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Investigation of Mechanical Behaviour of Laser Welded Butt Joint of Transformed Induced Plasticity (TRIP) Steel with effect Laser Incident Angle

Khot Rahul S[1, 2 *], Venkateswara Rao T[3]

[1]*Mechanical Department, K L University, Vaddeswaram, Andhra Pradesh 522502, India.*

[2]*Marathwada Mitra Mandal's College of Engineering, Karvenagar Pune, India.*

[3]*Mechanical Department, DBS Institute of Technology, Kavali, SPSR Nellore, Nellore, Andra Pradesh, India.*

ORCID: 0000-0003-1899-7112 (Rahul)

Abstract

This paper presents the impact of the angle of the Laser incident beam on transformed induced plasticity (TRIP) steel sheet subjected to robotic arm assisted Nd: YAG high density laser beam. The continuous laser beam source mode is used to produce a butt weld joint using a 2 mm sheet of standard ASME E8 with maximum power is used as a 2200W with zero gap. The experiments are conducted on the samples with varying incident angle as 80°, 90° and 100° from horizontal parallel plane to work piece. Along with this the laser welding speed are varying from 25 mm/sec, 28 mm/sec and 30 mm/sec effects are analyzed. The result shows that there is a significant change in the strength and deformation of the joint by growing the beam incident angle with constant beam power of 2200W and changing welding speed. In order to understand the effect of the laser angle on the microstructure of the heat affected zone, FESEM is performed on tested samples from tensile tests.

Keywords: Transformed Induced Plasticity (TRIP) Steel, Nd: YAG laser welding, Laser incident angle

1. INTRODUCTION

Latest innovations in the automotive industry have been taking place, with the primary goal of reducing manufacturing costs and improving the fuel economy. This is achieved by using two approaches: the use of recent technology for joining methods and the use of other advanced materials. In fact, welding is one of the major processes for the manufacture of auto-body and associated welded parts, fabricate the body-in-white in car manufacturing sector [1-3]. In the automotive industry, there are a variety of joining technologies used for welding processes such as TIG, MIG, ARC welding, hybrid welding, but one of the new methods is laser welding. Laser beam welding is flexible, provides low heat input and results in high welding speed and productivity. Hence now it is widely used in industrial production. The high energy density and low heat input process resulting in a restricted heat input process are Nd: YAG laser beam welding with a continuous wave resulting in a small heat–affected zone (HAZ). The efficiency of the welding depends mainly on the mechanical properties, the geometry of the welding bead and the distortion of the welded joint [4]. All these consistency features are directly related to the parameters of welding. The cooling rate of the weld puddle chamber is so high that the width of the confluence area (d/s) is slightly deformed [5-6]. Such benefits make laser welding one of the key-hole welding processes that are important In the automotive industry, In order to achieve reduced weight and increase fuel efficiency, advanced high-strength steels (AHSSs) have been commonly used [6].Third generation AHSS not only offers good formability compared to first and second generation AHSS, but also saves costs [7-8]**.**

LBW has decreased the weight of the Airbus A300 series structures by 5% and has also been used to link some parts of the fuselage [1].

However, high-strength laser welding has become difficult due to the complex state of the metal during Laser welding. If during welding by Laser there are extremely high speeds of heating and cooling, on welded connections there can be much smaller accumulation of a design that influences softening of welded connections [9-11]. During the laser welding process, a small part of the energy of the incident beam is absorbed directly by the metal due to surface reflection and/or conversion through the keyhole. Thus, the energy of the event laser beam can not be used directly to receive heat or t o measure the size of the heat cycle [12]. The characteristics of the joints, such as the penetration depth and the width of the beads, are increased by increasing the range of the laser incident angle while the length of the bed is reduced accordingly. Even the shape of the welded spot and the size is totally dependent not only on laser power, but also on the laser incident angle [13-14]. The intensity of absorption of laser radiation at welded joints is significantly influenced by the laser incident angle of light radiation. In addition, by limiting the welding size and the rotation of the laser head, the angle of incidence is reduced. It is evident from the literature that very few researches has raised combined issue of the effect of laser incident angle and laser velocity [15-20]. In view of this, in this research, the effect of the laser incident angle on the properties of the butt weld joint have been studied. The joint is made from Nd : YAG laser beam welding and has an effect on the ultimate tensile strength and deformation of the joint is investigated. Along with this depth of the joint, the impact of the laser incident angle with discontinuity in the joint was addressed. The joint microstructure in the Heat Affected Zone is also addressed along with the results of the EDS.

