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Microstructural evolution and mechanical properties of TLP bonded joints of Mar-M247 superalloys with Ni-Cr-Co-W-Ta-B interlayer

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ABSTRACT

The three-stage isothermal solidification process of TLP bonded Mar-M247 nickel-based superalloy was studied. The transient liquid phase bonding of Mar-M247 superalloys was conducted at 1150 °C for 1, 60, 120 and 240 min. Dendritic formation and solute partitioning governed the microstructure development. Ni-rich solid solution, Ni-rich boride W-rich boride and other carboborides were formed in the joint area. The maximum tensile strength of 443 MPa was obtained when TLP bonding at 1150 °C for 240 min. It had completed isothermal solidification. After isothermal solidification, the distribution of microhardness across the joints was more homogeneous. Enrichment of refractory elements in the Ni-Cr-Co-W-Ta-B interlayer was detrimental to the process of isothermal solidification. The presence of hard and brittle borides reduced the hardness and tensile strength of the bonded area. Post-bonding heat treatments are suggested to improve mechanical properties in future studies.

1. Introduction

Mar-M247 nickel-based superalloy is extensively used in the hot sections of aircraft engines, which experience service temperatures exceeding 600 °C and high stresses as demonstrated (Liu et al., 2008). Smid et al. (2016) studied the high temperature creep fracture properties of Mar-M247 and reported its excellent oxidation resistance and mechanical properties at high temperature. Joining of this alloy is widely applied to reduce the cost of repair processes as stated (Steuer and Singer, 2013). Three different industrial methods of joining (fusion welding, brazing and diffusion bonding) are used for materials joining as demonstrated (Lee et al., 1998). High sensitivity to fusion zone and heat affected zone (HAZ) cracking during welding make fusion welding impractical to join precipitation hardened nickel based alloys as proposed (Henderson et al., 2004). Brazing leads to degradation of elevated temperature joint properties, due to the involvement of a low melting point filler alloy. High pressure and long bonding time for diffusion bonding processes make them quite expensive as stated (Egbewande et al., 2010). Transient liquid phase (TLP) bonding, which can produce near-ideal joints, is regarded as an optimum method for joining nickel based superalloys as put forward (Wu et al., 2001).

Investigations concerning TLP bonding of nickel based superalloys have been documented in the literature. Jalilvand et al. (2013b) found that continuous centerline eutectic phases resulting from insufficient isothermal solidification consisted of gamma solid solution, Cr-rich boride and Ni-rich boride. The increase in bonding time led to decrease of athermally solidified zone width when TLP bonded IN-738LC with Ni-B-Si-Cr-Fe filler alloy. Pouranvari et al. (2013) found that the microstructural evolution in joint areas were controlled by solid state diffusion of B into the IN718 base alloy when a Ni-Si-B interlayer was used. This study also proposed that the microstructural evolution of athermally solidified zones was governed by B diffusion at low temperature. Dissolution and diffusion of base metal alloying elements took place at high temperature in a TLP bonded GTD-111 nickel based alloy as demonstrated (Pouranvari et al., 2009). Liu et al. (2011) reported that Cr-rich boride CrB, Ni-rich $M_{23}B_6$, Cr-W rich M_6C and M_3B_2 borides formed in TLP bonded single crystal DD98 and polycrystalline K465 superalloys.

Previous investigations have primarily focused on TLP joining of gamma prime strengthened nickel alloys using commercial filler alloys based on the Ni-Cr-Si-B systems. The compositions of resulting joints were dissimilar to those of the base materials. In the case of Mar-M247, an appreciable amount of high melting point elements, including W, Co and Ta, was added to the matrix. Results showed that the elevated temperature performance of Mar-M247 was highly dependent on these ingredients. An ideal interlayer would not only be similar to the base metal in composition, but

