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EMPIRICAL MODELING AND INVESTIGATION OF ND YAG LASER DRILLING PROCESS USING GREY TAGUCHI AND ANN

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ABSTRACT:
ND YAG laser drilling of austenitic stainless-steel material is studied here. Taguchi method with grey relational analysis to determine the laser drilling parameters with consideration of multiple quality characteristics, is studied in this paper. The effort has been made to minimize the drilling defects, such as hole taper. In present research, A pulsed ND: YAG (Neodymium- doped Yttrium Aluminum Garnet) laser which creates high intensity infrared radiation at a wavelength of 1064 nm, with output powers ranging 600W used for laser drilling of austenitic stainless steel, a material which has performed well in laboratory tests as well as in various fields of engineering and industrial, is perceived. It has wide range of applications in various fields like industrial, medical, heat engines etc. Laser drilling input factors such as lamp current, pulse frequency, air pressure and pulse width. The dimensional accuracy and quality of holes are very important for some specific applications of holes. circularity of drilled hole at entry and exit, and taper are very important attributes which influence the quality of a drilled hole in laser drilling. Using the taguchi method an L27 orthogonal array has been used for this experiment. From the grey analysis, a grey relational grade is obtained and based on this value an optimum level of drilling parameters has been identified. The result of the confirmation experiments show that optimal laser drilling parameters can be determined successfully so as to perk up numerous quality characteristics through this approach.

Keyword:
ND YAG. Taguchi, Laser drilling, Grey analysis. Aluminium.

1 INTRODUCTION

Laser beam machining is a non-conventional machining method. Collective demand for advanced challenging to process materials and the ease of use of high-power lasers has enthused interest in research and development associated to laser machining. In recent years there is an increasing trend towards miniaturization of various components involving different applications, such as MEMS, electronics, photonics, bio-medical devices. In view of this, micromachining techniques have become important in the fabrication of micro-components and micro-assemblies. So, lasers are also increasingly employed for a precise micromachining, the reason is their beams can be focused precisely on very small areas. Very fast increment in the use of lasers for manufacturing can be endorsed to various benefits which are basically pertinent to complete range of processing of materials like great productivity, noncontact processing, no need to finishing operations, compliance to automation, cheap processing cost, better product quality, superior material exploitation, negligible heat-affected zone (HAZ) and ecofriendly manufacturing, etc. Laser drilling is a thermal technique based progressive machining process; it is applicable to various materials. Present days laser drilling has wide range of applications in various industries. Laser drilling is a high energy density progression that works fast on multifaceted shapes and is applicable to various materials, produces no mechanical stress on work piece, reduces scrap, offers environmentally clean technology and has possibility to do work in small ranges. Automation of a manufacturing process has become the order of the day in industries in order to achieve high production rates and high quality of finished components. However, in order to automate a progression, it is vital to find the best values of input variables. In turn, this requires the establishment of precise. quantitative relationships among the input controllable parameters and the chosen output responses. The scope of the

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proposed work is intended to develop such relationships for the chosen responses in terms of input variables and utilizes those developed relations to find the optimal set of process variables in Laser Drilling and Laser machining. Once the optimal values are found, then the process could be automated based on them there by reducing the manpower thus reduces the drilling cost. Laser drilling is a thermal technique based progressive machining process. In this process material removal takes place in following sequence i.e., Melting, Vaporization, and Ablation (material degrade). While a high intensity laser beam is concentrated on outward of work piece the thermal energy is engrossed which generate heat and transmutes the work piece metal obsessed by molten and after vaporized. This can be ejected by using high pressure gas jet (which is fastening the transmuted metal & expel it from drilling zone). The expression "light" is by and large acknowledged to be electromagnetic radiation extending in wavelength from 1-1000 mm. The noticeable range is from more or less 400-700 nm. The interval from 700 nm – 10 mm is viewed as the close infrared (NIR), and whatever past that is the far infrared (FIR). Then again, 200-400 nm is known as bright (UV); underneath 200 nm is the profound bright (DUV).

