

Microstructure and mechanical properties of GTA weldments of titanium matrix composites prepared with or without current pulsing



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Abstract: The effects of current pulsing on the microstructure, hardness and tensile properties at different temperatures of gas tungsten arc (GTA) weldments of titanium matrix composites were studied. Full-penetration butt joints were made with or without current pulsing. Optical microscopy, hardness test and scanning electron microscopy were employed to evaluate the metallurgical characteristics of welded joints. Tensile properties of weldments at different temperatures were studied and correlated with the microstructure. The results exhibit that current pulsing leads to the refinement of the weld microstructure and TiB whisker and the redistribution of reinforcements resulting in higher hardness, tensile strength and ductility of weldments in the as-welded condition.

Key words: titanium matrix composites; pulsed current; welding; mechanical properties; grain refinement; microstructure

1 Introduction

In situ discontinuously reinforced titanium matrix composites (TMCs) have attracted much attention in academic research and industry applications because they offer a combination of good mechanical properties [1], superior creep resistances [2], high strength and metallurgical stability at room and high temperatures [3], which make them candidate materials for aerospace, nuclear, energy and automotive applications, etc [4]. However, the development of new manufacturing techniques plays a significant role in exploiting TMCs in new fields of applications. Recently, the interest in welding of TMCs has been increased rapidly, mainly concentrating on argon-arc welding, laser beam welding and friction welding [5–7].

Gas tungsten arc welding (GTAW) is the most widely used process for joining titanium and titanium alloys, especially for thin sheets owing to its easier applicability, flexibility and better economy [8,9]. The drive to improve the weld quality interrelated to the improvement in process parameters demands the use of improved welding techniques and materials. Welding of titanium leads to grain coarsening in the fusion zone and

heat affected zone. In conventional welding, weld fusion zones usually show coarse columnar grains, because of the prevailing thermal conditions during weld metal solidification [10]. This generally results in inferior weld mechanical property and poor resistance to hot cracking.

Pulsed current gas tungsten arc welding (PCGTAW) is a variation of GTAW which involves cycling the welding current at a given regular frequency. In current pulsing method, the peak current is selected to produce adequate penetration and bead contour, while the background current is set at a level enough to maintain a stable arc [11]. This permits arc energy to be used effectively to fuse a spot of controlled dimension in a short time producing the weld as a series of overlapping nuggets. Current pulsing enhances fluid flow, reduces temperature gradient, increases cooling rate and causes a continual change in the molten puddle size and shape leading to the microstructure refinement, and this in turn results in enhanced mechanical performance of the joint by changing weld pool solidification conditions [12]. Metallurgical advantages of PCGTAW include reduced width of heat affected zone, refinement of fusion zone grain size and substructure, control of segregation, etc [13]. Current pulsing has been applied to obtaining grain refinement in weld fusion zones and improvement in

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weld mechanical properties of Ti alloys [9–13]. However, there are no data available relating current pulsing and mechanical properties of TMCs joints. Therefore, an attempt has been made to study the effect of current pulsing on mechanical behaviors of TMCs joints by PCGTAW.

2 Experimental

2 mm rolled sheets of TMCs in the annealed condition were used as the base materials. The reinforcements used were TiB whisker (TiB_w) and La_2O_3 particle with the additions of 1.26% and 0.58% (volume fraction) respectively. Chemical compositions (mass fraction, %) of the base material were 6.0 Al, 3.6 Sn, 4.1 Zr, 1.0 Nb, 0.2 Mo, 0.34 Si and balance Ti. Coupons with dimensions of 130 mm×55 mm×2.0 mm sliced from the sheet were mechanically wire brushed, acid pickled in a $\text{HF}+\text{HNO}_3$ mixed solution and cleaned with acetone prior to welding. Square butt joint (Fig. 1(a)) was used to make the welds. Single pass, autogenous welding procedure (without filler metal addition), was performed to fabricate the joints perpendicular to the rolling direction of sheets with or without current pulsing. Due to the high affinity of titanium to atmospheric gases at high temperatures, high purity (99.99%) argon gas was used as shielding gas in the welding process. The welding parameters used are listed in Table 1.

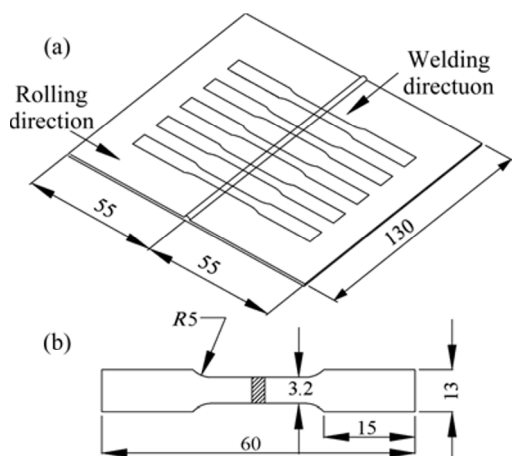


Fig. 1 Dimensions of joint configuration (a) and tensile specimens (b) (unit: mm)

After preparation of joints, the welded joint was sliced and then machined to the required dimensions (Fig. 1(b)) for preparing tensile specimens. Tensile tests were performed at a constant strain rate of $1.2 \times 10^{-3} \text{ s}^{-1}$ for the base metal and joints at different temperatures (298, 873 and 923 K). Three different samples were made to evaluate the longitudinal tensile properties.

For optical microstructural studies, the joints were transverse sectioned at the vertical axis of welding

direction by a linear cutting machine. Cross-sectional samples were grinded with different grades of water abrasive papers, polished with Cr_2O_3 water solution and finally etched with a 2% $\text{HF} + 8\% \text{HNO}_3$ (volume fraction) solution to reveal the microstructure. Microstructural analysis was conducted by an optical microscope (Make: ZEISS, Germany; Model: Axio Imager A1m) incorporated with an image analyzing software (Metal Vision) and scanning electron microscope (Make: FEI, America; Model: Quanta FEG 250). Vickers hardness tests were executed at intervals of 0.2 mm across the joint by a diamond pyramid indenter under a load of 1.96 N for 30 s.

Table 1 Welding parameters

Welding process	Parameter	Value
Unpulsed welding	Arc current/A	120
	Arc voltage/V	12
	Travel speed/($\text{cm} \cdot \text{min}^{-1}$)	30
Pulsed welding	Peak level (I_p)/A	125
	Background level (I_b)/A	50
	Pulse frequency/Hz	4
	Travel speed/($\text{cm} \cdot \text{min}^{-1}$)	30
	Pulse-on time	50%
	Arc voltage/V	14
	Shielding gas	Argon, 99.99%
	Shield gas flow rate/($\text{L} \cdot \text{min}^{-1}$)	14
	Electrode	Cerium–tungsten, 2 mm diameter

3 Results and discussion

3.1 Weld bead geometry

The molten pool profile, cooling speed and grain growth rate are all associated with the welding heat input in the base metal during welding. The heat input rate in the welding and the cooling rate after welding deeply affect the grain size and phase formation. It is necessary to study the effect of heat input on the bead shape. Typical weld bead profile is shown in Fig. 2(a) and macrographs in unpulsed and pulsed condition are shown in Fig. 2(b). The weld bead geometries are measured by a stereomicroscope. The weld bead profiles and related dimensions are seen in Table 2.

In both unpulsed and pulsed conditions, there is no evidence of welding defects in the joints. It can be seen from Fig. 2(b) and Table 2, in the constant current process, weld width and back height are obviously higher than those by pulsed current process, which is attributed to higher heat input of GTAW [9]. Comparatively, an appreciable variation in the width and reinforcement of

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