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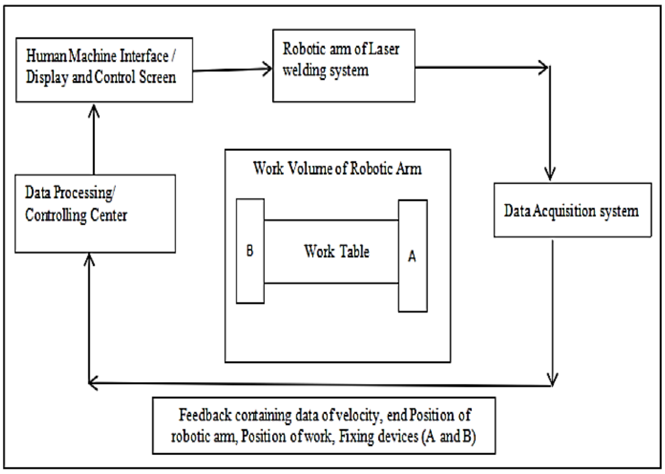

Fig. 1 Experimental set Laser welding machine.

2. MATERIALS AND EXPERIMENTAL PROCEDURES

The experiment is carried out on Transformed Induced Plasticity (TRIP) Steel with major constituents of elements represented in our previous publications. The joint is prepared according to ASME E8 Standards which is supplied by Nextgen Steels and Alloys Company in cold drawn sheet form with 2 mm plate thickness and test specifications for performing test is as shown in the Fig. 2. The chemical compositions, mechanical properties of the materials are the same as mentioned in previous publications [23]. The joining of material is done using GmbH 56218 (Karlich Germany) laser system with Nd:YAG Laser power welding systems with 50-60HZ frequency three phase with maximum power is 13.5 KW along with 400-480 V supply capacity. The mechanical testing (Universal Testing) has been done using SAR Testing machine with ±1% precision accuracy with SAR Testing System of Model No. STS 248 with operating speed as 5 mm/min. The chemical composition of materials is as tabulated in the table 1. Optical microscopy (Reichert, Austria) and field-emission scanning electron microscopy (make ZEISS model Gemini SEM 450) were used together with EDS on Transformed Induced Plasticity (TRIP) steel for characterization of microstructure analysis and content-associated components.

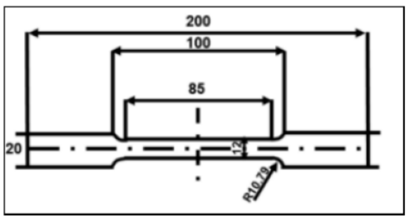

Fig. 2 Dimension of specimen used for mechanical testing.

Table 1. Chemical composition of base materials

Element	C	Mg	Si	Ni	Mb	P	Al
%	0.04-0.05	0.1-0.3	0.0.2-0.03	0.033	<0.01	0.01-0.03	<0.1

Table 2. Chemical Composition of base materials

Element Line	Weight %
C K	4.29
O K	12.56
Fe K	58.24
Mg K	10.25
Si	1.13
Ni	1.19
Mb	2.07
Al	10.27
Total	100.00

The welded samples are as shown in Fig No. 3. The fig. 3a shows the welded sample with the front plane of which clearly shows the welding plane and in Fig. 3b shows Back side of the plate which is shown condition of welding to the bottom end. The samples are prepared using different laser incident angle as 80°, 90° and 100° measure with respect to work holding table. Along with this velocity of laser is changed from 25 mm/sec, 28 mm/sec and 30 mm/sec and experiment was conducted which are in the form of butt weld joint. The few of the samples are as shown in the fig. 3.