2. EXPERIMENTAL WORK:

The fundamental material evacuation instrument included in laser shaft machining is subordinate upon the era of great warmth flux that sources dissolving as well as vaporization of the metal where the pillar is centered. An appropriate lasing medium is utilized to acquire the laser light emission wavelength. Fig 2.1 shows the working of a laser. The pulse impending out of a lasing medium has a micro dimension. The beam is then targeted on the surface of the work piece by means of lens. It has a pale or spherical distinct wave front. The beam should come to be focused to a small area, when beam passes through lens. By this a high energy focusing is get at small area. At first, the laser radiation is absorbed by surface of the work piece where the high energy is transformed into heat.

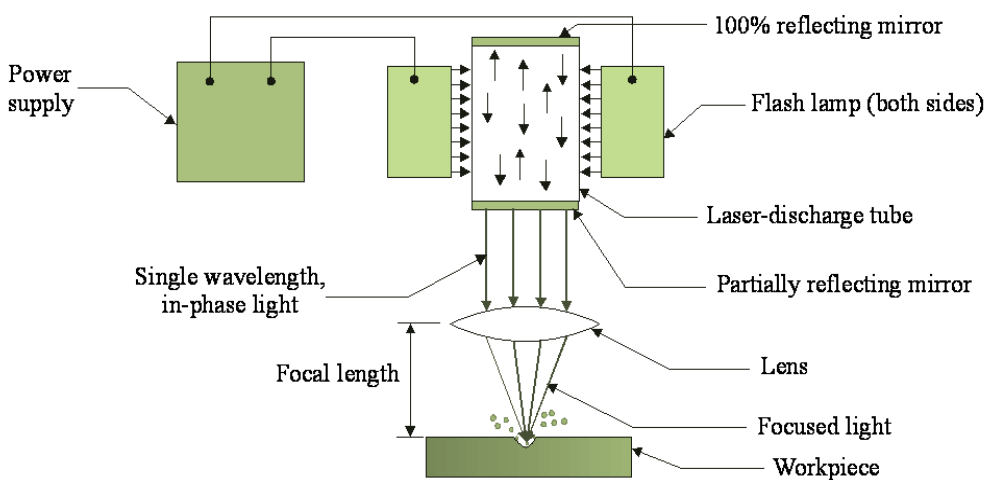

Fig 1: Laser beam machining schematic

Laser is an acronym of Light Amplification by Stimulated Emission of Radiation. The essential operation of laser, i.e. era of cognizant (both transient and spatial) light emission by "light intensification" utilizing "animated discharge" is termed as lasing. In the particle, adversely electrons (e^-) which are charged turn around the decidedly charged core in predetermined detour ways. The shape and radii of such detour ways rely on upon a mixed bag of constraints like count of electrons, vicinity of neighboring molecules and their structure of electrons, vicinity of electromagnetic field and so forth. Individually the orbital e^- is connected with extraordinary vitality stages. At total zero temperature an iota is thought to be at base level, when every e^- involves their particular most reduced probable vitality. The electrons at base condition can be eager to greater condition of vitality by engrossing vitality structure outside bases like increment in electronic vibration at lifted temperature, through compound response and additionally by means of retaining vitality of the photon. Fig.2.2 delineates the

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assimilation of a photon by an e^-. The e^- travels from a lesser vitality stage to an upper vitality stages. On coming to the greater vitality stage, the e^- achieves a precarious vitality band. Also, it returns to its base condition inside a little period by discharging a photon. This is known as unconstrained outflow. Schematically the identical is demonstrated in Fig.2.2.

