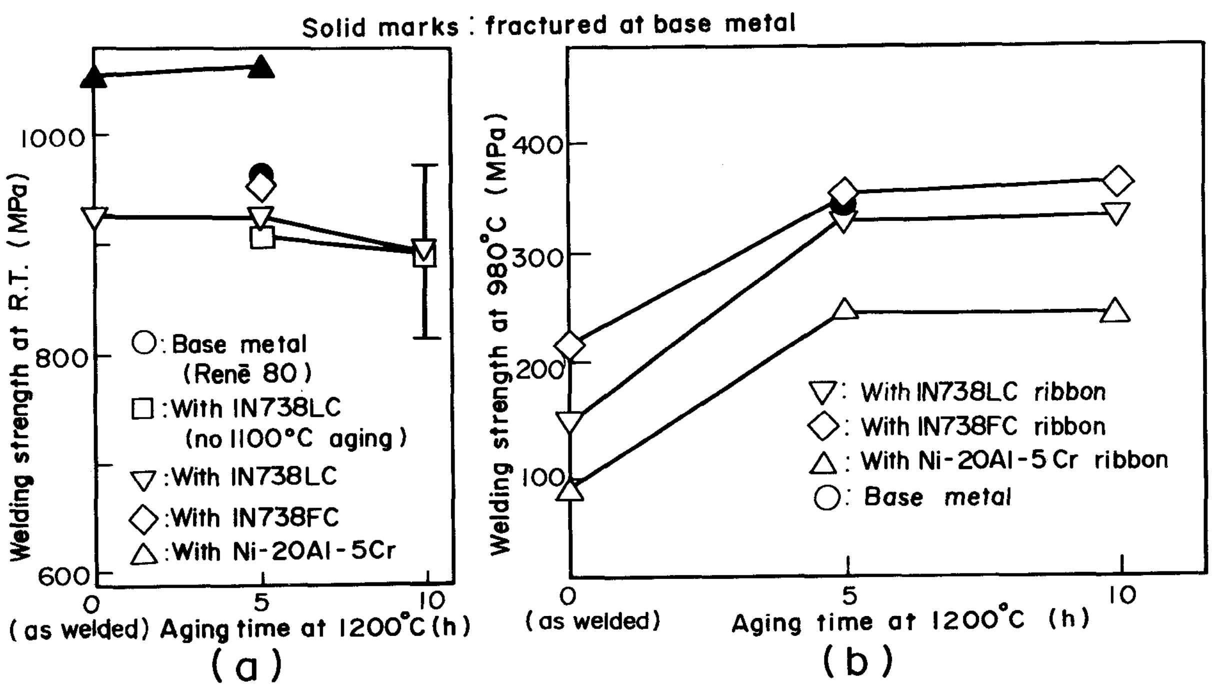


Figure 5 Relationships between welding strength (a) at room temperature or (b) at 980°C and aging time at 1200°C.

