OPTIMIZATION OF CO_2 LASER MACHINING PROCESS FOR ARMORED STEEL

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ABSTRACT

The current investigation presents a study of laser machining for armored steel (500HB). The effect of working parameters, laser power (P), gas pressure (GP) feed rate (F) and motor speed (S) on the process of grooving machining. The groove dimensions depth of cut (DC), upper cut width (UC) and lower cut width (LC), root round error and metal removal rate (MRR) were studied under different working parameters. For this purpose a test rig was designed and fabricated. The experimental results are mathematically modeled by response surface methodology (RSM). The results showed that, depth of groove and width of cut and roundness error increase with the increasing the Laser power and gas pressure, but MRR decrease with the increase of feed rate. The motor speed has a moderate effect on the machining process for steel under investigation. A trail has been given to optimize the process characteristics under different working conditions.

Keywords: Armored steel alloy, Material removal rate (MRR), Response surface methodology (RSM).

1- INRODUCTION

The laser is undoubtedly the most critical component of any machining system. As a kind of light, laser possesses certain wavelike properties, but also, it can behave as if composed of individual particles, called photons, which have a discrete amount of energy or quantum [1]. Laser light differs from ordinary light in that it consists of photons that are all at the same frequency and phase, called coherence. Basically, the mechanisms required to produce laser light are: stimulation, amplification and population inversion. The coherence of laser light is based upon the principle that photons of light can stimulate the electrons of atoms, thus, they emit photons of the exact same frequency. Stimulation occurs when a photon passes close to the electron, and can be explained using quantum mechanics. Davima, P. [2], introduced some experimental studies on CO_2 laser cutting quality of polymeric materials In generally, it is evident that the HAZ increases with the laser power and decrease with the cutting velocity. Nagels, E. [3], focused on the influence of sulphur content in steel on oxygen assisted CO_2-laser cutting. Sulphur is a highly surface active element that lowers the surface tension and the viscosity of a steel melt. Sulphur is known to have a large effect on laser welding due to Marangoni surface convection. Experiments show that steel with high-Sulphur content has a larger process window and consequently can support a more stable cutting process. De- Keuster, J. [4], referred to the applicability for monitoring purposes of two types of sensors is investigated: the microphone and the photodiode. For both types, correlation between the sensor output and the cut quality is investigated. Besides contour cutting, piercing is also covered in the study. The full break-through of the piercing can be monitored by both sensors. Furthermore quantitative relations between cut quality parameters and photodiode signal parameters could be determined. Ho ,C.Y. and Wen, M.Y.[5], investigated Temperature history for cutting of ceramics preheated by a CO_2 laser is analytically. During the cutting of ceramics the laser is utilized to maintain the work piece at a specified range of temperature where the yield strength of ceramics can be reduced below the fracture strength, changing the material deformation behavior from brittle to ductile and enabling the use of a single point cutting tool to remove material at rates approaching those of metal cutting. Therefore accurate temperature analysis is needed to obtain high efficiency and quality of cutting of ceramics. Assuming the system to be two-dimensional for sufficiently high velocity of rotation (RPM) and the heat flux generated by cutting to be negligible in the process of cutting ceramics, the thermal model accounting for temperature history is developed. The results calculated by this model agree with the experimental data. . The temperatures increase with the increasing laser power, decreasing feed rate and beam diameter. Yilbas,B.S. and Arif ,A.F. [6], studied Cemented carbide cutting tool: Laser processing and thermal stress analysis. It is found that temperature gradient attains significantly high values below the surface particularly for titanium and tantalum carbides, which in turn, results in high thermal stress generation in this region. SEM examination of laser treated surface and its cross section reveals that crack initiation below the surface occurs and crack extends over the depth of the laser treated region. Chwan-Huei , T. and Bor-Chang Lin, has studied Laser cutting with controlled fracture and pre-bending applied to LCD glass separation It was found that the unstable fracture growth mode can be divided into three types: delay breaking, in which the blind-crack is formed during the cutting process and complete separation, occurs at the end of the cutting process; nick breaking, in which the through-cut of substrate grows stably following the moving laser; and ahead breaking, in which the unstable fracture occurs in the middle of the cutting path. The surface quality along the cutting path is very good, and is better than that from the diamond scribing and breaking. The pre-bending operation can enhance the cutting speed that can be attained [7]. Dhupal, D, et al. [8], investigated Pulsed Nd: YAG laser turning of micro-groove on aluminum oxide ceramic (AL_2O_3). It was observed that The MRR decreases as the feed rate is increased and this may be explained in terms of increase in feed rate causes slower rate of laser beam interaction with work piece, so material removal rate is slow and the MRR becomes negative. The aim of the work is to study the effect of the working parameters such as laser power (P), gas pressure (GP), feed rate (F) and motor speed (S) on the process characteristics such as metal removal rate (MRR), upper cut width (UC), lower cut width (LC), depth of cut and root roundness error (RE).

