Materials and Design 91 (2016) 104–110

Contents lists available at ScienceDirect

Materials and Design

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

Microstructural evolution and mechanical properties of hot isostatic pressure bonded CM 247LC superalloy cast

Huei-Sen Wang [a,*], Yen-Ling Kuo [a], Chen-Ming Kuo [b], Chao-Nan Wei [c]

[a] Department of Materials Science and Engineering, I-Shou University, Taiwan
[b] Department of Mechanical and Automation Engineering, I-Shou University, Taiwan
[c] Materials and Electro-Optics Research Division, Chung-Shan Institute of Science and Technology, Taiwan

ARTICLE INFO

Article history:
Received 11 September 2015
Received in revised form 14 November 2015
Accepted 26 November 2015
Available online 27 November 2015

Keywords:
Nickel based superalloys
Bonding
Hot-isostatic pressing
Microstructure
Mechanical properties

ABSTRACT

To provide bonding pieces with the optimal strength, in this study, CM247LC nickel-based superalloy rods were joined using the hot-isostatic pressing (HIP) bonding technique with various bonding parameters, a specially designed canning process, and an intermediate layer formed by a powder filler. After tests, the microstructural evolution of the bonding area and mechanical properties of the bonded pieces were investigated.

The test results have shown that, under the proper conditions (HIP at 1220 °C/175 MPa/4 h) a sound HIP bonding piece was created; especially in the intermediate layer, where very fine matrix grain and carbides were found. The fine carbides were uniformly precipitated in the matrix and grain boundaries, which may play a role in inhibiting sliding and damage accumulation during tensile tests. The fracture location of the test piece indicated that the intermediate layer has excellent tensile strength, which is even stronger than that of the as-HIPed CM247LC cast.

1. Introduction

CM 247LC is a precipitation hardening nickel-based superalloy with low carbon content. This alloy is a modified superalloy with a chemical composition of Mar-M247, which is specifically designed for making the directionally solidified (DS) [1,2] turbine blade. It was reported that CM 247 LC's advantages include: improved resistance to grain boundary cracking during DS casting, and enhanced ductility, carbide stability, and fatigue properties, which can be used in the hot sections of aero-engines, turbines, or propulsion systems.

As the requirements of the operational efficiency of the propulsion system performance are increased, so does the complexity of the system parts, hence, the ability to join the superalloy components using various methods, such as fusion welding [3] or solid state diffusion bonding [4–6], becomes essential to produce a high-performance system. Regarding fusion welding, the weldability of Ni-based superalloys depends widely on their Al and Ti contents (γ' strengthening phase formers) [7–9], especially for a precipitation hardened Ni-based superalloy, which contains high Al and Ti concentrations that are highly susceptible to hot cracking in the weld fusion zone (WFZ) [3], liquation cracking [10,11] in the heat affected zone (HAZ), or reheat cracking [11] after the post-weld heat treatment. In addition, the micro-segregation and non-equilibrium phase transformation, which occurs in the WFZ, significantly affects the performance of the welds. Therefore, solid state diffusion bonding, such as hot isostatic pressing (HIP) diffusion bonding, which eliminates the abovementioned problems and manufactures net shape components with similar properties [12,13], can be considered as a potential process for the joining of precipitation strengthening Ni-based superalloys. From earlier works [4,5], we learned that the diffusion bonding of a Ni-based superalloy by HIP may be accomplished by three techniques, including: (1) solid to solid, (2) solid to powder, and (3) powder to powder bonding. The first and second techniques are particularly useful [4,5] in the application of a propulsion system. Here, the "solid" may be a forging or casting piece, and the powder is made using powder metallurgical techniques, e.g. vacuum induction melting and argon atomization technology. The solid pieces and powder may be similar or dissimilar materials. For the "solid to solid" technique, many factors affect the quality of the HIP bonding piece [4,5] including the soaking temperature, time, pressure, and special metallurgical effects, such as surface preparation and the use of intermediate layers (IL). Regarding IL, earlier studies suggest that [14], in order to effectively enhance the diffusion rate of bonding, the reduction of the temperature, or the pressure required for direct HIP bonding, especially to a superalloy, an IL is required. The IL can be applied in many forms, such as an electroplated surface, foil inserts, or evaporated or sputtered coating.

* Corresponding author.
E-mail address: huei@isu.edu.tw (H.-S. Wang).

http://dx.doi.org/10.1016/j.matdes.2015.11.102
0264-1275/

Table 1
Chemical compositions (wt.%) of CM 247 LC superalloy.

Ni	Co	Cr	Mo	W	Ta	Al	Ti	Hf	B	Zr	C
Bal.	9.2	8.1	0.5	9.5	3.2	5.6	0.7	1.4	0.015	0.015	0.07

In the past, considering cost and availability, most ILs were dissimilar materials [15,16] to the base metal/alloy, which may produce softer or lower strength pieces. To produce consistent HIP bonding, the CM 247LC powder filler made by powder metallurgical techniques is considered to form a HIPed IL.

Presently, the literature related to such an application (solid to solid HIP bonding and its IL made by powder filler) to a precipitation hardening Ni-based superalloy is limited. Therefore, in this study, various HIP parameters were conducted to bond two polycrystalline CM 247LC rods. To minimize the initial defects in the IL, typically spherical shaped particles, with finer and broad particle size distribution from 10 nm to 30 μm, were used. Before HIP bonding, solid rod pieces and powder filler were pre-assembled and entirely canned into specially designed stainless steel capsules. After HIP bonding, the effects of the HIP parameters on the microstructure and mechanical properties of the HIP bonded pieces were investigated.

