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Cracking of Ti_2AlNb-based alloy after laser beam welding

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Abstract. Crack formation process in the Ti-23Al-23Nb-1.4V-0.8Zr-0.4Mo-0.4Si (at.%) alloy based on orthorhombic titanium aluminide (Ti_2AlNb), especially in the weld zone (WZ), heat-affected zone (HAZ), and base metal (BM), during laser beam welding (LBW) at room temperature was considered. It was determined that the crack spread in the WZ throughout the crystallites of β-phase. In the HAZ, cracks spread throughout the globular β-phase crystals body and along the edges of globular α_2- and O-phases. The cracking stopped in BM due to a mechanism similar to shear ligament toughening. Cracking can be effectively suppressed by increasing the LBW temperature.

1. Introduction

Alloys based on orthorhombic titanium aluminide (Ti_2AlNb) are one of the most promising high-temperature alloys for the aerospace and automotive industries due to their high specific strength characteristics, creep and oxidation resistance, low density, and usage temperatures up to 750 °C [1]. However, the fabrication of structures of these alloys requires the usage of different welding techniques. Meanwhile, welding of Ti_2AlNb-based alloys usually results in the formation of pores or cracks in the welded joint. Cracks not only reduce the welded joint strength [2], but also lead to premature destruction of the welded structure [3] and, therefore, are unacceptable defects.

Crack formation in the Ti_2AlNb-based alloys depends strongly on the welding method and subsequent heat treatment mode [3,4]. To prevent cracking, special approaches such as solder design, alternating nanometric layers, welding using high currents, various structures of metal interlayers (brazing and diffusion welding), preheating are used [5,6]. Solders and interlayers can reduce residual stress and formation of brittle phases, but the intermediate metal affects the mechanical properties of the weld. In electron beam welding [7,8], local heating can be used to, for example, to reduce the residual stresses after welding by 30%. At the same time, they can also increase the grain size in the weld and heat-affected zone [7,8].

Laser beam welding (LBW) can be considered as one of the most promising techniques for the Ti_2AlNb-based alloys due to high energy density, relatively narrow welds, and no need for the inert gas atmosphere for the process. It is known that during laser welding of titanium alloys, weld ductility deteriorates due to gas saturation, and heat-affected zone is subjected to greater atmospheric influence and local stresses due to low thermal conductivity [9]. If local stresses exceed the critical values at the temperatures when the material exhibits limited ductility - cracking occurs [9,10].

Thus, to understand the ways of solving the problem of cracking during LBW, it is necessary to study the process of welding cracks formation. This article is devoted to the investigation of the crack formation process and growth in a welded joint made of an alloy based on Ti_2AlNb after LBW.

2. Experimental

The Ti-23Al-23Nb-1.4V-0.8Zr-0.4Mo-0.4Si (at.%) alloy based on Ti_2AlNb with the initial globular structure was chosen as the program material in the present study. Plates with the following dimensions were used: length 22 mm, width 15 mm, and thickness 2 mm. LBW of two plates was carried out in the lower position (PA ISO 6947) in a butt joint without grooving and filler materials at room temperature (RT) and 400 °C. LBW was performed using an 8.0 kW fiber laser in a controlled atmosphere chamber (Ar 4.6, gas flow rate 40 L / min). The following optimal LBW modes were determined in the experiment - a laser power of 2.5 kW, a welding speed of 3-5 m / min, with a laser defocusing distance of 0.0 mm. Images of the microstructure were obtained on a FEI ESEM Quanta 200 scanning electron microscope using a backscattered electron (BSE) detector at an accelerating voltage of 30 kV. The fine structure was examined on a JEOL JEM-2100 transmission electron microscope (TEM) at an accelerating voltage of 200 kV. Foils for TEM were made from 0.3 mm plates with subsequent thinning to a thickness of 0.1 mm. Next, these foils were subjected to jet electrolytic polishing on Struers Tenupol-5 with an electrolyte (60 ml $HClO_4$, 600 ml methanol, 360 ml butanol) at a voltage of 27 V and temperature of -30 °C. After electrochemical polishing, the foils were washed in distilled water and ethanol and dried.

3. Results and discussion

The initial structure of the examined alloy consisted of equiaxed α_2- and O-phase grains/particles with a mean size of 1.5 μm (Figure 1a). β-phase layers with a thickness of 0.4 ± 0.1 μm were found at the boundaries of the α_2/O grains/particles. TEM observations have revealed a rather high dislocation density inside the O-phase grains/particles. In some cases, dislocations were arranged in subgrain boundaries. In turn, the grains of the α_2-phase were mostly free of dislocations. However, many bending contours inside the grains indicated strong internal stresses (Figure 1b).

