Study on Pulsed Nd:YAG Laser Butt Welding of High Carbon steel

Thesis submitted to the National Institute of Technology- Rourkela in partial realisation of the requirements of

Bachelor of technology (mechanical engineering)

by

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CERTIFICATE

This is to certify that the project titled, "**Study on pulsed Nd:Yag butt Laser welding of High carbon steel,**" submitted by Mr. Sidharth Mallick in partial realisation of the requirements for the award of Bachelor of Technology Degree in Mechanical Engineering at National Institute of Technology-Rourkela is an genuine effort carried out by him underneath my direction and guidance, and all the information enclosed in this report is correct to the best of my knowledge.

DATE:

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ACKNOWLEDGEMENT

It’s with a sense of immense pleasure that I wish to express my most honest heartfelt appreciation to Prof. M.Masanta, Department of Mechanical Engineering, NIT Rourkela for his organised and able guidance throughout the duration of my project work. I am greatly obligated to him for his useful suggestions and reproach from time to time during the duration of progress of my work.

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ABSTRACT

Welded joints of high carbon steels have very important applications in the industries. This paper is about the experiments and investigation carried out to recognize the influence of variation of Laser parameters on strength, HAZ and microstructure of the resultant welded work piece. Nd:YAG Laser welding is done using laser welding machine(Alpha Laser, ALT200) for butt welding at altered values of beam power and beam Scan speed. The material dimension was -6 mm x 2.5 mm x .93 mm and there were a total of 12 weld pieces. Tensile testing of the prepared specimen was conducted using universal testing machine (UTM) to find out the peak load and the tensile stress at which the specimen breaks. The microstructure and weld zone was inspected using optical microscope. Result indicates that the tensile strength and weld depth increase with the increase in beam power and decreases with the increase in laser scan speed.

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CHAPTER ONE

1.INRODUCTION

1.1 Background

Light amplification by stimulated emission of radiation (LASER) is a mechanism that releases electromagnetic waves by simulated emission process. For many engineering applications laser is worldwide used as a source of thermal energy. The cause for that is Laser's advantages that include narrow treatment, accurate operation, and little processing time. Among the most significant applications of laser processing, laser welding is one that provides substantial benefits over the conventional welding processes. Laser beam of high intensity magnitude try to melt and evaporate partially the welded material in the process. Among the different types of laser offered in the market, CO2 and Nd:YAG lasers are the ones that dominate the materials processing. Currently, only these lasers provide a reasonably high beam power in packaged form is ergonomic in its application. Earlier, due to their superior beam quality and output power, the CO2 lasers normally functioned in continuous wave (CW) manner, went unopposed for years in the cutting and welding of unusually thick materials explosion ejection.

The laser's beam of coherent light sets it apart from sources of light that emanate incoherent beams of light. One of the non-conventional and non-traditional unique means to weld objects is laser welding. Laser beam welding has the following merits- high power density, high rates heating and cooling that produce comparatively minor heat affected zones (HAZ). LASER is usually a spatially coherent, electromagnetic spectrum narrow-wavelength monochromatic light. Helium/argon are used as inert gases to cover and protect the weld from contamination and to diminish the development of absorbing plasma. For the purpose of cutting, welding, drilling and surface treatment of a extensive variety of industrial materials. Depending upon the type of weld required a continuous or a pulsed laser beam could be used. LBW is a very nifty process, that's capable of welding a diverse materials like aluminium, stainless steels, tool steels, copper and carbon steels region. The rate of welding is proportionate to the amount of power delivered but also depends on the type and thickness of the job, etc. The weld quality is high although some cracking may occur in the weld.

1.2 laser welding equipment

Basically two types of laser equipment are in use- solid-state lasers and gas lasers. Solid-state lasers employ solid media like synthetic ruby, yttrium aluminum garnet crystals doped with neodymium (Nd:YAG), chromium in aluminum oxide, etc. Gas lasers use carbon dioxide, nitrogen, etc as medium.

Solid state laser

The most popular solid state design is a rod shaped single crystal approximately 20 mm in diameter and 200 mm long with flat grounded ends. A flash tube, containing xenon or krypton surrounds this tube. When flashed, a pulse of light lasting for about two milliseconds is emanated by the laser. Nd:YAG lasers may be operated in both pulsed and continuous mode providing power outputs between 0.04-6000 W. Solid-state lasers operate at very low wavelengths and hence cannot be operated with the naked eye

Nd-YAG laser

The Nd: YAG laser is an optically pumped solid state laser system that is capable of providing high power laser beam. The lasing medium here is a colourless and isotropic crystal Yttrium aluminium garnet (YAG: $Y_2Al_5O_{12}$) having a four operational levels of energy. The yttrium aluminium garnet is doped with some amount of neodymium. When sufficient intense light is allowed to fall on this crystal, population inversion occurs and atoms in the crystal structure absorb this incident light to undergo transitions from the ground state to the absorption bands. This is often done with the help of a flash tube. The transition from the absorption bands to the upper energy laser levels is very smooth. The decays from these higher levels back to the ground state are longer in duration than the transitions to the higher levels. Due to this long lifetime, the atoms de excite back to the ground states almost spontaneously, thus producing a laser beam.

