

Effect of parameters of Nd YAG laser welding on AISI 316 Stainless steel and Brass

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Abstract: Aspect Ratio (Depth/Width) is one of the most important factor to determine the quality of weld. For a weld to be a perfect one the Aspect Ratio should be maximum. Hence to get a perfect weld one has to ensure that the depth of penetration is good enough. In the current study we are optimizing the Nd-YAG welding system parameters (i.e. like laser peak power, pulse energy, welding speed, frequency) to get the best results on Brass and SS-316LN. Stainless Steel is one of the most widely used material at industry level and brass is already widely used in bearings, ammunition casing and for some electrical appliances. In this experiment the welding is being performed using TRUMPH HL- 506P Nd-YAG Laser Welding System and the welding speed is determined using a rotating mechanism to rotate the rod. The welds were inspected using metallography experiment and metallograph results were used to determine the Aspect Ratio. Based on those results the experiment was successfully concluded.

Key Words: Laser Welding, Optimization, Aspect Ratio, Metallography, Weld Under Cut, Weld Spatter

1. Introduction

Laser welding is advanced welding technique used for metal joining industrial process as it offers various advantages over the other widely used welding techniques. Laser welding have certain advantages like, narrow weld width high penetration and parallel-sided fusion zone. These advantages of laser welding are based on its high power density and low heat input. The edge laser welding offers over the other processes are its low heat input, low distortion, low heat affected zone and non-contact nature of the process.

Narrow welds result in solidification cracking [1] because of high stress concentration. Large aspect ratio will lead to excessive transverse strains in restrained joints and this in turn leads to



solidification cracking. Austenitic stainless steel of grade 316LN and commercially available brass has chosen as sample material. A depth of penetration of more than 50% of aspect ratio is preferred for steel sample for initial energy selection. Aspect ratio less than 0.5 leads to loss of heat as the energy utilized most in surface heating. Aspect ratio more than 1 percent increase the susceptibility for hot cracking. the weld obtained should be devoid of any defects like concavity and porosity etc.

Absorption of energy is dependent on resistivity of the material, wavelength of the light [3] and inclination of the work piece to the incident ray or vice versa. Absorption of light energy in case of metal is temperature dependent. The fact is that absorption is directly proportional with vapor pressure therefore metal in liquid phase absorbs more energy than solid [4]. So technically only a part of actual laser pulse energy is coming in use to melt the metal. The effect of parameter selection on heat input is effectively unknown despite the widespread use of laser spot welding. There is no way to know what fraction of actual light energy is needed due to the uncertainty in absorption. According to a few studies the fraction of absorption for stainless steel is in the range of 0.38 to 0.67[7]. Based on the absorption range, successful spot welds can be achieved by trial and error method. Absorption of stainless steel and brass are given in Table 1.

Variables like pulse energy, laser peak power, pulse duration, welding speed and frequency effect the heat flow and fluid flow in the weld pool. This will result in penetration depth, shape and final solidification structure of the fusion zone. The properties of the weldment are influenced by the shape and microstructure of the fusion zone. Optimization of parameters is aimed at lowest possible energy required to get the desired weld without any defects.

This paper presents a brief description about various parameters and their effect on penetration and optimisation of the parameters for SS316 LN and Brass rod.

Table 1: Absorption of materials for Nd YAG laser (wave length 1064 nm)

Material	SS	Brass
Absorption of Nd-YAG laser energy	35%	10%



Figure 1: Nd-YAG Laser Welding set-up

2. Experimental Procedure

Welding experiments are carried out on stainless steel 316LN and brass rods of 6.6 mm dia. Pulsed Nd-YAG laser (wave length 1064 microns) spot welds were produced with help of TRUMPH laser welding system, with fixed processing optics beam delivery [Figure 1]. Average power of the laser is employed at 500watts. A 200mm focal length convex lens with focal plane located at work piece surface is used to focus the laser beam and a stainless steel metal sheet is used to verify the initial focusing of the beam. Focus is fixed based on the results obtained and the plot is shown in Figure 2. Average power is measured using Optical Engineering power probe. To avoid any interaction of the reflected and incident beams the incident angle of the beam is maintained at 15 degrees to the work piece location.