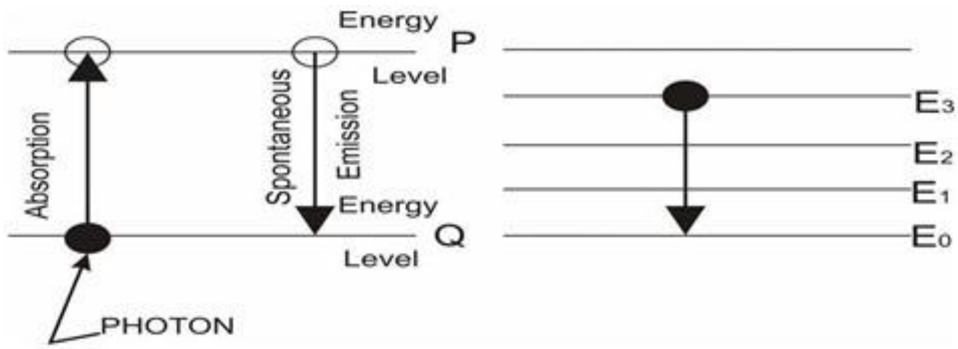

Fig. 2. Energy band in material

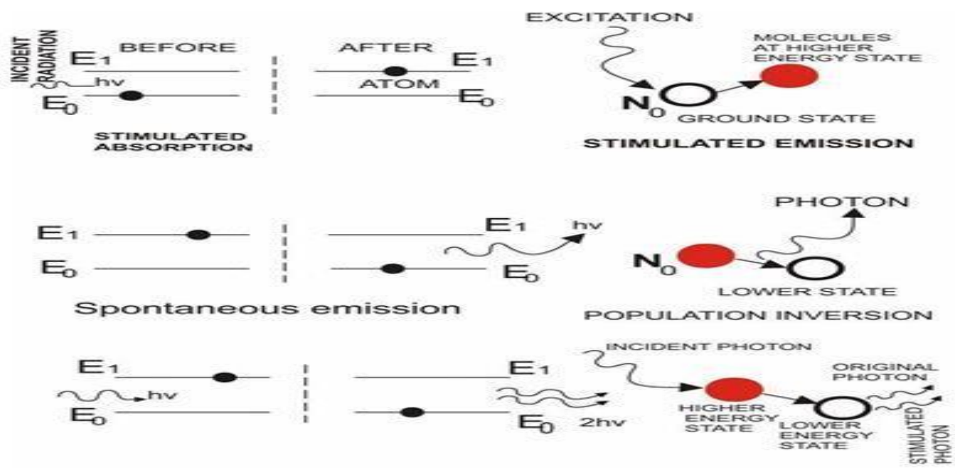

Fig. 3 Spontaneous and stimulated emissions

The Neodymium atoms are doped in this host. The concentration of Nd in YAG crystal is about 1% by weight. The entire Nd: YAGbar displays alluring photosensitive, perfunctory and warm possessions. Which makes it broadly utilized lasing means for great power lasing process. The pump source is typically a krypton bend light situated parallel to the Nd: YAG precious stone. Both the Nd: YAG bar and the krypton bend ligh tare situated inner a gold plated circular pit. The elliptical shaped pit is used because of the special property of the ellipse that it has two focuses, and the light emitted from one focus is totally concentrated on another focus. Therefore, in the cavity the krypton arc lamp is set aside at focus one and the Nd: YAG rod is set aside on one more focus. The gold-plated fissure is used for its high reflectivity to the wavelength of the pump light. The optical response is delivered by a 100% reflecting back mirror & a partially transmitting forward-facing mirror. The concentration of light produced by this propelling the Nd atoms in Nd: YAG rod. To start the lamp, which is having very high impedance, first it is to be triggered with high voltage pulse. Once the discharge in lamp is produced, then by altering the power input in lamp, the concentration of the light emitted by the lamp can be well-ordered. Now in many applications lasers is not used continuously and therefore the power supply is provided with a special feature of standby mode which keeps alive the discharge in lamp. This arrangement is very useful in increasing the operational life of the lamp and also

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that of power supply, because this will save the whole process of generating trigger pulse for igniting the lamp. This power supply unit is provided with inter locking arrangement because if cooling arrangement is not operational then the lamp will not get ignited. This saves both lamp and very expensive Nd: YAG rod from damage.

