Journal of Manufacturing Engineering, December, 2017, Vol. 12, Issue. 4, pp 214-217

EFFECT OF FOCAL POSITION ON THE MICROSTRUCTURE AND TENSILE STRENGTH OF Nd: YAG LASER WELDED UNS S32750

Sivagurumanikandan N[1], *Saravanan S[2] and Raghukandan K[1]

[1]Department of Manufacturing Engineering, Annamalai University, Annamalainagar.
[2]Department of Mechanical Engineering, Annamalai University, Annamalainagar.

ABSTRACT

Laser welding is a fusion welding process during which radiant energy is employed to generate necessary thermal energy for achieving a strong weld. This study reports the effect of varied laser focal positions on the weldability, microstructure and mechanical strength of super duplex stainless steel (UNS S32750) by a 600 W pulsed Nd: YAG laser welding machine. Porosities were observed on the weld zone, when the laser beam is positioned above the surface; whereas, a good weld devoid of undercut and porosities emerge, when the laser beam is positioned either on or below the surface. The micro-hardness and tensile strength of the joints is higher, when the laser beam is positioned below the base alloy.

Keywords: *Nd: YAG laser welding, super duplex stainless steel, Microstructure and tensile strength.*

1. Introduction

Super duplex stainless steels (SDSS) are extensively used in oil platforms and off-shore process equipments viz., pipes, pumps, pressure vessels, separators and heat exchangers [1]. Welding of SDSS is critical as the weld joints should exhibit similar or better properties than the base alloy. Though various methodologies are available for welding SDSS, laser welding, a non-contact welding technique shows high promise and suited for rapid production with minimum weld distortion [1]. Laser welding of metals is better than conventional thermal joining processes due to viz., high scanning velocity, narrow heat-affected zone (HAZ), low distortion, excellent controllability and the ability to produce a high-intensity heat source [2]. The quality of weld is characterized by the judicial selection of process parameters viz., laser power, welding speed, defocusing distance, beam incidence angle and shielding gas [3]. Although a wealth of publication [2-7] exists on the influence of process parameters on the nature and strength of the laser weld, studies on the effect of varied focal position in laser welding of SDSS UNS S32750 is limited and hence attempted herein. Further, mechanical testing viz., micro-hardness and tensile tests across the butt weld interface according to relevant standard are conducted and the results are presented.

2. Experimental procedure

Laser butt welding of super duplex stainless steel sheets UNS S32750 (chemical composition and microstructure shown in Table 1 and Fig.1 respectively) with dimensions 150 mm X 75 mm X 2 mm, using pulsed Nd: YAG laser with a pulse energy 100 J, repetition rate 1000 Hz, average power 600 W, peak power 10 kW and pulse duration from 0.2 to 20 ms is attempted.

