Weld Strength of Laser Welded SS316 and SS321

Muhammed Anaz Khan, A Vivek Anand, Lokasani Bhanuprakash

Abstract*: *Nowadays, due to economic considerations, stainless steel is frequently used in dissimilar welds configurations– alloyed steel, carbon steel, copper, titanium. Current research in laser welding aims at joining a large category of structurally dissimilar materials, like copper, stainless steel or aluminum components. The weld quality of 10mm thick stainless steel grades of 316 and 321 laser welded in butt configuration is studied. SS321 is well known for its corrosion resistance property especially dissimilar metal corrosion ie., galvanic corrosion. SS316 provides high strength to weight ratio even at high temperature which makes its as a potential candidate for aerospace application. The joint quality is characterized in terms of hardness, microstructure and inspected using NDT. Scanning Electron Microscope and Optical Microscope were used to study the microstructure of welded specimen. The microhardness test is conducted on the weld joints to quantify the effect of weld parameters in mechanical strength of the joints. Radiography test was conducted to identify the defects in the specimen.

Keywords*: *Laser welding, weld strength, hardness and radiography.

I. INTRODUCTION

The welding in dissimilar materials induces changes drastically in microstructural and mechanical characteristics of the parent material at the joints. The used aluminum and copper was respectively Al3003-H14 and Cu110-H00 [1-4]. The foil alloy has been used to improve the strength of the two metals; aluminum and copper, reducing the fragility of the intermetallic mixture that can shape and then strengthen the mechanical properties [5&6]. Continuous laser welding was tested for two different materials, aluminum and copper. Samples in which filler foil was used exhibited a better performance in the lap shear stress test (an average of 780 N) than the samples without tin foil (an average of 650 N) [7-9]. The improvement in the lap shear test could be attributed to the positive effects of the filler on enhancing the compatibility of the intermetallic compound formed via diffusion.

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* Correspondence Author

Muhammed Anaz Khan*, Department of Mechanical Engineering, MLR Institute of Technology, Hyderabad, India. Email: muhammedanazkhan@gmail.com

A Vivek Anand, Department of Aeronautical Engineering, MLR Institute of Technology, Hyderabad, India. Email: vivekanandbit@gmail.com

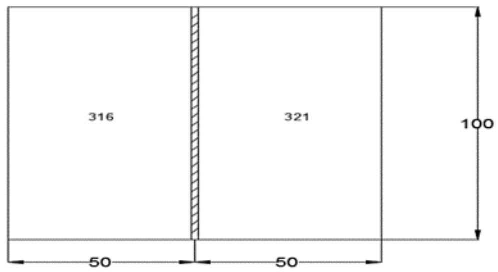
Lokasani Bhanuprakash, Department of Mechanical Engineering, MLR Institute of Technology, Hyderabad, India. Email: lokasanibhanu@gmail.com

The FE model's expected failure mechanism fits the experimental findings from the EDAX study fairly well. The findings of a laser welding investigation using a 350W pulsed Nd: YAG laser for dissimilar metals without filler materials [10 -12]. To reveal the welds ' microstructure, two etchants were made. Porosity analysis showed clear trends in welding speed. Copper's welding performance to aluminum is considered to be relatively good. The Cu–Al phase diagram shows a wide range of potentially forming Cu–Al phases. Furthermore, conditions of non-equilibrium cooling are known to encourage the formation of a cascade of metastable phases. Crack-free copper and Al 4047 welds were obtained under optimum processing conditions [13-15]. Attempts to weld copper with aluminum alloy 6061, a heat-treated Al–Mg–Si–Cu alloy with high mechanical strength, were not successful due to its poor weld ability and high crack susceptibility to examine the influence of welding speed and power on weld bead geometry and performance parameters such as bead diameter, pulse overlap, energy density and duty cycle. Compared to conventional welding process, the solidification time in this process is much lower [16&17].
The main objective of the work is to investigation the weld strength of laser welded SS 316 and SS 321. Enough studies have been carried out on welding of similar stainless steel grades like SS 316 with SS 316. So it was decided to carry out studies on welding of SS 316 and 321. Basic raw materials 316 and 321 of 10mm thickness, 100mm length, 50mm breadth have been procured from ANJANA METAL INDUSTRIES from Hyderabad.