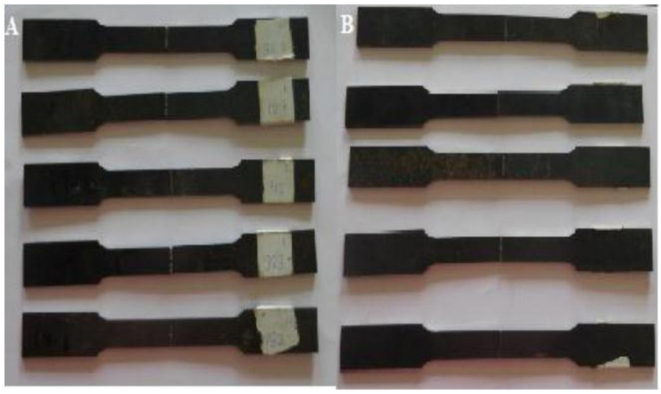

Fig. 3 Samples considered for testing purpose a) Indicates front side/Plane of sample on which laser welding has done and b) back side of same samples

3. RESULT AND DISCUSSION

The results of the experiments are divided into three parts: metallurgical analysis, microstructural analysis and mechanical analysis. In the metallurgical examination of the plate, the effects of FESEM on the heat affected zone (HAZ) are carried out after the test has been carried out. Using the Minitab software, the findings plotted in the mechanical analysis have been plotted and discussion has taken place.

3.1 Metallurgical Analysis

The samples were developed by wire-cutting after welding and followed by normal grounding and polishing processes after welding. The appearance of the welds and the crosses were first examined using an optical microscope and the cross sections were then inspected using ZEISS Gemini SEM 45050 for SEM with EDS analysis.

It was observed from the results that the major Constituents in the samples are ferrous, oxygen, carbon along with aluminium which have high peaks of 58.24%, 12.56%, 4.29% and 10.27%

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respectively as shown by percentage weight and confirmed in fig.4

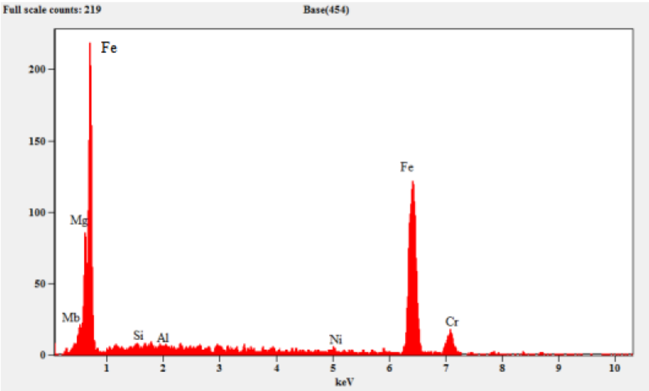

Fig. 4 EDS result of the sample shows constituents of elements.

3.2 Microstructure Analysis

The effect of laser incident angle by varying laser incident angle is as shown in the Fig.5. As the laser incident angle is 80º, the structure of material after tensile strength is shown in Fig. 5a, the ultra fine lamellar structure of austenite resulted in a Base Metal. No soft HAZ chains were observed in the background, probably due to martensite reduction in Base Metal, as the heat affected zone reduction was attributed to the martensite content and direct temperature in Base Metal [22]. The laser incident angle is changed form 80º to 90º, the structure and grain size of steel varied and the fractured surface demonstrated ductile type of fractures as like as a velocity [23]. From the above results it can be understood that there, it can cause oxides a nitrate component is formed during the welding process [24]. The angle of inclination of 100°C of the laser is similar to that of a small low angle, as shown in Fig. 5c, shows a structure with large openings in relation to the light source. A differential test of 90º, wider voids and 80º with greater voids as shown in Fig.5a, and 5b, and keeping laser power is 2200 W constant.

