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DIFFUSION WELDING OF A DIRECTIONALLY SOLIDIFIED γ/γ'-δ EUTECTIC ALLOY

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16. Abstract

In a cursory study, hot-press diffusion welding parameters were developed for a directionally solidified, γ/γ'-δ eutectic alloy. Based on metallography, a good diffusion weld was achieved at 1100° C under 34.5 MPa (5 ksi) pressure for 1 hour. In addition, a dissimilar metal weld between γ/γ'-δ and IN-100 was successfully made at 1100° C under 20.7 MPa (3 ksi) pressure for 1 hour.

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DIFFUSION WELDING OF A DIRECTIONALLY SOLIDIFIED γ/γ'-δ EUTECTIC ALLOY

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SUMMARY

To realize its maximum potential in gas-turbine-engine applications, satisfactory welding methods must be developed for the directionally solidified, γ/γ'-δ eutectic alloy. In this program a cursory diffusion welding study was undertaken in which a nickel-base γ/γ'-δ alloy was welded to itself to simulate split blade fabrication. Also, a simulated blade-to-base weld was made between γ/γ'-δ and IN-100, a nickel-base superalloy. The diffusion welding was accomplished by vacuum hot pressing.

The evaluation of joint integrity, based on metallography, showed that the γ/γ'-δ alloy can be readily diffusion welded. The best results for welding γ/γ'-δ to itself were achieved at 1100° to 1150° C and 34.5 megapascals (5 ksi) for 1 hour. For a γ/γ'-δ to IN-100 joint the conditions were 1100° C and 20.7 megapascals (3 ksi) for 1 hour.

INTRODUCTION

A directionally solidified eutectic γ/γ'-δ alloy is currently under evaluation for turbine-blade applications in advanced gas-turbine engines (ref. 1). The alloy offers a 40° C increase in use temperature or a 40 percent increase in strength at current blade temperatures compared with the best conventional directionally solidified alloy (ref. 2). In addition to strength, turbine blades must have other characteristics, such as good cyclic oxidation resistance, thermal fatigue resistance, and thermal stability (refs. 1 to 3). Furthermore, for full utilization of the γ/γ'-δ alloy as a turbine blade material, internal passageways for cooling air are a requirement. To meet this requirement, it may become necessary to fabricate cooled blades by welding halves that contain cast or machined passageways. The main portion of this cursory study was designed to determine the feasibility of diffusion welding (i.e., solid-state welding with no macrodeformation) the γ/γ'-δ eutectic for this kind of application.

Dissimilar material joints between the γ/γ'-δ eutectic alloy and conventional superalloys are also of interest to simulate blade-to-root weldments. Such weldments may be required to meet rotor shear strength requirements when using γ/γ'-δ eutectic airfoils (ref. 2). Under a U.S. Air Force eutectics technology program (ref. 4), promising results have been obtained using conventional brazing techniques and a proprietary diffusion brazing process (TLP bonding) to join γ/γ'-δ to Udimet 700. In the program reported herein, the feasibility of diffusion welding γ/γ'-δ to the IN-100 superalloy was investigated.

The evaluation of diffusion weld quality for both the similar and dissimilar weldments was based solely on metallographic examination.

MATERIALS

γ/γ'-δ Eutectic Alloy

The γ/γ'-δ eutectic alloy is an in-situ composite material containing intermetallic platelets as a reinforcement. Nominal composition by weight percent is nickel - 20 niobium - 6 chromium - 2.5 aluminum. The 12.7-millimeter-diameter bar stock was directionally solidified at a rate of 30 millimeters per hour with a thermal gradient of 20° C per millimeter (ref. 5). An optimum microstructure, consisting of alternate lamellae of γ-nickel solid solution and δ-phase Ni_3Nb, is shown in figure 1. A $Ni_3Al(\gamma')$ precipitate is contained within the γ-phase.

IN-100 Alloy

This is a conventional precipitation-hardened Ni-base superalloy which was in the form of 14-millimeter-diameter cast bar stock. The nominal analysis by weight percent is nickel - 15 cobalt - 10 chromium - 5.5 aluminum - 4.7 titanium - 3.0 molybdenum - 1.0 vanadium - 0.18 carbon - 0.26 zirconium - 0.014 boron.

