# Super Plastic Forming/Brazing Process for Inconel 718 Superalloy Components

*A new brazing process was successful in joining complex-shaped superalloy components*

BY M. S. YEH AND T. H. CHUANG

A8STRACT. A new method, combining superplastic forming (SPF) and the brazing process, has been proposed for the production of complex-shaped Inconel 718 components. The SPF/brazing process has been used as a substitute for superplastic forming with concurrent diffusion welding process in which welding pressure cannot be applied effectively. The SPF/brazing process can also shorten the total working time and save energy during fabrication.

Using this method, an Inconel 718[1] superalloy sheet was superplastically formed and concurrently brazed with a nickel-based filler metal, MBF-20[2]. The working parameters were as follows: superplastic forming was done at 985°C under an argon pressure of 2.45 MPa and the temperature increased to 1040°C for 10 minutes for brazing. The effect of pressure on the brazement during the SPF/brazing process was simulated on a single lap shear test specimen. The results show that the joint strength increased from 784.2 ±10.4 MPa to 868.4 ±12.5 MPa as the pressure applied increased from 0 to 2.45 MPa.

## Introduction

Superplastic forming (SPF) is an advanced technique used for manufacturing complex-shaped components. Hamilton, *et al.* (Ref. 1), has presented a method for the superplastic forming of metals with concurrent diffusion welding. In this case, a metal sheet was superplastically formed in contact with another part, which was then simultaneously joined to it by diffusion welding. However, this method can only be applied to titanium alloys. Nickel-based superalloys are difficult to join by diffusion welding. Several new methods have therefore been developed for producing diffusion welds in nickel alloys. Duvall, *et al.* (Ref. 2), found that superalloy Udimet 700, with an electroplated Ni-Co interlayer at the faying surface, joined when subjected to 7 MPa at 1172°C for 4 h. The resulting tensile and creep-rupture strengths were nearly equivalent to the base metal. A dispersion-strengthened nickel-based alloy (TD-NiCr) sheet was preformed by a two-step diffusion welding cycle method (207 MPa at 705°C for 1 h and then 15 MPa at 1190°C for 2 h). This process obtained a weldment strength equal to that of the base metal strength (Ref. 3). These diffusion welding processes require applications of pressure as high as 7 MPa (1000 lb/in.$^2$) or more. A longer operation time is required in order to guarantee the bonded efficiency of the components. These processes require expensive pressure equipment and consume large amounts of energy.

The high temperature brazing method has been widely used for joining complex workpieces such as engine components. For nickel-based superalloys, many filler metals have been developed (Ref. 4). The superplasticity of nickel-based superalloys has also been demonstrated by some manufacturers. Mahoney, *et al.* (Ref. 5), showed that the wrought and the powder-produced fine-grained Inconel 718 superalloys possess a total elongation of 500% and 150%, respectively, with a strain rate of $2 \times 10^{-4}$ $s^{-1}$ at 982°C. Therefore, the use of an innovative process, SPF/brazing, has been proposed (Ref. 6). Using this technique, a complex nickel-based superalloy component can be produced.

KEY WORDS

Inconel 718 SPF
Superalloy
Nickel-Based Filler Metal
Superplastic Forming
Brazing

## Experimental Procedure

A 1.3-mm-thick Inconel 718 superalloy sheet, manufactured by Inco Alloys International, Inc., Huntington, W.Va., was used for this study. Its chemical composition is shown in Table 1. The material possessed an equiaxed fine grain size of <10 μm. Specimen surfaces were prepared by first grinding with 150-grit SiC paper and then cleaned by ultrasonics in acetone for 5 min. The brazing filler metal used for this study was an amorphous alloy, MBF-20 (Ni-7%Cr-4.5%Si-3%Fe-3.2%B in wt-%), with a thickness of 37 μm. This alloy has a liquidus point of about 1035°C, as determined by differential thermal analysis (DTA).

A schematic of the SPF/brazing process in this study is shown in Fig. 1. The 75 x 75 mm Sheet 1 specimen was

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*1. Inconel 718SPF is a trade name of INCO Alloys International.*