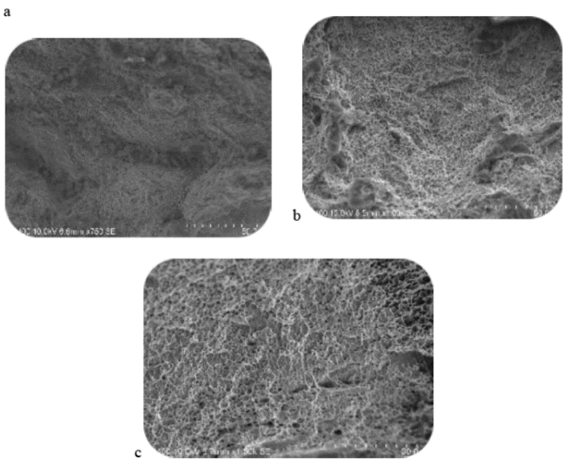

Fig. 5 FESEM result of the sample shows with conditions as a) 80º Laser Incident angle b) 90º Laser Incident angle c) 100º Laser Incident angle

As the power is kept constant as 2200 W the variation was rendered in the velocity and the angle of Laser incident and the quality of the joint as shown in the Fig. 6. As per the above Fig. 6 the position 1 and 2 instances where the blow holes are created in case 1 and edge points are not welded only because of the inclination of the laser gun, but for instance 2 the welding was done through the section. As for instance 3, all the errors are removed and the joint was looking good with no holes and no gaps at edges. Thus, in the case 4 and 5 the velocity was reduced to 25 mm/s and the angle increased to 100º, welding was spread over space but includes blow holes and the velocity was increased to 30 mm/s and the angle increased to 90º, the same thing was observed. The joint motion/orientation and joint formation is therefore entirely dependent on the process parameters of the system. Westerbaan et al.[19] find that contoured welding defects have decreased the tensile strength of the welds, as has also been reflected in these experiments..

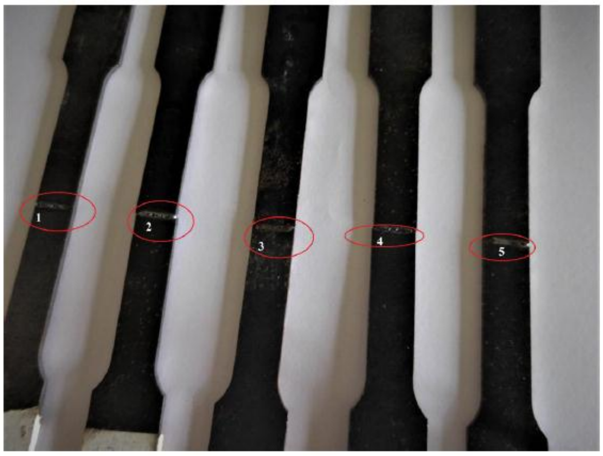

Fig. 6 Quality of the weld developed using changing process parameters of laser welding as 1) velocity as 28 mm/sec and laser incident angle as 80º 2) velocity as 28 mm/sec and laser incident angle as 100º 3) velocity as 25 mm/sec and laser incident angle as 90º 4) velocity as 25 mm/sec and laser incident angle as 100º 5) velocity as 30 mm/sec and laser incident angle as 90º

3.3 Mechanical Analysis

The test was carried out using Universal testing machine and the graph load verses displacement has shown in fig. 7. As the angle of the incident laser varies the shape of the curve is changed accordingly. The load-bearing capability of the joint is reduced as the laser incident angle has increased from 80º to 90º to 100º.

