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Study the effect of fiber laser parameter on bending stiffness of CoCr stent manufactured by fiber laser

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Abstract:

Cardiovascular stent is a kind of mechanical device, which is chronically implanted into arteries in order to physically expand and scaffold blood vessels narrowed due to the plaque accumulation [1,2]. Firstly stent was made from waving the wire material. After words EDM and Laser Micro Machining was introduced for manufacturing stent. Many clinical research has been carried out on the bare metal stent and drug eluting stent. The perseverance of this research is to study about stent manufacturing using fiber laser machining parameters on Cobalt L-605 material. In this study contribution of fiber machining parameter like gas pressure, laser power and frequency to bending stiffness has been carried out.

***Keywords**: Coronary stent, Fiber laser machining, ANOVA,* Cobalt L605*, bending stiffness machining parameters.*

I. INTRODUCTION

The most popular milling process using laser micro milling is Nanosecond finer laser [2]. Micro channel application relies on its geometric dimension, profile, and surface quality [8]. One of the main problems with laser cutting equipment is related to the wrong setting of cutting parameters. The mismatching of these parameters leads to a loss of cut surface quality, which is hardly re-established. This loss of quality is usually related to a burr problem, surface tropology etc [3]. I. amaralet. Al. has been investigated three important laser cutting parameters radiation power, cutting speed and gas pressure effects on surface tropology. The different values were performed cutting a stainless steel AISI 316L and a cold rolled steel St12. It was concluded that, at the micro structural level, there are no changes worthy of notating, leading to the conclusion that the temperatures reached during the cutting process were not high enough to promote changes [3]. W. Schmidt investigated the mechanical and geometric parameters of stents. All measurements were performed according to the requirements of prEN 12006-3:1998. The test protocol examined the following characteristics in9 samples: inner and outer diameter, length after expansion (as well as a visual inspection), elastic recoil, radial stiffness, fatigue, and an additional property, which surpasses the standard requirements, stent adherence and crimp firmness. It can be concluded that in comparing commercial products it is necessary to consider more than one property. The mechanical interactions and requirements on a coronary stent and its delivery system are complex and require complex treatment and evaluation.[4]. D. Pramanik has been reported a distinctive scope in the fabrication of desired products with specific standard has been achieved by the recent advancement in the technology. Also find extremely difficult for 50 Watt average power machine to achieve good quality cutting of the metal sheet upto 2 mm thickness. A unique parameter sawing angle acts as a significant use in kerf deviation in cutting titanium alloy sheet (Ti6Al4V) of 1 mm thickness in low power fiber laser beam machining. Also study the effect of sawing angle with other process parameters like cutting speed, power setting, duty cycle, and pulse frequency for a titanium alloy metal sheet to reduce kerf deviation [5]. Preeti Gautama has been study about two types of the composite, namely polymer-based composites and metal matrix composite materials are used in the industrial application and the demand for an increase in its production is rapidly growing. Laser machining method is used to cutting of composite materials due to its advantages of fast cutting speed and no contact with the work piece. In this experimental work, an erbium-doped fiber laser is used to study the machinability of carbon fiber reinforced polymer composite and effect of various machining parameters are observed on the performance responses like heat affected zone and surface roughness. The decrease in power with an increase in scan speed and standoff distance reduces surface roughness and heat affected zone in the material[6]. S. Borse at. Al. has been carried out the quality of the micro milled component mainly depends on appropriate selection of process parameters in laser beam micro machining process. The effect of laser process parameters on the quality of the features obtained by laser machining. In Fiber laser micro milling operation on Inconel 718, scanning speed, frequency, power have most significant effect on all responses [7]. Ashish Sahu at. Al. has been taken "Laser micro milling technique to manufacture micro channel on metals and nonmetals. In this study, an attempt was made to explore the impact of process parameters scanning times, scanning velocity, pulse repetition rate, and assist gas pressure on top kerf width, taper, surface roughness, and metal removal rate in laser micro milling experimentally. Micro channel developed with width varied between 45.5 and 70.9 μm" Thermal stress analyzed by surface cracks inside micro channel by Scanning Electron Microscope (SEM) images. Higher PRR, lower no. of scans, higher scanning speed and high air pressure found suitable for lesser surface cracks[8]. Erika García-López at. Al. has been carried out extensive experimentation was used to evaluate the effect of fiber laser micro-cutting parameters over average surface roughness (Ra) and back wall dross (Dbw) in AISI 316L stainless steel miniature tubes. Also study the different laser process parameters: pulse frequency, pulse width, peak power, cutting speed, and gas pressure. It was possible to achieve less than 1 micron in surface roughness at the edge of the laser-cut tube, and less than 3.5% dross deposits at the back wall of the miniature tube [9]. S.Kasman et.al. has been determine the laser optimal milling conditions. It was based on machining direction for minimizing the surface roughness and maximizing the milling depth. The analysis results show that the scan speed has the highest effect on the surface roughness of which percentage contribution is 39.68% and also the beam scan direction and fill spacing have significant effects which contribute19.67% and 16.09%, respectively. The experimental result for optimal condition is 2.23 μm. The results for milling depth show that only scan speed and fill spacing have significant effects which contribute 69.08% and 19.21%, respectively. Moreover, the scan direction has the least effect on the milling depth which can be neglected. The frequency has no effect on both surface roughness and milling depth. The result obtained from experiment at the optimal condition is 121.4 μm.[10]

