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Microstructure and mechanical properties of friction welded alloy 718

R. Damodaram, S. Ganesh Sundara Raman*, K. Prasad Rao

Department of Metallurgical and Materials Engineering, Indian Institute of Technology Madras, Chennai-600036, India

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ABSTRACT

The present work deals with the effects of pre- and post-weld heat treatments on microstructure and mechanical properties of alloy 718 friction weld joints. Prior to friction welding, alloy 718 rods were subjected to two types of heat treatments - solution treatment (ST) and solution treatment followed by aging (STA). In the as-welded condition, samples welded with prior ST condition exhibited higher hardness in the weld zone compared to the base material in ST condition and this is attributed to grain refinement due to dynamic recrystallization. Samples welded with prior STA condition exhibited decreased hardness in the weld zone and room temperature tensile properties in relation to the base material in STA condition. It is due to dissolution of γ'' (Ni_3Nb) phase as the temperature measured at weld zone was found to be 1118 °C. In order to retrieve the hardness and room temperature tensile properties, friction weld joints were subjected to direct aging (DA) treatment. A significant increase in hardness was observed in the weld zone after direct aging for both samples welded in ST and STA conditions. This is attributed to the grain refinement due to dynamic recrystallization and formation of precipitates by the DA treatment.

1. Introduction

Alloy 718 is a nickel-iron based superalloy extensively used in components for aircraft, chemical plant equipment and petrochemical equipment due to its excellent corrosion resistance and good mechanical properties at high temperatures. The primary strengthening is mainly produced by γ'' (Ni_3Nb) precipitates which are coherent disc shaped particles [1,2]. Fusion welding techniques are used in the joining of superalloys. The weldability of these alloys is generally considered to be good, mostly because of their resistant to strain age cracking due to the sluggish precipitation kinetics of γ'' phase [3]. But, it has been reported that some problems, such as Boron/Niobium segregation, Laves phase and microfissures (liquation cracking), which could occur in either fusion zone or heat affected zone (HAZ) of alloy 718 welds [4–6]. Laves phase is a brittle intermetallic phase, known for its deleterious effect on mechanical properties [7–9]. In order to eliminate these problems in fusion welding, use of solid state welding process like friction welding is attractive for alloy 718. Because melting and solidification are not involved in this process, welds are free from segregation, porosity and liquation cracking [10]. Friction welding is now extensively used in automotive, aerospace, petroleum and electrical industries [11].

Wang et al. [12] have reported the dissolution of δ phase and niobium carbides in the fine grain region of alloy 718 friction weld joint. In another work, the same investigators reported that the tensile strength of alloy 718 weld joint can be improved through optimization of friction weld parameters and post weld heat treatment [13]. Fine grain microstructure of the friction weld interface did not change even after post weld heat treatment [14]. Mary and Jahazi reported that higher friction pressure leads to structural degradation, very high temperature at the weld interface and narrow thermo-mechanically affected zone (TMAZ) in case of linear friction welds of IN 718 [15]. Bu et al. [16] reported that with increasing friction time, the temperature gradient in the axial direction decreases mainly due to very high energy given in the initial stage and low heat conduction of alloy 718. Kim et al. [17] have observed that an aging treatment after friction welding improves hardness and tensile properties of friction welded alloy 718 and SNCrW stainless steel (chemical composition (in wt.%) of SNCrW stainless steel is 0.2 C, 1.4 Si, 19.8 Cr, 9.5 Ni and 68.3 Fe). Peak temperature at interface can significantly affect microstructure in the weld zone and mechanical properties [18]. Doong et al. [19] used infrared temperature sensing equipment to observe the surface temperature of laser welding. The literature available on microstructure and mechanical properties of direct drive friction welds of alloy 718 is limited as the experiments conducted by Wang et al. [12–14] had machine constraints limiting the upset pressure to 350 MPa due to which the softening region was wide and the joint strength was low. Though the Laves phase and liquation cracking can be avoided in friction welds, they may

* Corresponding author. Tel.: +91 044 22574768; fax: +91 04422570509.
E-mail address: ganesh@iitm.ac.in (S.G.S. Raman).

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soften at the weld interface due to high temperature exposure and dissolution of γ'' phase. Aging treatment may be required to restore the mechanical properties. The aim of the present study is to characterize the microstructure and evaluate mechanical properties of alloy 718 friction weld joints before and after a direct aging treatment.