2. Materials and experimental procedure

CM 247 LC (chemical compositions are as shown in Table 1) rods, 65 mm in length and 14 mm in diameter, were machined from a cast ingot. The surfaces of the samples were carefully ground and polished (surface finish using a 1 μm diamond paste) and cleaned with acetone. The solid rods and powder filler were pre-assembled and entirely canned into specially designed SS304 stainless steel capsules (see Fig. 1a). The inner sleeve (see Fig. 1a) of the capsule was used to quantitatively pack the powder filler at the center of the bonding piece. To produce a consistent HIP bonding, the CM 247 LC powder filler, made by vacuum induction melting and argon atomization technologies, was used to form a HIPed IL. Powders used for HIP bonding are typically spherical shaped particles (Fig. 1b), with finer and broad particle size distribution from ϕ 10 nm to 30 μm, which may provide high packing density and reduce the percentage of voids [16,17].

Based on the thermal analysis (differential scanning calorimetry, DSC) results (Fig. 2), the average liquidus temperature ($T_{\gamma l}$) [18,19] of a CM247 LC alloy was about 1380 °C. Referring to earlier literature [4, 15], the initial HIP bonding parameters (Condition A, as shown in Table 2, a soaking temperature of about 0.87 $T_{\gamma l}$, and pressure of 150 MPa. Here a heating rate of 10 °C and a cooling rate of 15 °C were used for each HIP condition) were used. Due to the massive voids or cracks observed in the IL, the bonding piece broke during machining; however, this condition was improved when a higher pressure or temperature was used (Conditions B and C). Therefore, only the samples of HIP bonding under Conditions B and C will be discussed in the following section.

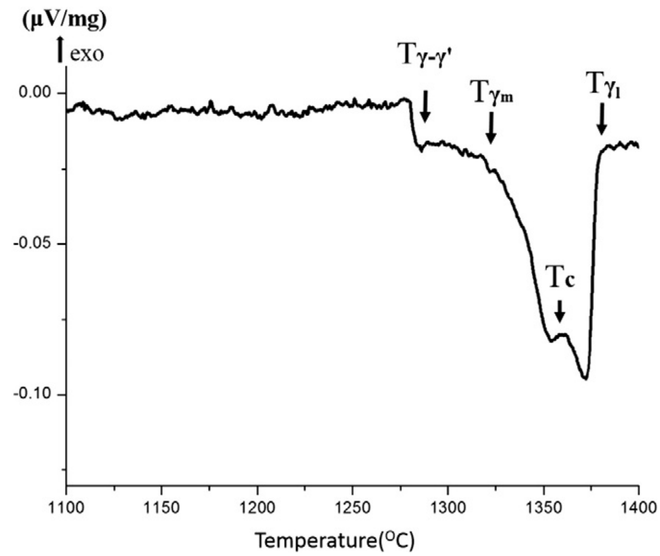

Fig. 2. Differential scanning calorimetry (DSC) results of CM247 LC alloy.

Table 2
HIP bonding parameters used in this study.

Conditions	Temperature (°C)	Pressure (MPa)	Soaking time (h)
Condition A	1200	150	4
Condition B	1200	175	4
Condition C	1220	175	4

After the bonding process, metallographic specimens were cut longitudinally from the HIP bonded joints. The specimens were then prepared by grinding, polishing, and etching with a 70% phosphoric acid electrolyte solution. The microstructures in the IL, interface boundary (IB), and the as-cast material (ACM), were then studied by optical microscopy (OM; Olympus BX51M), scanning electron microscopy (SEM; Hitachi S-4700) equipped with an energy dispersive spectrometer (EDS; HORIBA 7200-H) and electron back-scattering diffraction (EBSD; Carl Zeiss Microscopy). Detailed microstructure was observed by transmission electron microscopy (TEM; Philip Tecnai G2). A focused ion beam (FIB, SMI 3050), using a 5 keV, was employed to extract foils to identify the precipitated phases along the prior particle boundary (PPB) in the IL. To study the tensile properties, specimens from the HIP bonded

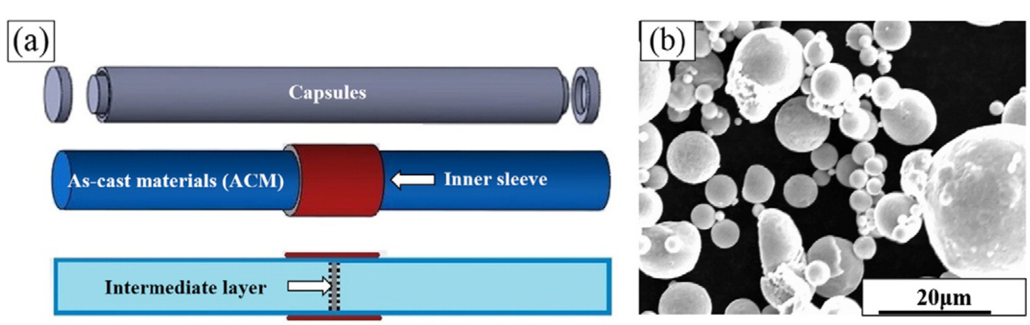

Fig. 1. (a) Assembly for CM 247 LC hot isostatic pressing (HIP) diffusion bonding tests, (b) CM 247 LC powder filler made by vacuum induction melting and argon atomization technologies.