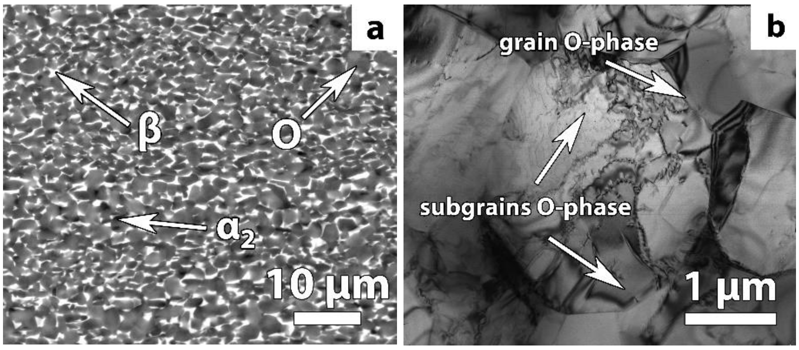

Figure 1. The initial structure of base metal (BM) before LBW (a) SEM-BSE and (b) TEM images.

After the LBW of the studied alloy at RT, a transverse crack appeared, propagating over the entire width of the weld zone (WZ) and the heat-affected zone (HAZ) that ended only in the base metal (BM) (Figure 2). The crack appeared in the center of the joint symmetrically to the weld axis (Figure 2a). Most likely, the crack was formed due to the tensile stresses that were generated because of the bending of the welded plates. The plates were likely bent because the laser heated them from only one side during welding. The crack propagated in step-wise nature; the crack boundaries were sharp. Besides, secondary smaller cracks were found near the main one.

Fracture in the WZ area occurred predominantly throughout crystallites of the β-phase. The crack in this area had a stepwise shape. In the HAZ, the crack propagated along the β-phase globular particles (Figure 2b). In this case, the formation of secondary cracks parallel to the main one was also observed.

In BM, cracking propagates mainly along the edges of the β-phase interlayers and globular crystals of α_2 and O-phase (Figure 2c).

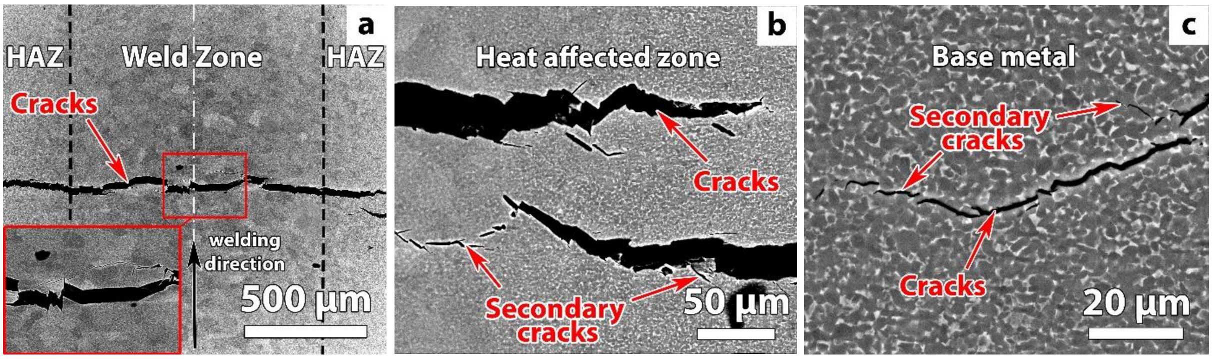

Figure 2. (*a*) transverse crack in a welded joint, (*b*) transverse cracks in HAZ, and (*c*) the top of the crack in base metal after LBW.

Cracking of Ti_2AlNb-based alloys with transverse cracks formation has been associated with high HAZ cooling rates (> 400 K/s) that resulted in the propagation of cracks into the base metal. The cracks deviated to an angle of 45° before blunting and stopping [10]. Crack development in the HAZ caused brittle transgranular cleavage [7], while crack propagation in the BM was prevented by a mechanism similar to shear ligament toughening with a deviation at an angle of 45° [11].

To avoid cracking in the Ti_2AlNb-based alloys after the LBW, it was necessary to reduce the HAZ cooling rate. This can be effectively done by pre-welding heating. For example, photographs of the welds obtained at RT and 400 °C are shown in Figure 3. The presence of cracks perpendicular to the welding direction after RT LBW is evident. In turn, no defects were found after LBW at 400 °C. This example shows that cracking can be effectively suppressed by increasing LBW temperature. However, attention must be paid to the effect of the welding temperature on other aspects, in particular on the structure and mechanical properties of the weld.

