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OPTIMIZATION OF PROCESS PARAMETERS IN LASER BENDING OF INCONEL-625 METAL SHEET

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ABSTRACT

In recent years, laser beam forming has been a new and promising technique in manufacturing. Laser sheet metal bending is a thermo mechanical process where a partially or defocused laser beam is used to induce localized heating and consequently deflection of the sheet along with the incident beam occurs. This paper presents a study on the bending behavior of inconel-625 sheet material which is highly tensile and has excellent weldability and brazebility. An experimental investigation is performed for getting the bending of the material by varying the laser power, beam diameter and scanning speed. In this study, a low power fiber laser was used to bend inconel-625 sheet material. The experimental result shows that at lower values of laser power, the bending angle tends to be almost negligible and with increasing laser power and scanning speed the bending angle increases. Furthermore, the Taguchi experimental method has been employed with L-16 orthogonal array and anova table has been used for statistical analysis.

Keywords*: *laser forming, laser bending, DOE, taguchi method

I. INTRODUCTION

Laser forming is a process of adding of plastic strain gradually to a metal component to generate desired bend shape. Laser forming can be used to bend high strength metal such in this case inconel625. The laser forming is a process which involves scanning a focused or partially defocused laser beam over the metal surface causing heating along the bend line. By repeating laser beam over the surface, desired bend angles can be obtained. The thermal gradients which is present in the material cause the sheet to bend towards or away from the laser source. Previously laser bending on inconel625 sheet has not been performed. Some of the earliest works on the laser forming process was first modeled by **Vollertsen, Geiger and Li** using both FEM and FDM **[1]**. **D.P. Shidid[2]** studied the effects of process parameters on titanium sheet metal bending using Nd:YAG laser. Experimental study and empirical modeling were carried out by **Gollo et al. (2008)[3]** in laser bending of sheet metal with a pulsed Nd:YAG laser using Taguchi experimental design, L-9 array with four factors (Laser power, beam diameter, scan speed and pulse duration) each at three level. Regression analysis was performed to find out the relationship between parameters and bending angle and a regression equation (first order polynomial) was obtained to predict bending angle. **Gollo et al. (2011)[4]** investigated the effects of process parameters, such as material, laser power, beam diameter, scan velocity, sheet thickness, number of passes and pulse duration on bending angle using numerical simulations and experiments. **Shichun and Jinsong (2001)[5]** studied the effects of different process parameters related to the laser source, material and work-piece geometry on bending angle in laser bending of sheet metals. The laser energy parameters included laser power, scan speed, beam spot diameter and number of scans. **Marya and Edwards(2001)[5]** investigated the laser forming of two titanium alloys and developed and empirical model for bending angle and section thickness. **Majumdar et al. (2004)[6]** investigated the effect of various process parameters on laser bending of AISI 304 stainless steel sheet using a high power (2 kW) continuous wave CO_2 laser.

II. EXPERIMENTAL EQUIPMENT AND SET UP

A continuous Fiber laser with maximum laser power of 50- 400W with wavelength of 1070nm was used for the experiments. The tests were performed focusing the laser beam on Inconel625 sheet with 200x25mm^2 area and 2.0mm thickness. No coating was applied on the metal sheets. Argon gas was used as shielding gas for protecting the optical system. Each sample is scanned 5 times continuously so to get better bending angle.