WELDING PROCEDURE AND EVALUATION

Specimen Preparation

Lap joint specimens were machined from γ/γ'-δ bar as shown in figure 2. The ground faying (mating) surfaces were wet sanded on 600-grit paper and degreased before welding. Small localized longitudinal cracks were observed on the as-ground surface of several specimens. These specimens were set aside and not used.

The surface preparation of the dissimilar metal butt joint specimens (fig. 3) was similar to that of the lap joints.

Welding Equipment

Diffusion welds were made in vacuum using a hot press evacuated to a pressure of 6.6×10^{-3} pascal (5×10^{-5} torr). A tantalum resistance heater was used to provide the welding heat. Sintered tungsten rams transmitted the welding force from a 220-kilonewton (25-ton) hydraulic press to the weld specimens.

Weld Cycles

The specimens to be welded were placed in the vacuum chamber and positioned between the loading rams. The chamber was then evacuated. Heat and pressure were applied (figs. 2 and 3) for the time required for diffusion welding. Dimensional checks before and after welding were used to determine percent deformation. The welding variables used for the lap joints in γ/γ'-δ specimens and for the single γ/γ'-δ to IN-100 dissimilar metal butt joint are listed in table I.

Evaluation

Two longitudinal sections (parallel to the growth direction) and two transverse sections of each lap joint were examined metallographically. A single longitudinal section was taken through the dissimilar metal butt joint. Weld quality was evaluated by metallographic examination of both unetched and etched samples.

Considerable care was required in metallographic sectioning using an abrasive cutoff wheel. The γ/γ'-δ eutectic has relatively low transverse ductility (ref. 2), and to avoid base metal cracks, cutting was done at a slow feed rate.

RESULTS AND DISCUSSION

The diffusion welding results are summarized in table I for six lap joints in γ/γ'-δ and for the γ/γ'-δ to IN-100 butt joint. Little or no measurable deformation was produced during welding. At the periphery of the joints, some small unwelded areas were observed. These unwelded areas resulted from a geometric effect on weld force distribution.

γ/γ'-δ Lap Joints

For runs 1 and 2 (table I) the diffusion weld quality (as illustrated in fig. 4) is excellent in that welding at the faying surfaces is complete. Coalescence is especially evident in the high magnification photomicrograph (fig. 4(a)), which shows a growing together of some of the light δ-phase plates that meet at the bond line. Gamma precipitates produced during the weld cycle are evident as dark lines within the δ phase (ref. 6). A variation in base metal structure is shown in figure 4(b). The material above the bond line shows lamellae growth parallel to the solidification direction. Below the bond line, the material is cellular or nonalined. These specimens contained a maximum of 25 percent of the cellular regions (refs. 3 and 6). However, recent optimization of the alloy specifies a fully lamellar structure (ref. 2).

The results for runs 1 and 2 (table I) show that a welding temperature of 1100° to 1150° C at 34.5 megapascals (5 ksi) of pressure and a hold time of 1 hour is adequate to produce high quality diffusion welds in the γ/γ'-δ eutectic alloy.

Quality of welds made at 1100° C and at lower pressures (runs 3 and 4, table I) was comparable to that of runs 1 and 2, except that very small unwelded areas and a few isolated pores were visible at the bond line at a magnification of 250 (not shown). For run 5, made at 1050° C and 34.5 megapascals (5 ksi) with a longer hold time (2 hr), the weld quality was good (see table I). This indicates that, with increased pressure or hold time at 1050° C, the diffusion weld quality would approach the quality achieved for runs 1 and 2.

The diffusion weld made at 1000° C (run 6, table I) was of poor quality, as shown by the unwelded areas in figure 5. This result indicates that 1000° C is too low to produce a good diffusion weld at 34.5 megapascals (5 ksi) for a hold time of 2 hours.

γ/γ'-δ to IN-100 Butt Joint

Diffusion weld quality for the dissimilar metal butt joint was excellent (fig. 6). Note that the light δ-phase has dissolved in the γ/γ'-δ base metal in a band just above the bond line. The dark, crosshatched γ areas between the δ-lamellae have been identified as Widmanstatten δ-precipitates (ref. 3). The light blocky particles in the IN-100 just below the bond line are believed to be carbide precipitates.