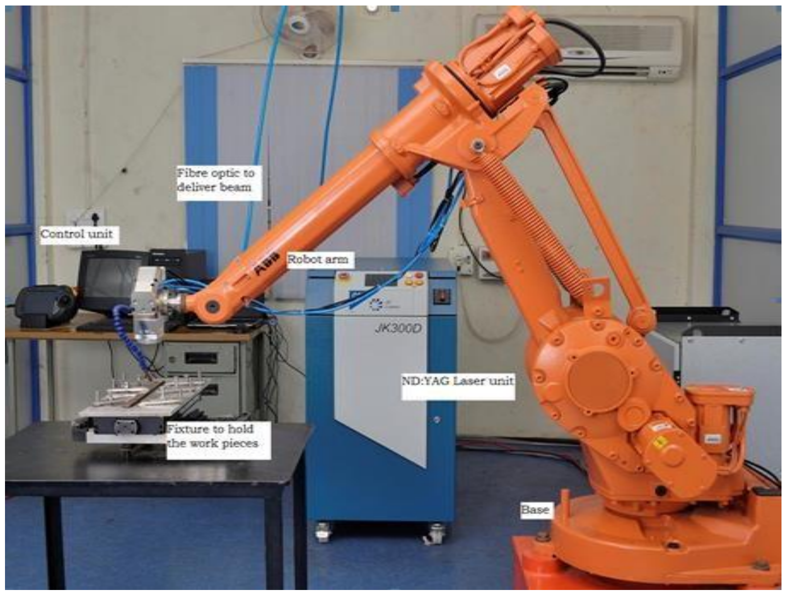

Fig. 4 Nd: YAG Laser machining setup

3. TAGUCHI, GREY RELATIONAL ANALYSIS & Artificial Neural Networks Methodology

Genichi Taguchi was developed a philosophy and methodology for improving the quality of Japanese Industrial Products at low cost in 1940, which depends majorly on Statistical tools, concepts, and designed experiments. This Taguchi technique was followed by several fields of industries, Engineers to approach good profit values by improving product's quality at optimal cost. For this he was received award and Medal for excellence in International Technology Institute, in 1986. The key of impact for this method is merging the statistical and engineering methods to reach hasty progress in quality and cost through optimizing product design and production steps. The Taguchi's system is the standardize approach, for deciding the best creation of information and to deliver the result of component influences. Taguchi was able to determine the control variables and levels. The product will be continued on performing at target value in the neighborhood of outer and internal variety. Methodologies utilize the immediate inspecting of framework implementation, ordinarily utilizing model and exceptionally minimal testing systems. This is expert through outline investigation of DOE, is an important tool for design great value classification on condensation of price. The method proposed parts of quality relation and the quality of cost.
The formulae for S/N ratio are tabulated in below table :1

S. No.	Sort	Formulae
01	Smaller the Better	$S/N = -10\log_{10} \sum_{i=1}^{n} (1/n)\,(Y^2{}_i)$ **or** $S/N = -10\log_{10} Y^2$
02	Nominal the Better	$S/N = -10\log_{10}(\overline{Y}^2/S^2)$, $S/N = -10\log_{10}(S^2)$
03	Bigger the Better	$S/N = -10\log_{10} \sum_{i=1}^{n} (1/n)\,(1/Y^2{}_i)$ **or** $S/N = -10\log_{10} \frac{1}{Y^2}$

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4. Grey Relational Analysis:

Grey relational analysis is an impacting measurement method in grey system theory that analyses uncertain relations between one main factor and all the other factors in a given system. In the case when experiments are ambiguous or when the experimental method cannot be carried out exactly, grey analysis helps to compensate for the shortcomings in statistical regression. Grey relational analysis is actually a measurement of the absolute value of the data difference between sequences, and it could be used to measure the approximate correlation between sequences.