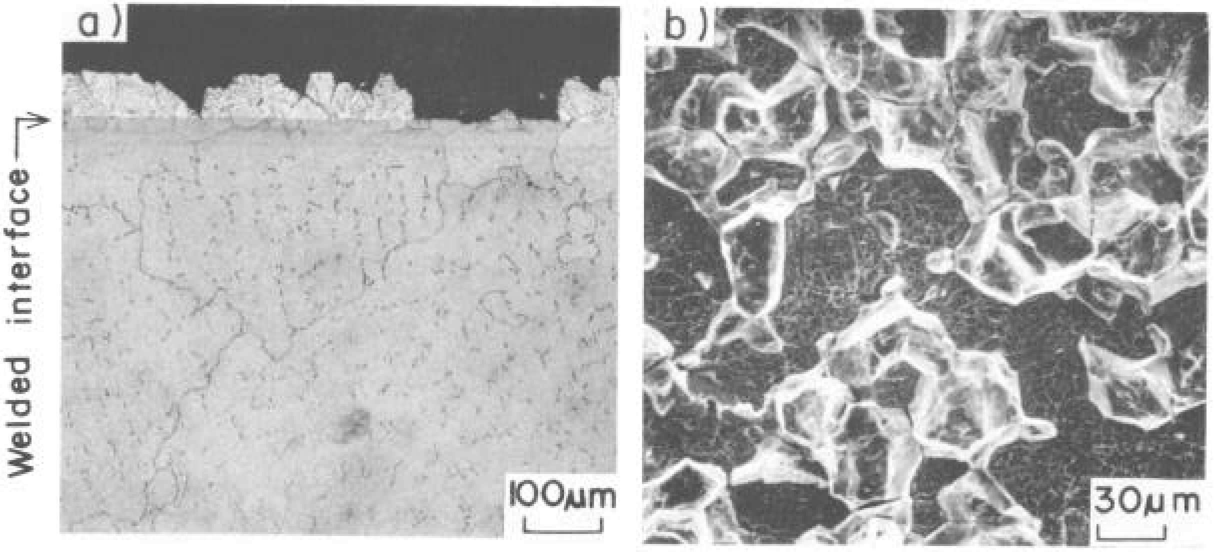


Figure 6 Microstructures of the joint using Ni-20Al-5Cr ribbon which fractured at 980°C: (a) cross-section of the fractured point and (b) fractured surface of the joint.

Figure 6 shows microstructures of the cross-section and the fractured surface of the joint using Ni-20Al-5Cr ribbon which fractured at 980°C. The intergranular fracture occurred in the insert metal, and grains in the insert metal seemed brittle and coarse, being about 50µm. In order to understand these results, microstructures of the cross-sections of the joints using Ni-20Al-5Cr ribbons were observed. Figures 7(a), (b) and (c) show microstructures of the joints as welded (no etching), aged at 1200°C for 5h→A.C., and aged at 1100°C for 1h→F.C. after the heat treatment of (b), respectively. In Figure 7(a), small carbide precipitates were observed on the base metal near the welded interfaces. On the other hand, a precipitation-free zone (PFZ) with no carbide existed near the welded

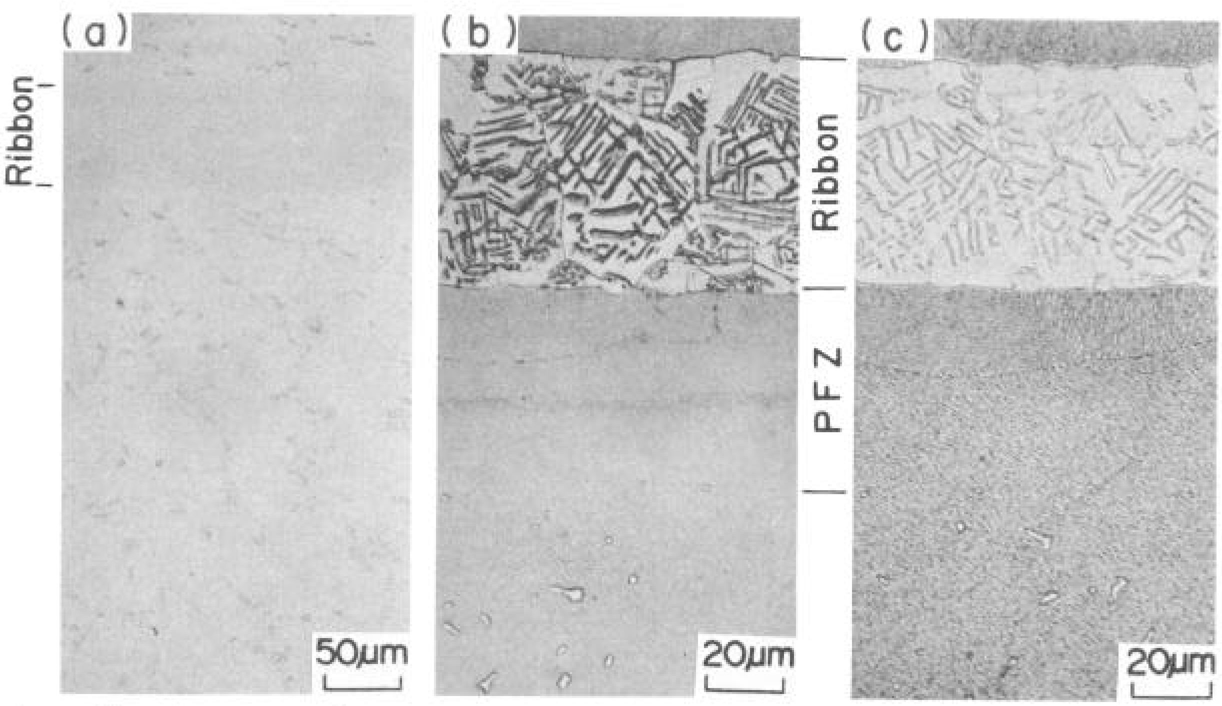


Figure 7 Cross-sections of joints with Ni-20Al-5Cr insert ribbons: (a) as welded at 1100°C (no etching), (b) aged at 1200°C for 5h→A.C. and (c) aged at 1200°C for 5h→A.C. and 1100°C for 1h→F.C. after welding.