Gas lasers

In gas lasers, the lasing medium (gas mixture) is excited by using high voltage, low current power sources. Power outputs for gas lasers are higher than solid-state lasers, and these lasers can operate both in continuous as well as pulse mode.

CHAPTER TWO

Literature review

Ref/Title	Material	Welding parameters used	Result
[1]Metallurgical investigations of pulsed Nd:YAG laser welding of AISI 321 and AISI 630 stainless steels	Stainless Steel Thickness =0.6mm	Avg Power (W)= 80 **Frequency (Hz):8-1** Pulse Duration (s):6-10 Scan speed:1 rpm Beam dia: 0.4-1.4 mm Gas flow rate = 10 L/min. Voltage=400-500 V	The paper shows that both welding depth and width increases with voltage. Also, the pulse duration has two-sided effect on the welding depth and width. Very good dendritic and cellular structures were attained in the weld zone. The martensitic microstructure was obtained in the weld metal next to the AISI 630 side and microstructure found near the AISI 321 side was that of austenitic–ferritic. The maximum hardness resulted in the 630 stainless steel region and the minimum hardness occurred for the 321 stainless steel region. This was inferred from the micro hardness test.
[2] Pulsed Nd:YAG laser welding of AISI 304 to AISI 420 stainless steels	stainless steel Thickness =0.8mm	Avg Power (W)=100 Peak power(kW)= 3 **Frequency (Hz)=500** Pulse Duration (s):0.2-10 Scan speed:300 mm/min Over Lapping (%): 30 Gas flow rate = 10 L/min.	Prepared work pieces were welded with the laser beam incident on the joint. Joints attained under all the welding parametric conditions were constant. Changes in beam position had no effect on weld fillet geometry. If the laser beam is positioned on the joint or is shifted in the direction of AISI 304 steel, it will tend to favor the joint. If the laser beam is shifted to the opposite direction of AISI 420 steel, the structure becomes martensite.
3. Pulsed Nd:YAG laser seam welding of AISI 316L	AISI 316L stainless	Frequency (Hz):39 Pulse Duration (s): $4x10^{-3}$ Scan speed: 525mm/min	The outcomes of the paper indicate that in case of the thin foil weld quality pulse energy control holds considerable significance because of its capability to create excellent

stainless steel thin foils	steel foil Thickness =100 um	beam spot size =0.2mm beam angle (Ab)=90 pulse energy (Ep) =1.0-2.25 J .	mechanical properties and minimise discontinuities in welded joints. The UTS of the welded joints tends to increase at first but then it decreased as the pulse energy goes on increasing.
4. Analysis of pulsed Nd:YAG laser welding of AISI 304 steel	stainless steel Thickness = 1, 2 &3 mm	Power (W): 20-45 **Frequency (Hz):5** Pulse Duration (s): 0.2 Scan speed:1 mm/s Irradiation=8 ms	A heat source prototype for choosing the laser beam parametric conditions was successfully constructed. A relational expression of the shape factors with the maximum energy density was established by matching simulated results with investigational. Estimate of the molten region and temperature dispersal with the heat source at different welding velocities and beam powers was verified experimentally .The percentage of the piled area rises with the beam power. The simulated results approved closely with experimental statistics obtained under the same parametric conditions.
5. Weld metal microstructural characteristics in pulsed Nd: YAG laser welding	St14 mild steel Thickness =0.7 mm	Avg Power (W)= 400 Peak powrer (kW)=1.1-2.2 **Frequency (Hz):1-1000** Pulse Duration (s): 0.2–20 Scan speed: <.011 Over Lapping (%): 65 pulse energy=0–40 J beam spot diameter = 1.2 ± 0.1 mm	With peak power densities higher than 2000 W/mm^2, the weld work piece shows more levels of hardness and hardness deviation due to the higher rates of cooling and the nature of the thermal effects of the subsequent pulse on the preceding weld spot.

6. Experimental study of temperature and clamping force during Nd:YAG laser butt welding	Ck-60 (AISI 305) steel	Avg Power (W)= 400 Scan speed:160 mm/min Beam dia: 6.3mm	This report examines the clamping strength during laser welding of steel work pieces. The clamping power and welding temperature for a welded joint during laser welding were evaluated. The predetermined clamping force is varied through the welding process for different thicknesses of work pieces and welded joint strengths. Factors like thermal expansion, work piece width reduction and cooling contraction during the welding process bring about the variations in the preset clamping force and subsequently alter the weld joint strength.
7. Laser welding of low carbon steel and thermal stress analysis	Mild steel Thickness =2mm	Avg Power (W)= 2000 **Frequency (Hz):** 1500 Scan speed:1000mm/min Gas flow rate = 10 L/min 2000 NozzleGap(mm)=1.5 Nozzle Dia(mm)=1.5 Focus setting(mm)=127 N2 Pressure (kPa) = 600	Mild steel strips is laser welded under nitrogen supporting gas ambient. FEM is used to compute the stress and Temperature fields in the weld region. The XRD technique measures the developed residual stress in the weld region and the results obtained are compared with the estimates. For the metallurgical inspection of the welding region optical microscope and the SEM were used. Another conclusion drawn was that von Mises stress achieves high values during the cooling period just after the solidification of the molten areas.
8.Parametric analysis of the pulsed Nd:YAG laser seam-welding process	Bare steel	Avg Power (W)= 400 Peak power (kW) =2 Pulse Duration (s): 4, 8, 12 ms Scan speed: 0.6-8 mm/s Over Lapping (%):93%,	The influence of pulse laser parameters on the heat stream for a rectangular pulse type of power has been described. For a specified mean power, scan speed and APPD, the heating effects are increased with increase in duration of pulse, and boosted by higher APPD, when the average power and the scan speed are not varied.