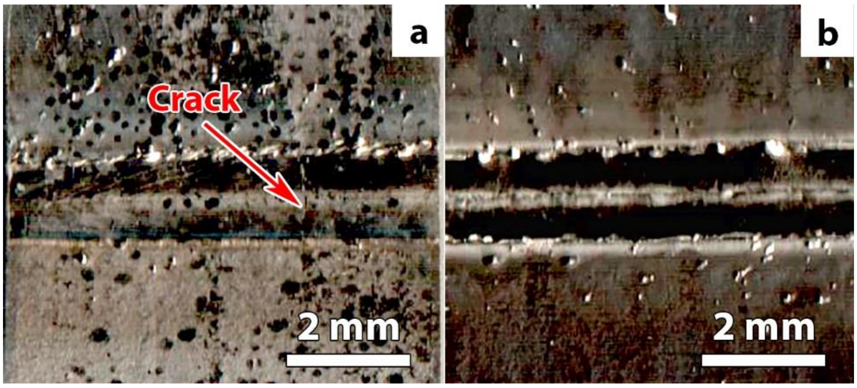

Figure 3. Photographs of joints welded (a) at RT and (b) at 400 °C.

4. Conclusions

The Ti-23.0Al-23.0Nb-1.4V-0.8Zr-0.4Mo-0.4Si (at.%) alloy after laser beam welding at room temperature was examined. Extensive cracking after welding was found. The crack growth in the WZ area occurred predominantly throughout crystallites of the β-phase. The crack had a stepwise profile. In the HAZ, the crack propagated along the β-phase globular particles. The formation of the secondary crack occurred parallel to the main one. In the BM, cracking propagated mainly along the edges of the β-phase interlayers and globular crystals of α_2 and O-phase. The crack growth in the BM stopped due to a mechanism similar to shear ligament toughening. It was also demonstrated that cracking can be effectively suppressed by increasing the welding temperature to 400 °C.

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References

[1] Banerjee D, Gogia A K, Nandi T K, Joshi V A 1988 A new ordered orthorhombic phase in a Ti3AlNb alloy *Acta Metall.* **36** 871-882

[2] Kulkarni A., Dwivedi D K, Vasudevan M 2020 Microstructure and mechanical properties of A-TIG welded AISI 316L SS-Alloy 800 dissimilar metal joint *Mater. Science and Engineering A* **790** 139685

[3] Cai D, Chen J, Mao X, Hao C 2013 Reheat cracking in Ti2AlNb alloy resistance spot weldments *Intermetallics* **38** 63-69

[4] Li Y-J, Wu A-P, Li Q, Zhao Y, Zhu R-C, Wang G-Q 2019 Mechanism of reheat cracking in electron beam welded Ti2AlNb alloys *Transactions of Nonferrous Metals Society of China (English Edition)* **29** 1873-1881

[5] Li H 2020 The causes and control of porosity in titanium alloy welding *Proceedings 3rd International Conf. on Electron Device and Mechanical Engineering ICEDME 2020* **9122191** 490-493

[6] Chen G, Zhang G, Yin Q, Zhang B, Feng J 2020 Research Progress on Welding Crack Control of TiAl Alloy (Review) [TiAl合金焊接裂纹控制研究进展] *Cailiao Daobao/Mater. Reports* **34** 05115-05119

[7] Lobanov L M, Asnis E A, Piskun N V, Vrzhizhevskii É L, Mikhodui O L, Statkevich I I 2020 Structure, Mechanical Properties, and Stressed State of Weld Joints of the Tial(Nb, Cr, Zr) Intermetallic System *Strength of Mater.* **52** 199-204

[8] Zhan Z, Chen Y, Wang S, Huang Y, Mao Y 2019 Prevention of Crack Formation in Electron-Beam Welded Joints of Dissimilar Metal Compounds (TiNi/Ti6Al4V) *Metal Science and Heat Treatment* **61** 373-378

[9] Li H 2020 Analysis and control of laser weld crack *Proceedings 3rd International Conf. on Electron Device and Mechanical Engineering ICEDME* 2020 **9122119** 192-195

[10] Patterson R A, Martin P L, Damkroger B K, Christodoulou L 1990 Titanium aluminide: electron beam weldability *Welding Journal* **1** 39–44

[11] Chan K S 1995 Evidence of Shear Ligament Toughening in TiAl-Base Alloys *Metall. And Mater. Trans. A V* **26A** 1407-1418