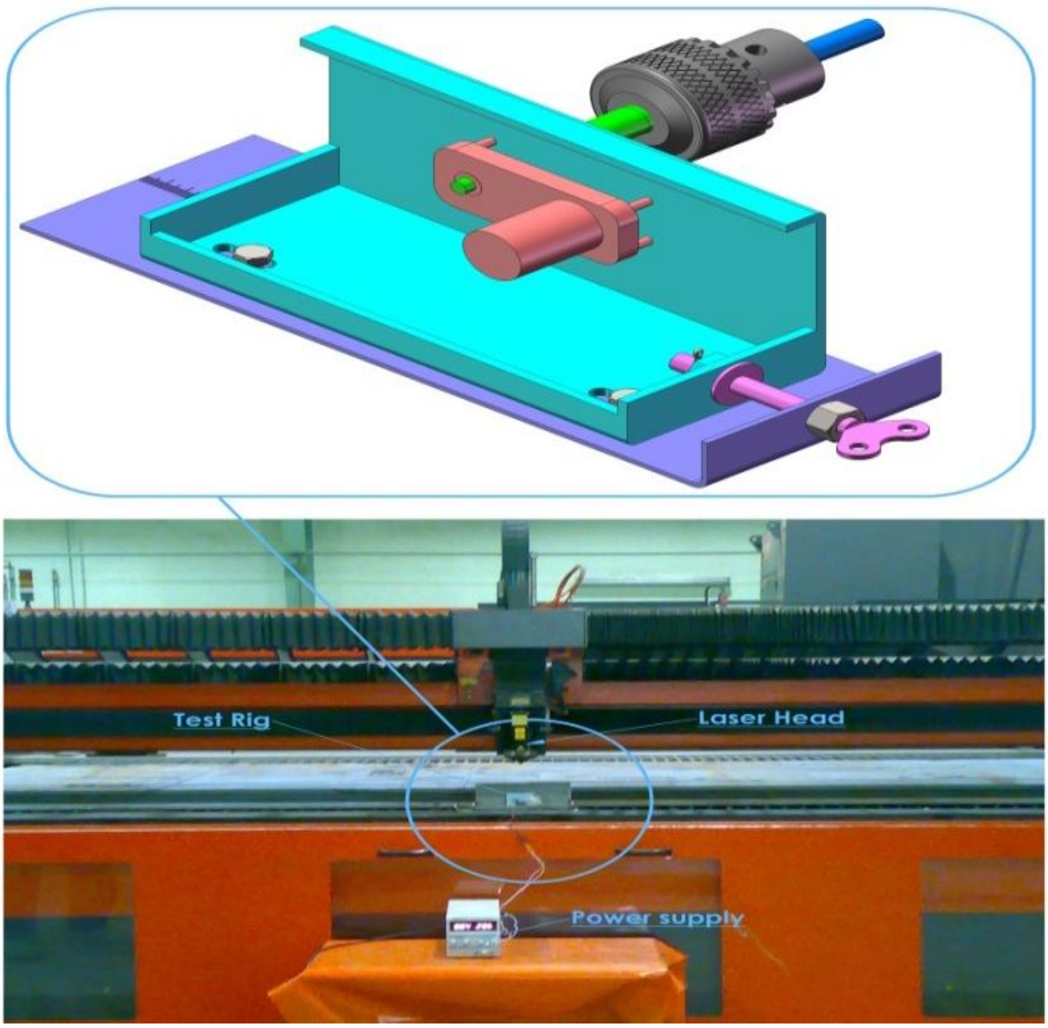

Fig. (1) CO_2 Laser machine and test rig

3-Experimental work based on response surface methodology:

3.1. Material

Micro – grooving operation was performed on cylindrical armored steel work piece of size of 12 mm diameter and 50mm length. The following table shows the chemical composition of armox steel.