		87% & 81% for a 4,8 & 12 ms Pulse respectively	
9. Pulsed Nd:YAG Laser Seam Welding of Zinc-Coated Steel	Zinc-Coated Steel	Power (W): 300-400 Pulse Duration (s): 4, 8, 12 ms Scan speed: .4-15 mm/s Over Lapping (%): Spot size = 0.8 mm	From experiments it was found that the average peak power density (APPD) is the most significant factor in pulsed laser beam welding process. Excess of APPD may result in cutting effects. Contrariwise, inadequate APPD has tendency to result in incomplete penetration. Other influences include average power and scan speed. Superior quality lap joint can thus be fashioned chiefly by appropriate choice of APPDs, mean powers and scan speeds.
10. Process Characterisation of Pulsed Nd:YAG Laser Seam Welding	Bare steel sheet thickness =0.7 mm	Power (W):300 - 400 Pulse Duration (s): 4, 8, 12 ms Scan speed: 4-15 mm/s Spot size = 0.8 mm	Widespread choice of laser welding parameters were recognized. These comprises of average peak power density (APPD), mean laser power, peak power, scan speed, duty cycle, pulse repetition rate, spot size, pulse energy and pulse duration. The ways in which weld dimension, heat flow ability, weld ability were affected by laser welding parameters was investigated. The report demonstrates that weld quality is predominantly governed by APPD, scan speed and mean power and out of these APPD is the most significant weld parameter.

Objective of the project:

- To weld band saw metal strips (high carbon steel) of thickness 0.9 mm using Pulsed Nd:YAG laser .
- To determine the effect of variance of parameters like laser power and scan speed on the properties of the welded piece.
- To determine the tensile strength, weld depth, weld width and Heat affected zone for welding done at various condition.

CHAPTER THREE

3. Experimentation

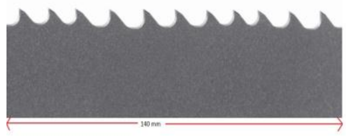
3.1 Material

The raw materials selected was high carbon steel. Band saw Blade (High carbon steel) was used having the following components along with their maximum % composition: carbon 2%, chromium 5%, cobalt 9%, Iron 90%, manganese 2% ,molybdenum 10%,nickel 2%, silicon 2%, tungsten 7%, Vanadium 3 %.

3.2 Specimen preparation

3.2.1 Cutting of specimen using saw

A band saw blade roll of .93 mm thickness and 25 mm breadth was cut into 12 equal pieces of 140 mm length each using bosch saw.



Blade roll Bosch saw blade pieces

Fig 3.1 cutting of specimen

The band saw blade roll was clamped in the table and then was cut with the saw. Lubricants are frequently used in order to provide better machining, keeping moving parts apart, reduce friction, transfer heat, carry away contaminants and debris and reduce wear and tear. Then it was again halved using band saw machine. 12 no of blade pieces of length 140 mm each were halved into 24 pieces of 70 mm. The feed rate given was low since the material was hard to cut. Coolant was used with maximum flow.

3.2.2 Surface finish in grinding machine

The teeth were removed from the edges to make it safe and weldable. It was done using grinding machine . One by one each pieces were held pressing the teethed edges against the grinder till it wore out.

3.3 Laser welding

Nd:YAG Laser

The small strips are checked for alignment before welding so that the best combination gets welded. After the 12 pairs are decided they are arranged in order.

Then the first pair is fitted in the laser machine clamp and the join is adjusted to make it linear and parallel to the laser scan line. The end bits of the join is welded at a point to prevent the strips from displacing at the time of welding. Then the laser parameters are set to the values required and the welding is started. This process is repeated for 12 times with only few parameters being altered from time to time.

