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Research Article

APPLICATION OF ARTIFICIAL NEURAL NETWORK FOR OPTIMISING CUTTING VARIABLES IN LASER CUTTING OF 304 GRADE STAINLESS STEEL

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ABSTARCT
Stainless steel is an important industrial material having wide application in aerospace engineering, Power plant, Petroleum refineries, Pharmaceutical industry, and House hold goods manufacturing. To obtain very good end product at lower cost, its mechanical properties must be controlled properly during processing. To achieve this objective, important process parameter namely surface roughness must be optimised by proper mathematical models. In this investigation, 304 grade stainless steel is cut using 2 KW carbon dioxide laser with oxygen as assist gas and an optimal condition for Surface roughness is identified to increase the productivity and reduce the operating cost. Optimisation is done using artificial neural network. In the present work 4-7-1 architecture for neural network model is developed to optimise the surface roughness using four cutting variables namely laser power, cutting speed, assist gas pressure, and work piece thickness. This approach can eliminate time-consuming and expensive trial-and-error process development and lead to rapid development of processes.

***Key Words**: Surface Roughness, Artificial Neural Network, Laser cutting*

INTRODUCTION
In the production industry modern production methods like laser machining are used widely because of their faster processing performance machining time is reduced as much as possible as well as the cost of production. Also the automation of the process using CNC, machine time can be reduced which increases productivity. Some of the important advantages of laser machining over mechanical machining are reduced contamination of work piece, easier work holding, reduced chance of warping, and better Precision. Also materials which are difficult to cut by more traditional means can be processed using laser. Therefore interest in the laser cutting process is increasing in production industries like aerospace, automobile, shipbuilding and nuclear industries because of the ability of laser to cut materials with attractive processing speed, high productivity, and ability to cut materials with complex shapes. One of the important objectives of the production industry is obtain lower value for the machined surface. If not the cost of production will increase because of other finishing operations.

For processing applications, the absorption of laser beam by the work piece material is of importance. All laser processes can be considered in this way, and our understanding of many of the phenomena of laser processing can be helped by this approach. If we assume that a significant proportion of the beam is absorbed by the target, then the three dominating factors namely average power of the laser beam, intensity of the laser spot on the target and the wavelength of the laser beam will play an important role in processing applications. Hence of the several lasers developed only a few are of interest for industrial applications. For sheet metal cutting processes, commercially available high-power CO_2 and Nd:YAG lasers are widely used(Ranganath B J et.al., 2005).

In cutting processes the energy is absorbed from the material in the zone in which the laser beam has focused (power densities 10^5 - 10^8 W/cm^2) becomes transformed in heat. The heat locally provokes to a quick increase of the temperature of the piece resulting in the melting of the material. When the irradiation level further increases, the molten material starts boiling followed by intense evaporation. The evaporation of the material results in the formation of a hole. If the passing hole moves along the work piece, it generates the separation of the two cutting pieces (Ranganath B J, 2006).

The production rate is limited by cutting variables. Maximum cutting rate is affected by a number of factors like laser power, material thickness, type of assist gas (reactive or inert,) and material properties. Each type of material requires the right combination of laser power, focusing lenses, and assist gas pressures and flows to do the job successfully. Laser cutting should produce consistent cut surface quality and groove width/ depth. Irregularities normally are caused by using incorrect assist gas pressure and flow or a cutting speed that is too fast or small. In view of the importance of surface integrity of any machined parts, it is therefore important to achieve better surface integrity during Laser machining process.

In material processing, the quality of laser-cut surfaces is often a critical consideration. Due to the viscosity of the molten metal, the gas jet can only expel a portion of the molten material out of the kerf. The remaining material resolidifies along the bottom edge, forming dross, which must be removed mechanically after laser processing. In addition to dross formation, several other surface quality issues like surface roughness, micro cracks etc., exist. Surface quality can be improved by using an assist gas jet in tandem with the laser beam to expel molten material from the kerf. Air, oxygen, and nitrogen are the most commonly used assist gases. Each assist gas has pros and cons for each material. The quality of the cut surface of metals using laser is dependent on the combination of the cutting parameters, including the Laser Power, the cutting speed, kerf width, the assist gas pressure, and the focal position of the laser beam (Ranganath B J et.al., 2005).