The ultimate tensile strength determined in the system is 549.20 N/mm^2 for 80º while that value has been improved to 504.11 N/mm^2 for 90º laser incident angle. Although the laser incident angle has shifted to 100º, this value has reached 436.69 N/mm^2. Percentage elongation also decreased from 9.2% to 6.3% to 4.5%. In the fig. 7(a) the curve has been extended until the full load has been extracted so, it indicates that a certain amount of joint strength is still present in the joint after the final peak point having laser incident angle 80 degree while, in the case Laser incident angle 90º as shown in Fig. 7(b), the elongation curve has been limited to a certain level of load, i.e. 6100N approximately, while in the case of a laser incident angle of 100º as seen in Fig. 7(c) break off line 8750 N after the load has not been supported by the joint. It is obvious that, as the incident laser angle increased from 80º to 100º, the ultimate tensile strength and elongation decreased. As the laser incident angle is going to increase Ultimate tensile strength behaves in opposite way as shown in Fig. 8. In the surface plot of the conditions, some unevenness has been found in Fig 8(a) and this may be due to the velocity of the laser gun. The fracture specimens are as shown in Fig .9. The broken part of the 80º TRIP sample was found to be high breaking. In combination, small gaps appear at 90º incident angle, while large gaps appear at higher degrees of laser incident angle as 100º as all the samples has broke at weld section it means that the joint section has weaken than that of the base metal. Almost all the pieces were destroyed in the portion of the Fusion field. So if the hardening and quenching process were to strengthen the properties of that portion, it would be more successful.

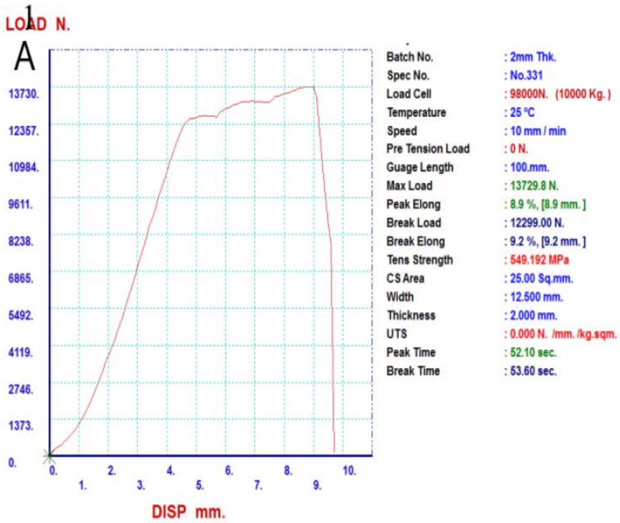

Fig. 7a Load vs displacement graph for different welding conditions 80º Laser Incident angle

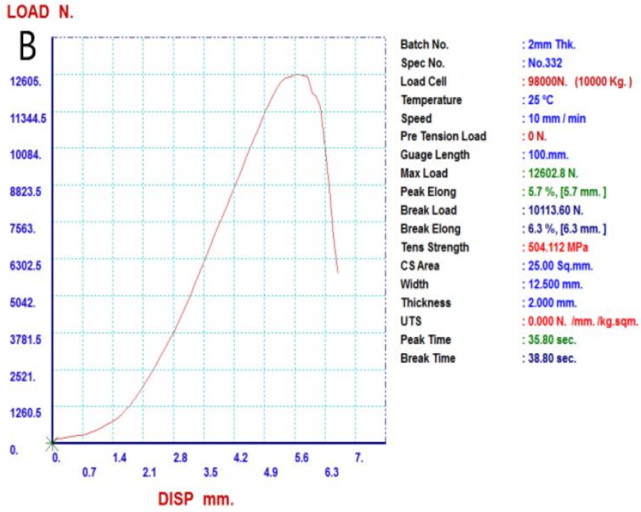

Fig. 7b Load vs displacement graph for different welding conditions 90º Laser Incident angle