In grey relational analysis, the measure of the relevancy between two systems or two sequences is defined as the grey relational grade. When only one sequence, x_o (k), is available as the reference sequence, and all other sequences serve as comparison sequences, it is called a local grey relation measurement.After data pre-processing is carried out, the grey relation coefficient $\xi_i(k)$ for the K_{th} performance characteristics in the i_{th} experiment can be expressed as:

$$\left.\begin{aligned} \Delta_{oi} &= \| x^*_o(k) - x^*_i(k) \| \\ \Delta_{min} &= \underset{\forall j \in i}{min} \; \underset{\forall k}{min} \| x^*_o(k) - x^*_j(k) \| \\ \Delta_{max} &= \underset{\forall j \in i}{max} \; \underset{\forall k}{max} \| x^*_o(k) - x^*_j(k) \| \end{aligned}\right\} \quad (1)$$

5. Artificial Neural Networks (ANN)

Neural Network us used to capture the general relationship between variables of a system that are difficult to analytically relate. Neural Network has been described as “brain metaphor of information processing” or as “a biologically inspired statistical tool”. It has capability to learn or to be trained about a particular task, its computational capabilities and the ability to formulate abstractions and generalizations. Neural network has an organization similar to that of a human brain and it is a network made up of processing elements called neurons.

Neurons get data from the surrounding neurons, perform some computations, and pass the results to other neurons. Connections between the neurons have weight associated with them. In neural network, the knowledge is stored in the network’s interconnection weights in an implicit manner learning takes place within the system and plays the most important role in the construction of an neural network system. The neural network system learns by determining the interconnection weights from a given data set.

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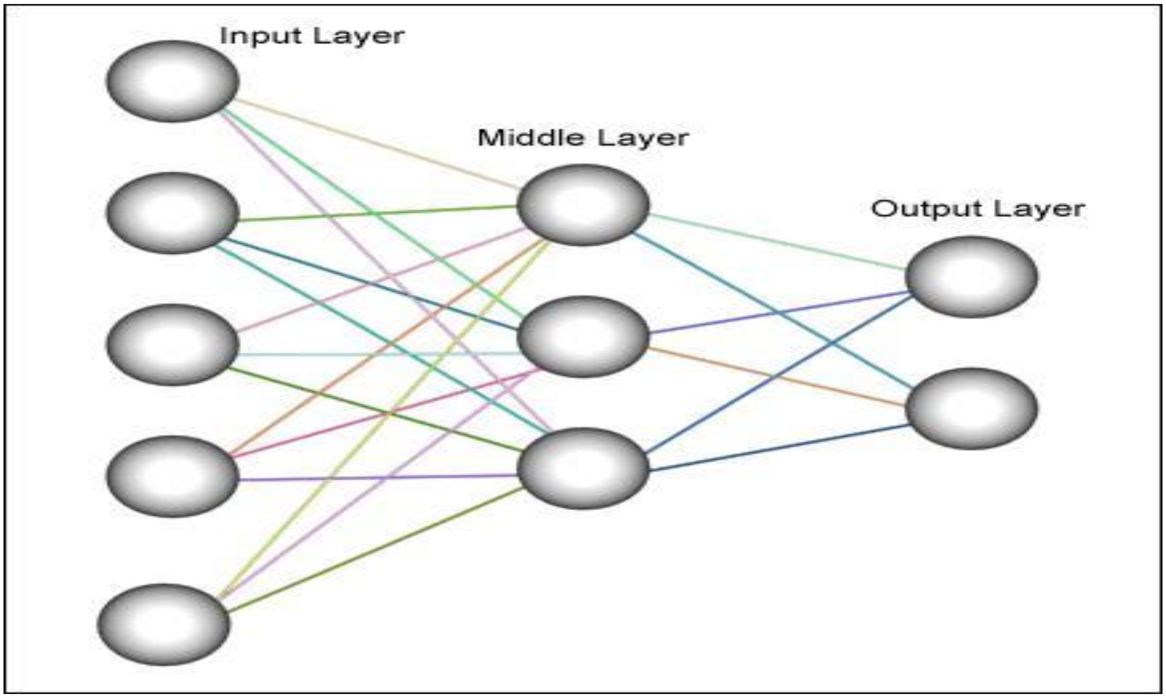