Surface Oxide Effects and Serviceability

The preceding results demonstrate diffusion welding feasibility at relative low pressure for γ/γ'-δ lap joints and γ/γ'-δ to IN-100 butt joints. Since there was little or no measureable deformation to break up surface oxides, it is assumed that no significant amount of aluminum and titanium oxides were present on the faying surfaces before diffusion welding. Additional studies that would include the elimination of small unwelded regions at the joint periphery plus mechanical property determinations are required in order to fully evaluate the serviceability of the diffusion welded joints.

CONCLUSIONS

The $\gamma/\gamma'-\delta$ eutectic alloy can readily be diffusion welded to itself and to the IN-100 alloy by hot pressing in vacuum. On the basis of metallographic evaluation, successful diffusion welds were made using the following parameters:

(1) $\gamma/\gamma'-\delta$ to itself: 1100° to 1150° C and 34.5 megapascals (5 ksi) for 1 hour

(2) $\gamma/\gamma'-\delta$ to IN-100: 1100° C and 20.7 megapascals (3 ksi) for 1 hour

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, February 4, 1977,
505-01.

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TABLE I. - HOT-PRESS DIFFUSION WELDING PARAMETERS AND WELD QUALITY AS DETERMINED METALLOGRAPHICALLY

[Chamber pressure 6.6×10^{-3} Pa (5×10^{-5} torr).]

Run	Materials	Temperature, °C	Pressure		Time, hr	Deformation, % Δt	Weld quality[a]
			MPa	ksi			
1	γ/γ'-δ	1150	34.5	5	1	0.1	Excellent
2	↓	1100	34.5	5	↓	---	Excellent
3	↓	1100	20.7	3	↓	None	Good
4	↓	1100	6.9	1	↓	None	Good
5	↓	1050	34.5	5	2	.1	Good
6	↓	1000	34.5	5	2	.1	Poor, unwelded areas
7	γ/γ'-δ to IN-100	1100	20.7	3	1	None	Excellent

[a]Determined metallographically on etched and unetched specimens.

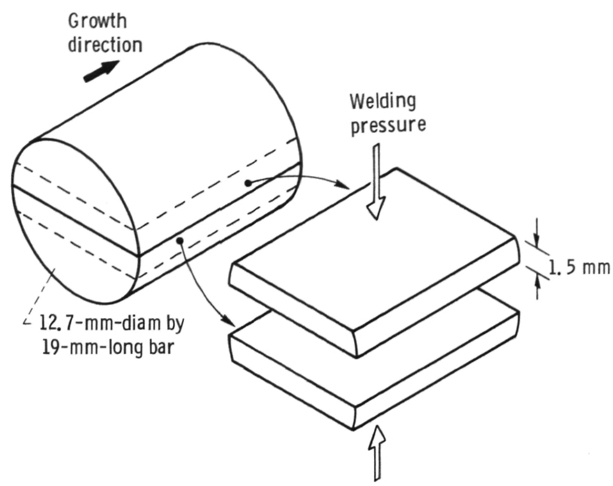


Figure 2. - Weld specimen design for lap joints in γ/γ'-δ eutectic alloy.

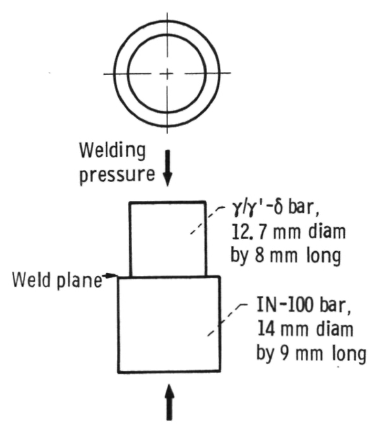


Figure 3. - Weld specimen design for butt joint between γ/γ'-δ eutectic alloy and IN-100 superalloy.

