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Cracking in dissimilar laser welding of tantalum to molybdenum

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ABSTRACT

Dissimilar joining of tantalum (Ta) to molybdenum (Mo) is of great interest in high temperature structural component applications. However, few reports were found about joining of these two hard-to-weld metals. The objective of this experimental study was to assess the weldability of laser butt joining of 0.2 mm-thick Ta and Mo. In order to study cracking mechanism in Ta/Mo joint, similar Ta/Ta and Mo/Mo joints were compared under the same welding conditions. An optical microscope observation revealed presence of intergranular cracks in the Mo/Mo joint, while both transgranular and intergranular cracks were observed in Ta/Mo joint. The cracking mechanism of the Ta/Mo joint was investigated further by micro-hardness testing, micro X-ray diffraction and scanning electron microscopy. The results showed that solidification cracking tendency of Mo is a main reason for crack initiation in the Ta/Mo joint. Low ductility feature in fusion zone most certainly played a role in the transgranular propagation of cracking.

1. Introduction

Tantalum (Ta) and molybdenum (Mo) are typical refractory metals (melting point of 3020 °C and 2623 °C, respectively) commonly used as structural materials in high temperature applications, such as sphere of missiles, aero-engines and aircraft, due to their good physical-thermal properties [1–3]. With the need of miniaturizations, dissimilar joining of small components of these two refractory metals is required to reduce material costs and improve the design of structure [1]. Nd: YAG pulsed laser welding is widely used to interconnect small refractory metals because of its advantages such as short welding cycle, high accuracy of energy input and so on [4,5].

In the past few decades, several research projects have been carried out aiming to join refractory metals [2,3,6–12]. However, joining these two metals is difficult because of their limited weldability [2], for example the poor mechanical properties of fusion welded Mo and its alloys, due to impurities and grain coarsening [7,8]. Although non-fusion welding, such as vacuum brazing, diffusion bonding and friction welding [6,9] could achieve good properties of Mo joints, their industrial applications have been limited due to the required small component size and complex geometry. On the other hand, joining of Ta to Ta or other alloys is generally easier [10–15], but their welding processes still need to be optimized to minimize the formation of brittle intermetallic phases [14,15].

To our knowledge, joining of Ta/Mo has not been reported in literatures despite it is in demand. This work aims to study the weldability of Ta to Mo sheets using Nd: YAG pulsed laser. The Ta/Ta, Mo/Mo joints welded at the same processing conditions were compared to analyze the cracking mechanism of Ta/Mo joints. The cracking mechanism in Ta/Mo joint was discussed in detail aimed at identifying successful welding strategies.

2. Experimental

The base metals in this study were annealed pure Ta and cold-rolled pure Mo both with a thickness of 0.2 mm and dimension of 25 mm × 20 mm. Table 1 shows some thermos-physical properties of Ta and Mo [3,16]. The surfaces and butting faces were ground to ensure proper joint fit-up and then cleaned with acetone and ethanol.

A SL-80 pulsed Nd: YAG laser system with a maximum mean laser power of 80 W was used in this study. The schematic of the welding process is shown in Fig. 1. A protective glass cover was used to protect the welding process in order to avoid oxidation of the fusion zone and its surroundings. Argon, entering from the lower side of the device and flowing out from the upper side, was used as shielding gas at a flow rate of 10 L/min. Notably, the protective cover may have slightly attenuated the laser energy. To optimize joint fit-up, the samples were fixed on a workbench made of pure copper through a contact force applied to the base metals. The laser beam was focused on the butt surface with no offset. The experiments were conducted at a constant welding speed of 300 mm/min. Preliminary welding tests were performed to

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Table 1
Thermo-physical properties of Ta and Mo [3,16].

Property	Ta	Mo
Melting point (°C)	2996	2620
Density (g/cm^3)	16.6	10.2
Thermal conductivity (cgs. units)	0.13	0.35
Specific heat (cge. units)	0.04	0.06
Coefficient of thermal expansion (10^{-6}/°C)	6.5	4.9
Absorption coefficient (%)	0.82	0.6

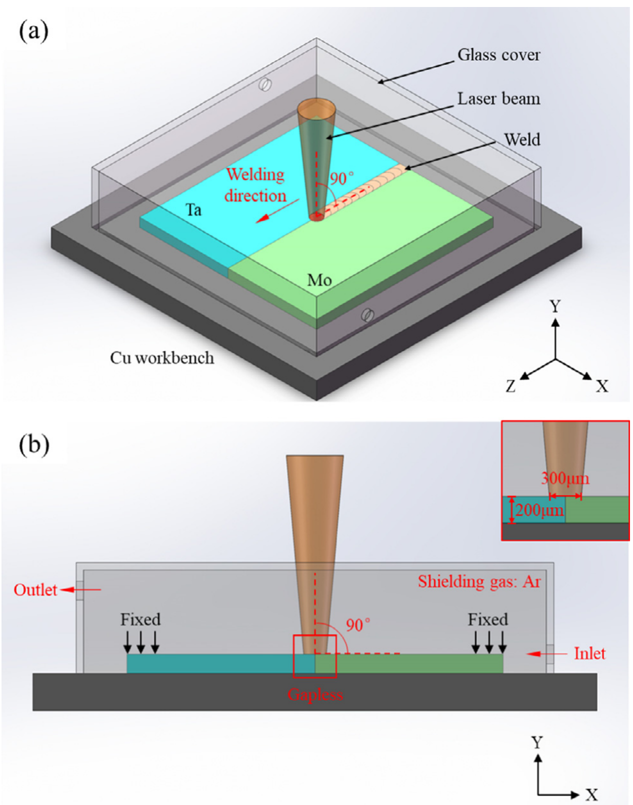

Fig. 1. Schematic of laser welding process for Ta to Mo: (a) isometric view, (b) Z-direction view. The similar joints were welded by the same processing conditions.