*2. MBF-20 is a trade name of Metglas Products, an Allied Signal Co.*

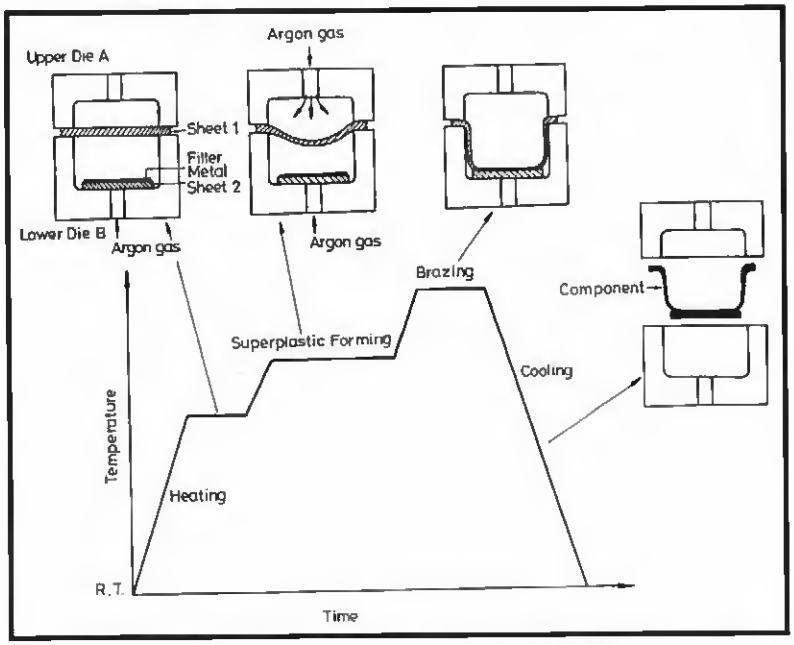


*Fig. 1 — Schematic of the SPF/brazing process.*

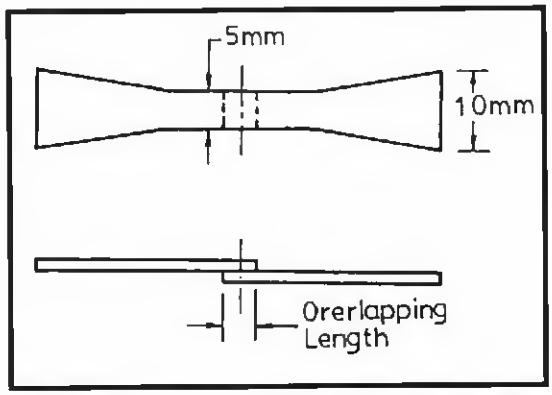


*Fig. 2 — Dimensions for single lap shear test specimens.*

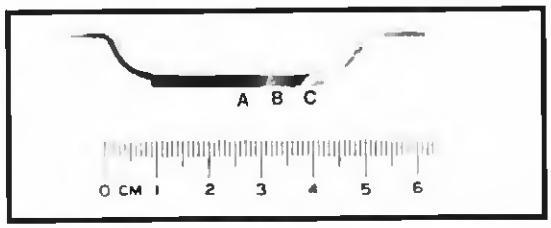


*Fig. 3 — Typical Inconel 718 superalloy component joined by the SPF/braze process.*

**Table 1 — The Chemical Composition of SP-Inconel 718 Superalloy**

| C | Mn | Fe | Si | Cu | Ni | Cr | Al |
|---|---|---|---|---|---|---|---|
| 0.03 | 0.08 | 17.9 | 0.11 | 0.09 | 53.85 | 18.26 | 0.53 |
| Ti | Co | Mo | P | B | S | Nb + Ta | |
| 1.06 | 0.15 | 3.01 | 0.011 | 0.002 | 0.001 | 4.92 | |

positioned between upper die A and lower die B, which were then tightened by hydropressure. The filler metal was laid on and fixed to the joining surface of the 35 x 35 mm Sheet 2 specimen, which was protected by argon gas. After the assembly was heated to 985°C, the sheet 1 specimen was superplastically deformed under an argon pressure of 2.45 MPa until it came in contact with the filler metal. The temperature was then increased to 1040°C for brazing. After maintaining this temperature for 10 min, the specimens were cooled. Following this, the SPF/brazed component was aged for 8 h at 720°C, furnace cooled to 620°C for 8 h, and finally air cooled. The brazed component was then cut along the centerline for metallurgical analysis. Microstructures were observed by optical microscopy (OM) and scanning electron microscopy (SEM). The composition was analyzed by electron probe microanalysis ( EPMA ).

To simulate the effects of argon pressure during the brazing process, 34 x 15 x 1.3 mm strips of Inconel 718 were used. These strips were brazed with MBF-20 alloy using an overlap of 3T (three times the sheet thickness), in a vacuum hot press, under a vacuum of $10^{-4}$ torr at 1040°C for 10 min, with applied pressure of 0–2.45 MPa. After brazing, three brazements were subjected to the heat treatment described above and then machined to the dimensions shown in Fig. 2 with a wire-cut electric discharge machine to determine the mechanical strength of the brazed component. This was determined by tensile shear testing in air at room temperature with a crosshead speed of 0.5 mm/min.