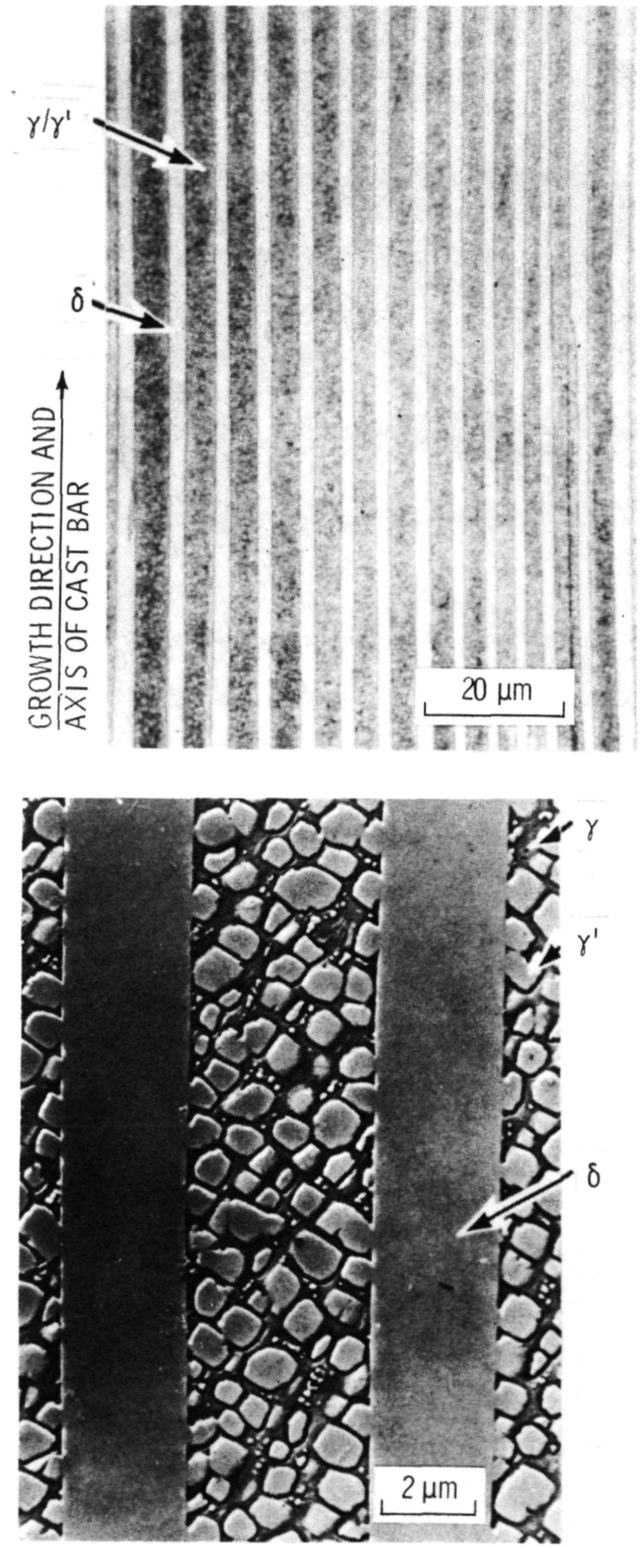
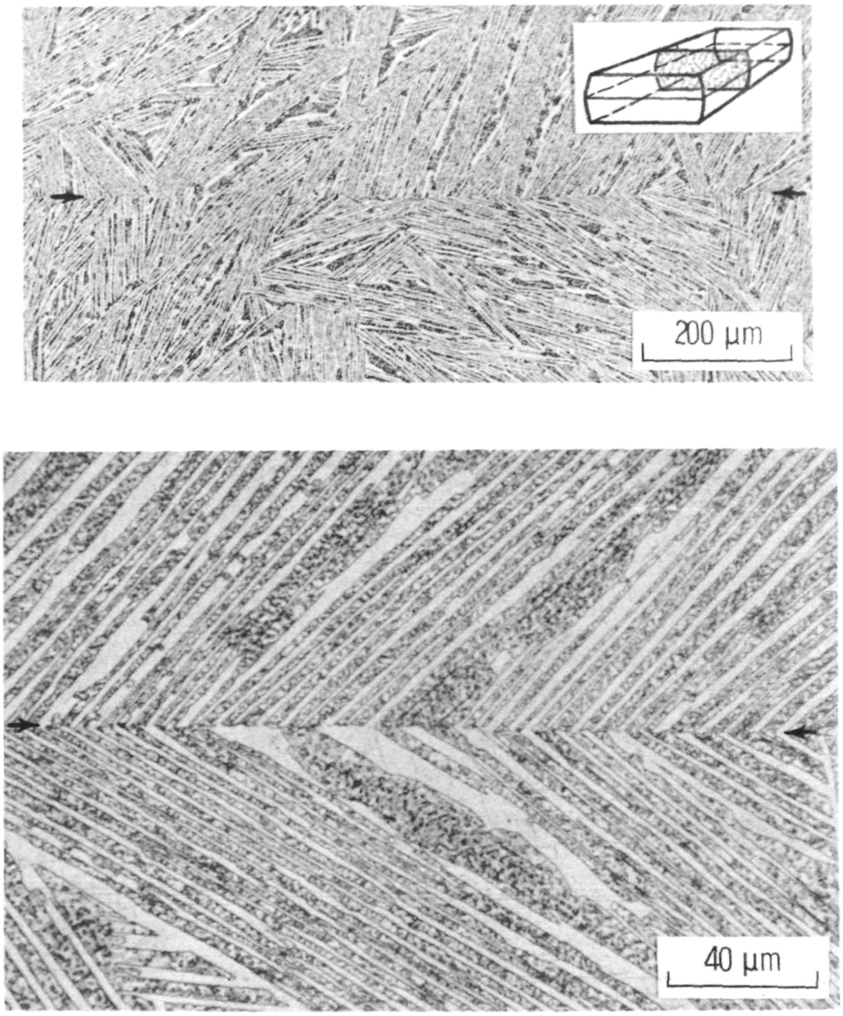