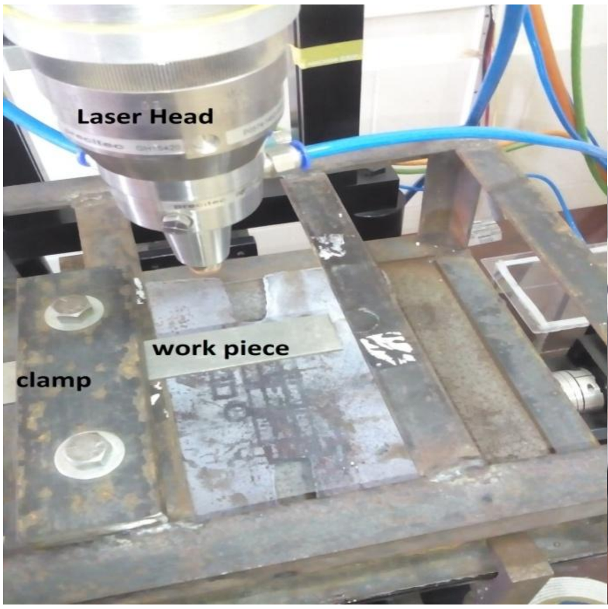

Fig.1 Experimental set up

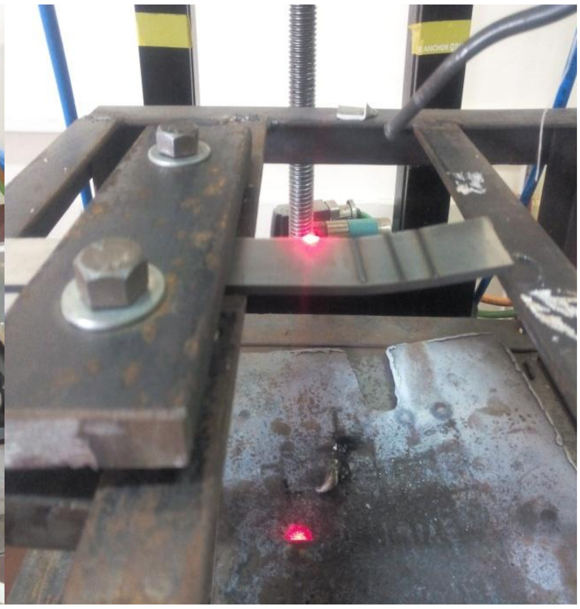

Fig.2 bending occurs during laser scan

Metal sheet had been clamped to make it fixed in the CNC table so that it metal sheet would not get disturbed during experiment. The material composition of the inconel sheet is given in table1.

Table 1. Material Composition of Inconel 625

Ni	Cr	Fe	Mo	C	Mn	Si	P	S	Al	Ti	Co
58%	20-23	5-0%	8-10%	0.10%	0.50%	0.50	0.01%	0.015%	0.40%	0.40%	1%

Fig.3 w/p before laser scan

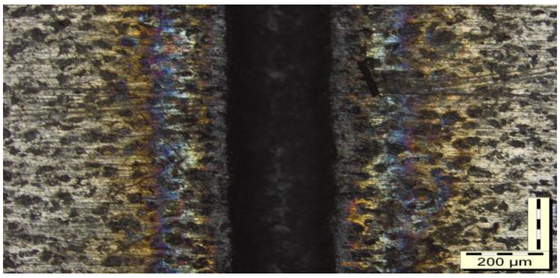

Fig4. w/p after laser scan beam

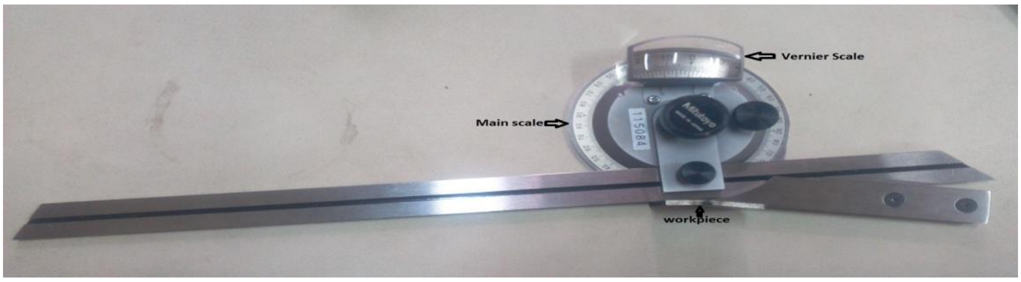

Fig5. Bevel protractor for measuring bending angles

For measuring the bending angles of the laser bend samples, bevel protractor was used. The samples were observed in the optical microscope.

III. DESIGN OF EXPERIMENT

3.1 Taguchi Experiments

A set of experiments were performed to get the bending angle of metal sheet components formed by the laser. The effects which were occurred by the parameters such as laser power, scan velocity and beam diameter on the bending angle were investigated experimentally.

Taguchi experiments design were used to limit the experimental costs. A L-16 Taguchi array with three parameters (Laser power, Scanning speed and beam diameter) and four levels for each factor is given in tables (2) and (3).