II. MATERIALS ANDMETHODOLOGY

The perseverance of this research is to study about stent manufacturing using Fiber laser machining parameters on Cobalt L-605 material. To achieve these objectives it is very important to plan consistent methodology. Fig. 1. shows the adopted methodology-flow chart.

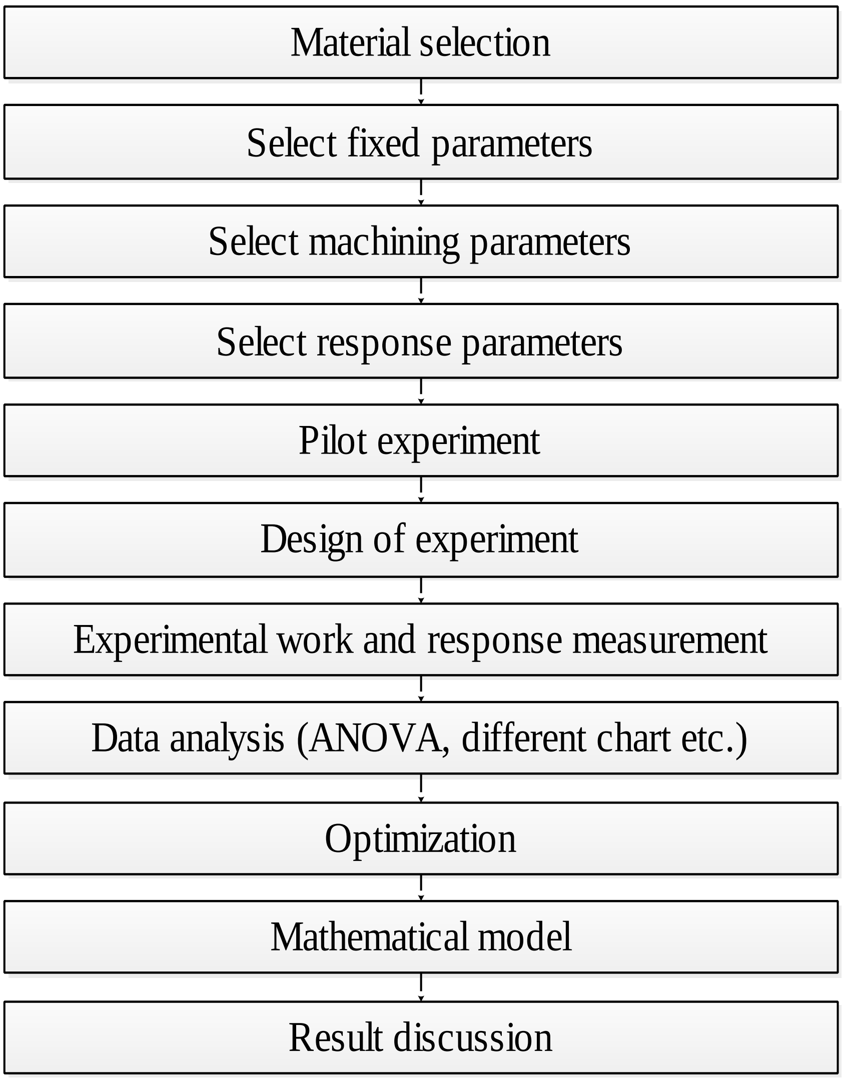


Fig 1. Experimental methodology

With kind permission at Sahajanand laser technology limited, this research could able to work on identified machine model "YLR-1000" which is ytterbium fiber laser cutting machine shown in fig. 2.

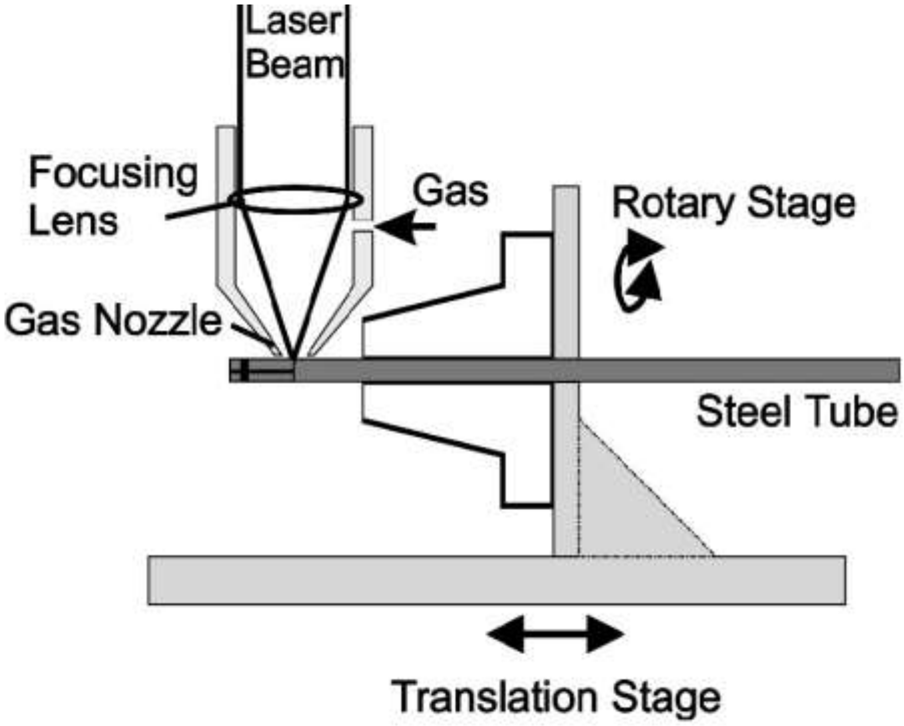


Fig. 2. Schematic diagram of stent cutting fiber laser cutting machine

Traditional coronary stent made with different metals like stainless steel (316L), cobalt - chromium alloys, nickel - titanium alloy (Nitinol), platinum, and tantalum alloys [8]. Cobalt L-605 (also known as alloy 25) is a cobalt-based super alloy with high levels of chromium and tungsten. It is characterized by outstanding high-temperature strength up to 1501 °F (816 °C), excellent oxidation resistance at high temperatures up to 2001 °F (1094 °C) in corrosive environments, and superior resistance to sulfidation wear and galling. Cobalt L-605 has other less-known qualities like high ductility and biocompatibility. Cobalt L-605 is non-magnetic. Thanks to its biocompatibility, Cobalt L-605 can also be used in the medical industry, mainly for manufacturing of heart valves. So, here elect Cobal L-605 Material for stent manufacturing and material chemical composition shows in table 1.