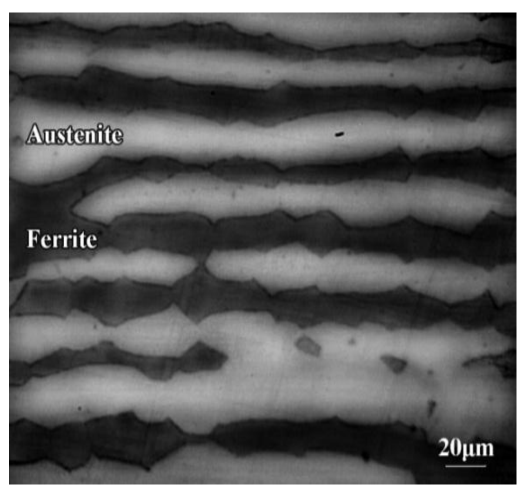

Fig.1 Microstructure of UNS S32750

**Corresponding Author - E- mail: ssvcdm@gmail.com*

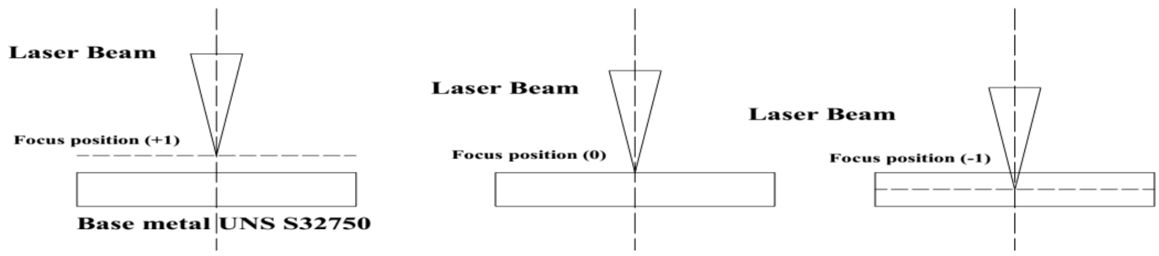

Fig.2 Schematic representation of various beam positions (a) above (b) on (c) below

The following parameter settings: pulse energy 29 J, average power 495 W, pulse width 7 ms and pulse frequency 17 Hz were adopted in this study. All the samples were polished by abrasive paper to have edges free from external impurities and dirt, which influences the weld quality. Prior to the welding, the samples were cleaned using acetone to avoid any contamination. The schematic diagram of the laser welding performed at various focal positions (-1 to +1) is shown in Fig.2.To study the influence of focal position, the other parameters viz., laser power (525 W), pulse frequency (15 Hz) and welding speed (175 mm/min) are maintained constant.

Table 1 Chemical composition of SDSS UNS S32750

Elements	C	Mn	P	S	Si	Cr	Ni	Mo	N	Cu	Fe
Wt %	0.02	0.712	0.024	0.002	0.454	25.27	6.52	3.70	0.306	0.87	Bal

Post welding, the cross section of the weld joints were prepared following standard metallographic practice viz., grinding, polishing and electro etched in a solution containing 10 % oxalic acid and the results are reported. Micro-hardness tests were performed as per ASTM-E 384 standard in a HMV-2T Vickers hardness tester applying a load of 500 g. Three set of tensile samples for each experimental condition were prepared and tested in a servo controlled universal testing machine (UNITEK-94100), with a cross head speed of 0.5 mm/min and the average values are reported.

3. Results and discussion

3.1 Macrostructure

Laser welding is advantageous in achieving a better weld, owing to the focused energy and controlled heat input [8]. A typical macrograph of the laser weld bead is illustrated in Fig.3.

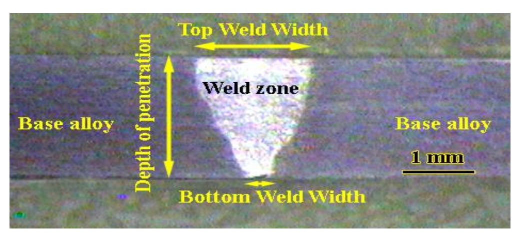

Fig. 3 Macrograph of the laser weld

Complete penetration and a sensible weld width are rendered as the principle requirement of a sound laser welding joint. The weld width is measured as the average length of weld in the top of the weld zone while the depth of weld is the distance between top and bottom of the weld joints (Fig.3).

3.2 Microstructure

The fusion line of UNS S32750 laser weld for the attempted conditions (Fig. 4) is continuous, clear and distinct with elongated primary ferrite grains oriented towards the direction of heat flux. The temperature developed on the base alloy is lower than the molten weld pool, and thereby, the weld zone begins to solidify with solid nuclei formation at the unmelted surface of the base alloy-molten pool interface. The nuclei continue to grow epitaxially into the molten pool (Fig. 4.a) and in the direction parallel to direction of heat flow [5]. Concurrently, the original grains in the base metal in contact with the molten zone grow epitaxially into the pool without nucleation [9]. Epitaxial growth is beneficial to the laser welds because of grain continuity with the base alloy.

