Materials Science & Engineering A 612 (2014) 414–422

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Hot tensile and stress rupture behavior of friction welded alloy 718 in different pre-and post-weld heat treatment conditions

R. Damodaram [a], S. Ganesh Sundara Raman [a,*], D.V.V. Satyanarayana [b], G. Madhusudhan Reddy [b], K. Prasad Rao [c]

[a] Department of Metallurgical and Materials Engineering, Indian Institute of Technology Madras, Chennai 600036, India
[b] Defence Metallurgical Research Laboratory, Kanchanbagh, Hyderabad 500058, India
[c] University of Utah, Salt Lake City, USA

ARTICLE INFO

Article history:
Received 2 April 2014
Received in revised form
12 June 2014
Accepted 21 June 2014
Available online 27 June 2014

Keywords:
Alloy 718
Friction welding
High temperature tensile test
Stress rupture test
Post-weld heat treatment

ABSTRACT

Alloy 718 rods in two different heat treated conditions (solution treatment (ST) and ST followed by aging (STA)) were friction welded. The weld joints were subjected to two different post-weld heat treatments (direct aging (DA) and STA). Tensile tests were carried out at 650 °C with an initial strain rate of 10^{-4} s^{-1}. Stress rupture tests were performed at 650 °C at a constant load with an initial stress level of 690 MPa. The ultimate tensile strength values for all conditions, expect for base material in ST condition and weld joints with prior ST or STA in the as-welded condition, were higher than the minimum value of 1000 MPa specified by the Aerospace Material Specification for the base material in STA condition. The weld joint specimen in the as-welded state with prior STA condition failed in heat affected zone (HAZ). Though strengthening precipitates (γ″) dissolved in weld metal and HAZ during welding, HAZ was weaker than weld metal due to coarser grains and so failure occurred in HAZ. In all other conditions, samples failed in base metal. The stress rupture properties such as minimum creep rate and time to rupture of the base material in ST condition and as-welded joints with prior ST or STA condition are almost same. The sample subjected to STA both before and after welding exhibits the best stress rupture properties. It may be attributed to homogenization as well as moderate coarsening of grain structure of weld zone and fine and uniform distribution of strengthening precipitates throughout the weldment. However, to obtain the best combination of tensile and stress rupture properties, the material should be welded in ST condition and it should be subjected to direct aging after welding.

1. Introduction

Alloy 718 is one of the most commonly used Ni–Fe based superalloys. It possesses excellent high temperature properties and corrosion resistance up to 650 °C. Alloy 718 is widely used in aircraft, marine, industrial, and vehicular gas turbines [1]. The principal strengthening precipitates in alloy 718 are γ′ (Ni_3 (Al, Ti)) and γ″ (Ni_3Nb) [2]. These alloys are prone to microstructural degradation leading to Laves phase ((Ni, Cr, Fe)$_2$ (Nb, Mo, Ti)) formation, and coarsening of strengthening precipitates as well as Nb segregation and liquation cracking in either weld zone or heat affected zone (HAZ) during conventional fusion welding processes [3–5]. Laves phase formation and coarsening of strengthening precipitates lead to inferior mechanical properties in the weld zone or HAZ compared to base material [6,7].

Friction welding is an alternative method to overcome the above limitations. Friction welding is a solid state welding process in which a very high temperature gradient is available at joint area and it results in narrow HAZ [8]. Chamanfar et al. [9] reported that due to high temperature exposure and higher cooling rates in the linear friction welding of WASPALOY, average size and volume fraction of strengthening precipitates decrease leading to reduction in the hardness of weld zone compared to base material. Neminathan and Mohandas [10] reported that IN 718 as-welded joints with prior solution treated and aged condition showed inferior room temperature and high temperature tensile properties compared to those of the base material in the solution treated and aged condition. Roder et al. [11] performed tensile tests on IN718 – Incoloy 909 inertia friction weld joints at different temperatures (20 °C, 450 °C and 650 °C) and reported that failure occurred in IN718 weld zone due to absence of γ″ strengthening precipitates. Roder et al. [12] observed that the weld joint samples showed inferior ductility compared to the base material due to higher plastic deformation on the Incoloy 909 side of the weld zone for IN718 – Incoloy 909 inertia friction weld joints tested at 650 °C.

* Corresponding author. Tel.: +91 44 22574768; fax: +91 44 22570509.
E-mail address: ganesh@iitm.ac.in (S. Ganesh Sundara Raman).

http://dx.doi.org/10.1016/j.msea.2014.06.076
0921-5093/

Cao [13] reported that dissolution/coarsening of strengthening precipitates and formation of δ phase in alloy 718 play a major role in degradation of mechanical properties such as tensile strength, stress rupture life, creep resistance and low cycle fatigue life upon thermal exposure up to 760 °C/500 h. Chang et al. [14] stated that a modified heat treatment ((1) solution treatment done at 1032 °C/1 h and aging done 843 °C/4 h followed by air cooling and again (2) solution treatment done at 926 °C/1 h, furnace cooling to 718 °C, then aging at 718 °C followed by air cooling to room temperature) showed an increased tertiary creep life by a factor of 1.5–2 at 650 °C and stress level of 593 MPa compared to the standard heat treatment in alloy 718.