II. EXPERIMENTAL WORK

2.1 Welding of SS321 and SS316

Welding of 10 sets of samples has been carried out with different power variables and parameters at Magod Laser Machining Pvt.Ltd. Bengaluru. The fabricate sample is shown in figure 1. The weld quality of the samples were examined qualitatively with the help of optical microscope and scanning electron microscope.



The laser welding parameters are listed in Table 1.

Denotation	Power (W)	Speed (mm/s)	Track Width (mm)	ED (J/mm^2)	PD (W/mm^2)
LW1	2700	5.0	1.79	301.33	859.87
LW2	2800	6.7	2.02	207.92	891.72
LW3	3000	11.7	2.26	113.78	955.41
LW4	3000	13.3	2.00	112.50	955.41
LW5	3000	15.0	1.88	106.38	955.41
LW6	3300	10.0	2.50	132.00	1050.96
LW7	3300	11.7	2.20	128.57	1050.96
LW8	3300	13.3	2.10	117.85	1050.96
LW9	3400	11.7	2.30	126.71	1082.80
LW10	3400	13.3	2.50	102.00	1082.80

Table1: Laser Welding Parameters

2.2 Sample Preparation

Samples of size approximately 20mmx30mmx10mm and 10mmx10mmx10mm were made from each weld sample with the main surface perpendicular to the welding direction for optical, micro hardness and SEM test by using wire cutting machine. Specimens were rough grinded in a belt gridded machine and series of emery papers in the sequence of 320—400—500—600—700—800 grit papers followed by 1/0—2/0—3/0—4/0 were used for intermediate polishing. The sample was moved perpendicular to the current scratches in all grinding and polishing operations. After grinding, polishing was carried out in wheel covered with velvet cloth; slurry of alumina was used for polishing. It removes all the scratches and mirror finish was obtained. A properly polished sample will show only the nonmetallic inclusions and will be scratch free. To reveal the structure, specific etchants are used depending on the alloy system used. Etchants attack at different rate at different areas depending upon the crystallographic orientations, crystallographic line imperfections, different phases and transformations. The resulting surface irregularities reflect the incident light providing contrast, colorization, polarization etc., and the structure is revealed (50 ml hydrochloric acid, 16ml nitric acid and a few drops of concentrated sulfuric acid) was used as an etchant. After the etchant is applied is it allowed to dried for 12 seconds. The prepared sample for the current work is shown in figure 2.

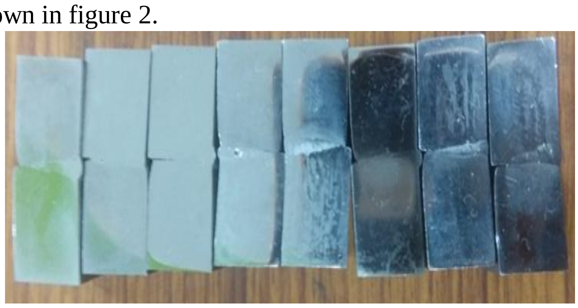
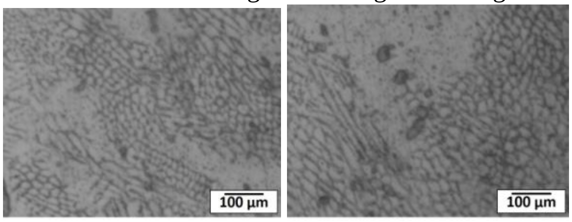


Fig. 2 Prepared samples for microscopic analysis

III. RESULT AND DISCUSSION

Microstructural Analysis of Weld Joint

The optical microscope image taken at weld joints of LW5 and LW8 is shown in figure 3. The parent material fused zone can be identified from the micrograph across the weld zone. It is possible to observe columnar dendrites extending from the fusion boundary to the center line of the weld. In fact, there is no apparent convergence area and HAZ in the two joints near the fusion boundaries. Higher scanning speed attribute to the formation of columnar grains through thermal gradient effect.