Table 1. Cobalt L-605- Chemical content

Element	Percentage (%)	Min (%)	Max (%)
Carbon, C	0.1	0.05	0.15
Manganese, Mn	1.5	—	≤ 2.00
Silicon, Si	0.4	—	≤ 0.40
Sulfur, S	-	—	≤ 0.015
Phosphorus, P	-	—	≤ 0.02
Chromium, Cr	20	19	21
Molybdenum, Mo	1.2	1.2	1.4
Iron, Fe	3	—	≤ 3.00
Tungsten, W	15	14	16
Nickel, Ni	10	9	11
Cobalt, Co	48.8	—	*Balance

The experiments was carried out on hollow tube having internal diameter 1.5 mm and thickness 300 micron and length 130 mm thickness of Cobalt L605. Machined final product as shown in Fig 3.

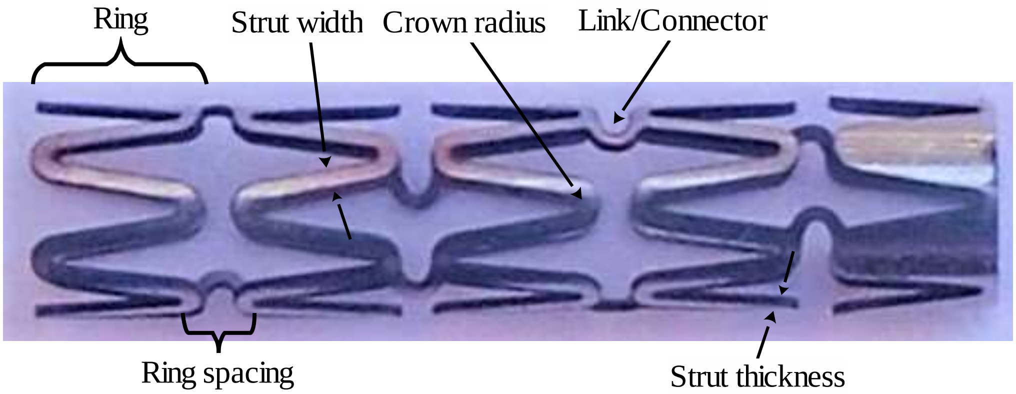


Fig 3. Machined specimen

Process parameters and their ranges of a fiber laser used for the experiment work are as e shown in Table 2. Ranges were taken after performing pilot experiment.

Table 2. Machining parameters/ranges after pilot experimentation

Parameters	Range in machine	Used range in stent manufacturing	Selected range after pilot experimentation
Gas Pressure (GP)	1-10 bar	1-10 bar	4-8
Laser power (LP)	1-1000 W	1-150 W	60-100
Frequency (FQ)	0-50 kHz	1-10 kHz	1-5

It is widely accepted that the most commonly used experimental designs in manufacturing companies are full and fractional factorial designs at two levels and three-levels. Factorial designs would enable an experimenter to study the joint effect of the factors (or process/design parameters) ona response [4]

Different parameters are considered as consistent parameters. The machining process parameters and its level are described in Table 3.

Table 3. Control parameter

Machining process parameter		Indicated name	Level		
			1	2	3
A	Gas Pressure (bar)	GP	4	6	8
B	Laser power (W)	LP	60	80	100
C	Frequency (kHz)	FQ	1	3	5

Consider response parameter as bending stiffness. Here, Two different methods available of measuring Bending stiffness. One is the one-point bending test and other is four-point bending test [5]. First one point bending stiffness test was used in this research. According to the European standard EN14299:2004, the flexibility of crimped stents on the bending force of the delivery system was measured in a one-point delivery test and according that develop a setup for measurement of bending stiffness as shown in Fig.4. The measurement principle for determining the Bending stiffness (flexural strength) of the stent is depicted in Fig. 5. Stent holding mechanism and dimensions as shown in Fig. 6. Some loading conditions on stent are shown in Fig. 7(a-d).

