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ORIGINAL ARTICLE

Metallurgical and mechanical properties of laser welded high strength low alloy steel

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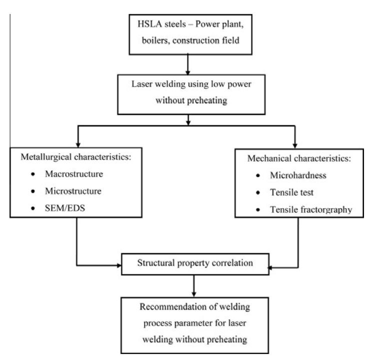
GRAPHICAL ABSTRACT



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ABSTRACT

The study aimed at investigating the microstructure and mechanical properties of Neodymium-Doped Yttrium Aluminum Garnet (Nd:YAG) laser welded high strength low alloy (HSLA) SA516 grade 70 boiler steel. The weld joint for a 4 mm thick plate was successfully produced using minimum laser power of 2 kW by employing a single pass without any weld preheat treatment. The micrographs revealed the presence of martensite phase in the weld fusion zone which could be due to faster cooling rate of the laser weldment. A good correlation was found between the microstructural features of the weld joints and their mechanical properties. The highest hardness was found to be in the fusion zone of cap region due to formation of martensite and also enrichment of carbon. The hardness results also showed a narrow soft zone at the heat affected zone (HAZ) adjacent to the weld interface, which has no effect on the weld tensile

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SA516 grade 70
Mechanical properties
Metallurgical properties

strength. The yield strength and ultimate tensile strength of the welded joints were 338 MPa and 549 MPa, respectively, which were higher than the candidate metal. These tensile results suggested that the laser welding process had improved the weld strength even without any weld preheat treatment and also the fractography of the tensile fractured samples showed the ductile mode of failure.

Introduction

Laser beam welding has become one of the important welding techniques used in modern industries because of its superior properties such as high welding speed, low thermal distortion, ease of automation, thin and small weld seams and the possibility of online control of quality during the process [1,2]. Nd:YAG and CO_2 lasers are being widely used in the industries such as ship building, defense and aerospace sectors. Recently, the solid state lasers such as disk laser, diode laser and fiber laser with high wall plug efficiency and superior beam quality have been developed [3–6]. With smaller heat input and higher cooling rate, the laser welding has more advantages compared to the submerged arc welding and the multi-pass gas metal arc welding. Similarly, compared to the friction stir welding and the resistance spot welding, the laser welding becomes more productive because of its automation and flexibility [7].

High strength low alloy (HSLA) steels are being widely used in structural applications because of its high yield strength and good weldability. Typically, HSLA steels have microstructures consisting mainly of ferrite, pearlite, small amount of carbides, carbonitrides and nitrides depending on the heat treatment and processing received during production [8]. The yield and tensile strength of HSLA steels range from 275 to 550 MPa and 380 to 620 MPa, respectively. ASME SA516 grade 70 steel is one of the widely used HSLA steels for service in lower than ambient temperature applications. This steel has high notch toughness and is used in several applications such as boilers, pressure vessels, bridges, wind turbine towers, oil and gas pipelines in which welding is one of the most critical manufacturing processes [9–11].

Amanie et al. [12] have used submerged arc welding (SAW) for joining of 17 mm thick sections of SA516 grade 70 steel to study the effect of welding parameters such as current and welding speed on impact strength, tensile strength, and microstructure. They observed that welding current was the major significant factor for affecting acicular ferrite in the weld metal. Cao et al. [13] examined weldability of HSLA steel of 9.5 mm thick plate using metal inert gas, laser welding and hybrid laser-arc welding techniques. The authors observed that there were improvements in reduction of distortion and porosity in the weldment while employing both laser and hybrid laser techniques as compared to MIG welding technique. However, the researchers noticed the martensitic and bainitic microstructures in the fusion zone that exhibited higher hardness. The laser welding gives a relatively narrow weld and restricted heat affected zone (HAZ) compared to the arc welding and thus minimizes the residual stress and distortion. Parkes et al. [14] investigated the welding of HSLA using fiber laser. The result shows the formation of martensitic structure, due to the fast cooling at fusion zone (FZ). Sharma and Molian [15] employed Yb:YAG disk laser for joining of advanced high strength steels. They observed a slight concavity at the bottom of the joint. Saha et al. [16] studied on microstructure properties correlation in fiber laser welding of HSLA steels. The tensile fracture showed the stretched out dimpled structures. Further, the author also noticed the fine carbide precipitates in the weldment acting as the crack initiation sites which lead to the formation of the micro voids. Teske and Martins [17] have investigated the influence of the shielding gas composition on Gas Metal Arc (GMA) welding of ASTM A516 steel. The author witnessed fewer inclusions in the welds produced with helium mixtures as the shielding gas. It was also observed that the impact resistance of the welds obtained was influenced by the different compositions of gas mixtures.

The review of literature on welding of HSLA steels indicates that GMAW, SAW and laser welding could be the possible welding methods to meet the industrial needs [18]. However, the published data on laser welding of HSLA SA516 grade 70 steel are very limited. In the view of the above, the present work focuses on an autogenous welding of SA516 grade 70 steel using Nd:YAG continuous wave laser with a minimum power. The effect of laser power and welding speed was analyzed to achieve the minimum bead width and maximum penetration depth. Further, the metallurgical and mechanical characteristics of weldment have been studied. The outcomes of the study would be greatly helpful to the power plant industries employing SA516 steel weld joints.

Table 2 Mechanical properties of base metal SA516 grade 70 steel.

Yield strength, MPa	341.00
Ultimate tensile strength, MPa	563.00
% of elongation	30.00
Impact energy, J	5.50

Table 1 Chemical composition (wt%) of base metal SA516 grade 70 steel.

Element	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Nb	Ti	V	B	N
Observed values	0.222	0.320	1.12	0013	0.007	0.048	0.006	0.012	0.018	0.014	0.002	0.005	0.001	0.006