Many investigations using neural network are done by various researchers to study the process performance, modelling and optimisation of laser cutting of metals & alloys. Ranganath BJ et.al.,(2006) have developed a Neural network model to predict kerf width for laser cutting of mild steel. Sobih M (2008) and others have studied the laser cutting of mild steel using a 1 kW single-mode fibre laser, a relative newcomer in the field of laser metal cutting. Striation-free laser cuts are demonstrated when cutting 1mm thick mild steel sheets. Their results show that the surface roughness decreases as the cutting speed increases until an optimum cutting speed is reached. Beyond this the surface roughness gradually increases again. This effect becomes more pronounced at higher powers. Dong Gyu Ahn et.al.,(2008) in their study on laser cutting of cold rolled steel sheets using a high-power Nd:YAG laser have found out critical cutting speeds for obtaining minimum surface roughness and a maximum average striation angle. Also, the optimum cutting conditions for each work piece thickness have been estimated to improve both the quality of the cut section and the cutting efficiency. Yilbas BS et.al., (2008) introduced neural network to classify the striation patterns of the cut surfaces by laser cutting of wedge surfaces in sheet metal processing mild steel by CO_2 laser. Ulas Caydas et.al.,(2008) used the grey relational analysis based on the Taguchi method for the optimization of laser cutting process of St-37 steel to determine optimum laser cutting parameters with multi-performance characteristics**.** The quality characteristics of kerf width and material removal rate are studied by Dubey AK et al., (2008). In their study it reported that Kerf Width is of the smaller-the-better type, while MRR is of the higher the better type.

An artificial neural network approach on parametric optimization of laser micro-machining of die-steel(Rex M2 high speed steel) is carried out by Srijib Kr. Dhara et al., (2008) in which LBM process model using cascade forward back propagation network. The effects of the cutting parameters on the surface roughness, the striation formation and the microstructure of the cut section of Inconel 718 sheet using Nd:YAG laser with the maximum power of 2.8 kW was studied in by Dong-Gyu AHN et.al.,(2009). Their results show that variation of the surface roughness of the cut section is affected mainly by the cutting speed. Ciurana J et al.,(2009) have done the artificial neural networks (ANN) modelling studies of AISI H13 hardened tool steel micro machined by pulsed Nd:YAG laser system. In their studies the relation between process parameters and quality characteristics has been modelled. Sivarao et.al.,(2009a,b) used the multilayer back-propagation neural network model with 3-8-1 architecture for the Ra predictions and cut quality of Manganese Molybdenum (Mn-Mo) pressure vessel plate processed by Laser. They have also studied the adaptive network-based fuzzy inference system (ANFIS) to model and predict the laser cut quality of a 2.5 mm plate of manganese—molybdenum (Mn—Mo) alloy.

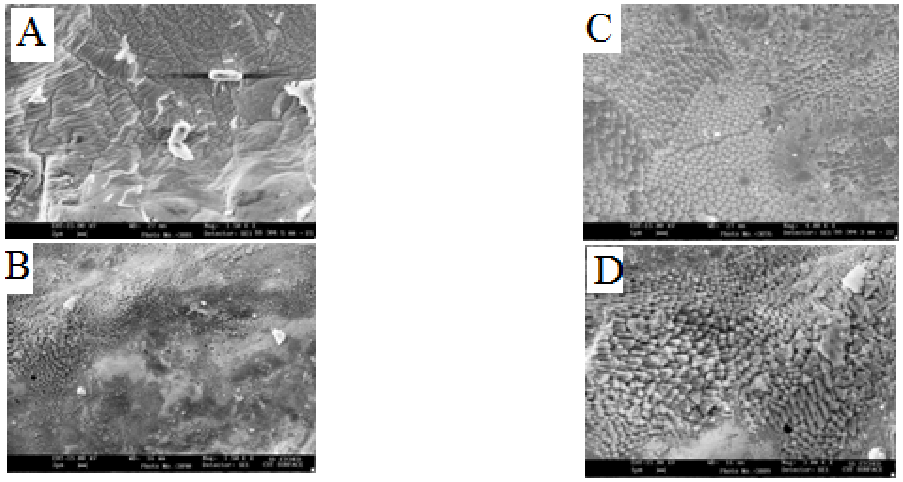

Figure 1: SEM Micrograph of laser cut Stainless Steel-304 for different cutting variables using Oxygen as assist gas.
Sample A – 5 mm thick, 2kw laser power, 1.5m/min cutting speed, 4.5 bar gas pressure, 1500X magnification.
Sample B – 3mm thick, 1kw laser power, 2.0m/min cutting speed, 3.5 bar gas pressure, 1500X magnification.
Sample C – 2mm thick, 1.4kw laser power, 6.0m/min cutting speed, 5 bar gas pressure, 1500X magnification. Etched surface.
Sample D – 2mm thick, 1.4kw laser power, 6.0m/min cutting speed, 5 bar gas pressure, 3000X magnification. Etched surface.