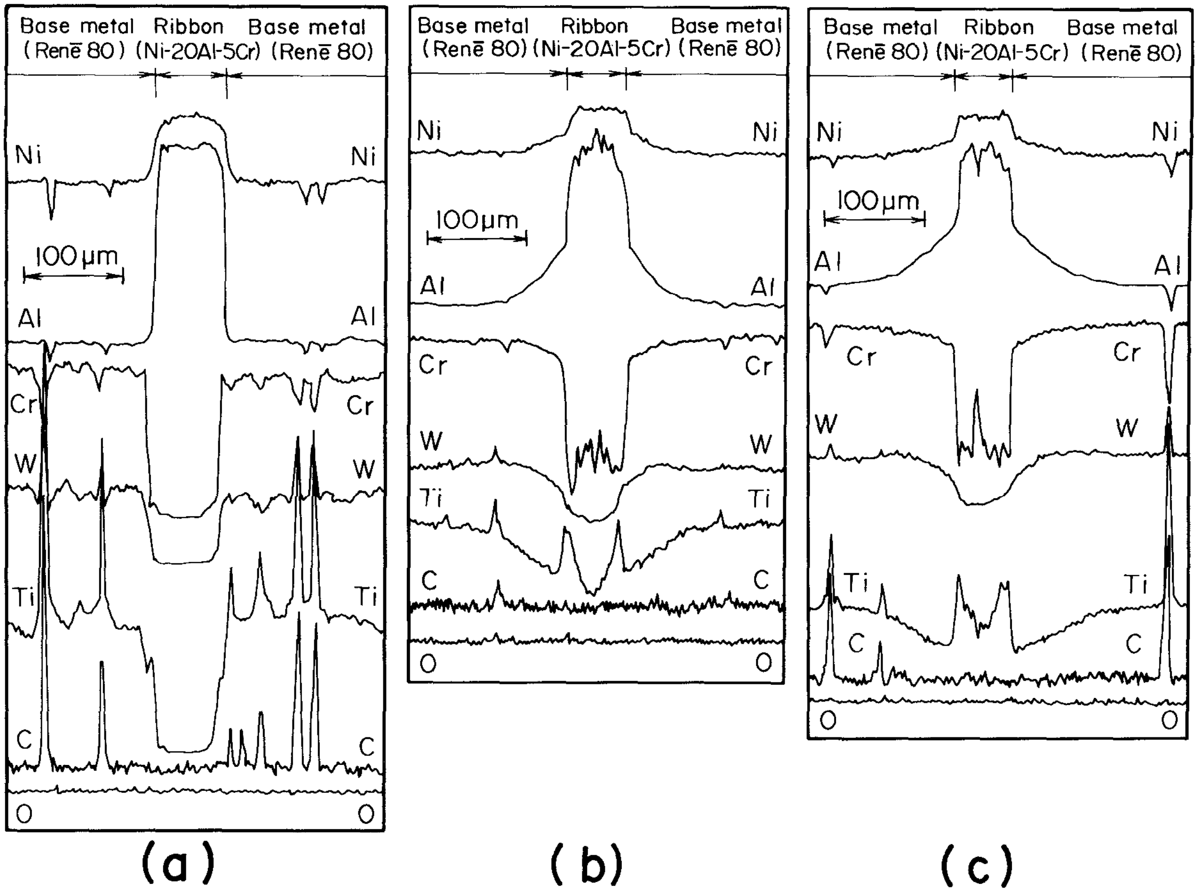


Figure 8 Results of EPMA analysis of the welded interfaces of the joints using Ni-20Al-5Cr ribbons: (a) as welded at 1100°C, (b) aged at 1200°C for 5h→A.C. and (c) aged at 1200°C for 10h→A.C. after welding.