During the initial set of experiments, energy was varied and the best bead profile was selected for desired results. After this the energy was made constant and pulse peak power and pulse duration were varied for the next set of experiment. Finally frequency and speed of welding were varied in the final set of experiments to attain the best weld bead geometry. An abrasive wheel cutter was used to section the samples. Etching was carried out on polished samples using aquaregia with 2 parts of HCl and 1 part of HNO₃. Reagents which were used for etching of stainless steel and brass are given in Table 2. Microstructure of the samples were then examined using a Optical microscope.

Table 2: Etching reagents used for evaluation

Metal	Etchant	Concentration
Stainless Steel	aqua Regia with HCl and HNO ₃	2 parts of HCl and 1 part of HNO ₃

Brass	Distilled water	100ml
	Ferric chloride	5grams
	Hydrochloric acid	50 ml

3. Results and Discussion

AISI SS 316 and commercially available brass are chosen as a sample materials for this study. As mentioned earlier, aim should be to obtain a defect less smooth bead at lowest possible energy. To know the actual contribution from energy it is varied in a square matrix. Penetration was considerably low at focus below this energy limit. Welding at focus was not smooth as a result there is a possibility of concavity at weld bead surface. hence a defocusing of -4mm is uniformly chosen for all welds. The more energy you put in, the more will be the liquid pool generation. Energy is varied in initial set of experiment to find out the width and depth of weld bead. Energy can be varied either by power or duration. Parameters chosen for energy variation are mentioned in table 3.

Table 3: Parameters for Energy variation

Sample No	Power (watts)	Pulse duration (m.sec)	Pulse Energy(joules)
1	720	7	5
2	1000	10	10
3	1200	13	15
4	1410	14	20
5	1590	16	25
6	1750	17	30

Weld metallographs of stainless steel and brass are shown in figure 3 and 4 respectively. Weld bead penetration and bead width are plotted against sample number is shown in figure 5. Objective is to pick the lowest energy parameters required to achieve an aspect (Depth to Width) ratio of 0.5. An aspect ratio of 0.5-1 is ideal for conduction mode of welding. Pulse energy is the base parameter , an aspect ratio of 0.5 needs to be aimed. As this is a conduction mode of welding, it needs to be ensured that at least 50% of the linear interaction path should be conducted to the bottom layers.

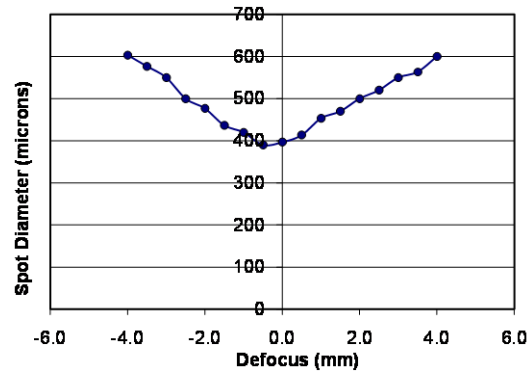


Figure 2: Spot diameter of the pulsed laser Vs Defocusing

It is clearly evident from the figure 5 that the increase in energy will lead to more penetration for both stainless steel and brass. stainless steel penetration and weld bead width are given in table 4. After a threshold energy, width is not changing. Rate of increase of penetration is gradually decreasing with the mass of pool. This can be attributed to the limitation arising out of convective heat transfer. But in case of brass, penetration is increasing at a faster rate after 20 joules. Because absorption of laser increases with temperature. As higher energy leads to more temperature rise of the sample, penetration will increase.

