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Abstract

Conventional technology for leather processing comprises leather cutting which operates at slower speeds, less in quality and involves high manpower resources. As a result it drastically restrains the development of the leather industry. Due to small size and low power consumption, diode lasers can process leather rapidly, efficiently and continuously. In the present work, an attempt has been made to analyze the machinability of cow leather using 445nm blue diode based laser beam machining (LBM) process. Since the process related with more than one performance measure, it is essential to establish the multiple response decision making for optimizing the process parameters in this process. Taguchi's L25 orthogonal array was used to design experimental trials with different levels of input parameters such as frequency, amplitude, duty cycle, standoff distance and cutting speed. Taguchi – Data Envelopment Analysis based Ranking methodology has been used to enhance the performance measures such as geometrical inaccuracy and carbonization in the present study.

Keywords: LBM, Taguchi, DEAR

Introduction

In the present scenario, the usage of leather materials is being increased in different industrial sectors such as shoes and fashion, furniture and automotive. Owing the growth of higher utilization of such materials, it is needed an advancement in the machining of those materials to produce the final product. Conventionally manual cutting of leather material using scissors and draw-gauge knifes were performed. However the quality of such technique is not noteworthy (Stepanov et al 2013). Hence it is necessary to introduce untraditional cutting processes such as water jet machining (WJM) process and laser beam machining (LBM) process (Patowari et al 2011). Nevertheless water jet machining process could produce the jamming of top layer of leather. Hence it is proposed to use LBM process to cut the leather material with complex geometry shape (Kim and Lee 2016). Laser beam machining is a non-traditional machining process in which a controlled laser is directed towards the work piece for removing the material. This process utilizes the thermal energy to remove material from the work piece by the sequence of heating, melting or vaporization of the material. There are many different types of lasers including gas, solid states lasers, and excimer lasers are available (Nasim and Jamil 2014). Gas lasers are mostly preferred among which owing to its ability of low maintenance and operating costs. It is very essential to analyze the effect of input process parameters on response parameters in LBM process to improve the efficacy of the system (Ayed et al 2014). Hence an attempt has been made to analyze the machinability of leather using CO_2 based LBM process in the present study (Caiazzo et al 2015).

Various multi response optimization techniques are available to optimize the process parameters such as Taguchi Grey relational analysis (TGRA), response surface methodology (RSM), Artificial Neural Network (ANN) approach and assignment of weights method. The selection of suitable grey co-efficient is a very tedious process in TGRA method. The incompatible value of grey efficient may lead to poor selection of process parameters in any machining process (Jayakrishnan et al 2018). RSM based multiple performance decision making approach can also provide suitable combination of process parameters for maximizing the response parameters in any machining process. Nevertheless the interpolation of the results needs highest expert knowledge to derive the optimal combination (Saravanakumar et al 2014). ANN based model predictive control and optimization can be used for optimizing the process parameters. Nevertheless the prediction accuracy depends on the number trials used for deriving the empirical relationship (Pourrahmani et al 2019). The steps involved in such approaches are considerably tedious. Taguchi – Data Envelopment Analysis based Ranking (DEAR) based multiple criteria decision making (MCDM) is very simplest and efficient approach (Manoj et al 2018). It has been proved that the accuracy of the Taguchi-DEAR method has extensive accuracy on determining the optimal process parameters in any manufacturing process. Even though many literatures are available on machining of engineering materials, only very little attention has been given to analyze the influence of parameters on performance measures on machining leather specimens. Hence the present investigation has been carried out.

Methodology

Due to its importance in industrial manufacturing system, buffalo leather has been used as workpiece material in the present study. Due to the significance of such process parameters in the LBM process, frequency, amplitude, duty cycle, standoff distance and cutting speed have been selected as the input process parameters for the present study. Leather specimens of 3mm thickness have been machined for producing rectangular specimens for analysis purpose. The selection of input process parameters and their ranges have been shown in Table 1. Since the present study has been considered with five input process parameters along with five levels, L_{25} orthogonal table design has been selected based on Taguchi design of experiments (Ayed et al 2014). Owing to its importance on determining the machining characteristics, material removal rate (MRR) and overcut (OC) have been selected as the response parameters in the present study. The material removal rate has been found by finding the weight difference of the workpiece before and after the machining process. It is denoted by mm^3/min. The overcut can be calculated by finding the average difference between width of machined zone after cut and spot diameter of laser beam.