interfaces in Figure 7(b). In Figure 7(c), a fine γ' phases precipitated, but no carbides existed in the PFZ. Figure 8 shows the resutlts of the EPMA analysis of the welded interfaces of the joints using the Ni-20Al-5Cr ribbons as welded and aged at 1200°C for 5 or 10h. Here, the remarkable distributions of Ti were observed. On aged joints, Ti content in an area of the base metals which corresponded to the PFZ decreased to the welded interfaces, and increased abruptly at the welded interfaces. This suggested that the insert metal became a brittle compound due to Ti movement from the base metal to the insert metal. Consequence, it was considered that the low welding strength at 980°C using the Ni-20Al-5Cr ribbon was caused by the brittleness at 980°C of the compound formed in the ribbon. A similar phenomenon was observed in other Ni-Al-X system ribbons, so the Ni-Al-X system ribbons were considered to be unsuitable as insert metals for welding of Ni-base superalloys.

On the other hand, in Figure 5, the joints using the IN738FC and IN738LC ribbons exhibited high welding strength at 980°C, almost equal to the base metal strength when aged for only 5h. Figure 9 shows microstructures of cross-sections of the joints with the IN738LC and IN738FC ribbon aged at 1200°C for 5h followed by A.C. and 1100°C for 1h followed by F.C. after welded. On the joint with the IN738LC ribbon, white lines were observed at the welded interfaces. Figure 10 shows microstructures of cross-sections of the joints with the IN738LC ribbons aged at 1200°C for 5-10h followed by A.C. (γ' phase was prevented from precipitating). Here, fine carbides were found at the welded interfaces, and the white lines observed in Figure 9 were such carbides. From the above results, the

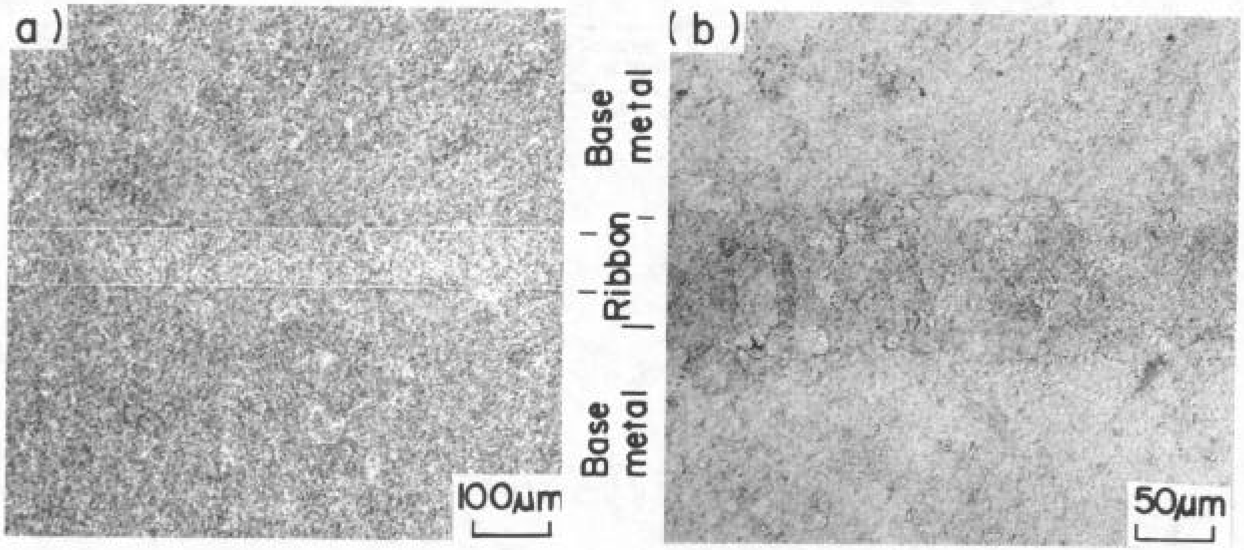


Figure 9 Cross-sections of joints with various insert ribbons aged at 1200°C for 5h → A.C. and 1100°C for 1h → F.C. after welding at 1100°C: (a) IN738LC, (b) IN738FC.