Table 1: Chemical composition of armox steel

C%	Si %	Mn %	%P	S %	Cr %	Ni%	Fe %
0.32	0.28	0.81	0.0073	0.0005	0.46	0.87	Rest
Mo %	%Al	Co %	Cu %	V %	%W	Sn %	
0.34	0.47	0.017	0.21	0.34	0.005	0.001	

3.2. Metal Removal Rate.

The specimen were weighted before and after machining using a precise electrical balance

The metal removal rate was specified using the following equation:

$$MRR = [(W_b - W_a) / t] \quad (1)$$

Where:

MRR Metal removal rate (g/min).

W_b : Weight for specimen before machining (g).

W_a: Weight for specimen after machining (g).

t : laser turning time for each experiment (min).

3.3. Upper cut (UC), lower cut (LC) and depth of cut (DC).

Upper cut, lower cut and depth of cut was measured using Optical measuring microscope each value was obtained by averaging five measurements at various positions of the work piece surface for each machining condition

3.4. Roundness error (RE)

Roundness error was measured using Roundness testing machine.

The following steps were used to design experimental:

1- Primary experimental were performed to find the affective rang of the process parameters as shown in Table (2).
2- The response surface methodology (RSM) was used to design experimental program.
3- The working parameters by RSM were conducted experimentally.
4- The responses under consideration were feeding to the model.
5- Then the optimization working parameters can be determined.

3.5. Mathematical modeling

The response surface methodology (RSM) is a useful tool to find the relationship between various process parameters and the machining criteria. Furthermore; these models can be used to explore the effect of these parameters on the response criteria of the machining process. The objective of the response surface methodology is to develop the mathematical link between the response surface and the predominant machining parameters. Through the use of the design of experiments and applying regression analysis, the modeling of the desired response to several independent input variables can be gained. Table (3) shows the arrangement and the results of the 30 experiments carried out in this work, based on the central composite second-order rotatable design. These results are used to deduce the mathematical models, which is one of the main objectives of this work. If all variables are assumed to be measurable, the response surface can be expressed as follows

$$Y_u = f\,(X1, X2, X3 \ldots X_k) \pm \xi \qquad (2)$$

Where y_u is the corresponding response function (or response

surface), X1, X2, X3…X_k are coded values of the machining process Parameters and ξ is the fitting error of the u^{th} observations.

In this study, for four variables under consideration {Power (p), Gas Pressure (GP), Feed rate (*F*), and Motor Speed(*S*),}, a second-order polynomial regression model, which is called quadratic model, is proposed [9]. The quadratic model of Yu as follows:

$$Y_u = b_o + \sum_{i=1}^{n} b_i X_{iu} + \sum_{i=1}^{n} b_{ii} X_{iu}^2 + \sum_{j>i}^{n} b_{ij} X_{iu} X_{ju} + \varepsilon \qquad (3)$$

The coefficient b_o is the free term, the coefficients b_i are the linear terms, the coefficients b_{ij} are the interaction terms, and the coefficients b_{ii} are the quadratic terms. Using the results presented in table (3), the full form of the derived models can be presented. The mathematical models of metal removal rate (MRR), depth of cut (DC), upper cut (UC), lower cut (LC) and round error (RE) can be expressed as follows:

$$MRR = +0.041 + 9.333\times10^{-4}P + 0.000\,(GP) - 1.950\times10^{-3}F + 1.150\times10^{-3}S - 3.044\times10^{-4}P^2 - 8.294\times10^{-4}(GP)^2 - 2.855\times10^{-3}F^2 - 5.919\times10^{-4}S^2 + 1.600\times10^{-3}P(GP) + 5.750\times10^{-4}PF - 8.625\times10^{-4}PS - 3.950\times10^{-3}(GP)F + 5.375\times10^{-4}(GP)S + 1.263\times10^{-3}FS \qquad (4)$$

$$\text{Depth of cut} = +0.82 + 0.22P + 0.014\,(GP) + 0.015F + 2.205\times10^{-3}S - 0.056P^2 - 0.027\,(GP)^2 - 0.023F^2 - 0.021S^2 - 6.063\times10^{-5}P(GP) - 6.612\times10^{-3}PF + 3.563\times10^{-3}PS - 6.250\times10^{-7}(GP)F - 6.250\times10^{-7}(GP)S + 7.063\times10^{-3}FS \qquad (5)$$

$$\text{Upper cut} = +0.41 + 0.022P + 9.292\times10^{-3}(GP) - 5.458\times10^{-3}F - 0.033S + 3.517\times10^{-3}P^2 + 0.016\,(GP)^2 + 0.015F^2 + 9.61\times10^{-3}S^2 + 5.438\times10^{-3}P(GP) + 0.021PF - 3.812\times10^{-3}PS - 1.437\times10^{-3}(GP)F + 0.014\,(GP)S - 1.875\times10^{-3}FS \qquad (6)$$

$$\text{Lower cut} = +0.23 + 0.015P + 4.708\times10^{-3}(GP) - 1.708\times10^{-3}F - 4.042\times10^{-3}S + 0.013 + 0.015P^2 + 8.917\times10^{-3}(GP)^2 - 3.708\times10^{-3}F - 1.708\times10^{-3}S^2 - 3.563\times10^{-3} + 0.015P(GP) - 2.313\times10^{-3} + 0.015PF + 4.437\times10^{-3} + 0.015PS + 7.812\times10^{-3}(GP)F - 4.688\times10^{-3}(GP)S - 2.438\times10^{-3}FS \qquad (7)$$

$$\text{Roundness} = +5.34 - 0.48P - 0.35(GP) + 10.84F - 0.13S + 2.07P^2 + 1.62(GP)^2 + 18.55F^2 + 0.65S^2 + 0.29P(GP) - 0.43PF + 0.16PS + 5.12(GP)F + 2.61(GP)S - 8.70FS \qquad (8)$$

Table 2: Coded and actual values of the input parameters

Input parameters	Symbols	Levels					Output parameters
		-2	-1	0	+1	+2	
Power ,Watt, (A),	X1	1000	1500	2000	2500	3000	MRR, (g/min) RE(μm) LC, UC &DC, (mm)
Gas pressure, bar, (B) [O2].	X2	0.2	0.3	0.4	0.5	0.6	
Feed rate, mm/min,(C)	X3	200	250	300	350	400	
Motor speed , rpm,(D)	X4	10	15	20	25	30	

