ARTICLE IN PRESS

Journal of Materials Science & Technology ■■ (2016) ■■–■■

Contents lists available at ScienceDirect

Journal of Materials Science & Technology

journal homepage: www.jmst.org

Transient Liquid Phase Bonding of IN738LC/MBF-15/IN738LC: Solidification Behavior and Mechanical Properties

B. Binesh *, A. Jazayeri Gharehbagh

Materials Research Center, Technology Development Institute, ACECR, Tehran 1459974111, Iran

ARTICLE INFO

Article history:
Received 28 March 2016
Received in revised form
18 May 2016
Accepted 13 July 2016
Available online

Key words:
Transient liquid phase bonding
IN738LC superalloy
Isothermal solidification
Amorphous brazing foil
Mechanical properties

Transient liquid phase (TLP) bonding of IN738LC superalloy was carried out using a rapidly solidified MBF-15 Ni-based foil. The effects of bonding temperature (1130–1170 °C) and time (5–120 min) as well as foil thickness (35–140 μm) were studied on the microstructure of joint region and its mechanical properties. The solidification sequence in the joint region was found to be (i) formation of γ solid solution in the isothermally solidified zone, followed by (ii) ternary eutectic of $\gamma + Ni_3B + CrB$, and finally (iii) binary eutectic of $\gamma + Ni_3Si$ in the athermally solidified zone. Fine Ni_3Si particles were also formed via a solid state transformation within the γ matrix in the vicinity of eutectic products. A deviation of isothermal solidification kinetics from the standard parabolic TLP model was observed by increasing the bonding temperature to 1170 °C, which resulted in the formation of eutectic constituents at the joint centerline. The analysis of mechanical and fractographic test results revealed that the samples with complete isothermal solidification exhibit the highest shear strength, whereas the hard eutectic constituents act as preferential failure sites and lead to a significant reduction in the joint shear strength in samples with incomplete isothermal solidification.

Copyright © 2016, The editorial office of Journal of Materials Science & Technology. Published by Elsevier Limited.

1. Introduction

The high operating temperature of turbine and combustor components made from superalloys like IN738LC leads to a rapid degradation of the material by fatigue, creep and oxidation reaction[1–3]. In general, welding and brazing processes are used as cost-effective techniques to repair damaged parts[4,5]. However, IN738LC contains a considerable amount of γ' promoting elements ($Al + Ti > 6$ wt%), which makes it difficult to weld due to its high susceptibility to heat affected zone (HAZ) cracking during welding and the post-weld heat treatment[6–8]. Substantial volume fraction of γ' precipitates which are the main strengthening phase of the alloy and the presence of other secondary particles such as carbides, borides and γ-γ' eutectic mixture along the grain boundaries accompanying high level of segregation in the microstructure of cast alloy result in liquation cracking during welding[9]. In addition, large shrinkage stresses due to rapid γ' precipitation during weld cooling contribute to subsequent cracking in welded IN738LC[10]. On the other hand, the brazed joints show brittleness and lower strength in high temperatures due to low melting point of the braze material and the formation of hard and brittle eutectic microconstituents during the joining process[4,11]. In order to prevent the formation of these deleterious phases, a new joining technique called transient liquid phase (TLP) bonding was developed by Duvall et al.[12].

Transient liquid phase bonding is a hybrid process that combines the beneficial features of liquid phase joining and diffusion bonding techniques[13,14]. In TLP process, a filler metal, containing melting point depressant (MPD) elements such as B, P, and Si, is placed between the well-cleaned mating surfaces of the base metal (BM). The joining operation is carried out at a temperature between the liquidus of the filler metal and the solidus of the base metal. While the joint is held at the bonding temperature, interdiffusion of alloying elements between the liquid and the base metal occurs, which eventually results in isothermal solidification[15,16].

