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MECHANICAL STRENGTH EVALUATION OF PULSED ND-YAG LASER WELDING OF AUSTENITIC STAINLESS STEEL 304L

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ABSTRACT

This work focused on the welding of austenitic stainless steel 304L using the laser beam welding technique, in the room and high temperatures. Two pieces of the AISI 304L sheet with thickness of one millimeter are arranged on a special fixture and welded under the protection of high purity argon gas. For laser welding, a pulsed Nd-YAG laser beam with the beam frequency of 20 Hz, the welding speed of 84.5 millimeters per second, the pulse width of 6.5 milliseconds, and the average beam power of 220 watts are used. After welding, the samples of the tensile test cut using an electrical discharge machine, for tensile tests. The uniaxial tensile tests carried out at room and high temperature. Tensile tests have shown that it is possible to perform the laser joining of this alloy, and suitable joints can be obtained with this technique so that the average strength of joints is equal to 73.5% of the base alloy strength in the room temperature, and 64.7% of the base alloy strength at high temperature.

1. INTRODUCTION

Austenitic stainless steels are used in many industries, such as chemical processing, petroleum, gas and petrochemical industries, at different temperature ranges (Davis, 1994). These alloys are one of the most widely used engineering alloy groups. One of the most important properties of austenitic stainless steels is their welding ability. Arc welding, TIG welding, and laser welding are among the most common welding methods for joining of this alloys (Soltani & Tayebi, 2018; Yan et al., 2010). Different methods of fusion welding use different energy sources with a variety of power densities, due to high power density in laser welding as well as electron beam welding, the weld seams created by these energy sources have the properties and strength that are suitable for welding similar and even dissimilar alloys (Olson,1993). Laser welding uses a high-energy laser beam and can create deep and narrow weld seams (Katayama, 2013). These features have led to many studies in the use of laser beams for welding of various materials (Ma et al., 2016; Zhang et al., 2018). Also, due to the local nature and the ability to apply laser radiation accurately, various methods of hybrid welding

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have been developed using the laser beam (Mahrle & Beyer, 2006; Zhang et al., 2015). Giridharan and Murugan (2009) examined various parameters affecting the 304L austenitic stainless steel welding and obtained optimum seam welding conditions. Yan et al. (2010) investigated the different austenitic stainless steel 304 welding methods and concluded that laser welding is one of the best welding methods for this alloy. Kuryntsev and Gilmutdinov (2015) investigated the effect of using a defocused laser beam on AISI 321 stainless steel laser welding. They concluded that the use of defocusing leads to an increase in the volume of the weld pool and reduces the need for precise preparation of the edges of the weld.

Kumar et al. (2017) examined the effect of laser beam position in AISI 304 alloy welding using Nd-YAG pulsed laser beam. They concluded that the best results would be achieved in the case where the laser beam is about perpendicular to the surface of the specimen. Mohammed et al. (2017) studied the microstructure and microhardness of SAF 2205 duplex stainless steel laser joints. Shah et al. (2018) examined the weld pool during laser welding of AISI 304 alloy and developed a numerical model for simulating the weld seam profile. Bhatt, and Goyal (2018) investigated metallurgical properties of the austenitic stainless steel 316 and brass.

Studies on laser welding show that many studies have been done to investigate the microstructure and the possibility of laser joining of stainless steels. However, the strength of the resulting laser joints (especially at high temperatures) has not been completely studied. Stainless steels are used in a vast temperature range, so the strength of the joints must be examined in different temperatures. In this study, the strength of the laser joining of AISI 304L alloy has been investigated in the room and high temperature (Saravanan et al., 2017).

2. EXPERIMENTAL PROCEDURE

The alloy used in this study is the 304L austenitic stainless steel alloy with the combination of the elements listed in Table 1. As shown in this table, the most important alloying elements of this stainless steel are Chrome with 17.84% and nickel with 56.6%. Chromium has been added to increase the resistance of the alloy to oxidation and the nickel element due to the austenitic matrix stability at ambient temperature, increasing the strength at high temperatures and increasing weldability, formability and toughness (Davis, 1994).