However very few papers are reported on neural network modelling studies on Stainless steel for prediction of surface roughness. Predictive modelling using ANN helps to reduce the machine lead time thereby reducing the material wastage and cost of production.

MATERIALS AND METHODS

The aim of this study is to obtain the optimal cutting condition of laser cutting variables namely power, the cutting speed, assist gas pressure and the thickness of the work piece, for better surface characteristics of stainless steel -304 and lower cost of production using a continuous wave CO2 laser with Maximum power of 2KW. 304 grade Stainless steel of different thickness was cut by carbon dioxide laser with oxygen as assist gas for different cutting conditions. The Laser beam was focussed on the top surface of the work piece using Zinc selenide lens of focal length 190mm. The surface roughness of the laser cut surface was measured using the instrument Mitutoyo Surftest-211.The cut surface characteristics are studied using SEM.

RESULTS

Figure 1 shows the SEM micrographs of laser cut surface of 304 grade Stainless Steel sample for various cutting parameters. From these micrographs it is seen that the Surface irregularities are present in the laser cut surface of 304- grade Stainless steel cut by CO2 laser using oxygen or nitrogen as assist gas. Due to these surface irregularities the process has to be properly controlled for better cut surface roughness. One of the modern popular techniques is to apply neural network modelling for multivariable analysis.

Artificial Neural network

Artificial neural networks (ANN) are biologically inspired computer programs designed to simulate the way in which the human brain processes information. ANNs gather their knowledge by detecting the patterns and relationships in data and learn (or are trained) through experience, not from

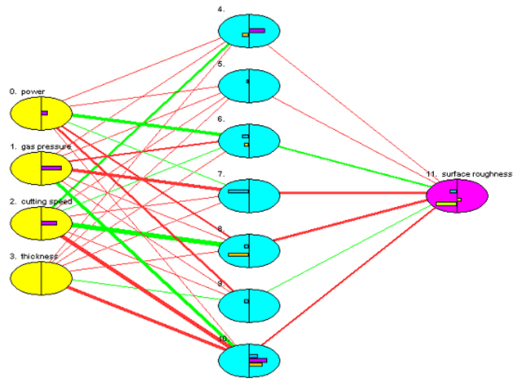

Figure 2: Neural network Model with 4-7-1 architecture for optimizing surface roughness of laser cut surface of SS-304

programming. An ANN is formed from hundreds of single units, artificial neurons or processing elements (PE), connected with coefficients (weights), which constitute the neural structure and are organised in layers. The power of neural computations comes from connecting neurons in a network. Each PE has weighted inputs, transfer function and one output. The training algorithm adjusts the connection weight values to minimize the error i.e. the difference between desired outputs. The learning process of a Neural Network can be viewed as reshaping a sheet of metal, which represents the output. The training set acts as energy required to bend the sheet of metal such that it passes through predefined points. However, the metal, by its nature, will resist such reshaping. So the network will attempt to find a low energy configuration that satisfies the constraints (training data).

During training, the inter-unit connections are optimized until the error in predictions is minimized and the network reaches the specified level of accuracy. Once the network is trained and tested it can be given new input information to predict the output resulting in a predicted pattern. In a nutshell a neural network can be considered as a black box that is able to predict a pattern when it recognizes a given input pattern. When an input is applied to a trained neural network the response indicates the class of quality. In practice, ANNs are especially useful for mapping problems which are tolerant of some errors but to which hard and fast rules cannot easily be applied (Ranganath BJ 2006).

ANN Modelling and Optimisation for Surface roughness

A unit process can be considered optimized when the value added in terms of the required configuration and property changes is delivered to the work piece in the most cost-effective manner from the system as a whole. This involves minimization of factors such as energy use, scrap generation, labour costs, and capital equipment requirements. In addition, rapid response to the quality needs of customers and a safe working environment are essential. Therefore, many factors must be considered in Process optimisation to get cost-effectiveness. In the present paper four input parameters are considered to study the optimisation of surface roughness.

