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Fatigue crack growth behaviour of gas tungsten arc, electron beam and laser beam welded Ti–6Al–4V alloy

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ABSTRACT

The present investigation is aimed to evaluate fatigue crack growth parameters of gas tungsten arc, electron beam and laser beam welded Ti–6Al–4V titanium alloy for assessing the remaining service lives of existing structure by fracture mechanics approach. Center cracked tensile specimens were tested using a 100 kN servo hydraulic controlled fatigue testing machine under constant amplitude uniaxial tensile load. Crack growth curves were plotted and crack growth parameters (exponent and intercept) were evaluated. Fatigue crack growth behavior of welds was correlated with mechanical properties and microstructural characteristics of welds. Of the three joints, the joint fabricated by laser beam welding exhibited higher fatigue crack growth resistance due to the presence of fine lamellar microstructure in the weld metal.

1. Introduction

Ti–6Al–4V alloy has important characteristics such as high strength to weight ratio, excellent corrosion resistance, good toughness, low thermal expansion rate, high temperature creep resistance and good formability. The welds and welded joints of Ti–6Al–4V alloy fabricated in nuclear engineering, civil industries, transportable bridge girders, military vehicles, road tankers and space vehicles [1–3] are subjected to fluctuating loads. This kind of loading causes small cracks to grow during life of the component and leads to fatigue failure. A detailed study of this crack growth measurement could prevent the failure with prediction, which could ensure that the crack will never propagate and fail prior to detection. This necessitates a fatigue crack growth measurement of the Ti–6Al–4V alloy welded joints to avoid catastrophic failure.

The welding technology of titanium is complicated due to the fact that at temperatures above 550 °C, and particularly in the molten stage, it is known to be very reactive towards atmospheric gases such as oxygen, nitrogen, carbon or hydrogen causing severe embrittlement [4]. Gas tungsten arc welding (GTAW) is a most preferred welding method for reactive materials like titanium alloy due to its comparatively easier applicability and better economy [5]. Laser beam welding (LBW) process is used for welding of titanium alloys due to its advantages such as precision and noncontact processing, with a small heat affected zone (HAZ), consistent and reliable joints, etc. [4]. Electron beam welding (EBW) is highly suitable for joining of titanium, due to high vacuum inside the chamber where the process is carried out, which shields hot metal from contamination [2].

Fatigue crack growth behavior of $\alpha + \beta$ Ti–Al–Mn alloy welded by an automated GTAW, manual GTAW and EBW processes was investigated by Keshava Murthy and Sundaresan [6]. They reported that a significant increase in fatigue crack growth resistance was due to the presence of tensile residual stress normal to the fatigue load in addition with lamellar microstructure. Saxena and Radhakrishnan [7] variegated the effect of phase morphology of fatigue crack growth behavior of $\alpha + \beta$ titanium alloy and reported that the fatigue crack growth was strongly influenced by the phase morphology. A study was carried out by Sinha et al. [8] variegated the effects of positive stress ratios on the propagation of long and short fatigue cracks in mill annealed Ti–6Al–4V alloy. They opined that the effects of stress ratio on fatigue crack growth rates can also be rationalized largely by crack closure arguments. Differences between the long and the short crack behaviour at low stress ratios are attributed to lower levels of crack closure in the short crack regime. Boyce and Ritchie [9] investigated that the influence of load ratio and maximum stress intensity and found that crack growth and threshold are independent of loading frequency up to 50–1000 Hz. The fatigue thresholds were found to vary significantly with positive load ratio ($R = 0.1–0.95$). At load ratios larger than 0.5–0.95, where (global) crack closure could no longer be detected.

Tsay et al. [10] explored the influence of porosity on the fatigue crack growth behavior of Ti–6Al–4V alloy laser welds and concluded that the effect of porosity against fatigue crack growth

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