Fig3.2 Alfa laser AL-T200

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3.4 Laser parameters:

Fixed Laser parameters

Beam Diameter = 1 mm

Pulse Duration = 7 ms

Frequency = 5 Hz

Pulse on time = 5 ms

Variable Parameters

Peak power

Scan speed

The following table gives the detailed technical specifications of the laser welding equipment used:

Table 3.1: Technical specifications of the laser welding equipment

Wavelength	1064 nm
Average power	200 kW
Peak pulse power	10 kW
Pulse energy	96 J
Pulse duration	0.5 -20 ms
Pulse frequency	Single pulse, 20Hz
Welding spot diameter	0.3 mm - 2.2 mm
Pulse shaping	Adjustable power-shaping within a laser Pulse
Control	User-specific operation with up to 128 parameter sets
Focusing lens	150 mm
Viewing Optics	Leica binocular with eyepieces for spectacle users
Dimensions	(L*W*H) 820*400*810 mm
WeightApprox	98 kg

Software - The software used in the CNC equipment was WIN Laser NC software (NC 4-axis control).

3.5 choices of parameters

For the welding purpose, the beam diameter and frequency were fixed at 0.7 mm and 5 Hz respectively. Laser scan speed and the peak power values were varied.

Peak power = 3 kW , 4 kW , 5kW

Scan speed (in mm/sec) = 1, 1.5 , 2 , 2.5

Table3.2 Experimentation Table

Ex no.	Peak power (KW)	Scan speed (mm/sec)
1	3	1
2	3	1.5
3	3	2
4	3	2.5
5	4	1
6	4	1.5
7	4	2
8	4	2.5
9	5	1
10	5	1.5
11	5	2
12	5	2.5

Fig. 3.3 welded samples as per the Experiment no

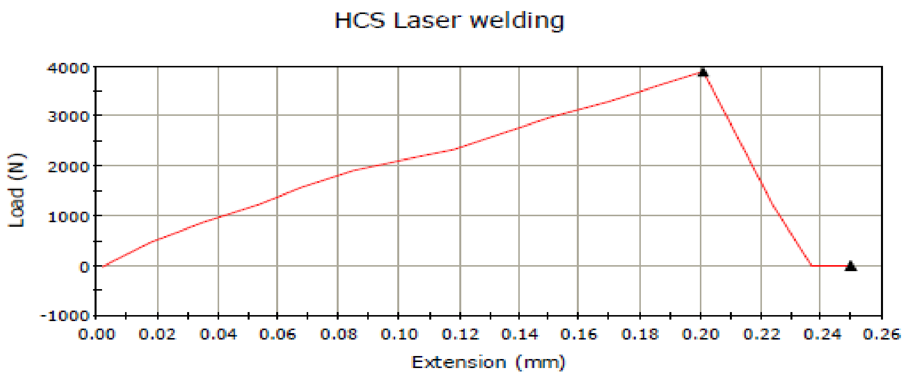
3.6. Cutting small pieces using Wire EDM

To see the microstructure and the weld zone tiny pieces of dimension – 10mm x 3mm were cut using Wire EDM across the weld line from each sides of the welded strips.

Fig 3.4 Wire EDM process

3.7 Tensile testing

The tensile strength and stress were measured using INSTRON electronic universal testing machine(UTM) that has a capacity of 600kN. The outputs of the tensile test for ex 1 was as follows :



	Extension at Break (Standard) (mm)	Load at Break (Standard) (N)	Tensile stress at Break (Standard) (MPa)	Area (cm^2)
1	0.25000	2.10850	0.11933	0.17670

	Extension at Maximum Tensile extension (mm)	Load at Maximum Tensile extension (N)	Maximum Tensile extension (mm)	Tensile stress at Maximum Tensile extension (MPa)
1	0.25000	2.10850	0.25000	0.11933

	Extension at Tensile Strength (mm)	Load at Tensile Strength (N)
1	0.20100	3,895.69988

Figure 3.5 Instron universal testing machine (UTM)

3.8 Preparation of mould

Out of the 24 small cut pieces, 12 were moulded in 2 different moulds. First an aluminium holder was cut with grooves in it to fit the pieces. After that the mould box was cut accordingly. Then the mould was prepared using the appropriate chemicals. After that the mould were polished using sand papers at first and then using gold cloth.

Fig 3.6 Moulds

3.9 Viewing the microstructure and the weld zone using optical microscope

The mould was viewed with and without etching. The etching solution used was Nitral (ethanol-100ml,nitric acid- 3 ml). The images were taken using 50 X of magnification.

CHAPTER FOUR

RESULTS, ANALYSIS AND DISCUSSION

The weld zone was observed through the optical microscope and images were taken for each welded pieces.

Weld geometry:

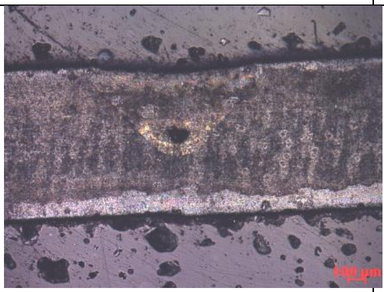
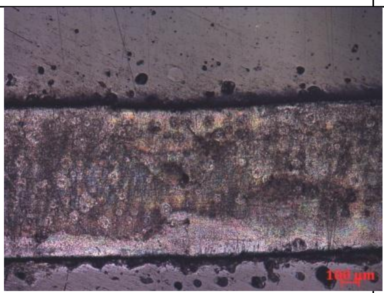
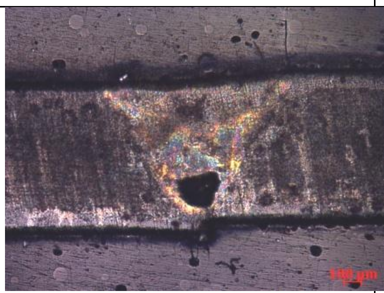
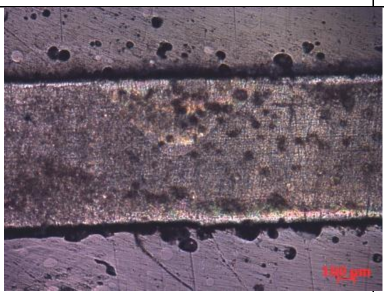
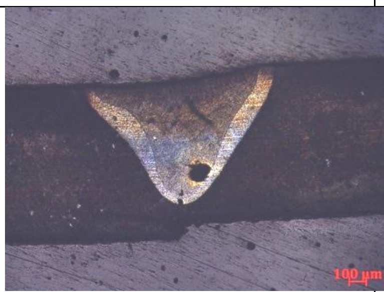
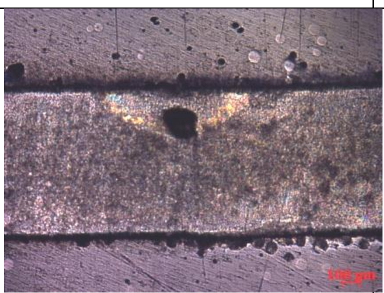
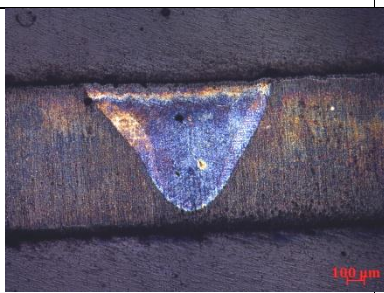
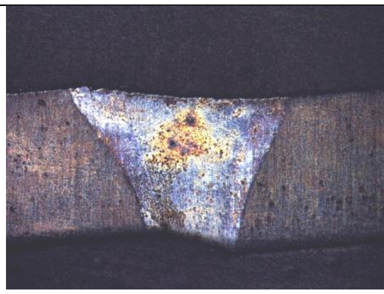
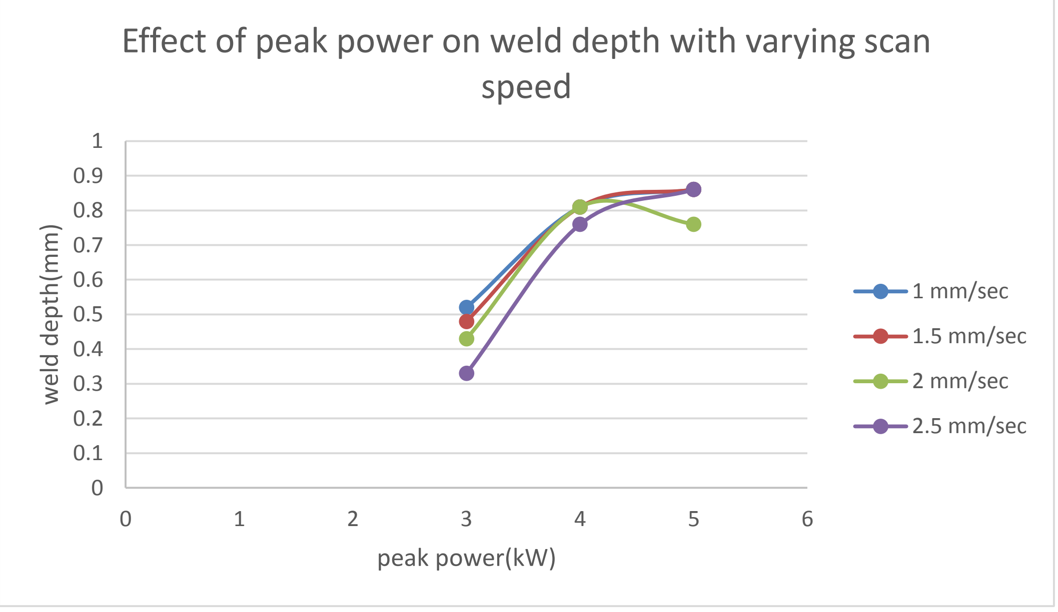
	3 kW	4 kW	5 kW
1 mm/s			
1..5 mm/s			
2 mm/s			
2.5 mm/s			