Table 1. Compositions of 304L stainless steel (wt. %).

Element	Fe	Cr	Ni	C	Mn	Si	S	P
Weight percent	69.73	17.84	9.56	0.025	1.285	0.351	0.018	0.021

Parts of a sheet with the thickness of one millimeter are arranged side by side using a sheet fixture and are welded using an Nd-YAG pulsed laser beam. Two pieces of the 304L sheet are placed side by side in the butt welding configuration, which is shown in Figure 1. The location of the laser beam is centered, and the center of the laser beam is in the two-piece contact line (Bernadskiy, 2014).

The welding procedure is performed using an Nd-YAG pulsed laser beam with the maximum output power of 400 watts. Also, during welding, argon gas with a flow rate of 10 liters per minute was used as a protective gas for welding. Welding parameters used for joining, are given in Table 2. At 220 watts of welding power and 6.5-millisecond pulse widths, each pulse has a maximum power of about 1692 watts, which results in high penetration depth. Also, since the laser beam diameter is 750 micrometers at the surface of the sheet and the welding speed is 5.84 millimeters per second, the overlapping percent of the pulses is equal to approximately 80.5%.

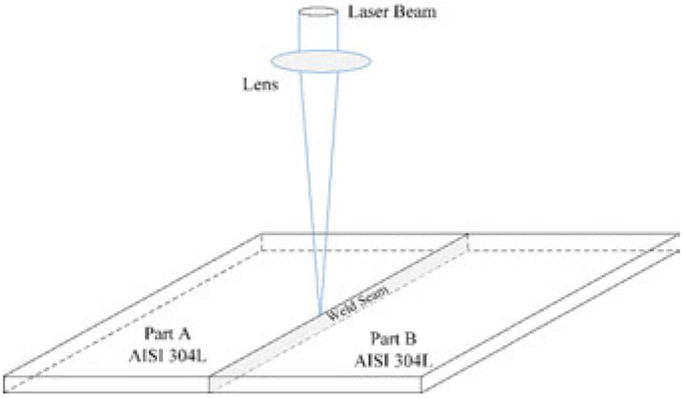

Figure 1. Butt welding configuration

Table 2. Laser Welding Parameters

Parameter	Welding power	Pulse width	Welding speed	Beam frequency	Beam diamater on sheet surface
Value	220 W	6.5 ms	5.84 mm/s	20 Hz	750 micro meters

After welding, an electric discharge machine (EDM) was used to cut the proper tensile samples. The welded parts after the cutting are shown in Figure 2. The number of eight samples is cut off from the welding parts, *see* Figure 2.

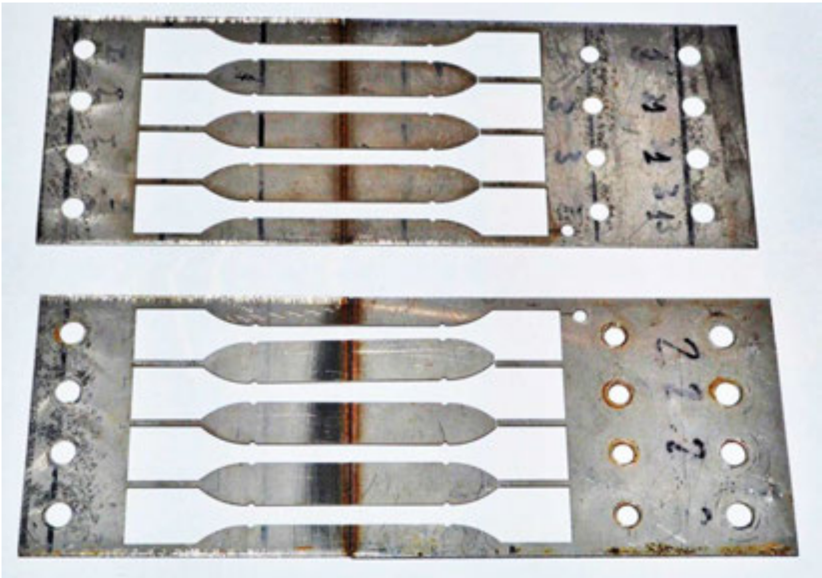

Figure 2: Welded parts.