Figure 5. Configuration of Neural Network

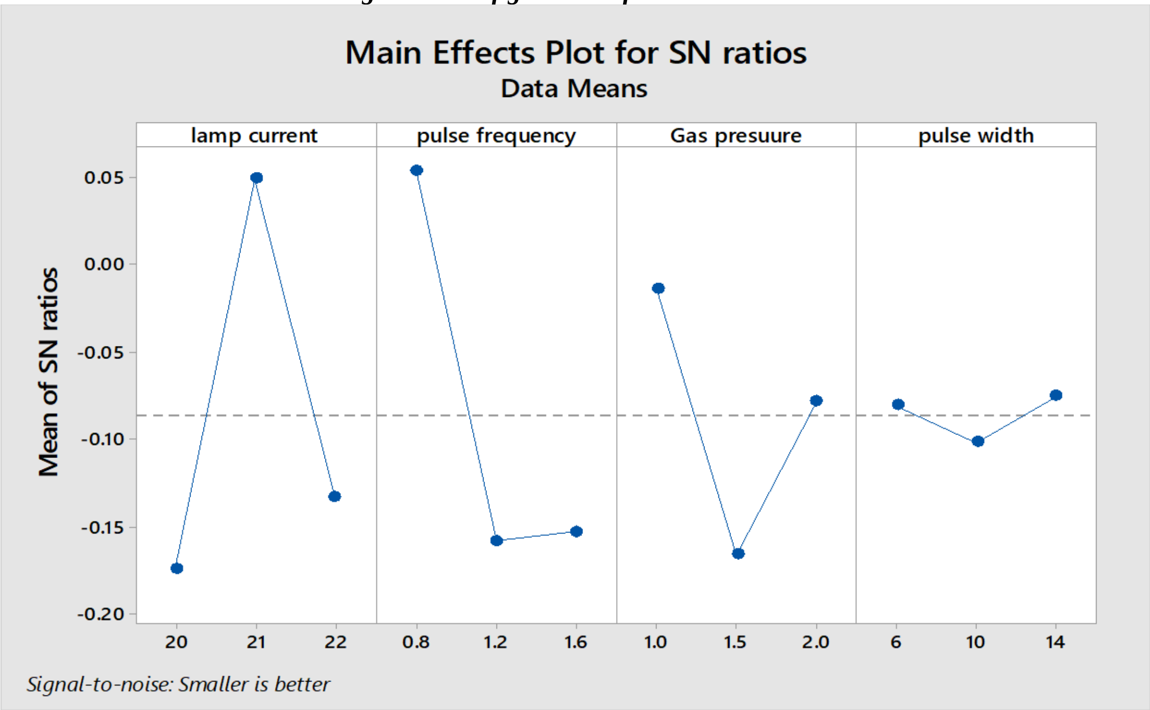

Table 2 Taguchi S/N response for Diameter at Entrance
Response Table for Signal to Noise Ratios
Smaller is better

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Level	lamp current	pulse frequency	Gas presuure	pulse width
1	-0.17410	**0.05367**	**-0.01314**	-0.08038
2	**0.04948**	-0.15781	-0.16557	-0.10132
3	-0.13233	-0.15281	-0.07825	-0.07526

Table 3. The experimental values and predicted value of Diameter at exit.