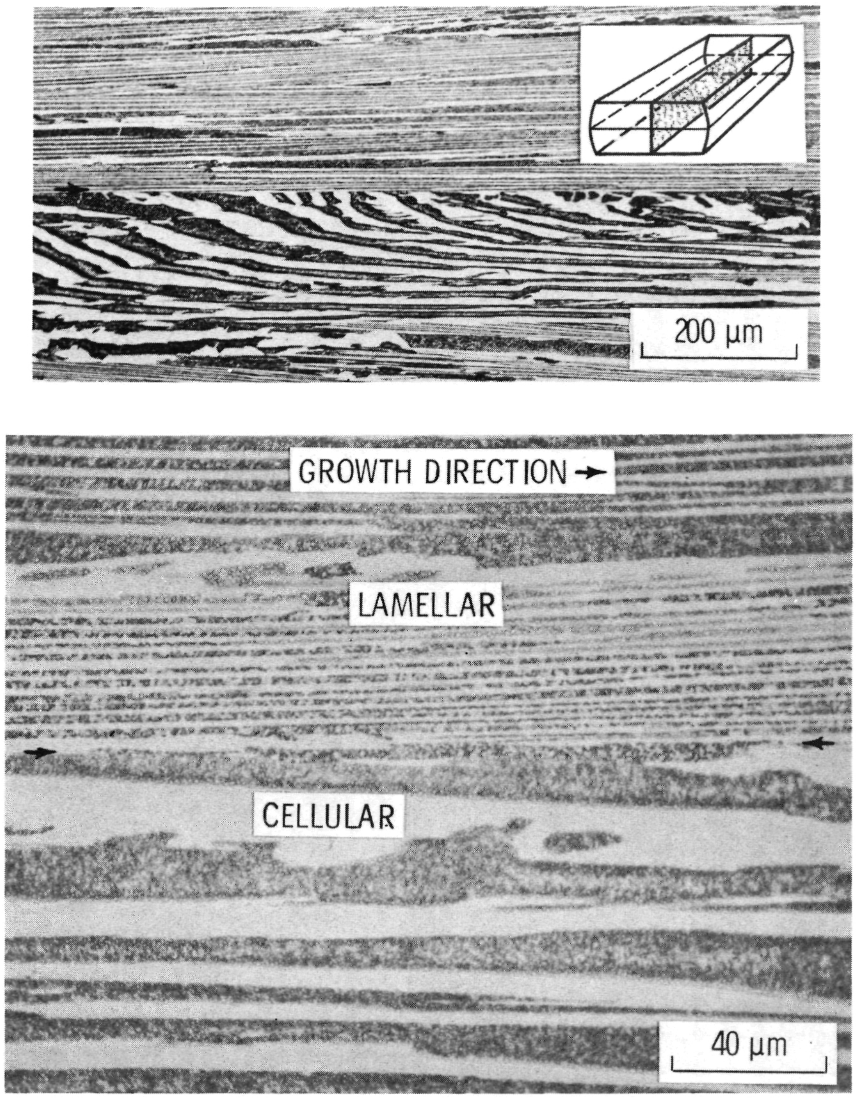