Table2. Control factors and their selected levels

	Level 1	Level 2	Level 3	Level 4
Laser Power(W)	100	150	200	250
Beam Diameter(mm)	0.5	1.0	1.5	2.0
Scanning speed(mm/min)	240	480	720	960

Table 3. design of experiments by Taguchi method

SL.NO	Laser power(W)	Beam Diameter(mm)	Scan velocity(mm/min)	Bending Angle(degree)	SNRA1
1	100	0.5	240	1.0830	0.6926
2	100	1.0	480	2.1660	6.7132
3	100	1.5	720	2.3330	7.3583
4	100	2.0	960	2.7500	8.7867
5	150	0.5	480	1.0833	0.6950
6	150	1.0	240	5.3330	14.5394
7	150	1.5	960	2.8333	9.0459
8	150	2.0	720	1.8333	5.2647
9	200	0.5	720	1.0833	0.6950
10	200	1.0	960	1.3333	2.4986
11	200	1.5	240	3.2500	10.2377
12	200	2.0	480	1.4166	3.0249
13	250	0.5	960	4.500	13.0643
14	250	1.0	720	4.3333	12.7364
15	250	1.5	480	5.5000	14.8073
16	250	2.0	240	2.4166	7.6641

Table4. Response table for signal to noise ratios (larger is better)

Level	Laser power	Beam diameter	Scanning velocity
1	5.888	3.787	8.283
2	7.386	9.122	6.310
3	4.114	10.362	6.514
4	12.068	6.185	8.349
delta	7.954	6.576	2.039
Rank	1	2	3

3.2 Data Analysis

The bending angle which is influenced by parameters laser power, scan velocity and beam diameter usually indicated by the ANOVA. ANOVA is used to investigate which bending parameters is affecting the response and its effective contribution. The individual contribution of the process parameters that affecting the most and least affecting can be calculated by ANOVA.

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Table5. ANOVA table for bending angle

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Laser power	3	13.8466	4.6155	2.47	0.159
Beam diameter	3	7.5732	2.5244	1.35	0.344
Scanning velocity	3	0.9770	0.3257	0.17	0.910
Error	6	11.2146	1.5691	-	-
Total	15	33.6114	-	-	-

3.2.1 Effect of parameters on bending angle

Effects plots by the parameters can be used to to draw towards the conclusion on bending angle. These plots are shown in figure6.