## Results and Discussion

Two conditions are necessary to join Inconel 718 superalloy components using the SPF/brazing process. First, the selected filler metal has to have a higher melting point than the superplastic forming temperature of the Inconel 718 to avoid the melting and loss of the filler metal. In our previous study, the optimum superplastic forming conditions for Inconel 718 superalloy were shown to be obtained at a temperature range of 975°–995°C, with an argon pressure above 2.8 MPa (400 lb/in.$^2$) (Ref. 7). On the other hand, the primary age hardening phases of Inconel 718 superalloy ($\gamma'$ or $\gamma''$) dissolved at temperatures exceeding 1010°C and permitted grain growth. Since a fine and stable grain size is required for superplasticity, temperatures exceeding 1010°C will decrease its level of superplasticity. A compressive load

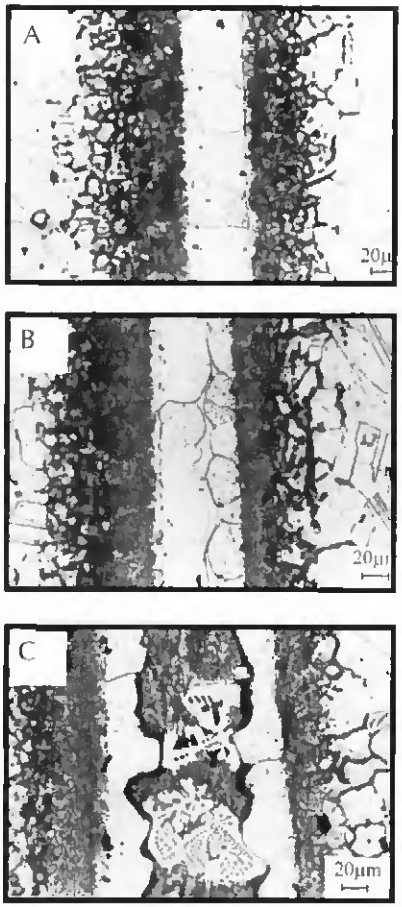


*Fig. 4 — Microstructure of the Inconel 718 SPF/braze component. (a), (b) and (c) are taken from the cross section positions A, B and C of Fig. 3, respectively.*

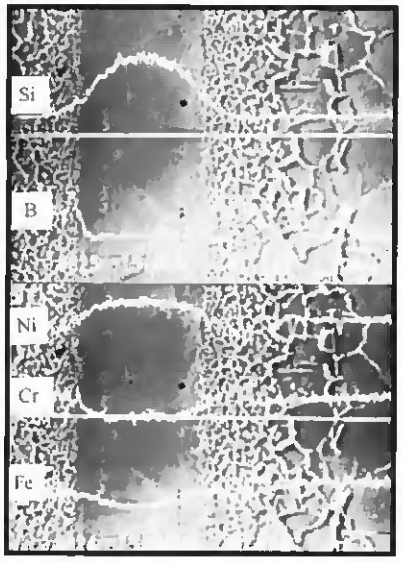


*Fig. 5 — Concentration profiles of various elements analyzed across the brazing interface by EPMA on position A of Fig. 3.*

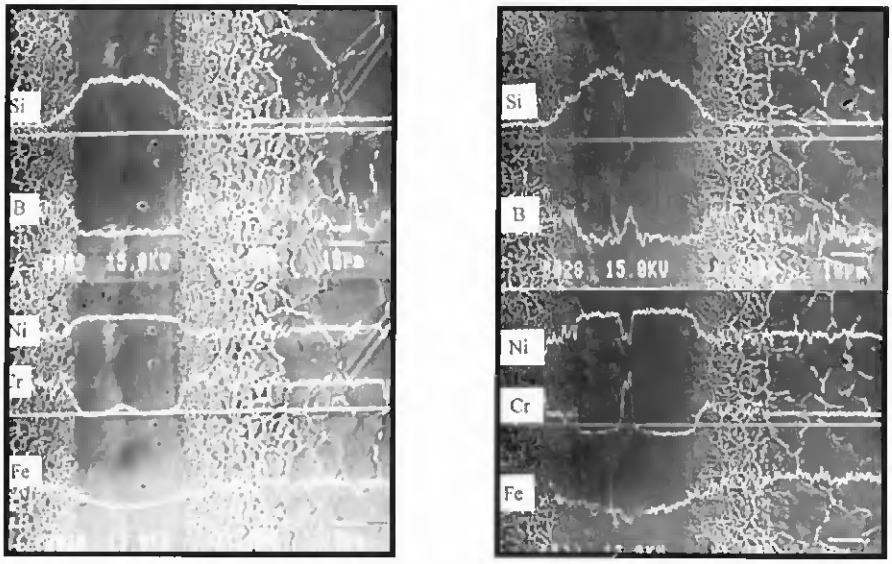


*Fig. 6 — Concentration profiles of various elements of MB-20 brazements brazed at 1040°C for 10 min. Analyzed by EPMA. A — 2.45 MPa; B — 0 MPa.*

can be applied during copper brazing with a copper-phosphorus filler metal (Ref. 8). This has a more positive effect than conventional brazing methods. The liquid phase enriched with phosphorus was ejected out of the brazing joint by pressure, which resulted in the disappearance of brittle intermetallic phases and the increase in ductile phases. The mechanical properties of the brazements were thus improved. In the SPF/brazing process, applying external pressure for superplastic forming will simultaneously affect the brazements. Therefore, the effects of load on the brazing process should be evaluated.