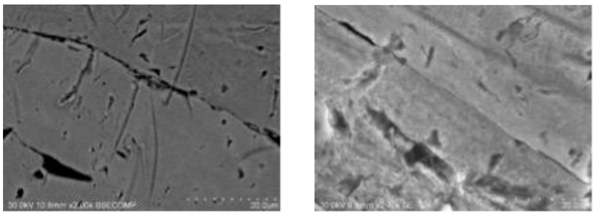


(a) (b)

Fig. 3 OM image of (a) LW5 and (b) LW8 across the weldment

During the laser welding process, steel surfaces are prone to micro-cracks. The induced thermal gradient and the sudden solidification of the molten surface give the solidifying layer thermal stress, which causes micro cracks to form. The laser parameters should therefore be optimally selected to prevent these defects from developing.

The SEM image taken along the boundary between weldment and substrate material SS316 is shown in figure 4. It was observed that higher laser power induced larger thermal gradient and cooling rate. This attribute to the formation of longitudinal cracks along the boundary. It was also observed that the intensity of the cracks decreases with welding speed. The intensity of the crack was observed to be minimal with LW3, this indicate that, the laser power of 3000W with a laser weld speed of 11mm/s induces minimal thermal distortions and provided better bonding compared with higher laser speed.



(a) (b)

Fig 4: SEM Image of (a) LW6 and (b) LW3

3.2 Hardness Test

Hardness across the weld bead have significant influence on laser weld parameters. The micro-hardness profile of the laser welded dissimilar joint is shown in figure 5. Relative to the base metals, significantly higher hardness was observed in the fused region. It was observed because refined grain was produced. For all the welded parts, HAZ was small. Dislocation density and mobility greatly affect a material's hardness. With the density of dislocation and their mobility, the surface hardness increases.

The mobility of dislocation is regulated by solid solution hardening, hardening of precipitation, hardening of operation, dispersion and grain refining. Lower cooling levels are due to grain refinement.

Relative to the hardness of the two surface material, the weld area shows higher hardness. This increased hardness would be due to the grinding of grains along with the development of strong intermetallic phases. It is also observed that weld bead hardness reduces with higher laser power and speed for samples welded. The decrease in hardness is caused by the formation of columnar grains. From the obtained results, LW9 exhibited a highest hardness value of $295HV_{0.3}$ compared to the lowest value of $265HV_{0.3}$ exhibited by LW1. High laser power and lower weld speed impart lower levels of thermal gradient and favour refinement of equi-axis grains. All samples exhibited an increase in hardness value compared to SS316 and SS321.

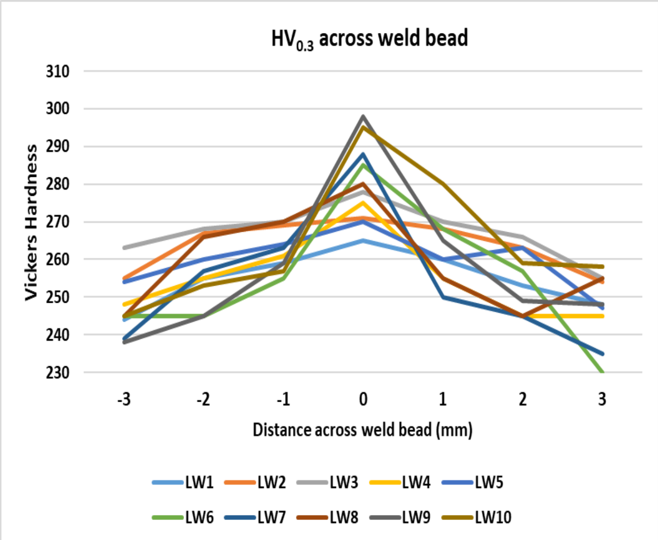
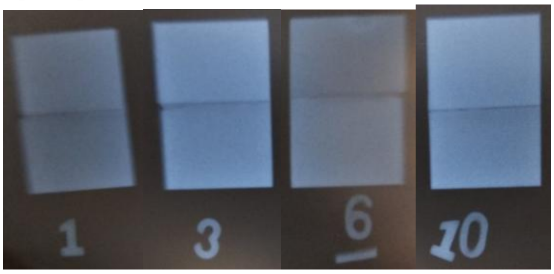