When the laser beam is focused above the surface, gases may be entrapped in the molten metal during the weld pool solidification, resulting in metallurgical porosity (Fig.4.b). The sources of gases involved in pore formation are viz., rejection of dissolved gases, chemical reactions, environment, shielding gas and/or the properties of base alloy. Researchers [5, 8-10] have opined that hydrogen picked up from the environment during welding supports the formation of metallurgical porosity. In addition, bubbles nucleate from the growing solid interface as the molten metal solidifies. The small gas bubbles then proceed to coalesce into larger ones as they rise in the molten metal. If the weld metal completely solidifies before the bubbles escapes to the top, they are entrapped as porosity. This porosity causes cracks in metals/alloys that reduce the fatigue resistance of the alloys [5, 11], and hence it is beneficial to suppress the formation of pores.

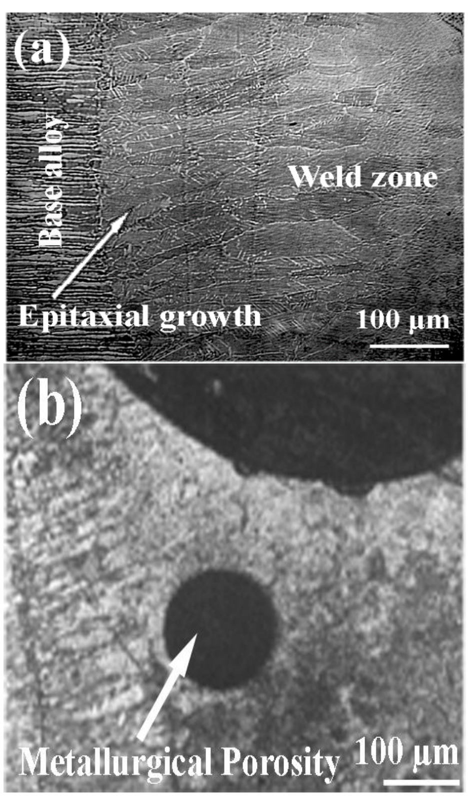

Fig. 4 Microstructure of the laser welded SDSS (a) fusion line (b) porosity

3.3 Micro-hardness

Laser welding favours solidification with a fine microstructure and promotes better mechanical properties in weld regions. The micro-hardness profile (Fig. 5) across the weld zone, for varied focal positions, reveals a harder weld zone than base alloy. The higher micro-hardness is witnessed in the weld zone, due to the formation of finer and uniform grains, following higher cooling rate and the presence of nickel as reported by Keskitalo et al [12]. The maximum micro-hardness is obtained in the weld zone, when the laser beam is focussed below (-1) the base alloy. On the contrary, hardness of the weld zone reduces by 8 %, when the laser beam is focussed above the surface (+1).

Fig.5 Micro-hardness variation across the interface

3.4 Tensile strength

The measured tensile strength of laser welded samples, with respect to the focal position, for the attempted conditions is shown in Fig.6. The tensile strength of the laser welded SDSS, with the laser beam focussed below the base alloy is higher, while minimum tensile strength is obtained when the laser beam is focussed above the surface. The variation in tensile strength is attributed by the microstructure variation between the weld zone and base alloy. The development of dentritic structure in the weld zone (detailed in the previous section) supports the tensile strength enhancement. Formation of metallurgical porosity, for a focal position of +1, marginally reduces the tensile strength of the welded joint. The size of the grains influences the tensile strength as well. However, the minimum tensile strength of the weld is higher than the base alloy as testing samples were broken in the base alloy. The tensile fractograph (Fig.7) features elongated dimples supporting the increase in tensile strength.

