Tensile Properties and Structural Integrity of Electron Beam Welded α-Titanium Alloys for Neutron Absorption Applications

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1. Introduction

Titanium is widely recognized as a high-performance structural metal owing to its high specific strength and excellent mechanical stability at elevated temperatures. With a relatively low density of approximately 4.5 g/cm³ combined with high tensile and yield strength, titanium offers superior strength-to-weight performance, making it suitable for lightweight structural applications [1]. Its stable high-temperature mechanical behavior and inherent creep resistance further ensure structural reliability in demanding environments, leading to its widespread use in aerospace and energy-related systems [2].

In nuclear applications, particularly in spent nuclear fuel storage systems, structural materials are additionally required to exhibit high neutron absorption capability to effectively attenuate neutrons emitted from the fuel. Among various neutron-absorbing materials, including boron compounds, gadolinium (Gd), and samarium (Sm), natural gadolinium possesses a thermal neutron absorption cross section of approximately 48,800 barns, which is about 64 times greater than that of natural boron [3]. Owing to this superior absorption capability, Gd is considered one of the most effective neutron-absorbing elements. Therefore, gadolinium-alloyed titanium alloys are expected to simultaneously ensure structural reliability and effective neutron absorption.

In this study, electron beam welding was applied to gadolinium-alloyed titanium alloys to evaluate their structural integrity, and the effects of welding parameters and tensile test temperature on the mechanical properties and microstructural characteristics were systematically investigated.

2. Methods and Results

2.1 Electron Beam Welding

Rolled gadolinium-alloyed α-titanium plates with a thickness of 15 mm were butt-welded using electron beam welding (EBW). The welding was conducted under a vacuum level below 3.0×10^{-4} torr, with a welding speed of 600 mm/min and an accelerating voltage of 150 kV. The beam current was varied between 30 mA and 35 mA, while the focusing current was fixed at 1940 mA. Full penetration was achieved in a single pass, resulting in a characteristic keyhole-shaped fusion zone (FZ).

2.2 Tensile Test

Tensile tests were conducted using sub-size round specimens with a gauge length of 25 mm and a gauge diameter of 6.25 mm, machined along the rolling direction (RD). The weld centerline was positioned at the middle of the gauge section. Figure 1 presents the fractured specimens after tensile testing. Under all welding conditions, fracture consistently occurred in the base metal (BM). No apparent reduction in cross-sectional area was observed in the FZ; instead, pronounced necking developed in the adjacent base metal regions, leading to final fracture.

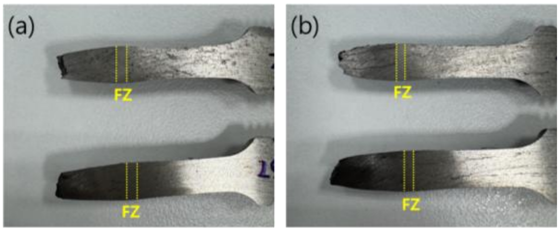

Fig. 1. Longitudinal sections of fractured tensile specimens tested at (a) room temperature and (b) 400 °C. For each condition, the upper and lower specimens represent beam currents of 30 mA and 35 mA, respectively.

Figure 2 presents the stress–strain curves for each condition. At room temperature, the tensile strength of the welded joints was slightly lower than that of the base metal, while the elastic modulus remained comparable across all conditions. The elongation showed a pronounced dependence on beam current, with the 30 mA condition exhibiting higher ductility than the 35 mA condition. A similar trend was observed at 400 °C, where the tensile strength decreased the elevated temperature, and the lower beam current condition consistently demonstrated greater elongation. Overall, the results indicate that beam current primarily affects ductility rather than strength under the present welding conditions.

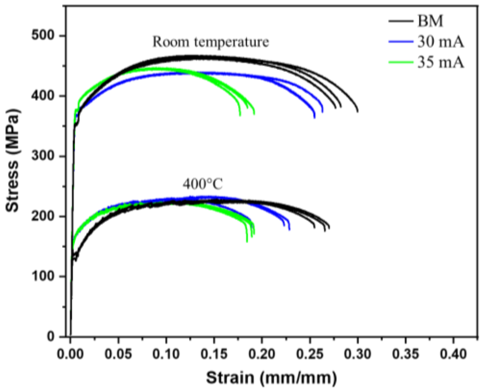

Fig. 2. Stress–strain curves of the base metal and electron beam welded joints tested at room temperature and 400 °C. The welded conditions correspond to beam currents of 30 mA and 35 mA.

3. Conclusions

Gadolinium-alloyed α-titanium plates were butt-welded by electron beam welding, achieving full penetration and forming a characteristic keyhole-shaped fusion zone. The elastic modulus and tensile strength of the welded joints were comparable to those of the base metal under both room temperature and 400 °C conditions, indicating no significant strength mismatch between the weld region and the surrounding material. Fracture consistently occurred in the base metal, further confirming the structural compatibility and adequate mechanical integrity of the joints.

The elongation exhibited a clear dependence on beam current, with the 30 mA condition consistently showing higher ductility than the 35 mA condition at both testing temperatures. These results demonstrate that, under the present welding conditions, beam current primarily influences ductility rather than strength, while maintaining overall joint structural integrity.

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