After the cutting process, the tensile samples were tested using a Zwick Z100 tensile machine under a uniaxial tensile test at room temperature and also using a Santam SCT-30 machine at high temperature (600°Celsius). An image of one of the tensile samples is shown in Figure 3 before performing the tensile test.

Figure 3: Tensile test sample

3. RESULTS AND DISCUSSION

Three tensile tests were performed on the samples at room temperature. The results of the tensile test on these specimens as well as the base alloy (AISI 304L) are presented in Table 3. The strength of sample No.1 is 73.5% of the base alloy strength, and sample No.2 is 72.5% of the base alloy strength, as well as the sample No.3, is 74.03% of the base alloy strength at room temperature and under the same conditions. The average joint strength is equal to 462.8 MPa or 73.3% of the strength of the base alloy 304L, which is a very good value.

Table 3. Tensile strength of base alloy and laser welded joints at room temperature

Sample No.	Ultimate Strength (MPa)	The strength of the joint to the base alloy (%)	Breaking Point
AISI 304L	631.2	-	-
1	463.8	73.5	Joint
2	457.3	72.5	Joint
3	467.3	74.0	Joint

Two high-temperature tensile tests (600 °C) were performed on the welded specimens and their results, along with the results of the 304L base alloy test, are presented in Table 4. The strength of sample No.4 at 600 °C is 64.7% of the base alloy strength and for sample No.5, is 62.6% of the strength of the base alloy. The average joint strength at high temperature is 230.63 MPa or 63.65% of the base strength.

Table 4. Tensile strength of base alloy and laser welded joints at high temperature (600°C)

Sample No.	Ultimate Strength (MPa)	The strength of the joint to the base alloy (%)	Breaking Point
AISI 304L	362.3	-	-
4	234.39	64.7	Joint
5	226.87	62.6	Joint

It can be readily seen that tensile strengths of base alloy and laser welded joints at room temperature are higher than those at high temperature (600°C). Laser welded joints techniques can be used. However, all samples the breaking points are at joint, cautions should be applied for the uses of any particular applications.

Three elevated-temperature (600 °C) creep tests at 240MPa constant stress, were performed on the welded specimens and base alloy samples. The creep tests results are presented in Table 5. In Table 5, at 240 MPa constant stress and 600 °C test temperature, the creep test rupture time of base alloy is 68.3 hours and rupture time for sample 6 at is 46.4% of the base alloy rupture time and for samples 7 and 8, is 42.2%, and 38.4%, respectively.

Table 5. Tensile strength of base alloy and laser welded joints at high temperature

Sample No.	Creep Rupture Time (Hours)	Breaking Point
AISI 304L	68.3	-
6	31.7	Joint
7	28.8	Joint
8	26.2	Joint

4. CONCLUSION

In this research, the welding of austenitic stainless steel 304L was studied using the laser beam welding technique. Two pieces of the AISI 304L sheet with a thickness of one millimeter are arranged on a special fixture and welded under the protection of high purity argon gas. The 304L austenitic stainless steel laser welding was performed using Nd-YAG pulsed laser beam welding machine, and the samples obtained from the welding were subjected to tensile tests at room temperature as well as high temperature. The results of the tensile tests show that suitable joint for the 304L alloy can be obtained using this method. The average joint strength at the room temperature is 73.3% of the base alloy strength. Also, the average joint strength at the high temperature (600 °C) is 64% of the base alloy strength.

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