Diameter at exit			
sl.no	**Experimental**	**predicted**	**% error**
1	0.91	0.8672	4.935424354
2	0.896	0.9013	-0.588039499
3	0.929	0.9054	2.606582726
4	0.899	0.9113	-1.34972018
5	0.899	0.9006	-0.177659338
6	0.914	0.9325	-1.983914209
7	0.897	0.8987	-0.189162123
8	0.901	0.8834	1.992302468
9	0.921	0.9239	-0.313886784
10	0.875	0.8679	0.818066598
11	0.925	0.9168	0.894415358
12	0.865	0.935	-7.486631016
13	0.929	0.9284	0.064627316
14	0.924	0.9479	-2.521363013
15	0.915	0.9514	-3.825940719
16	0.891	0.9354	-4.746632457
17	0.966	0.8953	7.896794371
18	0.921	0.9285	-0.807754443
19	0.89	0.8677	2.570012677
20	0.881	0.8928	-1.321684588
21	0.9	0.9542	-5.680150912
22	0.919	0.9285	-1.023155627
23	0.932	0.9484	-1.729228174
24	0.938	0.9357	0.245805279
25	0.929	0.9368	-0.832621691
26	0.929	0.9134	1.707904533

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27	0.942	0.9119	3.300800526
	Average % error		-0.279437354

$$\% \, Error = \frac{\exp erimental - predicted}{predicted}$$

For experiment number 1 % error is calculated as $=\frac{0.91-0.8672}{0.8672}$ =4.9354354

Average % of Error is $=\frac{\text{Sum of total \% error}}{\text{No of sample}}$ = -0.27937354.

Table 4. The experimental values and predicted value of Diameter at Entrance

Diameter at entrance			
Sl.no	**Experimental**	**predicted**	**% error**
1	1.015	1.0211	-0.597394966
2	1.013	1.0294	-1.593161065
3	1.042	1.056	-1.325757576
4	1.03	1.0257	0.419225895
5	1.006	1.0479	-3.998473137
6	1.038	1.0145	2.316412026
7	1.01	1.0188	-0.863761288
8	1.026	1.0543	-2.684245471
9	1.003	1.0382	-3.390483529
10	0.962	0.9992	-3.722978383
11	1.003	0.9915	1.1598588
12	0.95	1.0338	-8.106016638
13	1.01	1.0169	-0.678532796
14	1.001	1.0166	-1.534526854
15	0.986	1.005	-1.890547264
16	0.968	1.0209	-5.181702419
17	1.053	1.0559	-0.27464722
18	1.02	1.0394	-1.86646142
19	0.984	1.0002	-1.619676065
20	0.973	0.9802	-0.734543971
21	1.006	0.9818	2.46486046
22	1.016	1.0426	-2.551314023
23	1.08	1.0097	6.962464098
24	1.001	0.9924	0.866586054
25	1.021	1.0366	-1.504919931
26	1.022	1.0602	-3.603093756

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27	1.039	1.0351	0.376775191
	Average % error		-1.228002046

$$\% \, Error = \frac{experimental - predicted}{predicted}$$

For experiment number 1 % error is calculated as $=\frac{1.015-1.0211}{1.0211}$ = - 0.597394966

Average % of Error is $=\frac{\text{Sum of total } \% \text{ error}}{\text{No of sample}}$ = -1.228002046.

CONCLUSIONS

In this paper, we examined pulsed Nd: YAG laser drilling of austenitic stainless steel. The effects of process parameters (i.e., lamp current, pulse frequency, gas pressure, and pulse width) on the quality of drilled holes (i.e., diameter of drilled hole at entrance, at exit, and hole taper) were investigated by doing experiments based on grey relational analysis that led to the following conclusions:

1. From above Grey relational analysis we conclude that run12 processed with lamp current 21[A], pulse frequency 0.8 [KHZ], gas pressure 2 [KG/CM^2] , pluse width 14 [%] gives the best results for the outputs.
2. Grey relational analysis in the aguchi method for the optimization of multi response problem is a very useful tool for predicting the hole taper in the laser drilling of austenitic stainless steel.
3. The Nd: YAG laser drilling framework has proved to be efficient in performing the drilling operations on austenitic stainless steel.
4. The predicated values by the ANN and optimization of diameter of exit , diameter of entrance, & hole taper.
5. It can be inferred that the process parameters (i.e., lamp current, pulse frequency, gas pressure, and pulse width) can be ideally controlled for attaining the better-quality hole in laser drilling process.

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