Fig. 5: Vickers Hardness across weld bead

3.3 NDT Test –X ray Imaging

The radiation used in radiography research is a variant of the electromagnetic waves of higher energy (shorter wavelength). The radiation can come from an X-ray generator or a source of radioactivity. Discontinuities are interruptions in a material's typical structure. In the base metal, weld material, or HAZ, these interruptions can occur. The presented data of the radiography conducted is done with 150 kV source and recording films of suitable size are used as per the dimensions of the required sample. The developed samples are subjected to X-ray Radiography tests for the weld quality analysis in terms of fusion process, any significant defects like pores, lack of fusion or under cuts etc.

The developed samples with Laser welding are subjected to NDT evaluation with X-radiography technique which is shown in figure 6. It is unavoidable to find weld defects free in samples even though highest care is taken during the preparation. In case of dissimilar samples, it was observed that they had some porosity and incomplete penetrations. The Radiography report has revealed clearly the indication of porosity. Laser welded samples welded 3000W and 3300W with lower weld speeds were produced with least porosity and almost good quality weld path. Where as in case of laser power of 2700W, incomplete penetration was observed. Combination of lower power and weld speed resulted in incomplete penetration.



(a) (b) (c) (d)

Fig. 6: Radiographs of laser weld sample (a) LW1, (b) LW3, (c) LW6 and (d) LW10

IV. CONCLUSION

The following results are drawn from our work.

- Laser welding with minimal volume fraction of cracks and porosities created total penetration of joints. The area of width and fusion is different with each other for all the joints.
- Hardness across the weld bead have significant influence on laser weld parameters.
- Compared to the base metals, significantly higher hardness was observed in the fused region. It was observed because refined grain was produced. HAZ was minimal for all the welded samples.
- Dislocation density and mobility have a major impact on the hardness of a material. Thanks to the dislocation density and their mobility, the surface stiffness increases.
- The mobility of dislocation is regulated by solid solution hardening, hardening of precipitation, hardening of operation, dispersion and grain refining.
- The refinement of grain is attributed to higher cooling rates. The weld zone exhibits higher hardness compared to the hardness of the two substrate material. This increased hardness would be due to the grinding of grains along with the development of strong intermetallic phases.
- Welding bead hardness for specimens welded with higher laser power and speed is also observed to decrease. The decrease in hardness is caused by the formation of columnar grains.
- The Radiography report has revealed clearly the indication of porosity. Laser welded samples welded 3000W and 3300W with lower weld speeds were produced with least porosity and almost good quality weld path.
- In case of 2700W laser power, incomplete penetration was observed. Combination of lower power and weld speed resulted in incomplete penetration.

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AUTHORS PROFILE

Dr. Muhammed Anaz Khan, is presently working as an Associate Professor in the Department of Mechanical Engineering, MLR Institute of Technology, Hyderabad, Telangana, India. He obtained his Ph.D. from NIT Trichy and is specialized in Material Science and Composite Materials.

Dr. A Vivek Anand, Professor in the Department of Aeronautical Engineering, MLR Institute of Technology, Hyderabad, Telangana, India. Ph.D. specialization on Wettability and Corrosion Behavior of Micropatterned SS304 Steel in Anna University, Chennai.

Dr. Lokasani Bhanuprakash, is presently working as an Associate Professor in the Department of Mechanical Engineering, MLR Institute of Technology, Hyderabad, Telangana, India. He obtained his Ph.D. from NIT Calicut and is specialized in Material Science and Composite Materials.