Originating from Sexton and Decristofaro's work[17] on the manufacturing of amorphous brazing foils by means of rapid solidification technique, this new group of filler metals has found extensive applications in the TLP bonding of many classes of substrates such as superalloys, stainless steels, cemented carbides, etc. The most important advantages of amorphous foils compared to the conventional powder and paste filler metals are their flexibility and ductility. The amorphous brazing foils also show superior flow characteristics, good wettability, and narrower melting temperature range and are free from contaminating organic materials, which is an attractive feature for vacuum brazing[18,19]. Because of these unique properties, amorphous brazing foils display an effective role as the most advanced

---

* Corresponding author. Fax: +98 21 66075200.
E-mail address: binesh.kntu@gmail.com (B. Binesh).

http://dx.doi.org/10.1016/j.jmst.2016.07.017
1005-0302/Copyright © 2016, The editorial office of Journal of Materials Science & Technology. Published by Elsevier Limited.

Please cite this article in press as: B. Binesh, A. Jazayeri Gharehbagh, Transient Liquid Phase Bonding of IN738LC/MBF-15/IN738LC: Solidification Behavior and Mechanical Properties, Journal of Materials Science & Technology (2016), doi: 10.1016/j.jmst.2016.07.017

filler metal used in applications related to the aerospace industry, precision machinery and tools and modern medical equipment[18].

To date, transient liquid phase bonding of similar and dissimilar super-alloys has been studied by a number of research groups[20–23]. Meanwhile, TLP bonding of γ' precipitation hardened nickel-based superalloys has received more attention due to the widespread use of these joints in industries[23–25]. The various ranges of amorphous brazing foils such as BNi2[21], MBF-30[26], MBF-80[15], and Nicrobraz 150[3,27], have been used for TLP bonding of nickel-based alloys. However, there is little information on application of MBF-15 amorphous filler alloy in the TLP bonding process. It is important to note that achieving optimized TLP process conditions requires technical data related to the identification of precipitates and investigation of solidification behavior in the joint region, diffusion mechanism of the alloying elements and the effect of bonding temperature, hold time and thickness of the interlayer on joint microstructure and strength. Previous investigations have mainly been devoted to study these issues separately. For example, the solidification behavior of TLP joints has been studied for some bonding systems. Duvall et al.[12] examined the TLP bonding of some nickel- and cobalt-based superalloys and suggested an isothermal solidification mechanism for the first time. Ohsasa et al.[28] in their work on numerical modeling of transient liquid phase bonding of nickel using a Ni—B—Cr interlayer studied the solidification sequence of the residual liquid during the cooling stage using Scheil simulation. They showed that the solidification sequence of eutectic phases at the joint centerline is γ solid solution, Ni$_3$B and CrB, respectively. Similar observations were also reported by Sheng et al.[29] in the case of solidification behavior of TLP bonded single crystal nickel-based superalloy using a Ni—Cr—B interlayer. Pouranvari et al.[26] studied the TLP bonding of IN718 superalloy using a Ni—Si—B filler alloy and proposed a ternary eutectic of γ/Ni$_3$B/Ni$_6$Si$_2$B as solidification products at the joint centerline. There are also some studies on the effect of bonding parameters on the microstructure evolution of TLP joints[2,15,20]. However, few systematic attempts have been made to consider all the above mentioned issues during TLP bonding of a multicomponent system.

This research aims to establish a comprehensive knowledge about the microstructural and phase evolution during TLP bonding of IN738LC superalloy using MBF-15 amorphous foil and the effects of bonding parameters on the microstructure and mechanical properties of the joints. Solidification and solid state precipitation behaviors during bonding process have been discussed. A comparison between experimental results and theoretical predictions concerning isothermal solidification rate was also carried out for TLP joint of IN738LC/MBF-15/IN738LC.

2. Experimental Procedure

2.1. Materials and thermal analysis

Cast polycrystalline IN738LC superalloy was used as the substrate material with the chemical composition given in Table 1. TLP bonding process was carried out using MBF-15 amorphous foil prepared by planar flow casting method as the filler metal. The chemical composition of MBF-15 foil is also presented in Table 1.