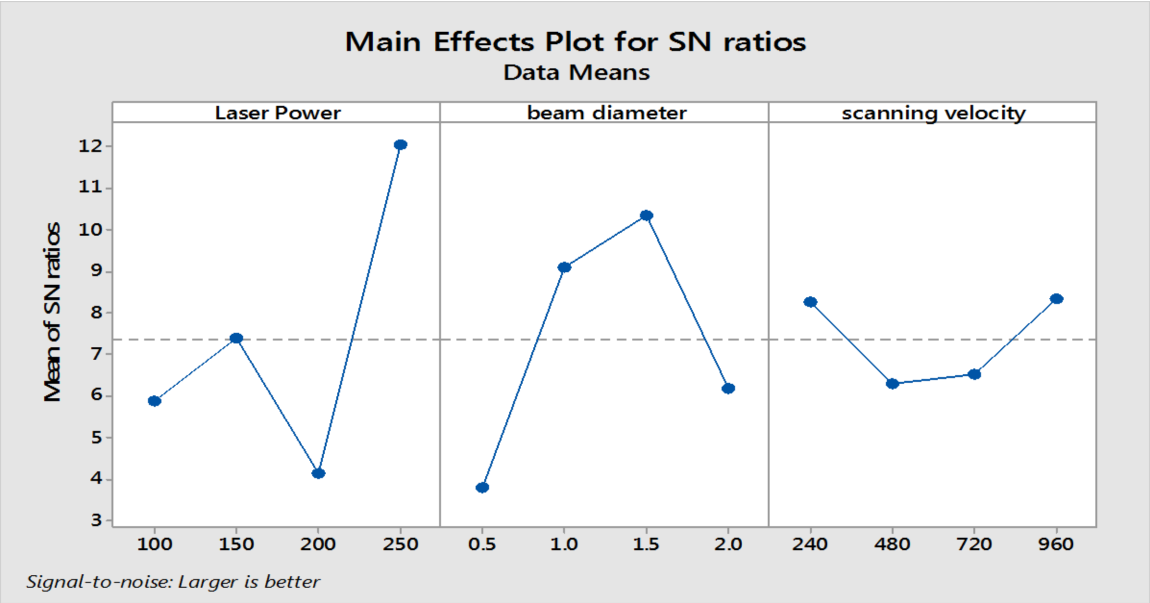


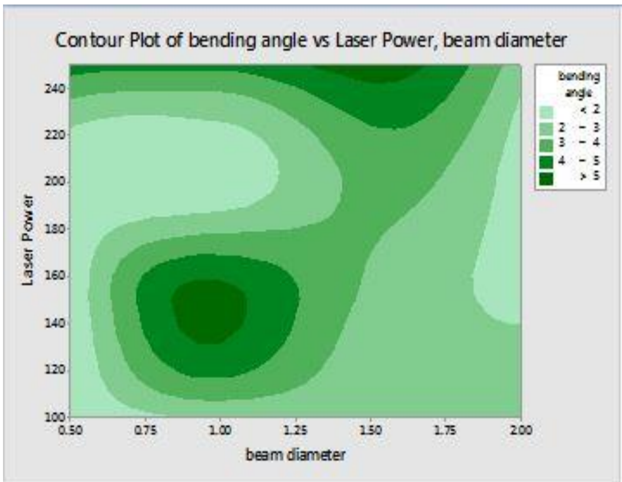
Figure6. Main effects curve for S/N ratios

Figure 6 shows that how laser power has a significant effect on bending angle. As increase with the laser power, bending angle also increases significantly. It can also seen from this figure that effect of the laser power is proportional with the bending angle.

Figure6 also shows about the effects of beam diameter on bending angle. It can be seen that increasing rate of bending angle is reduced by increasing beam diameter. It can also seen that bending angle is inversely proportional to the beam diameter.

Figure6 also shows about the relationship between the bending angle and the scan velocity. It can be seen as in case of beam diameter the bending angle is getting decreased by increasing scanning velocity.

3.2.2 Effect of laser power and beam diameter on bending angle



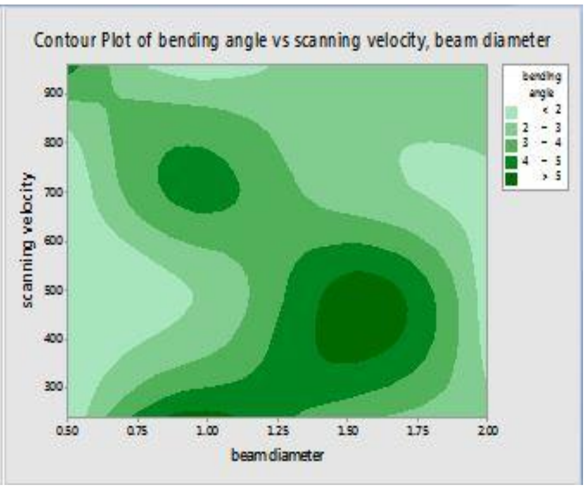


Fig.7 contour plot of laser power and beam Diameter on the bending angle

Fig.8 Contour plot of scan velocity and beam diameter on bending angle

Figure7 shows the relationship between laser power and beam diameter. It can be seen from the figure that maximum bending angle is obtained by high laser powers and at high beam diameter of 1.50mm approximately.

Effect of beam diameter and scan velocity on bending angle

Figure8 shows the interaction between beam diameter and scan velocity on bending angle. The maximum bending angle is found at the increasing section of beam diameter and also at the higher scan velocity.