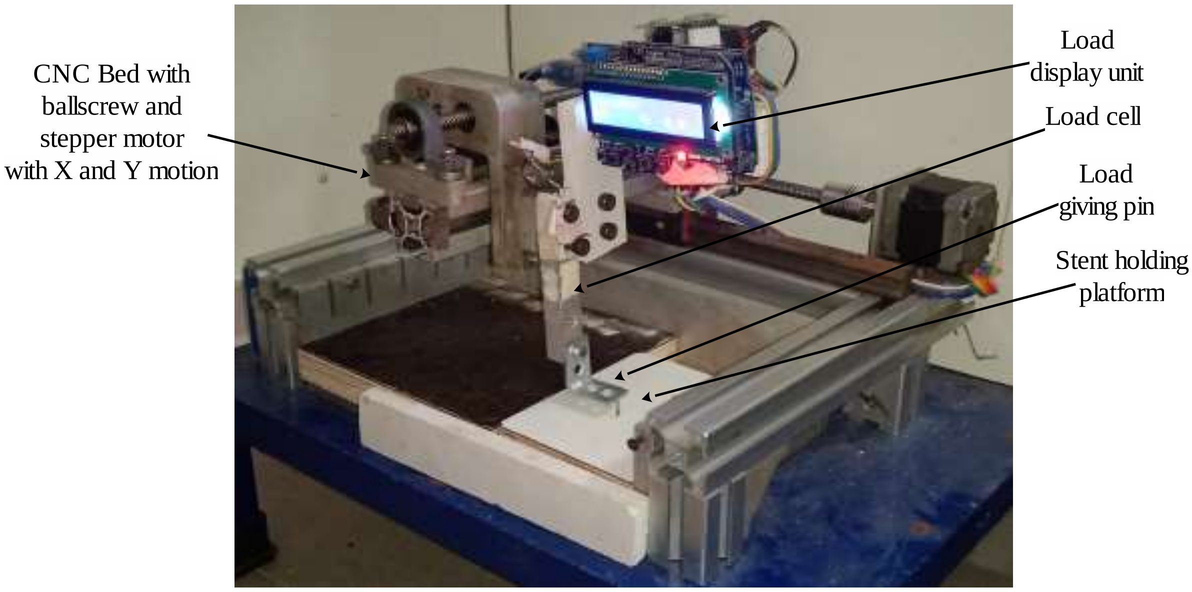


Fig. 4. Setup for the measurement of the bending stiffness of a coronary stent system.

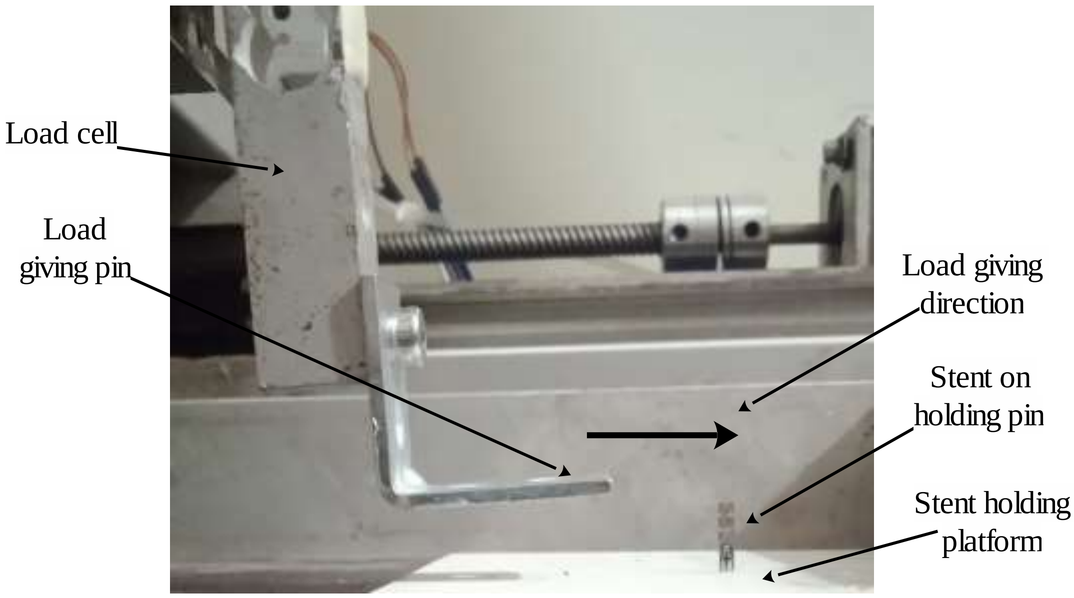


Fig. 5. The measurement principle for determining the Bending stiffness (flexural strength)