NETZSCH STA 409 PC/PG deferential thermal analysis (DTA) apparatus was used to determine the solidus and liquidus temperatures of the brazing foil. A small piece of the foil (30 mg) was placed into an alumina pan and heated up to 1300 °C at a rate of 20 °C/min under argon atmosphere. The solidus and liquidus temperatures of the foil, based on the DTA curve, were found to be 976 and 1115 °C, respectively.

2.2. TLP bonding

Test specimens (10 mm × 10 mm × 5 mm) were cut from as-cast IN738LC using electro discharge machine (EDM). The mating surfaces of the specimens (10 mm × 10 mm) were polished to remove the surface oxide layer and then were ultrasonically cleaned for 15 min in an acetone bath. The MBF-15 interlayer with various thicknesses of 35, 70, 105 and 140 µm was placed between two specimens. A fixture, made from 304 stainless steel, was used to prevent the movement of assembled samples due to melting of the interlayer at bonding temperature. The pressure on assembled brazing samples during TLP bonding was only the weight of specimens which was constant for all the samples. TLP bonding process was carried out in a resistance tube furnace at 1130, 1150 and 1170 °C for various holding time of 5–120 min under a vacuum of 5.33×10^{-3} Pa (4×10^{-5} torr). The samples were heated up to brazing temperature at a rate of 20 °C/min and held for specified time and then furnace cooled to room temperature in vacuum.

2.3. Microstructural characterization and mechanical tests

Cross sections of the samples perpendicular to the bonding surface were ground with standard SiC abrasive papers and polished using 0.25 µm diamond paste. Samples were etched conventionally using Marble etchant solution (10 g CuSO$_4$, 50 mL HCL, 50 mL H$_2$O) and were etched electrolytically with 10% aqueous oxalic acid (C$_2$H$_2$O$_4$•2H$_2$O) solution at 6 V for 4 s. Microstructural examinations were carried out using a Neophot 32 optical microscope (OM) and Mira3Tescan field emission scanning electron microscope (FE-SEM) equipped with a beryllium window energy dispersive spectrometer (EDS) system.

X-ray diffraction (XRD) analysis of the phases present in the joint area was carried out using a Philips X'pert X-ray diffractometer equipped with a Cu$K\alpha$ target. The wave length of Cu$K\alpha$ radiation was 0.15406 nm.

Microhardness and shear strength examinations were used to evaluate the mechanical properties of bonded samples. Hardness variations across the bonding region were measured using a Leco microhardness apparatus at a load of 50 g, according to ASTM standard E384[30]. The hardness values at each point were the mean of five measurements. Shear strength tests were carried out using a Schenck tensile machine at a crosshead speed of 1 mm/min, according to ASTM standard D1002[31]. A fixture, made of VCN 150 hardened tool steel, was used to apply the shear stress on the joints during the tensile test (Fig. 1). Three tests were carried out at each condition and mean values were reported. The fracture surfaces were examined using SEM.

Table 1
Chemical composition of cast IN738LC superalloy and MBF-15 interlayer (wt%)

Alloy	Ni	Cr	Co	Al	Ti	Mo	Si	Ta	W	B	Fe	Zr	Nb	C
IN738LC	Bal.	16.1	8.3	3.5	3.3	1.7	0.05	1.6	2.9	0.013	0.09	0.05	0.8	0.11
MBF-15	Bal.	13.0	1.0	–	–	–	4.5	–	–	2.8	4.2	–	–	0.03

Please cite this article in press as: B. Binesh, A. Jazayeri Gharehbagh, Transient Liquid Phase Bonding of IN738LC/MBF-15/IN738LC: Solidification Behavior and Mechanical Properties, Journal of Materials Science & Technology (2016), doi: 10.1016/j.jmst.2016.07.017

Download English Version:

https://daneshyari.com/en/article/5451635

Download Persian Version:

https://daneshyari.com/article/5451635

Daneshyari.com