Figure 2 shows the neural network used in the present work to model the Surface roughness of the CO_2 laser cut surface of stainless steel -304. The designed network is having 4-7-1 architecture. The Four input nodes correspond to the process parameters namely Laser power, assist gas pressure, cutting speed and thickness of the material to be processed. The output layer consisting of one node corresponds to the Laser cut surface roughness.

The input node and the output nodes are mapped through the hidden layer consisting of seven nodes which helps to process the received by the input layer. The output layer sends the processed information to the user. Fifteen experimental values given in table 1 were used to model the training the network. After training the network five values were used for validating the results. The error goal was set as 0.05 using a learning rate of 0.6 and momentum rate of 0.8.The network was trained with the experimental results using the back propagation algorithm. The error goal was achieved after weights were randomized up to 41 and 29653 iterations.

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DISCUSSION

The neural network model developed to predict and optimise the cutting parameters gave excellent results within the limits of error goal for the surface roughness of CO_2 laser cut surface of stainless steel -304. It is found that the relative importance of cutting speed is more dominant in optimising the surface roughness as compared with the other cutting parameters.

Table: 1 Experimental values of Cutting parameters for ANN modelling

S. No.	Work piece thickness (mm)	Laser power (watts)	Gas pressure (Bar)	Cutting speed (mm/min)	Surface Roughness Ra (microns)	ANN Model results (microns)	Deviation %
1	3	1200	6	3000	6.07	6.126	0.92
2	3	1300	6	3000	5.86	5.919	1.00
3	3	1400	6	3000	4.53	4.600	1.54
4	3	1600	6	3000	5.32	5.540	4.13
5	3	1700	6	3000	6.97	6.954	0.22
6	2	1400	5	4500	3.73	3.850	3.21
7	2	1400	5	5000	3.79	3.728	1.64
8	2	1400	5	5500	3.25	3.394	4.4
9	2	1400	5	6000	4.56	4.628	1.49
10	2	1400	5	6500	3.63	3.657	0.74
11	2	1400	4	4000	3.37	3.22	4.45
12	2	1400	4.5	4000	3.51	3.67	4.56
13	2	1400	5	4000	3.62	3.680	1.65
14	2	1400	5.5	4000	3.17	3.364	6.12
15	2	1400	6	4000	3.03	3.295	8.74

It is observed that the predicted values agree with the measured values for the surface roughness of the CO_2 laser cut surface of stainless steel. The model results have been validated for the experimental results and found to be within a maximum error of max 8.74% and minimum error of 0.22%. The errors are within the range of acceptable errors of 12% for modelling studies (Sivarao et.al 2009b). A comparison of the results obtained with the current model is made with the experimental values in table 1. Figure 3 shows the comparison of results obtained. It is observed that the predicted values agree with the measured values for the surface roughness of the CO_2 laser cut surface of stainless steel.

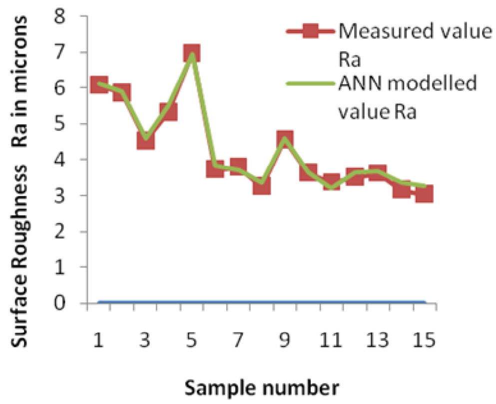

Figure 3: Comparison of experimental results and ANN model results for predicting surface roughness

Conclusion

In mass production applications the dimensional stability and roughness of the machines surface are important indicators of

the cut surface roughness and consequent optimisation of cutting at cutting process.

The present study shows that optimum quality in laser cutting systems is achieved with4-7-1 architecture ANN model comprising of four

inputs (Power, speed of cutting, assist gas pressure and thickness) and one output for surface characteristics is predictable by an ANN modelling combinations of input parameters.

It is found that the importance of cutting speed is more dominant in optimizing the surface roughness as compared with the other cutting.

Hence cutting speed should be selected based on the process requirements, and the machine automated for optimum quality production.

The predictive ANN model is found to be capable of predicting surface roughness within the range that they had been trained.

The result of the ANN model gives good results in estimating the values of surface roughness.

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