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Optimizing the mechanical properties of weld joint in laser welding of GTD-111 superalloy and AISI 4340 steel

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ABSTRACT

The present research pertains to the optimization of the mechanical properties of weld joint between GTD-111 superalloy and 4340 steel through Nd:YAG pulsed laser welding process. For this purpose, the response surface methodology in combination with desirability function technique were employed to optimize the laser welding parameters. The parameters of laser power (1500, 2000, 2500 W), welding speed (0.5, 1, 1.5 mm/s) and pulse frequency (5, 10, 15 Hz) were considered to improve the responses of tensile strength, elongation, hardness and weld penetration, simultaneously. The microstructure characteristics of the weld joint were examined using optical and scanning electron microscopy. The results indicated that an increase in the laser power up to 2500 W decreased the tensile strength (from 1017 to 705 MPa) and hardness (from 460 to 375 kgf) due to formation of the Laves phase and nucleation of solidification cracks, arising from segregation of Nb, Ti, Mo, W and Ta elements. The increase of welding speed decreased the amount of Laves particles due to lower heat input, which resulted in an improvement in the tensile strength and hardness up to 911 MPa and 417 kgf, respectively. However, an increase of welding speed reduced the elongation and weld penetration to 12.7 % and 1147 µm, respectively. Concurrent increase of the laser power and pulse frequency associated with the formation of shrinkage voids in HAZ of 4340 steel side and the nucleation of liquation cracks in HAZ of GTD-111 superalloy side. The optimal values of parameters were found to be a laser power of 1812 W, pulse frequency of 15 Hz and welding speed of 1.3 mm/s. Under the optimal conditions, the following values of responses have been obtained: tensile properties = 1013 MPa, elongation = 16.9 %, hardness = 416 kgf and weld penetration = 1165 µm.

1. Introduction

Nickel-based superalloys are a special class of structural materials with applications in high temperature environments such as turbine blades of jet aircraft, guide blades of industrial turbines, extrusion dies and etc. [1,2]. Among the various classes of nickel-based superalloys, GTD-111 is one of the newest superalloys used today as gas turbine blades. GTD-111 alloy is also well-known for its high tensile strength, high creep resistance and good oxidation resistance. However, the GTD-111 superalloy is very expensive and in moderate temperature environments it can be replaced by high strength alloys such as AISI 4340 steel [3–5]. AISI 4340 steel is a high strength steel used in power transmission gears and shafts, aircraft landing gear, and other structural parts [6,7]. Considering the mechanical properties of the two alloys, dissimilar welding of 4340 steel and GTD-111 superalloy can be applied to expand their capabilities and reduce the production costs. However, traditional fusion welding of dissimilar materials is difficult due to segregation of elements and formation of solidification and liquation cracks [8,9]. Laser beam welding (LBW) is a suitable method for welding dissimilar metals in the industry because of its beneficial characteristics such as low heat input, narrow HAZ and low distortion of work-pieces [10–13]. One of the most important laser welding methods is Nd:YAG pulsed laser welding that widely used by engineers and researchers [8]. Nd:YAG pulsed laser welding was applied by Ahmad et al. [14] for dissimilar welding of Inconel 625 superalloy and duplex 2205 stainless steel. They stated that by increasing the welding speed and consequently the reduction of heat input to the joint, the micro segregation and micro cracks decreased. They also observed that the microstructure of the weld metal was composed of fine cellular and columnar dendritic at low heat input due to fast cooling rate. Neves et al. [15] investigated dissimilar joint of Inconel 600 superalloy and AISI 304 stainless steel using the Nd:YAG pulsed laser welding. They found that the morphology of weld metal was typically dendritic and cellular, and it was influenced by the temperature gradient, solidification rate and chemical composition. They also pointed out that the weld samples were failed from the weld metal. Li et al. [16] investigated dissimilar joint of Inconel 625 superalloy and AISI 304 stainless steel using laser welding and concluded that the microstructure of weld metal near the 304 stainless steel side was

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