Table 1. *Design of Experiments*

Factors	Symbol	Units	Level 1	Level 2	Level 3	Level 4	Level 5
Frequency	F	Hz	4000	8000	12000	16000	20000
Amplitude	A	V	3	3.5	4	4.5	5
Duty cycle	DF	%	18	36	54	72	90
Standoff Distance	SD	mm	4	8	12	16	20
Cutting Speed	V_C	mm/min	200	400	600	800	1000

In Data Envelopment Analysis based Ranking (DEAR) method, a combination of original responses is plotted into a ratio so that the better suitable levels can be computed based on this ratio. The value can be assumed as MRPI to compute the optimal combinations of the input parameters of LBM process. The following rules are involved in Data Envelopment Analysis based Ranking Methodology (Muthuramalingam et al 2018).

1. Compute the weights (w) for each response for all experiments. Weight of performance measure is fraction between the responses at any trial to the summation of all measures.
2. Convert the response data into weighted data by multiplying the obtained value with its own weight.
3. Find the ratio between larger the better (LB) and smaller the better (SB).
4. Treat this value as multi response performance index (MRPI).

MRPI is the ratio between the summation of LB data to the summation of quality characteristics. The following Eq. (1-5) has been used to find the MRPI for the present study.

$$\text{MRPI} = \frac{A}{B} \quad (1)$$

$$A = \text{MRR} * W_{\text{MRR}} \quad (2)$$

$$B = \text{OC} * W_{\text{OC}} \quad (3)$$

$$W_{\text{MRR}} = \frac{\text{MRR}}{\sum \text{MRR}} \quad (4)$$

$$W_{OC} = \frac{1/_{OC}}{\Sigma 1/_{OC}} \qquad (5)$$

Results and Discussion

The machining processes have been performed based on the L_{25} based Taguchi methodology on machining leather specimens using LBM process. The experiments have been conducted and tabulated as shown in Table 2.

Table 2. *Experimental Results of the Present Study*

S. NO.	F	A	DF	SD	V_c	OC	MRR
1.	1	1	1	1	1	0.2	0.000153846
2.	1	2	2	2	2	0.32	0.0000769231
3.	1	3	3	3	3	0.2	0.000153846
4.	1	4	4	4	4	0.215	0.0000769231
5.	1	5	5	5	5	1.27	0.000230769
6.	2	1	2	3	4	0.325	0.0000769231
7.	2	2	3	4	5	0.385	0.000230769
8.	2	3	4	5	1	0.395	0.000384615
9.	2	4	5	1	2	0.125	0.000230769
10.	2	5	1	2	3	0.315	0.000069231
11.	3	1	3	5	2	0.455	0.000230769
12.	3	2	4	1	3	0.28	0.000230769
13.	3	3	5	2	4	0.175	0.000307692
14.	3	4	1	3	5	0.365	0.000153846
15.	3	5	2	4	1	0.385	0.000384615
16.	4	1	4	2	5	0.38	0.000307692
17.	4	2	5	3	1	0.2	0.000153846
18.	4	3	1	4	2	0.305	0.000153846
19.	4	4	2	5	3	0.42	0.000153846
20.	4	5	3	1	4	0.075	0.000230769
21.	5	1	5	4	3	0.5	0.000153846
22.	5	2	1	5	4	0.4	0.0000769231
23.	5	3	2	1	5	0.225	0.000153846
24.	5	4	3	2	1	0.75	0.000153846
25.	5	5	4	3	2	0.115	0.000153846

The MRPI value of each trial with different combinations of input LBM process parameters has been computed using Taguchi - DEAR approach. Table 3 shows the MRPI values of all the experiments along with weights. Table 4 shows the consolidated MRPI of all the input process parameters with all levels. The parameters have been computed by the summing the all MRPI values for corresponding level of each process factors. The maximum level value of each process parameters indicates the optimal level of input factors on determining the performance measures in any machining process. From the Table 4, it has been found that the optimal combination of input process parameters of LBM process in the present study are 20KHz (F), 3V (A), 18% (DF), 16mm (SD) and 600 mm/min (VC) respectively. The higher value of max – min indicates the higher significance of process parameters on machining characteristics. It has been observed that frequency has higher influence on determining the performance measures owing to its importance on determining plasma energy over the surface of the work piece specimens.

