How ultra high frequency of pulsed gas tungsten arc welding affects weld porosity of Ti-6Al-4V alloy

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Abstract Ultra high frequency of pulsed gas tungsten arc welding (UHFP-GTAW) has been considered as a promising method to improve weld quality of titanium alloys. This paper studies the effect of UHFP-GTAW on weld porosity of Ti-6Al-4V alloy, which shows how liquid pressure/viscosity/temperature of molten pool influences nucleation, growth, detaching, and escaping of gas pore. Results indicated that compared to conventional GTAW, the liquid pressure and curvature radius of the gas pore were increased significantly while viscosity and filtration angle of the gas pore reduced simultaneously caused by UHFP-GTAW, leading to high escaping speed and easy detaching process of the weld gas pore. It is suggested that the elimination of weld porosity of Ti-6Al-4V alloy can be achieved by UHFP-GTAW process.

Keywords Ultra high frequency pulsed welding · Weld porosity · Molten pool · Titanium alloy

1 Introduction

Titanium alloys have been widely used in industries including aeronautics, astronautics, and vehicle due to good plasticity, high toughness, low density, high strength-to-weight ratio, desirable welding properties, corrosion resistance, and fatigue resistance [1–5]. As the most common Ti alloy, Ti-6Al-4V alloy is usually manufactured by gas tungsten arc welding (GTAW) for actual applications. Welding defects, especially porosity, have been regarded as a crucial factor for successful welds in Ti-6Al-4V alloy [6]. Therefore, it is necessary to apply surface treatment including chemical solutions and dry-cleaning utensils before welding to minimize weld porosity. Wanjara et al. have suggested that the two-step preparation procedure as pickling and grit blasting is effective in preventing porosity of Ti-6Al-4V welds [7]. Innovations in welding methods are another ways to improve the porosity, and pulsed welding has been attracted attentions from researchers. Compared with conventional welding, heat-affected zone in the base materials is much narrower after applying pulses during welding process since there is limited energy to heat or melt the base material during peak current pulses [8]. Experimental results indicated that pulsed welding had impact on the refinement of β-grain structure and also for fusion zone microstructure in Ti-6Al-4V alloy [9]. Zhaodong and Xiangyu have found lower porosity caused by pulsed GMAW process [10]. Similar results were also demonstrated by other researchers that welds were sound without any visible cracks or defects [11–14]. The work with improved methods or process can avoid weld porosity depending on well surface treatment for Ti-6Al-4V before welding.

As known, there are four stages for formation of weld porosity, such as nucleation, growth, detaching, and escaping as illustrated in Fig. 1 [15], which were affected by pressure, temperature, viscosity of molten pool, and cooling rate.

Nucleation and growth have been studied systematically based on previous work about arc behavior and fluid of molten pool. Viscosity is a property of specific welding system, which is a function of temperature and pressure instead of an inherent property of liquid metal [16, 17]. Major investigations in viscosity research have been focused on temperature dependence on atmospheric pressure. Seeton indicated that with the increasing temperature, it was able to generate a new geometric stability based upon a decrease in the fluid viscosity [18]. Finally, weld porosity can be decreased
significantly when escaping speed of gas pore is higher than cooling rate.

We have been studying pulsed welding technology as ultra high frequency pulsed (UHFP)-GTAW in previous work. UHFP-GTAW has current switch frequency in the range of 10–80 kHz and current upslope/downslope rate ($\frac{di}{dt}$) of more than 50 A/μs. The schematic of the weld current is illustrated in Fig. 2. UHFP-GTAW shows promising results for improving welding quality including grain refinement, little porosity, and good mechanical properties.

Previous work of Qi et al. [13] has introduced novel pulsed welding technology called UHFP-GTAW, which owned current switch frequency of 10–80 kHz and current upslope/downslope rate ($\frac{di}{dt}$) of more than 50 A/μs. The schematic of the weld current is illustrated in Fig. 2. Duty cycle of pulse duration could be deduced as $\delta=t_p/(t_b+t_p)$.

![Fig. 2 Schematic of pulse and background currents. $I_b/I_p$ is the background/pulsed current, $f$ is the pulse frequency, and $t_b/t_p$ is the background/pulsed current time](image)