Table 3: Experimental design matrix and experimental results

Exp. No.	Input process parameters				Experimental results				
	Power Watt	Gas pressure Bar	Feed rate mm/min	Motor speed R.P.M	MRR g/min	DC mm	UC Mm	LC mm	RE μm
1	1500	0.3	250	15	0.358755	0.44816	0.491074	0.230695	16.407
2	2500	0.3	250	15	0.351171	0.89325	0.489822	0.263573	17.039
3	1500	0.5	250	15	0.395005	0.47629	0.473656	0.240989	3.952
4	2500	0.5	250	15	0.451421	0.92113	0.494156	0.259615	-0.176
5	1500	0.3	350	15	0.361995	0.47813	0.441407	0.221157	47.756
6	2500	0.3	350	15	0.377411	0.89677	0.524155	0.244783	44.711
7	1500	0.5	350	15	0.240245	0.50625	0.418241	0.262699	49.841
8	2500	0.5	350	15	0.319661	0.92465	0.522741	0.272073	49.94
9	1500	0.3	250	25	0.362995	0.43132	0.405073	0.227989	29.674
10	2500	0.3	250	25	0.320911	0.89066	0.388573	0.278615	28.972
11	1500	0.5	250	25	0.420745	0.45944	0.443655	0.219531	21.717
12	2500	0.5	250	25	0.442661	0.91854	0.448907	0.255905	24.159
13	1500	0.3	350	25	0.416755	0.48954	0.354656	0.208699	24.236
14	2500	0.3	350	25	0.397671	0.92243	0.422156	0.250073	19.857
15	1500	0.5	350	25	0.316505	0.51766	0.38749	0.231489	38.722
16	2500	0.5	350	25	0.361421	0.95031	0.476742	0.258611	37.487
17	1000	0.4	300	20	0.183418	0.15824	0.375624	0.252	13.597
18	3000	0.4	300	20	0.72075	1.03598	0.463624	0.312	12.994
19	2000	0.2	300	20	0.381084	0.68745	0.449416	0.254792	12.842
20	2000	0.6	300	20	0.381084	0.74345	0.486584	0.2736624	10.114
21	2000	0.4	200	20	0.33908	0.69824	0.474916	0217124	56.864
22	2000	0.4	400	20	0.26108	0.75998	0.453084	0.210292	101.542
23	2000	0.4	300	10	0.367584	0.73504	0.51	0.229792	7.214
24	2000	0.4	300	30	0.413584	0.74387	0.378	0.213624	8.028
25	2000	0.4	300	20	0.42	0.83947	0.4	0.23	5.342
26	2000	0.4	300	20	0.42	0.83	0.405679	0.235556	5.312
27	2000	0.4	300	20	0.399999	0.79947	0.42	0.24	5.322
28	2000	0.4	300	20	0.42	0.80947	0.397658	0.225678	5.332
29	2000	0.4	300	20	0.409888	0.83947	0.4	0.23	5.342
30	2000	0.4	300	20	0.415678	0.81947	0.41	0.21	5.36

4. Results and Discussion

4.1. Effect of Machining Parameters on Metal Removal Rate (MRR).

MRR in the Laser turning process is a vital and significant factor due to its effect on the industrial economy of machining process.

The following symbols are used during the current discussions.

X1=A=Power, (Watt) X2=B= Gas pressure, (bar)

X3=C=Feed rate, (mm/min) X4=D= Motor speed, (r.p.m)

4.1.1. Effect of Laser power on MRR.

Fig. 3 (a, b and c) illustrate the effect of the laser power on the MRR at various values of feed rate, Motor Speed and Gas pressure. The non linear variation of the MRR with laser power has been recorded. Generally, the MRR increases as the laser power is increased and this may be explained in terms of heat and energy generated the laser power has been recorded , the MRR increases as the laser power is increased and this may be explained in terms of heat generated during the laser process.

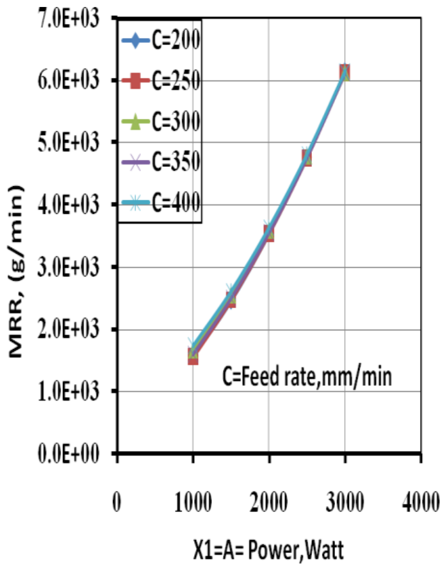

Fig. 2 (a)

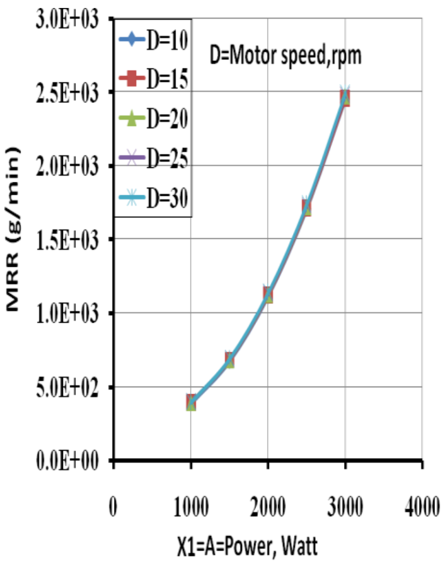

Fig. 2 (b)