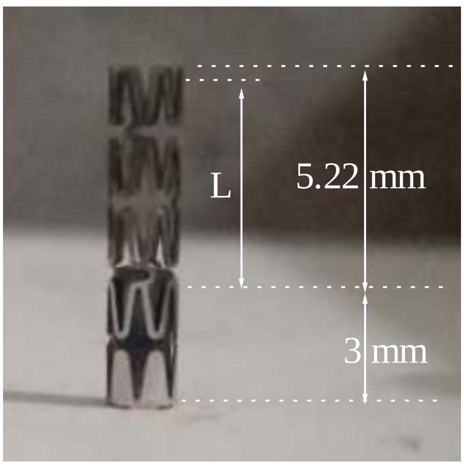


Fig. 6. Stent holding mechanism and dimensions

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

Fig. 7. Different load conditions applying on stent

The bending stiffness EI of the stent is determined by reconstructing the relationship of bending deflection (f) with the point force (F in N), based on the general bending theory for a cantilever:

$$EI = \frac{F.L^3}{3f}$$

Where, E- Young modulus, I- Moment of inertia, L- Free length, f- bending deflection, F- point force in N

Here found different bending stiffness at different bending deflection. So, we required to select fixed bending stiffness and fixed orientation. So, here doing pilot run with L4 (4) taguchi design with 6 different rotational orientation of stent and performed at 6 measurement points, each shifted by 45° along the perimeter as shown in table 2.22. Give deflection step by step with 250 micron gap addition from 0.050 mm to 3mm. For this pilot experiment measurement develop one CNC code as follow.

```
N010 G01 X0.050 F10
N015 G00 X0
N020 G01 X0.100
N025 G00 X0
N030 G01 X0.250
N035 G00 X0
N040 G01 X0.500
N045 G00 X0
N050 G01 X0.750
N055 G00 X0
N060 G01 X1.00
N065 G00 X0
N070 G01 X1.250
N075 G00 X0
N080 G01 X1.500
N085 G00 X0
N090 G01 X1.750
N095 G00 X0
N100 G01 X2.000
N105 G00 X0
N110 G01 X2.250
N115 G00 X0
N120 G01 X2.500
N125 G00 X0
N130 G01 X2.750
N135 G00 X0
N140 G01 X3.000
N145 G00 X-5
N150 G00 X0
```

III. Design of experiment with result table

The analysis uses full factorial DOE with L27 orthogonal array for experimentation. The experimental results are shown in Table 4.

Table 4. Experiment result table for EI

Run	Point force in gram at 0^o orientation	Point force in N	Bending stiffness(EI)
	Average		
1	51.88	0.509	10.604
2	38.63	0.379	7.896
3	57.42	0.563	11.729
4	56.88	0.558	11.625
5	54.63	0.536	11.167
6	39.77	0.390	8.125
7	58.07	0.570	11.875
8	66.23	0.650	13.542
9	46.31	0.454	9.458
10	48.83	0.479	9.979
11	53.89	0.529	11.021
12	35.53	0.349	7.271
13	57.18	0.561	11.688
14	49.68	0.487	10.146
15	44.61	0.438	9.125
16	41.03	0.403	8.396
17	51.41	0.504	10.500
18	63.20	0.620	12.917
19	61.77	0.606	12.625
20	61.66	0.605	12.604
21	43.22	0.424	8.833
22	42.85	0.420	8.750
23	49.64	0.487	10.146
24	53.51	0.525	10.938
25	73.22	0.718	14.958
26	64.87	0.636	13.250
27	71.58	0.702	14.625

III. Analysis of Experimental Work

In design of experiment the results obtained are analyzed for getting one or more of the below quoted objectives:

1. To set up the best or the optimum condition for a product or a process of interest,
2. To estimate the contribution of individual factors.
3. To estimate the response under the optimum conditions.