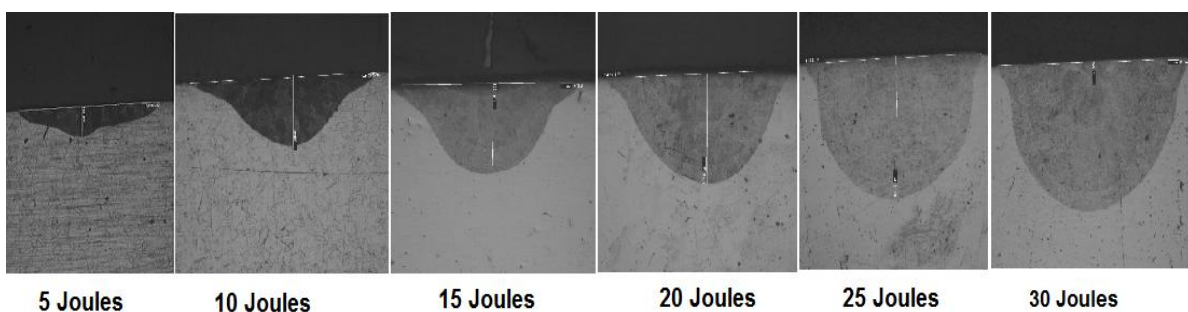


Figure 3: Weld pool geometry with energy of stainless steel

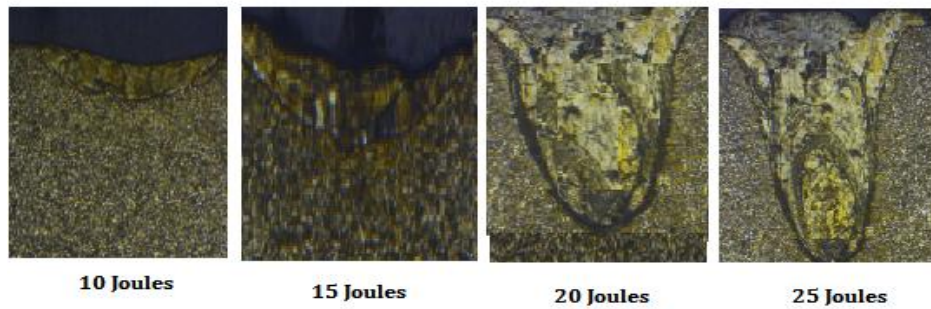


Figure 4: Weld pool geometry with energy of Brass

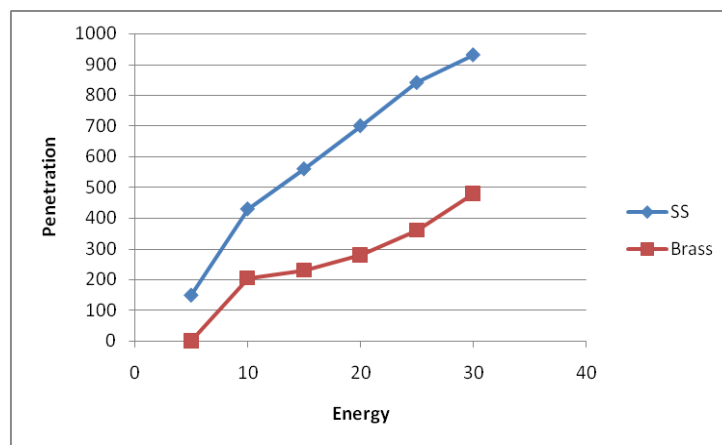


Figure 5: Effect of Energy on Penetration

Table 4. Output for Energy Variation

Sample	Energy (Joules)	Depth of penetration (Microns)	Width of weld (Microns)	Aspect ratio
1	5	150	1150	0.13
2	10	430	1240	0.35
3	15	560	1510	0.37
4	20	700	1520	0.46
5	25	840	1520	0.55
6	30	930	1530	0.61

At second stage the energy was kept constant and the peak power of pulse was varied. Peak power and Pulse Duration are interrelated with energy. Peak power was chosen as an independent

variable. The variation of peak power and pulse duration at constant energy is shown in Table 5. Pulse energy is fixed at 25 joules for further experiments as it is the minimum energy required for an aspect ratio of 0.5 as mentioned earlier. Weld penetration variation versus peak power is graphically shown in Figure 6. In case of brass, peak power is having more impact compared to stainless steel as energy coupling with the sample is better.

Table 5 : Parameters for variation of peak power at const. energy

Sample No	Power (watts)	Pulse duration (m.sec)	Pulse Energy(joules)
1	1250	20	25
2	1565	16	25
3	2085	12	25
4	3125	8	25
5	6250	4	25

Even at constant energy, depth of penetration increased continuously from sample number 1 to 5. This plot concludes that the effect of peak power on penetration was more than pulse duration. There was no significant variation in the penetration with increasing peak power at the expense of pulse duration. Hence increase in penetration because of peak power was not satisfying. A trace of weld spatter was noticed at 3125 watts. Beyond this power range, the effect of spatter was severe. To be on the safer side, the peak power was adjusted at 2085 watts. High peak power results in high penetration but after a limit, it leads to weld under cut and spatter that is clearly shown in figure 7.