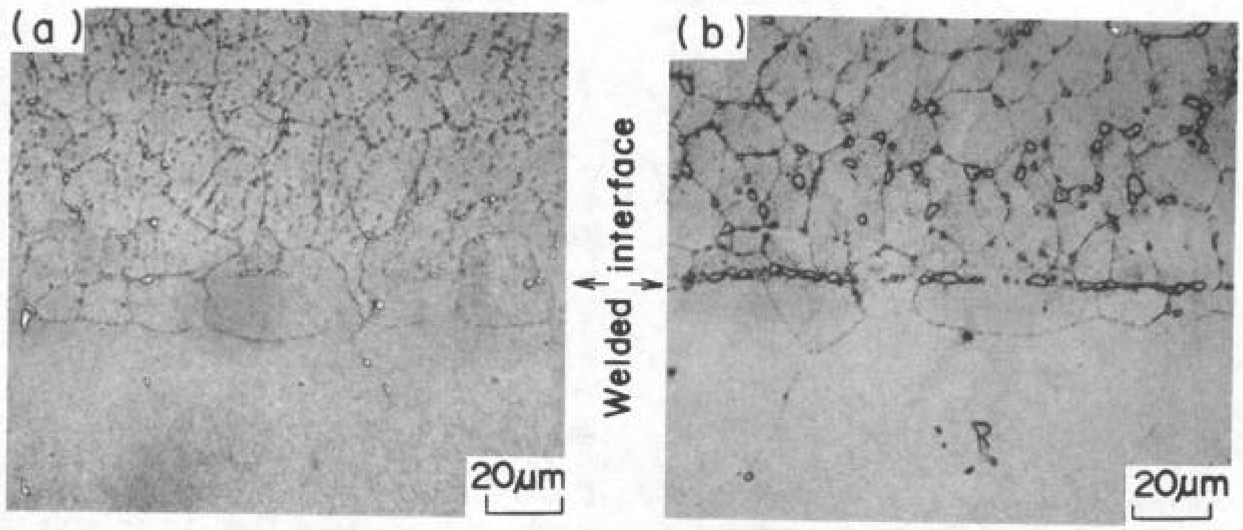
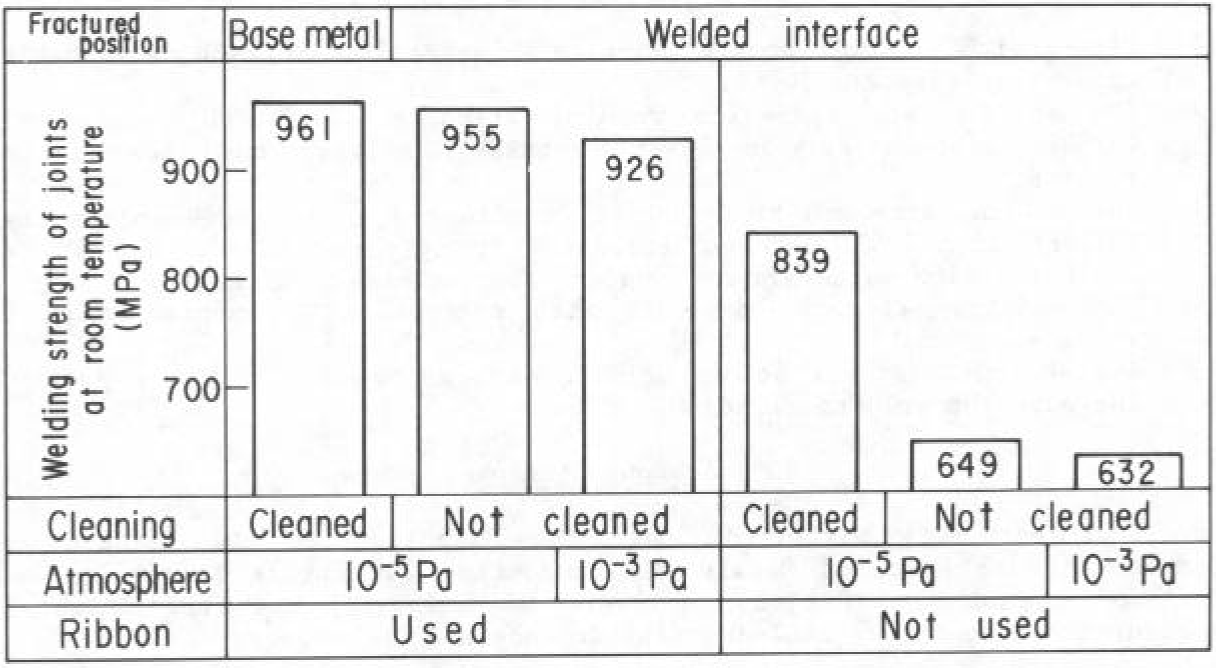