The optimum condition is determined by studying the main effects of each of the factors. The process consists of minor arithmetic manipulation of the numerical results. The main effect shows the general trends of the influence of the factors. Considering the characteristics, i.e., whether a higher or lower value produces the desire results, the level of the factors which are expected to produce the best results can be predicted. The knowledge of the contribution or role of individual factors is a key to decide the nature of the control to be established on a production process [11] [12] ANOVA technique has been preferred for analysis; the results for the same are as follow.

The percentage contribution of GP is 7.83%, LP is 53.83% and FQ is 37.88%. Parametric analysis has been carried out for the quality of the sample. i.e. EI. This parametric analysis (ANOVA) shows the percentage contribution of parameters individually as shown in below table:

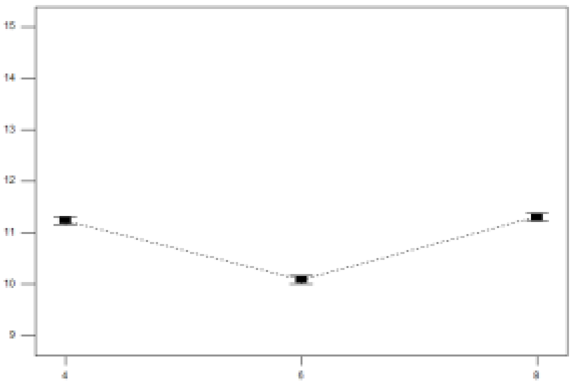
Table 5

Sources of Variation	DOF	Sum of squares S	Variance (Mean square)	Variance ration F	Percentage contribution P
Factor A	2	8.4676	4.2338	169.0992	7.83
Factor B	2	58.2296	29.1148	1162.8474	53.83
Factor C	2	40.98	20.49	818.3719	37.88
Error (O)	20	0.5007	0.025	1	0.46
Total	26	108.178			100

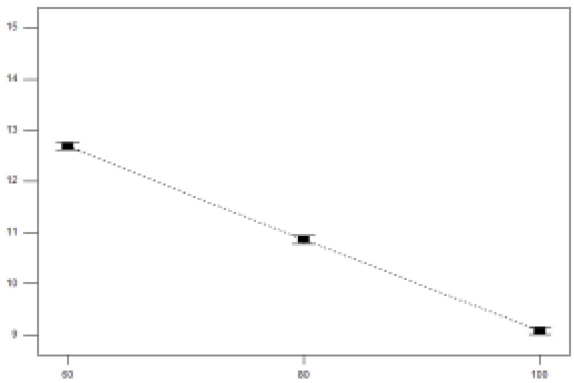
III. Graphical representation of response parameter effected on EI

Effects of EI

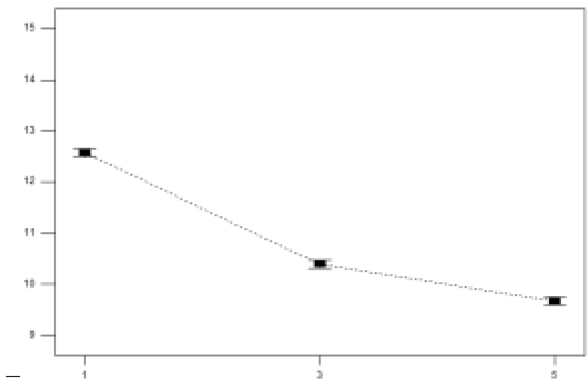
Fig. 9 assists the point of graphical valuation and illustrates the plots of mean effects on changes of EI.