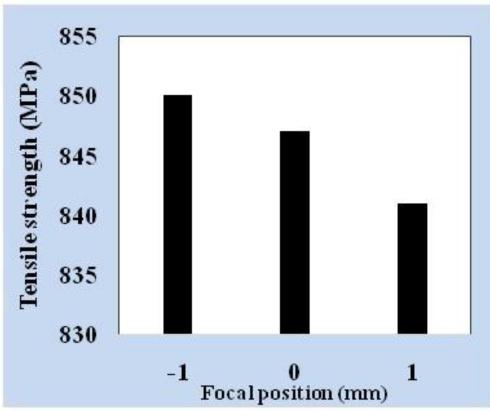

Fig.6 Tensile strength of the weld joints

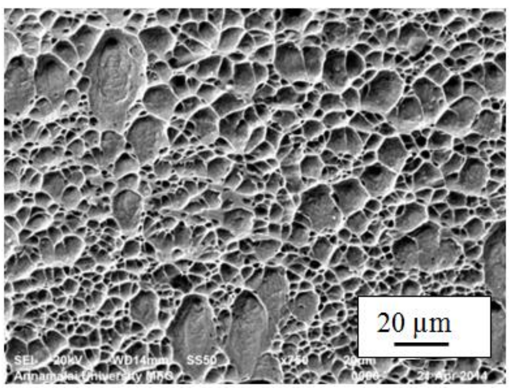

Fig.7 Tensile fractograph

4. Conclusion

Laser welding of SDSS at varied focal positions was attempted in this study and the prominent results are

1. Metallurgical porosities were formed when the laser beam was focussed above the interface of the base alloy.
2. Epitaxial grain growth across the weld zone and base alloy was witnessed for all attempted conditions, which supports better mechanical strength.
3. Maximum hardness was obtained at the weld zone, when the laser beam was focussed below the base alloy.
4. When the beam is focussed above the base alloy, tensile strength reduces owing to the metallurgical porosity.

References

1. *Muthupandi V, Bala Srinivasan P, Seshadri S K and Sundaresan S (2003) "Effect of weld metal chemistry and heat input on the structure and properties of duplex stainless steel welds". Materials Science and Engineering A, Vol. 358 (1-2), 9-16.*
2. *Torkamany M J, Sabbaghzadeh H and Hamedi M J (2012), "Effect of laser welding mode on the microstructure and mechanical performance of dissimilar laser spot welds between low carbon and austenitic stainless steels" Materials and Design, Vol. 34, 666–672.*
3. *Saravanan S, Raghukandan K and Sivagurumanikandan N (2017), "Studies on metallurgical and mechanical properties of laser welded dissimilar grade steels", Journal of the Brazilian Society of Mechanical Sciences and Engineering, Vol.39, 3491-3498.*
4. *Farabi N, Chen D L, Zhou Y (2011), "Microstructure and mechanical properties of laser welded dissimilar DP600/DP980 dual-phase steel joints". Journal of Alloys and Compounds, Vol.509 (3), 982-989.*
5. *Steen W and Mazumder M J (2010), "Laser material processing", 4th ed. Newyork: Springer Publications.*
6. *Sivagurumanikandan N, Raghukandan K and Saravanan S (2016), "Pulsed wave Nd: YAG laser welding of UNS S32750 super duplex stainless steel", Journal of Manufacturing Engineering, Vol. 11(2), 75-78.*
7. *Shantos kumar G, Sivagurumanikandan N, Saravanan S and Raghukandan K (2016), "Effect of welding speed on microstructural and mechanical properties of pulsed Nd: YAG laser welded dissimilar metals", Journal of Manufacturing Engineering, Vol. 11(3), 161-165.*
8. *Sivakumar G, Saravanan S, Raghukandan K (2016), "Intelligent and integrated soft computing techniques for the prediction and graphical generation of Nd: YAG laser weldment macrostructure", Optik Vol. 127, 9727-9733.*
9. *Saravanan S, Raghukandan K and Sivagurumanikandan N (2017), "Pulsed Nd: YAG laser welding and subsequent post-weld heat treatment on super duplex stainless steel", Journal of Manufacturing Processes, Vol. 25, 284-289.*
10. *Mai T A, Spowage A C (2004), "Characterisation of dissimilar joints in laser welding of steel–kovar, copper–steel and copper–aluminium". Materials Science and Engineering A, Vol 374, 224–233.*
11. *Yu Y, Wang C, Hu X, Wang J, Yu S (2010), "Porosity in fiber laser formation of 5A06 aluminum alloy", Journal of the Mechanical Science and Technology, Vol 24(5), 1077–1082.*
12. *Keskitalo M, Mäntyjärvi K, Sundqvist J, Powell J, Kaplan A F H (2015), "Laser welding of duplex stainless steel with nitrogen as shielding gas". Journal of Materials Processing Technology Vol 216, 381–384.*