determine the welding power intensity required. In current experiments, an average laser power of 22.4 W, a pulse width of 6 ms, a pulse frequency of 4 Hz, and a spot diameter of 0.2 mm were selected as optimized welding parameters.

To characterize joints, the welds were sectioned transversely, polished and etched for metallographic examinations. The Ta/Ta and Ta/Mo joints were etched by immersing them in HF: HNO_3: HCl = 1: 2: 2(vol.) solution, while in HF: HNO_3: H_2O = 1: 3: 5(vol.) solution for Mo/Mo joint. The microstructures of joints were observed by optical microscopy (OM). The phases in the Ta/Mo joint were identified by a Rigaku Rapid IIR micro X-ray diffractometer (micro-XRD) with a beam size of 100 μm. The micro-hardness of the joints was measured using a Vickers micro-indenter at load of 200 g and dwelling time of 10 s. The fracture surfaces of Mo/Mo and Ta/Mo joints were analyzed by a FEI Inspect S50 scanning electron microscopy (SEM).

3. Results and discussion

3.1. Cross-section morphologies

Fig. 2 shows the cross-sectional morphologies of Ta/Ta joint and Mo/Mo joint, respectively, in which the fusion zone (FZ), heat affected zone (HAZ) and base metal (BM) were labeled. Both joints were of typical weld bead shape characteristic of conduction welding mode. While no cracking or any other defects were found in the Ta/Ta joint, intergranular cracking (as will be also shown later with fracture surfaces) occurred mainly along the centerline in the FZ of Mo/Mo joint (Fig. 2b).

The width of FZ and HAZ of Ta/Ta joint was slightly larger than that of Mo/Mo joint, despite the melting point and density of Ta are greater than those of Mo (Table 1). This is because the thermal conductivity of Mo is three times larger than that of Ta, and the absorption coefficient of Ta is about 22% higher than that of Mo. Therefore, the energy absorbed in Ta is higher than that in Mo while the heat dissipates faster on Mo base metal.

Fig. 3 shows the cross-sectional morphologies of Ta/Mo joint. The FZ of Ta/Mo joint looks like a "wine-cup" separated by an evident transition line with both base metals as shown in Fig. 3(a). Difference in the thermal characteristics of Ta and Mo metals also resulted in slightly difference in the shape and symmetry of the FZ. It should be expected that there is more Ta than Mo melted into the FZ of Ta/Mo joint. More importantly, there is a severe cracking (Fig. 3a) separated the FZ mostly along weld centerline. Under careful observation, as will be evidenced later with fracture surface, indicated most of these cracks were transgranular (Fig. 3b) with few cracks were intergranular. The grain size was measured to be about 150 μm in the FZ (Fig. 3a) of Ta/Mo joint, similar as that in the FZ (Fig. 2) of Ta/Ta joint (about 170 μm) and Mo/Mo joint (about 120 μm).

3.2. Weld microstructure and micro-hardness

Fig. 4 shows the micro-XRD analysis of regions A and B (circled in Fig. 3a) in the FZ of Ta/Mo joint. It displays the presence of

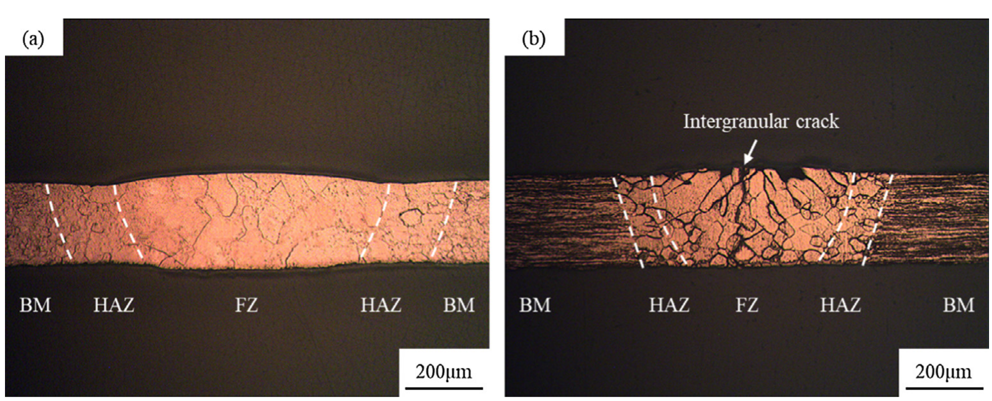

Fig. 2. Cross-sectional morphology of (a) Ta/Ta joint and (b) Mo/Mo joint.