Fig 4.1 Weld Zone for various experiments

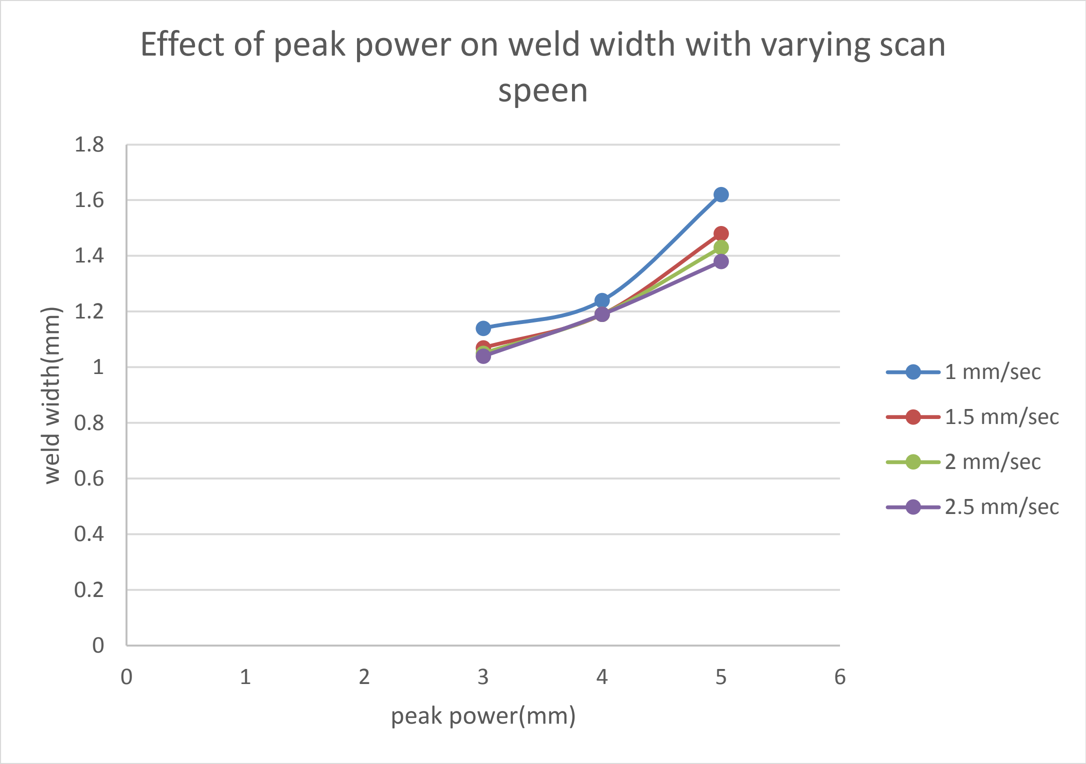
Table 4.1 Weld depth and weld width values

Ex no.	Weld depth(mm)	Weld width at top (mm)
1	.52	1.14
2	.48	1.07
3	.43	1.05
4	.33	2.5
5	.81	1.24
6	.81	1.19
7	.81	1.19
8	.76	1.19
9	.86	1.62
10	.86	1.48
11	.76	1.43
12	.86	1.38

From the images along with their scale the weld depth and width were measured and tabled. Their variance with the parameters (peak power and scan speed) is plotted.