Figure 1. - Optimum microstructure of directionally solidified γ/γ'-δ eutectic alloy parallel to the growth direction.



(a) Transverse section of lap joint (normal to growth direction).

Figure 4. - Lap joint diffusion weld in γ/γ'-δ bar showing excellent weld quality.



(b) Longitudinal section of lap joint (parallel to growth direction).

Figure 4. - Concluded.

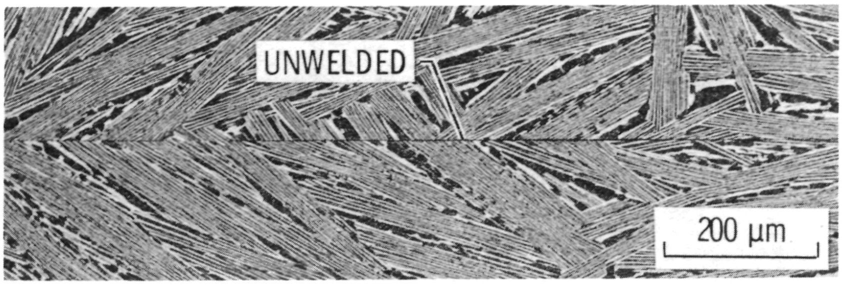


Figure 5. - Transverse section of lap joint diffusion weld in γ/γ'-δ bar showing unwelded region.

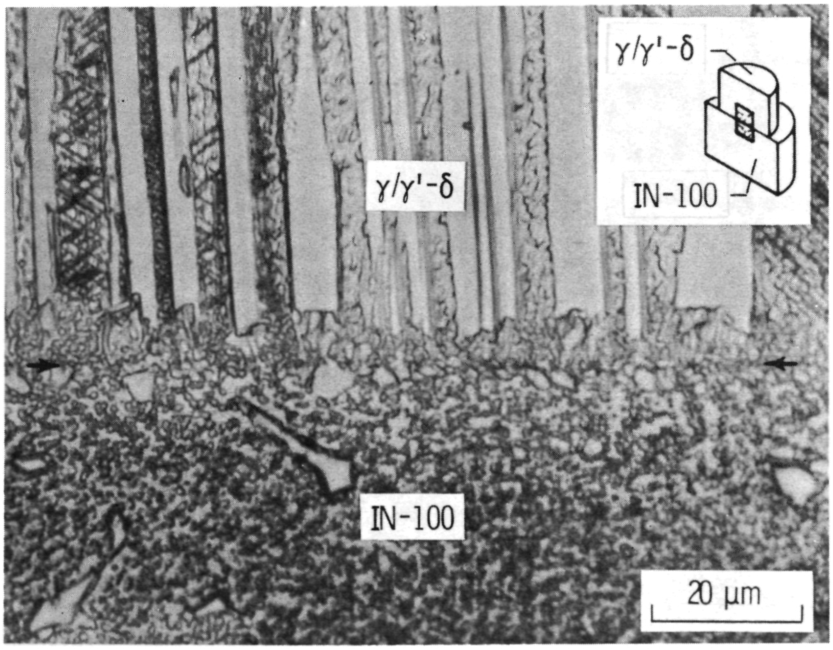


Figure 6. - Butt joint diffusion weld between γ/γ'-δ and IN-100 bar illustrating excellent weld quality.

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