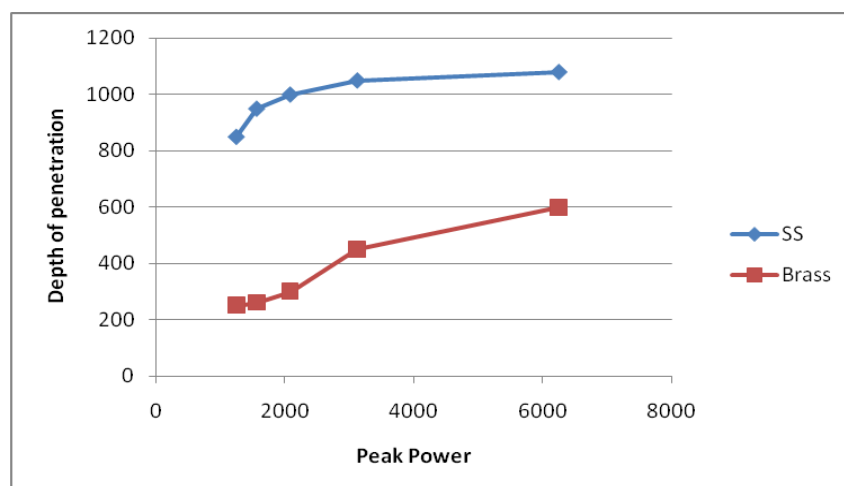


Figure 6: Effect of Peak power on penetration.

Choosing lower peak power allows more pulse duration. More pulse duration results in reduced rate of heating of the material, which in turn minimizes any distortions during heating. Optimization of parameters was done at 25joules of pulse energy, 2085 watts of peak power, 12 m.sec of pulse duration.

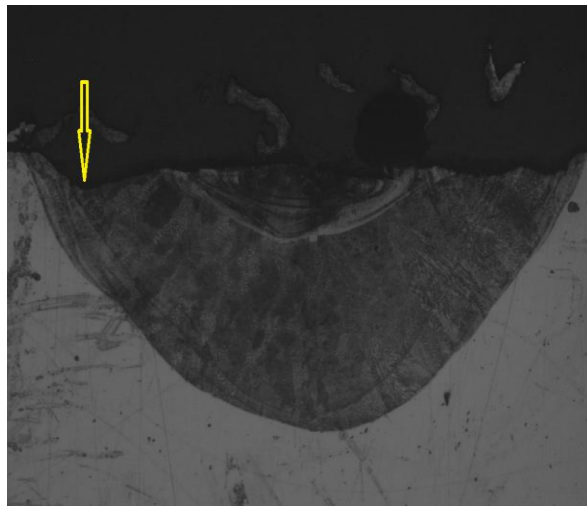


Figure 7: Weld under cut and spatter

Frequency was then altered to decide the effect of overlapping of spots. Frequency was varied at 5Hz, 7Hz, 9Hz and 11Hz. This frequency was varied according to equation-1, which is based on overlapping and welding speed.

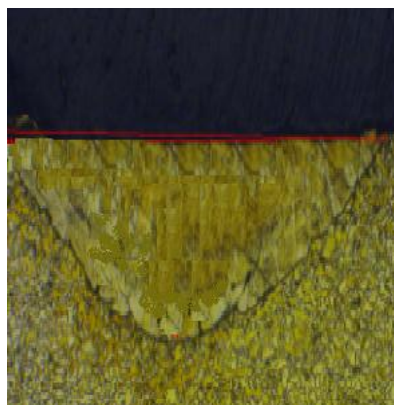


Figure 8: Microstructure of Brass weld

$$V \text{ (welding speed)} = \text{Frequency} \times (1 - \text{overlap}) \times \text{Spot Diameter} \quad (\text{Eq-1})$$

At 7 rpm, and for a spot dia of nearly 1 mm, the overlapping is tabulated below in table 6 with respect to frequency.

Table 6: Frequency and its Overlapping fraction of spots

Frequency	Overlapping
5	0.52
7	0.65
9	0.73
11	0.78

Increase in degree of overlapping i.e. more than 0.7 not only gave a good seam of the weld bead but also resulted in increase in the heat input.