Figure 10 Cross-sections of joints with IN738LC insert ribbons: (a) aged at 1200°C for 5h → A.C. and (b) aged at 1200°C for 10h → A.C. after welding at 1100°C.

difference in the welding strength between IN738FC and IN738LC ribbons was due to carbide formation the source of which was the insert metal, at the welded interfaces. In Figure 5, the effect of the aging treatment at 1200°C on the welding strength at 980°C was remarkable, though that was little effect on the room temperature strength. This was caused by the grain sizes. That is, a large grain was more favorable to high temperature strength than a small grain was. In Figure 10, the coarse grains of the ribbon were observed on aging at 1200°C.

Next, a new apparatus was developed and the welding strength was examined in order to realize higher welding strength. In this apparatus, the surfaces of the base metals and ribbons were cleaned by Ar ion beam bombardment before welding in order to remove the oxide film, and all processes in solid phase diffusion welding could be carried out in a better vacuum atmosphere (10^{-5}Pa) without exposing the base metals and ribbons to air. Figure 11 shows the effects of welding atmosphere and cleaning of welded surfaces on the welding strength at room temperature, with or without



Welding conditions: Pressure 49MPa, Time 3.6ks, Temperature 1100°C

Figure 11 Effects of welding atmosphere and cleaning of the welded surfaces on welding strength of René80 joints with or without IN738LC ribbons.

the IN738LC ribbons, using the developed apparatus and the standard welding conditions. Only the joint welded using the ribbon with the cleaning treatment at 10^{-5}Pa fractured in the base metal, the other joints fractured at the welded interfaces. Moreover in Figure 11, the welding strength of all joints increased when the welded surfaces were cleaned or welding was done at 10^{-5}Pa. From these results, the cleaning treatment and the improvement of vacuum atmosphere were considered to increase the welding strength.

Figure 12 shows the microstructure of a cross-section of a MA6000 (ODS alloy) joint aged at 1200°C after welding using the IN738FC ribbon using the developed apparatus and the standard welding conditions. This joint fractured in the base metal at room temperature, so this welding method was judged as also effective for ODS alloys.

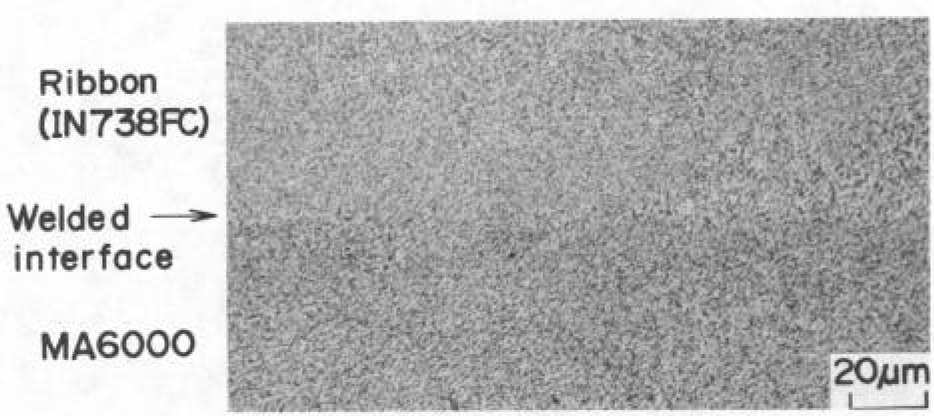


Figure 12 A cross-section of MA6000 joint with IN738FC insert ribbons aged at 1200°C for 5h→A.C. and 1100°C for 1h→F.C. after welding at 1100°C.

Conclusions

1) Fine-grained melt-spun Ni-base superalloy ribbons exhibit superplasticity at 1100°C.
2) The solid phase diffusion welding strength of René80 joints using IN738LC ribbons as the insert metals is higher than that without ribbons.
3) The welding strength at 980°C in tensile tests of René80 joints using IN738FC or IN738LC ribbons increases by aging at 1200°C for 5h, and exhibit a high value almost equal to the base metal strength.
4) The welding strength increases with decreasing C composition of the ribbons.
5) A cleaning treatment before welding and improvement of the vacuum both increase the welding strength.

Acknowledgement

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