2. Experimental Details

The chemical composition (in wt %) of base material alloy 718 was 51.6 Ni, 18.2 Cr, 5.1 Nb, 3.28 Mo, 1.06 Ti, 0.56 Al, 0.33 V, 0.09 Mn, 0.01 S, 0.004 C, 0.003 B and 19.763 Fe. Alloy 718 rods of 13 mm diameter were used with two prior thermal histories (1) solution treated (ST); (2) solution treated and aged (STA) conditions. Solution treatment was done at 995 °C for 1 h and two stage aging, i.e. aging was done at 720 °C for 8 h followed by furnace cooling to 620 °C and then aging at 620 °C for 8 h followed by air cooling to room temperature.

Friction welding was carried out in a continuous drive friction welding machine of 200 kN capacity. The main welding parameters in continuous drive friction welding are friction pressure, upset pressure, burn-off length and spindle speed. The values of the process parameters used in the present study are given in Table 1. An infrared (IR) thermometer with a noise equivalent temperature of 1 °C (peak to peak) was used to measure surface temperature during friction welding. The thermometer was operated in the nominal spectral response of 0.75 to 1.1 μm, and response time of 10 ms. The IR thermometer used in this study measures from 600 to 3000 °C. The IR thermometer was placed at an appropriate distance (1 m) from friction weld zone and focused to the weld region. After friction welding, flash was removed by machining.

According to Wang [20] the maximum content of γ' and γ'' phases in alloy 718 base material can be obtained by using a double aging treatment - 720 °C/8 h+620 °C/8 h. As per the recommendation, weld joints were subjected to direct aging (DA) (720 °C for 8 h followed by furnace cooling to 620 °C and then aging at 620 °C for 8 h and then air cooling to room temperature). Specimens for microstructural observations were prepared as per standard metallographic practices. Etching was done using Kalling's agent consisting of 5 g $CuCl_2$, 100 ml HCl and 100 ml ethanol. Microstructural characterization was carried out by using optical microscopy, scanning electron microscopy (SEM) and transmission electron microscopy (TEM). For TEM studies, samples were mechanically polished to 100 μm. Thin foils for TEM study were prepared by using twin jet electro polishing with an electrolyte of 10% perchloric acid in methanol at −30 °C. Microhardness measurements were made across the weld interface on polished and etched samples using 0.5 kg load for 15 s. ASTM - E8-04 standard specimen configuration was employed for room temperature tensile testing. Fracture surfaces were examined using a scanning electron microscope.

Table 1
Welding process parameters.

Friction pressure (MPa)	300
Upset pressure (MPa)	600
Burn off length (mm)	4
Spindle speed (r.p.m.)	1500

3. Results and Discussion

3.1. Temperature measurement using IR thermometer

Thermocouples have been used to measure the temperature variation during a typical friction welding cycle. However, the thermocouple readings are usually unreliable due to the damage brought during rubbing and upsetting operations [21]. In the present study, an IR thermometer was used to measure the temperature at the interface. The IR thermometer was placed in such a way that the field of view was focused at the plasticized region confined between the rubbing surfaces. A gradual increase in the temperature along with friction time was observed in the weld region for the first few seconds, after that the temperature rapidly increased to 1118 °C which was maintained for 4 s and then temperature rapidly decreased to room temperature. Based

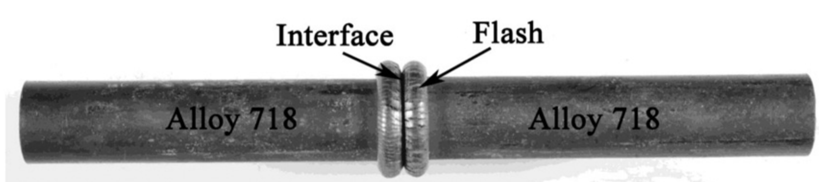

Fig. 1. Photograph of friction welded alloy 718 joint.

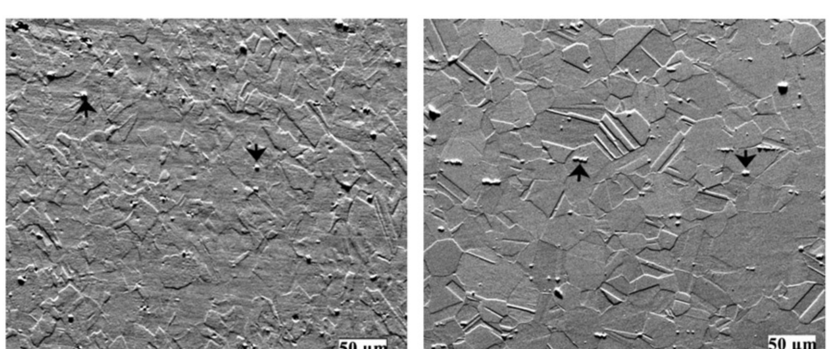

Fig. 2. Scanning electron micrographs of alloy 718 base material in two different conditions: (a) ST condition, (b) STA condition.