Chen and Chaturvedi [15] observed that solution treatment at 1000 °C resulted in superior stress rupture time and higher strain compared to solution treatment at 975 °C due to less volume fraction of δ phase formation at grain boundaries. In a study on creep behavior of alloy 718 samples tested at a stress level of 795 MPa and at 625 °C, Korth [16] reported that long term thermal aging of alloy 718 at 650 °C for up to 50,000 h resulted in reduction of creep rupture properties at 650 °C due to coarsening of γ'' and γ' strengthening precipitates, which reduces coherency between the strengthening precipitates and the matrix tested. In a study on friction deposited alloy 718, Dilip and Janaki Ram [17] have reported inferior stress rupture life of the samples in the as-deposited condition compared to stress rupture life of the bulk material due to the formation of very fine grains and absence of grain boundary δ phase in as-friction deposited alloy 718. To improve stress rupture properties, friction deposits were subjected to two step solution treatment (solution treatment at 1080 °C/30 min (for grain coarsening) followed by furnace cooling to 950 °C and then holding at 950 °C/30 min (for δ phase precipitation)) and then standard aging treatment.

In an earlier work [18,19], the authors reported microstructure and room temperature tensile properties of continuous drive friction welded alloy 718 joints in as-welded condition and post-weld heat treated conditions. Friction welded tensile test samples with prior solution treatment and aging (STA) condition failed in the weld zone due to dissolution of strengthening precipitates. However, post-weld heat treatment (PWHT) involving STA resulted in failure of friction welded tensile samples in the base material. Post-weld direct aging treatment resulted in superior microstructure and room temperature tensile properties compared to post-weld STA.

The main objective of the present study is to produce friction weld joints of alloy 718 with optimum high temperature tensile and stress rupture properties through appropriate prior and post-weld heat treatments.

2. Experimental procedures

The chemical composition (in wt%) of base material alloy 718 is given in Table 1. Alloy 718 rods of 13 mm diameter were subjected to two different heat treatments prior to friction welding viz., (i) solution treatment (ST) and (ii) STA. Typical STA treatment involves solution treatment at 995 °C/1 h, 1st step aging at 720 °C/8 h followed by furnace cooling to 620 °C and then 2nd step aging at 620 °C/8 h followed by air cooling to room temperature. A continuous drive friction welding machine of 200 kN capacity was used for friction welding. The weld joints were produced using the process parameters – friction pressure of 300 MPa, upset pressure of 600 MPa, spindle speed of 1500 rpm and burn off length of 4 mm.

After friction welding, the welded joints were subjected to two different PWHTs- (i) two-step aging, as mentioned earlier (hereafter referred to as direct aging (DA)) and (ii) STA. DA after welding was performed to re-precipitate strengthening phases as they go into solution due to high temperature exposure during welding. On the other hand, STA after welding was carried out to homogenize weld metal as well as to promote uniform and fine distribution of strengthening precipitates [20].

High temperature tensile and stress rupture tests were performed on friction welded samples in both the as-welded and post-weld heat treated conditions. Drawings of specimens used for high temperature tensile and stress rupture tests are shown in Fig. 1. Specimens were fabricated in such a way that the friction weld joint interface was located at the center of specimens. High temperature tensile tests were carried out at 650 °C at an initial strain rate of $10^{-4}\,s^{-1}$ on an electromechanical screw driven machine of 250 kN capacity. The specimens were soaked at 650 °C for 1 h before starting the tests. Two samples were tested in each condition. The stress rupture tests were conducted at 650 °C and an initial applied tensile stress of 690 MPa. The stress rupture tests were carried out in a constant load creep testing machine of 30 kN capacity. The specimen temperature during stress rupture tests was measured in the gage and gripping portions using R-Type thermocouples and specimen temperature was controlled within ±1 °C. The displacement was measured using a high temperature extensometer and linear variable differential transducers assembly. The specimens were heated to 650 °C

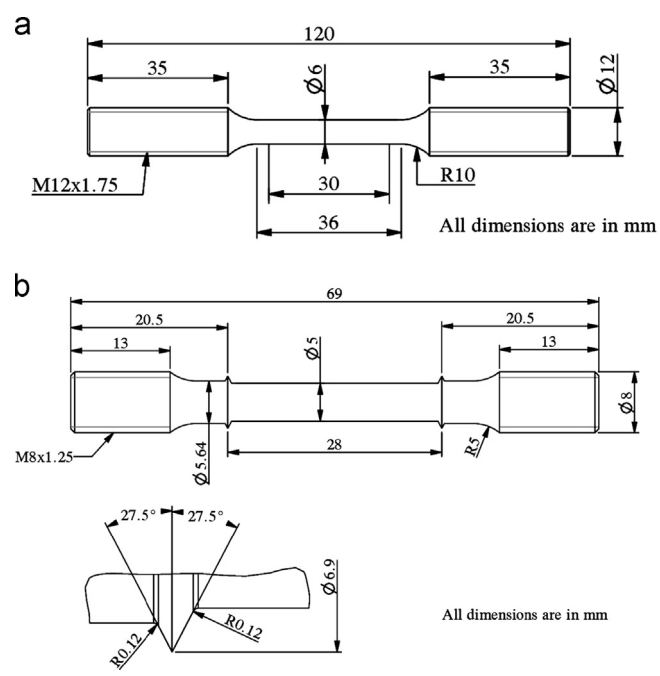

Fig. 1. Specimen drawing for (a) high temperature tensile test, (b) stress rupture test.

Table 1
Chemical composition (in wt%) of base material alloy 718.

Ni	Cr	Fe	Nb	Mo	Ti	Al	V	Mn	S	C	B
51.6	18.2	19.763	5.1	3.28	1.06	0.56	0.33	0.09	0.01	0.004	0.003