GP



LP



FQ

Fig.9. Mean effect of parameters on EI

Through this result response parameter effect of bending stiffness graphically plotted in fig. 9. It is pbserved that as gas pressure increases in the range of 4 to 8 bar, bending stifness decreasing and increasing in the range of 11 to 11.5

Same effect of bending stiffness gradually decreasing in the range of (12.7 to 9.2) as laser power increases in the range of (60GP to 100GP). As well as bending stiffness also reducing in the range of (12.6 to 9.7) in manner as frequency increases from the range (1 to 5)

Model and it's R-Square for EI

R-Square for EI $=1-\left[\dfrac{0.50}{108.18+0}\right]$ =1-0.0046 =0.9954 (Eq. 1)

- ➢ R^2 esteem shows that the indicators clarify 99.54% of the fluctuation in EI.
- ➢ Adjusted R^2 is 99.40% which records for the quantity of indicators in the model. The two qualities show that the model fits the information well.
- ➢ Actual and predictive results plots generated by Design-Expert Software shown in Fig. 10.

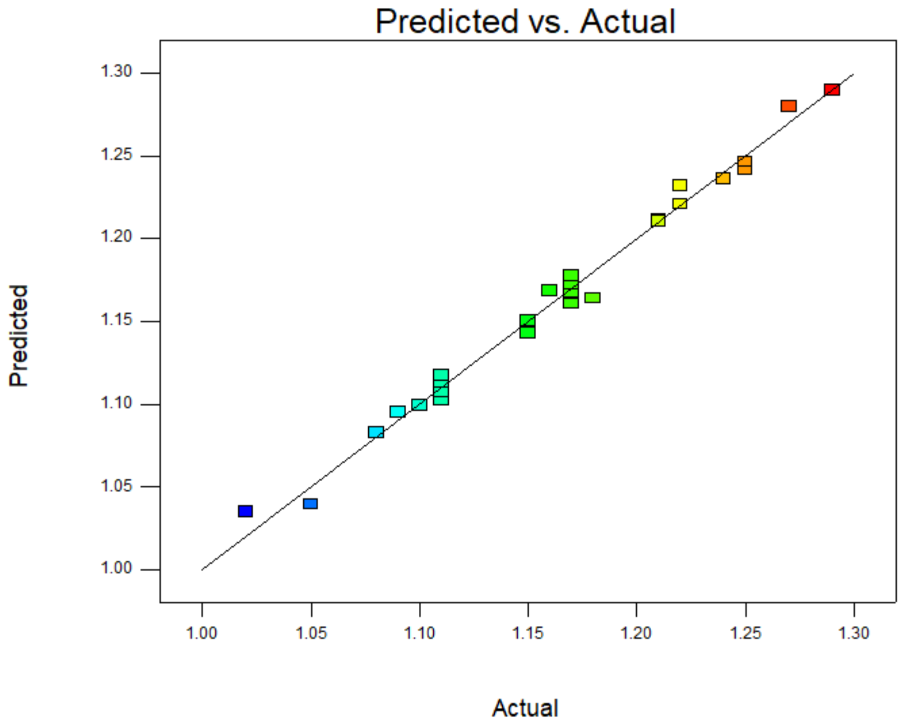


Fig.10. Plot of actual to predictive values

The regression formula was found using the Design Expert software and the regression equation is mentioned as below:

Final equation in terms of actual factors:

$EI = 10.88 + 0.36 * A[1] - 0.79 * A[2] + 1.81 * B[1] - 0.015 * B[2] + 1.69 * C[1] - 0.48 * C[2]$ ....(Eq.2)

IV. CONCLUSION

Looking to the measured output parameter that is bending stiffness, in concern with respective in put parameters. It is found that there is less effect of gas pressure contributed only 7.83% the reason is gas is utilized for smoother execution of operation as well as protective cutting from environmental effect which will not make much effect on cutting quickly.

It is also observed that bending stiffness decreeing as laser power increasing. Material removal increases eventually strut width will reduces which will increasing elasticity but decreasing bending stiffness. This is shown in graph fig. 9,

In case of frequency behavior of frequency is also similar to laser power contributing 37%, reason behind this as frequency increases heat dissipation time increases, as a result material removal rate increases as a rest strut width decreasing as a result bending stiffness decreases as shown in fig. 9

So, it is concluded that one can predict bending stifness without performing actual operation using derived mathematical equation no. 2 by putting value of input parameter in to he range specified.

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