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Technical Report

Fatigue resistance of titanium laser and hybrid welded joints

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ABSTRACT

This paper presents a detailed study on fatigue strength of welded joints made of two titanium alloys, grade 2 and grade 5, and welded by laser or hybrid process. Fatigue strength curves obtained for each alloy and each welding technique are compared in terms of safety factors with fatigue design curves of welded joints provided by standards. Material and welding process effects on fatigue strength are discussed; the influence of the weld seam geometry is assessed by evaluating the fatigue strength reduction factor. This parameter is computed by using the Volumetric Method of the Notch Fracture Mechanics and defined as the ratio of the effective stress and the gross stress. Effective stress is defined on the weld toe stress distribution by the minimum of relative stress gradient method. Distribution of opening stress at weld toe is analysed also with the finite element analysis.

1. Introduction

Welding of titanium is still considered a quite uncommon process because titanium alloys are utilized only in highly specialized engineering applications. Considerations on the lifetime costs of the structure make this material the preferred option in view of its unique mechanical properties. However, special cares must be taken in executing the weld process because pure titanium and titanium alloys are highly susceptible to contamination from atmospheric gases. Shielding with inert gases may solve this problem but introduces complications in the technological process. The following fusion-welding processes are used for joining titanium and titanium alloys:

- Gas-tungsten arc welding (GTAW);
- Gas-metal arc welding (GMAW);
- Plasma arc welding (PAW);
- Electron-beam welding (EBW);
- Laser beam welding (LBW);
- Friction welding (FRW);
- Resistance welding (RW).

Gas-tungsten arc welding is the most widely used process for joining titanium and titanium alloys except for parts with thick sections. Square-groove butt joints can be welded without filler metal in base plates up to 2.5 mm thick.

Gas-metal arc welding is used for joining parts more than 3 mm thick. The technological process, realized by means of pulsed current or in the spray mode, is less costly than gas-tungsten arc welding.

Laser beam welding is the most used technique for commercially pure titanium and titanium alloys. High energy beams are focused onto a very narrow area. This allows the welded and heat-affected zones to be much smaller than for other welding processes and a more uniform thermal distribution to be achieved. Consequently, high quality smooth welded joints without inclusions and distortions as well as lower residual stress can be realized. Laser welding technology entails more expensive equipment. Welding process parameters such as the laser beam power, welding speed and shielding gas purity govern the final geometry of the weld seam and the joint quality.

Weldability of titanium alloys is in general good although the metal itself may be exposed to contamination during the welding process and during the subsequent cooling phase, till the temperature decrease beneath 700 °C. Titanium is a reactive metal forming compounds that exhibit sub-optimal thermo-physical properties. Part surfaces heated in air contain brittle carbides, nitrides and oxides that can reduce fatigue strength and notch toughness of the welded joint and heat-affected zone (HAZ). The backside of the weld also must be carefully protected because it is as sensitive as the weld surface. Since atmospheric gasses (oxygen, nitrogen and hydrogen), surface dust and impurities can diffuse into the material, thus generating porosity and causing embrittlement, the material must be handled with the greatest care in order to avoid possible contaminations. Surface impurities can be removed by properly preparing the edges to be welded. Furthermore, shielding devices must be specifically designed and

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