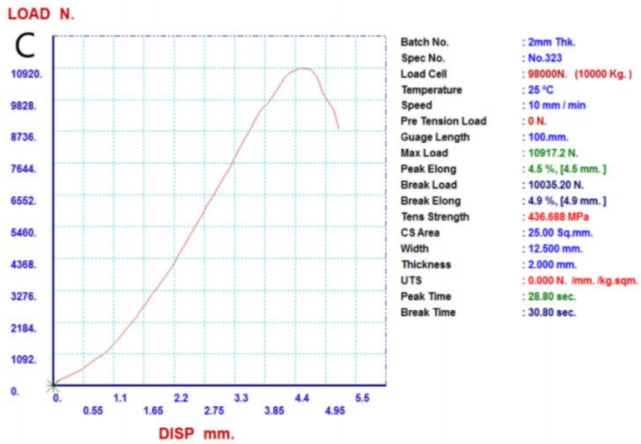

Fig. 7c Load vs displacement graph for different welding conditions 100º Laser Incident angle

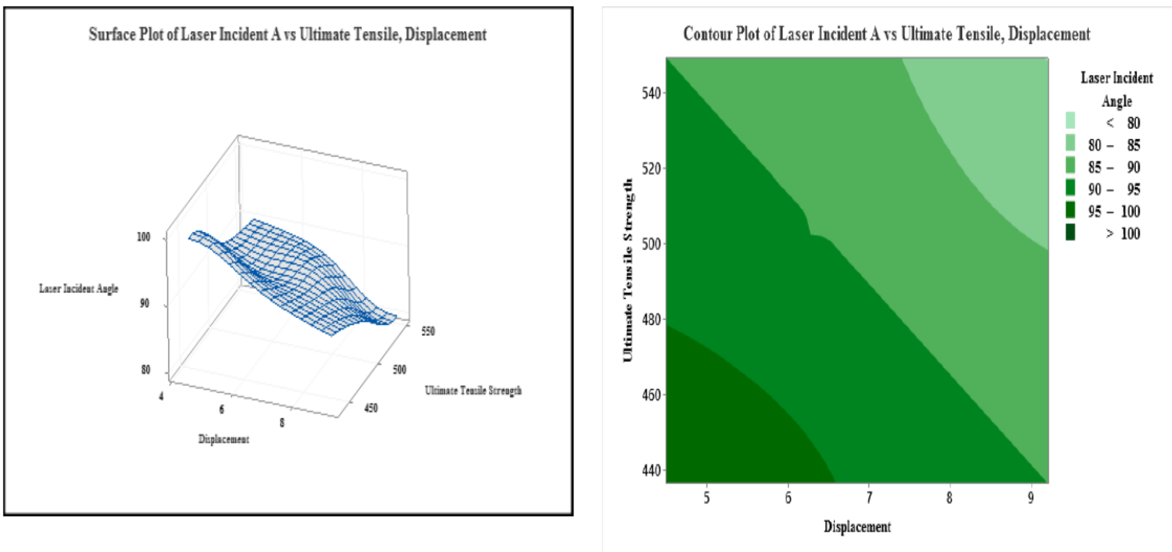

Fig. 8 a) Surface plot and **b)** Contour Plot for Laser Incident Angle vs Ultimate tensile strength and Displacement

Fig.9 Tested samples after performing test on machine

4. CONCLUSION

In summary, Laser welding produced using Nd:YAG laser produce a reasonable on strength of the joint. The Laser Incident angle has changed from 80º to 100º the structure and grain size of steel varied and the ductile fractured surface demonstrated also the laser incident angle has changed from 80º to 90º the strength of the joint was reduced up to 8.2% while angle is again changed to 100º the considerable effect was observed as 20%. The deformation has also changed up to 31% in case of 90º while 51.09% in case of 100º laser incident angle. As far as concern to the quality of the weld laser incident angle changes with respect velocity, voids and blow holes are observed on the steam line of weld. There are some other process parameters which play a vital role in improving the efficiency of the joint and required optimizing parameters for Laser welding such as Laser Beam Power, Focal distance, Laser

Beam Diameter, Types of laser etc.

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