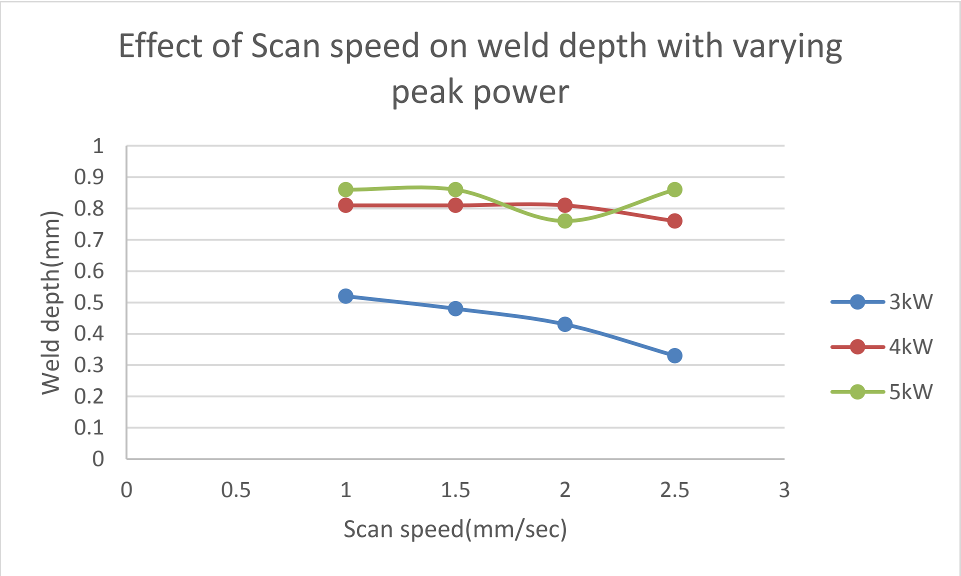


Graph 4.1

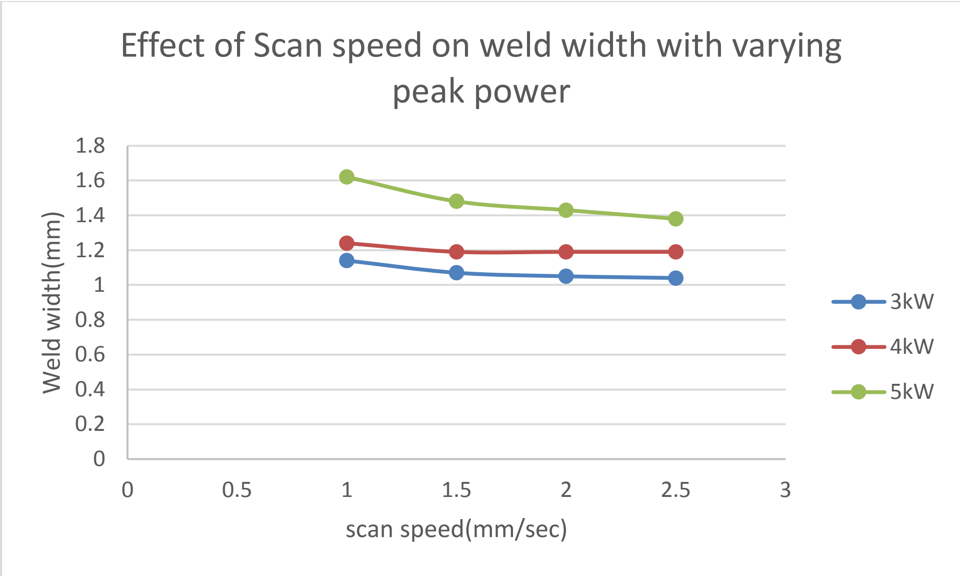


Graph 4.2

From the graph 4.1 and 4.2, it was observed that the weld depth and width increases with increase in the peak power.



Graph 4.3



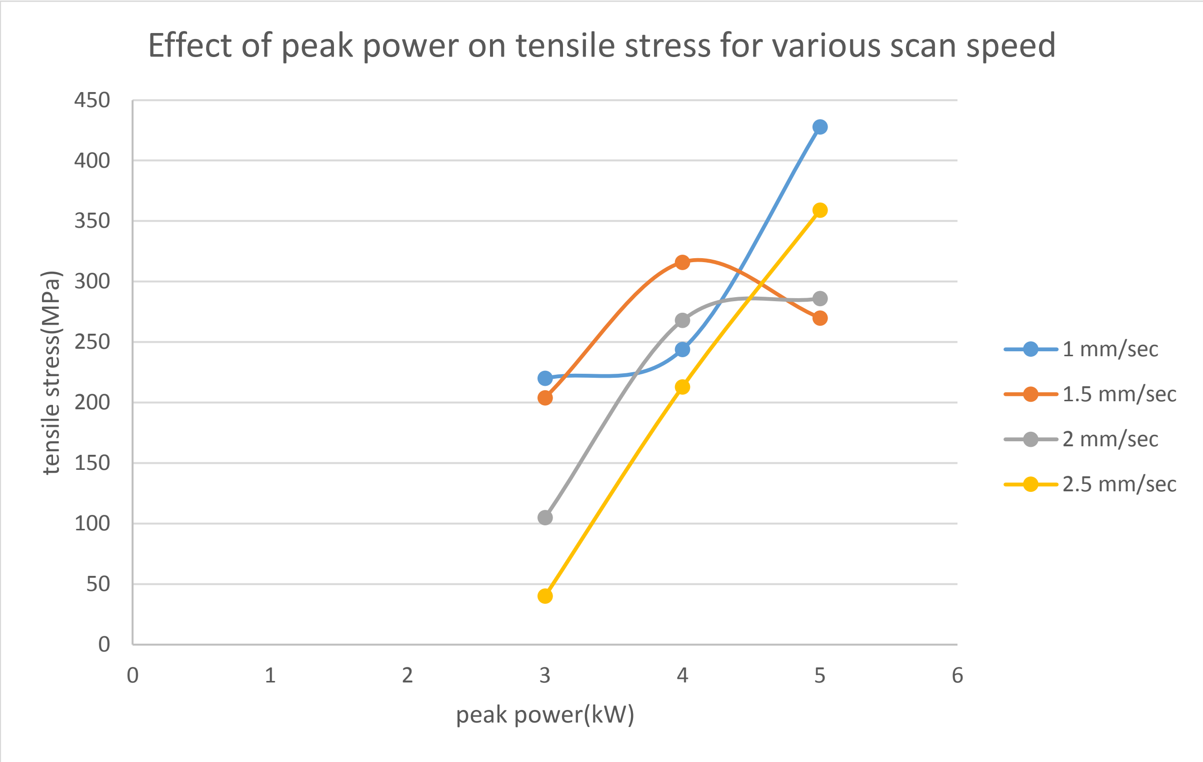
Graph 4.4

From the graph 4.3 and 4.4, it was observed that weld width and weld depth decreases with increase in scan speed.