A cross section of a typical SPF/brazing joined component cut along the centerline is shown in Fig. 3. The microstructures of positions A, B and C of Fig. 3 are shown in Fig. 4A–4C, respectively. During the brazing process, the concentration of temperature depressants in the filler metal were lowered by diffusing them into the base metal. Boron and silicon were used as melting point depressants in the MBF-20 alloy. Position A of Fig. 3 had the narrowest clearance, and after brazing for 10 min at 1040°C, no intermetallic phases appeared in the joint — Fig. 4A. The joint was formed in a complex Ni-Cr-Si-Fe solid solution with a microhardness of about 285 ± 5 HV. In the adjoining joint area, precipitates were formed in the base metal grains and at the grain boundaries. Microhardness was 520 ± 15 HV in this region. EPMA line scans on position A of Fig. 3 show that the boron diffused into the base metal and formed chromium borides in the grains and at the grain boundaries — Fig. 5. This was the cause of higher microhardness in the region. For an intermetallic-free joint, it is necessary to increase brazing time for a larger joint clearance (Ref. 9). Therefore, by increasing the joint clearance at positions B and C, intermetallic phases were formed along the centerline of the joint after brazing for 10 min — Figs. 4B, 4C.

In another case, EPMA line scans of the simulated tests of MBF-20 brazements with and without applied pressure are shown in Fig. 6. The joint clearance was reduced under applied pressure and boron was able to diffuse into the base metal after only 10 min of brazing — Fig. 6A. In contrast, boron had longer diffusion distance for the MBF-20 brazements without applied pressure for wide joint clearance. Thus, intermetallic compounds formed in the joint because boron cannot diffuse into the base metal in such a short time — Fig. 6B. The tensile strength of MBF-20 brazements with an applied pressure of 2.45 MPa is greater (868.4 ±12.5 MPa) than that of the MBF-20 brazements without applied external load (784.2 ±10.4 MPa). Failure is always a result of shear of the joint. This never occurs in the SP-Inconel 718 superalloy. A brittle fracture surface of the MBF-20 brazements without applied pressure was observed — Fig. 7A. This is caused by the intermetallic compounds formed in the joint. The MBF-20 brazements with applied pressure produced a ductile fracture surface — Fig. 7B. The increase in brazing strength with applied pressure can be attributed to a decrease in the joint clearance of the brazements and the existence of an intermetallic-free joint.

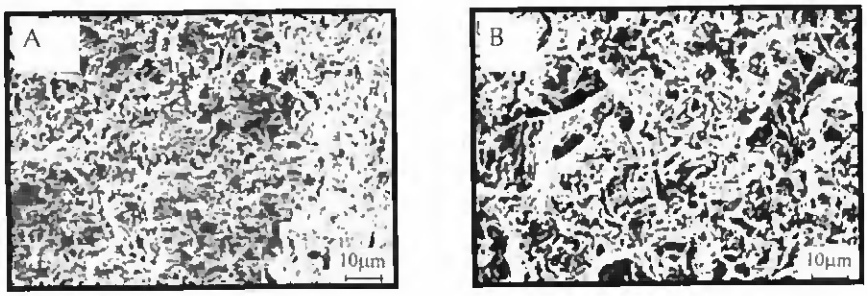


*Fig. 7 — Fractographs of MBF-20 brazements after brazing at 1040°C for 10 min under various pressures. A — 0 MPa; B — 2.45 MPa.*

## Conclusions

The innovative SPF/brazing process has been used successfully to manufacture a complex-shaped component out of Inconel 718 superalloy. The process consists of four stages. In the first stage, the Inconel 718 superalloy assembly was protected by argon gas and heated to 985°C. Second, the Sheet 1 specimen was superplastically deformed under an argon pressure of 2.45 MPa until it came into contact with the MBF-20 filler metal. Third, the temperature was raised to 1040°C for 10 min for brazing, followed by cooling. Finally, the SPF/brazed component was subjected to a suitable aging heat treatment to produce optimum mechanical properties. In the brazing joint microstructure, chromium borides appeared in grains and at grain boundaries. Furthermore, the benefit of the application of pressure in this process resulted in improving the mechanical properties of the Inconel 718 superalloy SPF/braze component.

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