3.2.3 Effect of scan velocity and laser power on bending angle

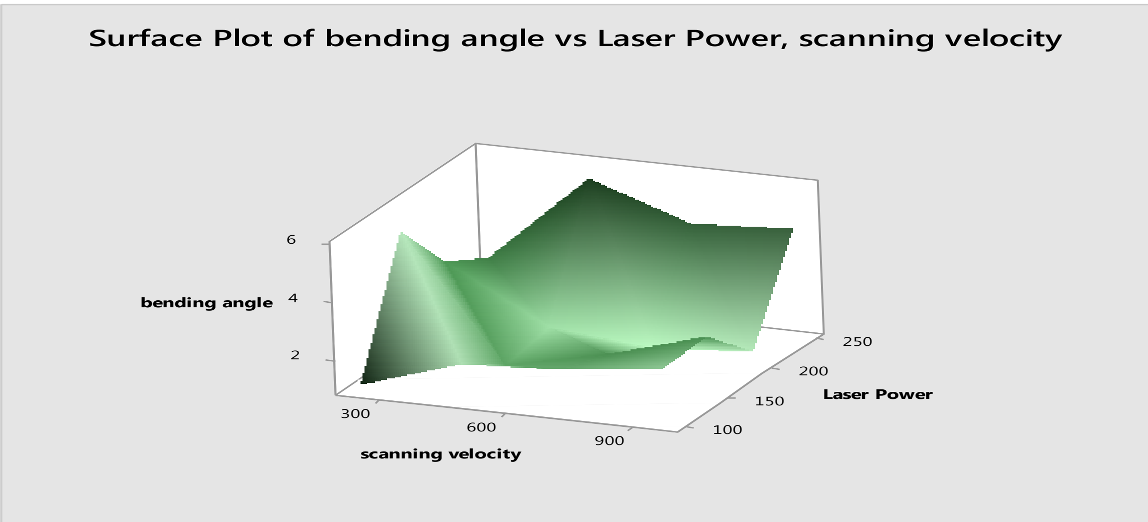


Fig9. Surface plot of bending angle between laser power and scanning velocity

Figure 9 indicates about the interaction of laser power and scan velocity on bending angle. It can be seen that maximum bending angle is obtained in the high laser power and at low scan velocity.

3.2d Interaction plot for bending Angle

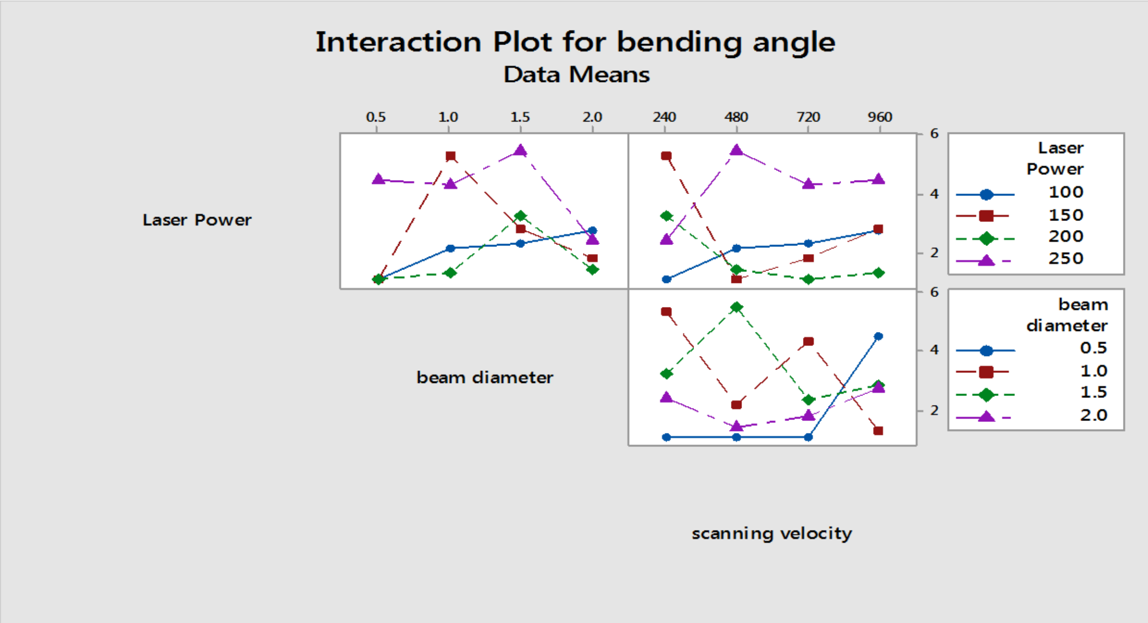


Figure10. Interaction plot for the bending angle

3.3 Regression analysis

This analysis is usually performed to find the relationship between the parameters and bending angle.

Bending angle(degree)=0.83-0.00027scanning velocity+0.138 beam diameter+0.01063 laser Power

The R^2 value gives 66.63% which indicates this model can be used with sufficient accuracy.

IV. CONCLUSION

In this paper laser bending of inconel625 sheet has been studied experimentally. The effects of main process parameters including laser power, beam diameter and scan velocity on bending angle were investigated.

- Bending angle is strongly affected by the parameter laser power and beam diameter. It increases as the laser power and beam diameter increases.
- Bending angle decreased with increasing of scanning velocity.
- A formula is obtained using a regression analysis to obtain the bending angle.

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