Table 3. *MRPI values of the Present Study*

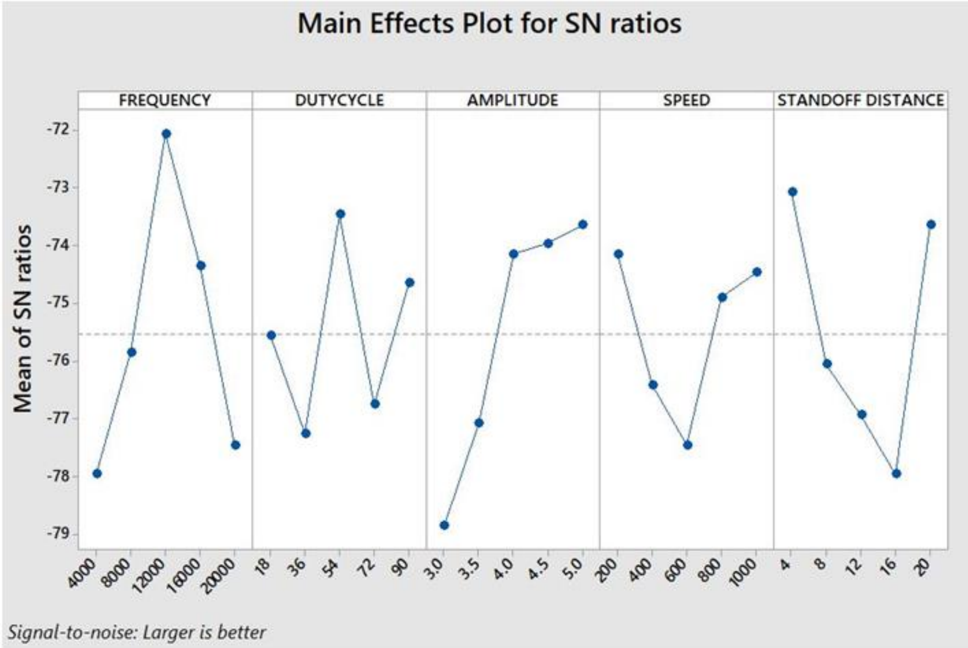
Trial	Weights		MRPI
	MRR	OC	
1	0.037807	0.049819	0.000584
2	0.018904	0.031137	0.000146
3	0.037807	0.049819	0.000584
4	0.018904	0.046343	0.000146
5	0.056711	0.007846	0.001313
6	0.018904	0.030658	0.000146
7	0.056711	0.02588	0.001313
8	0.094518	0.025225	0.003648
9	0.056711	0.079711	0.001313
10	0.017013	0.031631	0.000118
11	0.056711	0.021899	0.001313
12	0.056711	0.035585	0.001313
13	0.075614	0.056936	0.002335
14	0.037807	0.027298	0.000584
15	0.094518	0.02588	0.003648
16	0.075614	0.026221	0.002335
17	0.037807	0.049819	0.000584
18	0.037807	0.032668	0.000584
19	0.037807	0.023723	0.000584
20	0.056711	0.132851	0.001313
21	0.037807	0.019928	0.000584
22	0.018904	0.02491	0.000146
23	0.037807	0.044284	0.000584
24	0.037807	0.013285	0.000584
25	0.037807	0.086642	0.000584

Table 4. *Optimal Combination from DEAR Methodology*

	L1	L2	L3	L4	L5	Max-Min
Frequency	0.000554571	0.000992	0.000403	0.001022	**0.0018097**	**0.001407**
amplitude	**0.001838841**	0.001547	0.001022	0.000496	0.0006366	0.001343
duty cycle	**0.001307912**	0.000701	0.001022	0.001104	0.0007881	0.000607
SOD	0.000496195	0.001395	0.001226	**0.001401**	0.0012259	0.000905
speed	0.001079954	0.000642	**0.001605**	0.001255	0.0008172	0.000963

The main effects plot is used to analyze the significance of the input process factors on performance measures in any process. The deviation of response line from the horizontal line indicates the most significance nature on machining characteristics. In the present study, the main effects plot has been developed using Minitab software package as shown in Figure 1. From the main effects plots, it has been revealed that the frequency has highest contributing nature on material removal rate and over cut while machining leather specimens using LBM process.

Figure 1. *Effects of Process Parameters on Performance Measures*



Conclusion

In the present study Taguchi- DEAR based multiple response optimization methodology has been performed to compute optimal process factors on machining leather specimens using LBM process. From the experimental investigation, the following conclusions have been obtained.

(i) The optimal process parameters of AWJM process has been found as 20KHz (F), 3V (A), 18% (DF), 16mm (SD) and 600 mm/min (V_C) among the chosen parameters and their ranges.
(ii) Frequency has higher influence on determining the performance measures owing to its importance on determining plasma energy in LBM process.Source: radicalcartography.net, 2013

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