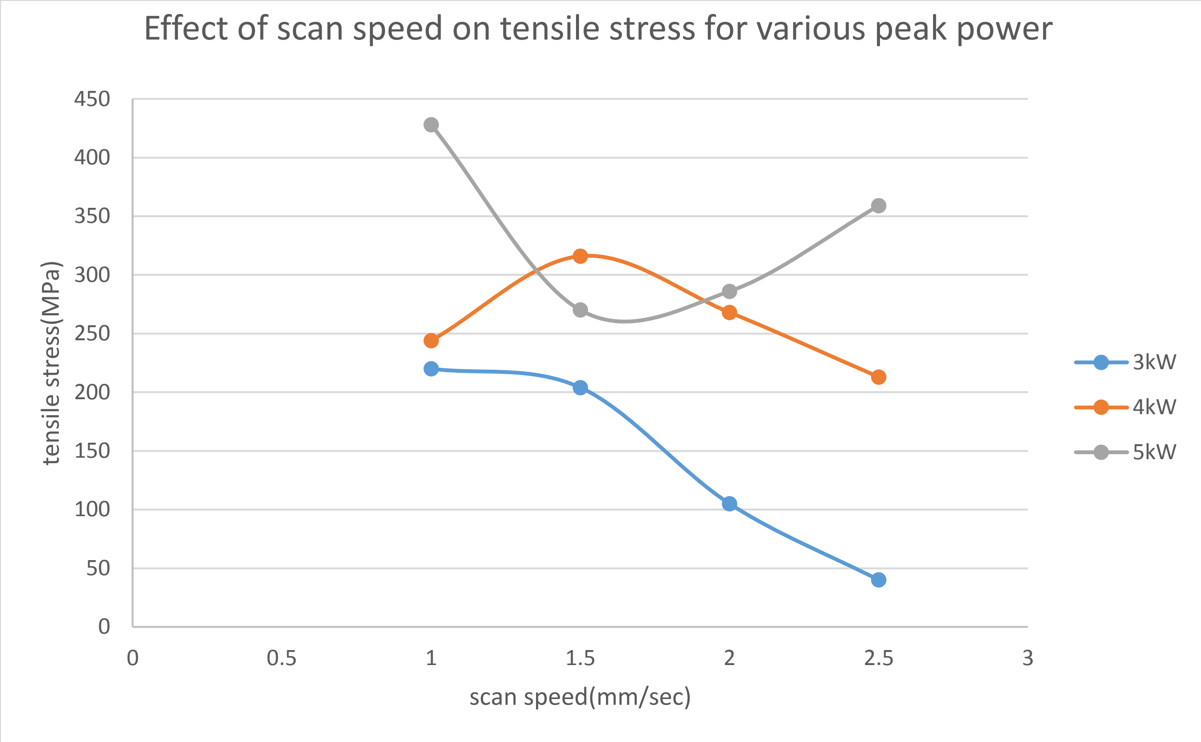
Table 4.2 Values from the Universal testing machine

Ex no.	Extension at Break (mm)	Load at Break (N)	Tensile stress at break(MPa)	Extension at Tensile strength(mm)	Tensile stress (MPa)
1	0.25	2.1085	0.11933	0.201	220
2	0.215	-0.01597	-0.0009	0.184	204
3	0.133	2.37707	0.13453	0.083	105
4	0.073	1.31983	0.07469	0.035	40
5	0.226	-0.85577	-0.04843	0.198	244
6	0.326	-0.94157	-0.05329	0.301	316
7	0.278	-3.45097	-0.1953	0.25	268
8	0.222	-2.27737	-0.12888	0.185	213
9	0.421	4,274.25	241.89294	0.401	428
10	0.322	-3.3258	-0.18822	0.285	270
11	0.293	-2.73635	-0.15486	0.268	286
12	0.407	3,592.14	203.29037	0.384	359

The table shows the output values from the universal testing machine. Out of these values only tensile stress is of our interest. The values of the tensile stress for the welded pieces are below that of high carbon steel (around 400-550 MPa). But at high peak power condition the tensile stress value is near to the value of parent material.



Graph 4.5



Graph 4.6

From graph 4.3 and 4.6, it was observed that the tensile stress increases with increase in peak power while it decreases with increase in scan speed

CHAPTER FIVE

CONCLUSIONS

Welding of band saw metal strips (high carbon steel) of thickness 0.9 mm using Pulsed Nd:YAG laser has been done successfully. From the experiments following conclusions can be made:

- Weld depth and width increases with increase in the peak power and decreases with increase in scan speed.
- Tensile stress increases with increase in peak power while it decreases with increase in scan speed
- The tensile stress values of the welded pieces are comparable to that of the High carbon steel. This shows the effectiveness of Laser welding in providing strength. Also using the best parameter values the tensile strength (428 MPa) value obtained is around 90 % of the original material tensile strength.
- Also faster welding rates, low distortion, no debris build-up, shorter cycle and higher uptime as observed during experimentation makes Laser welding a better welding option.
- Different power and scan speed affected the HAZ of the welded joint. It was more evident from observation that more the power and less the scan speed, more will be the HAZ. So in case ex-9 (5 KW, 1 mm/s) had the most heat affected zone.

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