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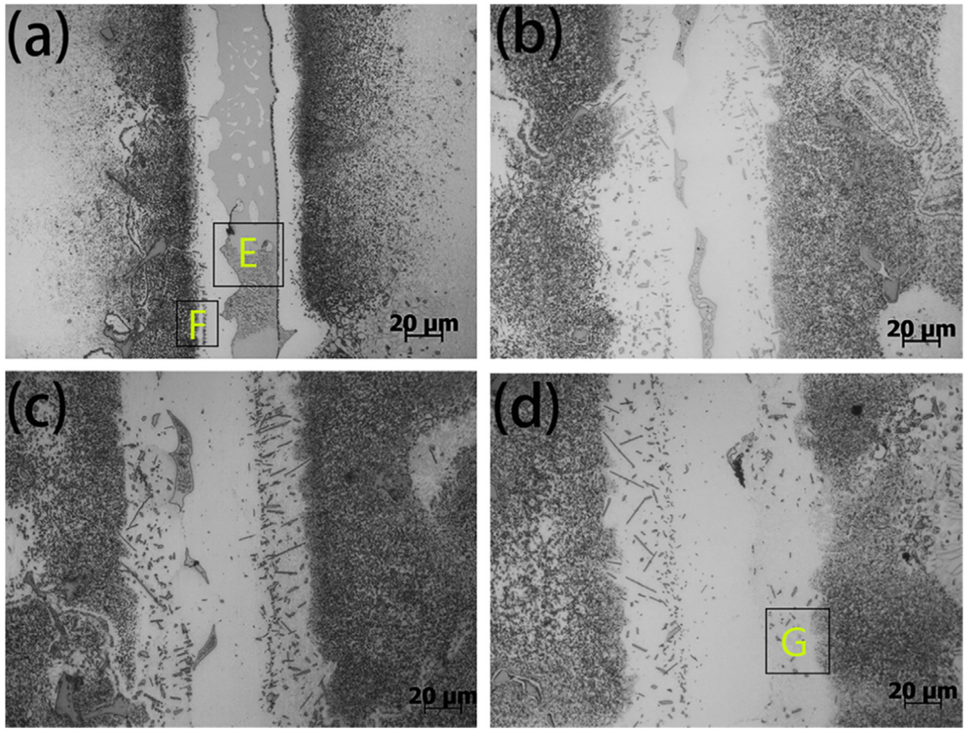

Fig. 1. Typical optical micrographs of the TLP joints (a) holding for 1 min, (b) holding for 60 min, (c)holding for 120 min and (d) holding for 240 min.

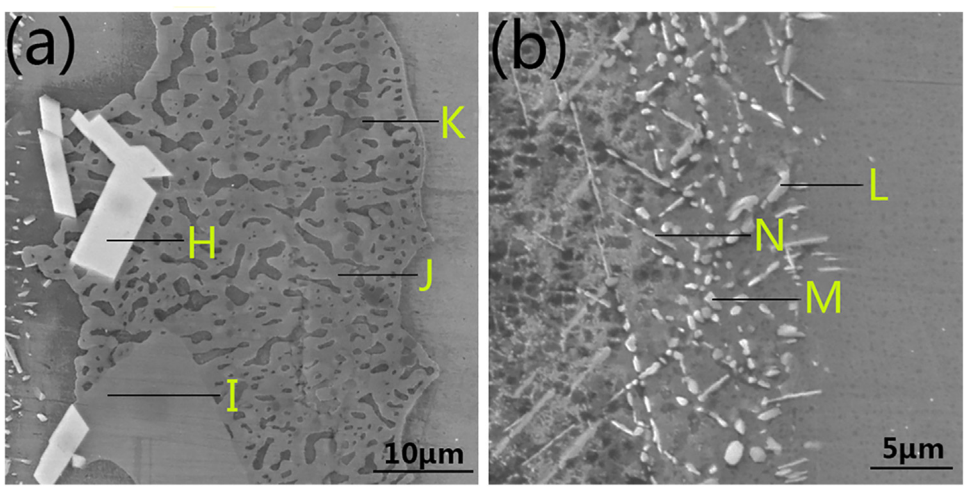

Fig. 2. SEM-SE images showing microstructure of the joints. (a) is a high magnification image of area "E" in Fig. 1a and (b) is a high magnification image of area "F" in Fig. 1a.

also contain elements to decrease the melting point. The interlayer should mainly contain Ni to form gamma and gamma prime phase. A Cr addition will dissolve in the gamma phase and improve the hot corrosion resistance. In order to get diffusion and solid solution reactions similar to the base metal and comparable mechanical properties, high melting point elements like Co, W and Ta should be added to the interlayer. In order to depress the melting point and ensure an amorphous structure, current interlayers for nickel based alloys contain 2.5–4.0 wt.% B. Therefore, a Ni-Cr-Co-W-Ta-B interlayer designed for Mar-M247 was chosen for TLP bonding. Li et al. (2003) reported that completed isothermal solidification was achieved successfully at 1494 K for 35 h when a Ni-base single crystal superalloy was bonded with a Ni-Cr-Co-W-Mo-B interlayer. Due to the high content of refractory elements in the interlayer, TLP bonding would experience a significantly retarded isothermal solidification. It is reasonable to expect that TLP bonding of Mar-247 using Ni-Cr-Co-W-Ta-B interlayers will produce a joint with similar microstructure and mechanical properties to the base metal.

The bonding parameters were systematically varied to investigate the influence of filler composition and process parameters on the microstructure and mechanical properties of TLP bonded polycrystalline Mar-M247 superalloy.

2. Experimental procedure

The parent alloys used in this work were as-cast polycrystalline Mar-M247 superalloys, which were divided into two types: A series were rectangular specimens with dimensions of $14 \times 7 \times 7\,mm^3$. B series were rectangular specimens with dimensions of $14 \times 7 \times 14\,mm^3$.The thickness of the Ni-Cr-Co-W-Ta-B amorphous foil was 50 µm. The compositions of the parent alloy and the interlayer are listed in Table 1. The surfaces of the par-