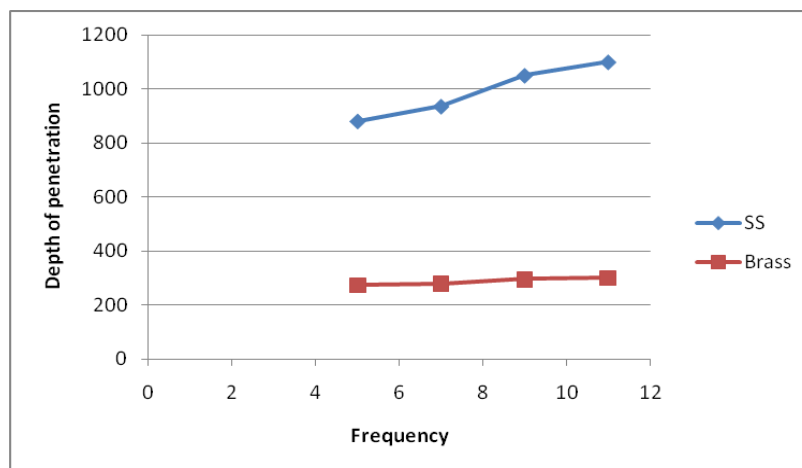


Figure 9: Penetration with Frequency

73% of the overlapping has proved to give optimum results. Slight increase in penetration was also noticed with increase in frequency [Figure 9]. Metallograph of brass shown for a spot overlapping of 73% and is shown in figure 8. As laser-cooling rate was very high and the heat build-up due to frequency was small. At a frequency of 9 Hz, desired weld was obtained.

Last variable chosen was speed of welding. Speed was varied continuously from 7 rpm to 13 rpm. Increase in speed resulted in decrease in penetration as shown in figure 10. Heat input per unit length is decreasing and hence the penetration also coming down. Heat transfer rate is faster for a high speed welding.

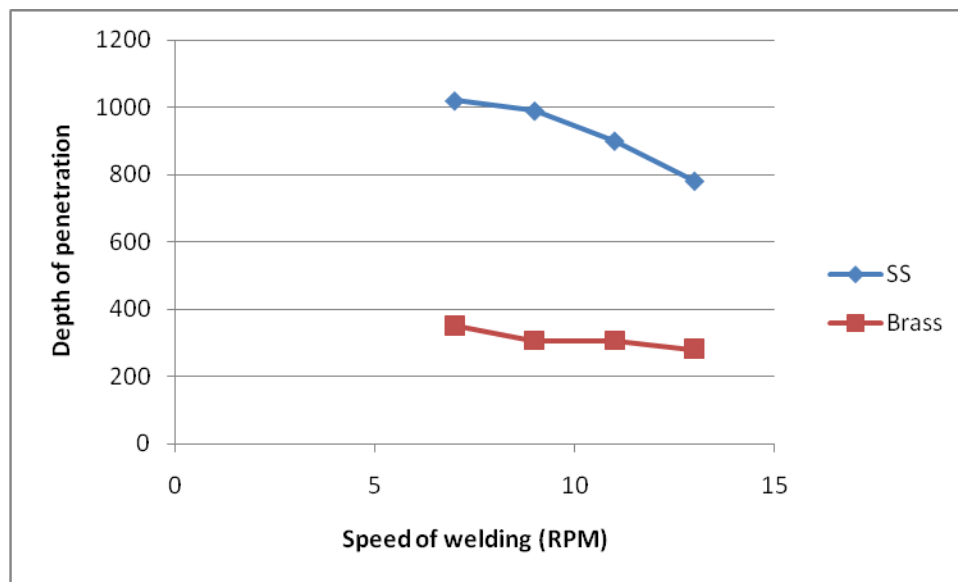


Figure 10: Penetration with speed of welding

Welding at higher speed led to defective welds as the cooling rate further increased. Finally all the parameters were adjusted to get a desired weld without any sort of defects.

Laser welding technique has been promising in terms of consistency of results. Throughout the circumference of the rod the depth of penetration was almost same. Uniform penetration was obtained during each weld on the rod.

4. Conclusions

Effects of Laser welding parameters on penetration of stainless steel and brass have been studied. Optimization of parameters was done for stainless steel to achieve an aspect ratio in the range of 0.5 to 1 is carried out .

Higher energy lead to increased penetration in both the cases rate of rise in penetration is lower for stainless steel but reverse is true for brass at higher energies.

Effect of peak power is most predominant in brass compared to stainless steel because of the better coupling at higher powers.

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