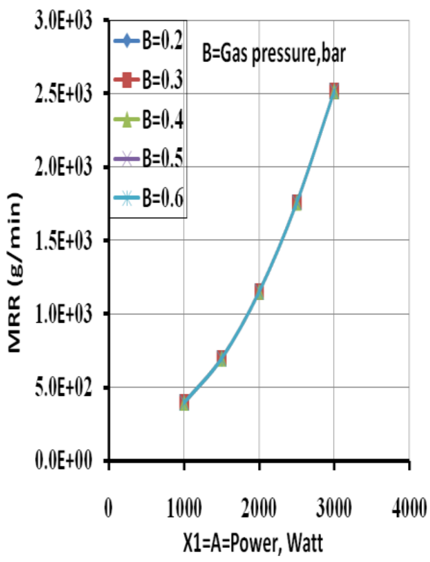

Fig. 2 (c)

Fig. (2). Effect of laser power on the MRR at a various (a) feed rate, (b) motor speed, and (c) gas pressure.

4.1.2. Effect of feed rate on MRR.

Fig. 3 (a, b) illustrates the effect of the feed rate on the MRR at various values of Motor Speed. The non linear variation of the depth of cut with feed rate. Generally, the MRR decreases as the feed rate is increased and this may be explained in terms of increase in feed rate causes slower rate of laser beam interaction with work piece, so material removal rate is slow and the MRR becomes negative.

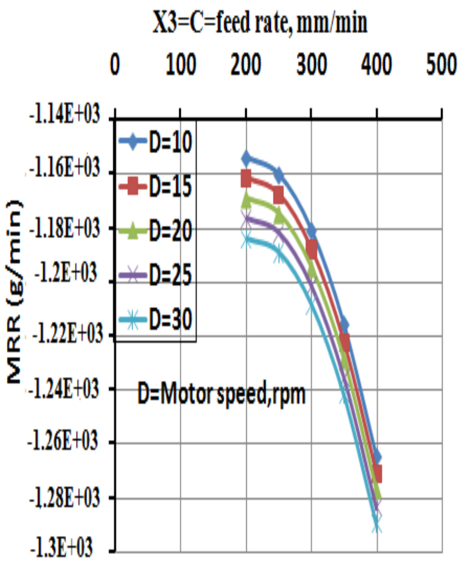

Fig. (3) Effect of feed rate on the MRR at a various motor speed.

4.1.3. Effect of gas pressure on MRR.

Fig. 4 (a, b) illustrate the effect of gas pressure on the MRR at various values of feed rate and Motor Speed. The linear variation of the MRR with the gas pressure has been recorded. Generally, the MRR increases as gas pressure is increased and this may be explained because laser energy melts the target material and the gas jet blows the molten material away.

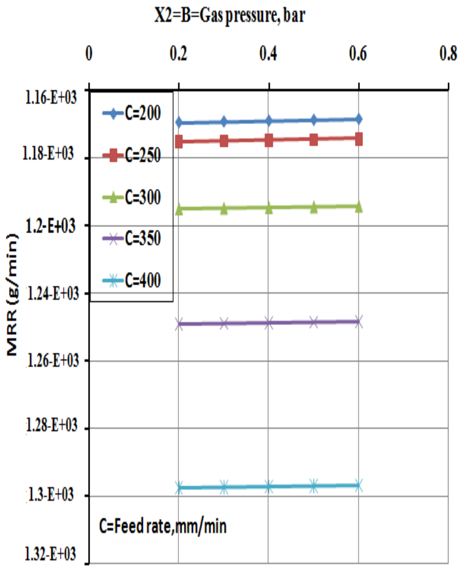

Fig. 4 (a)

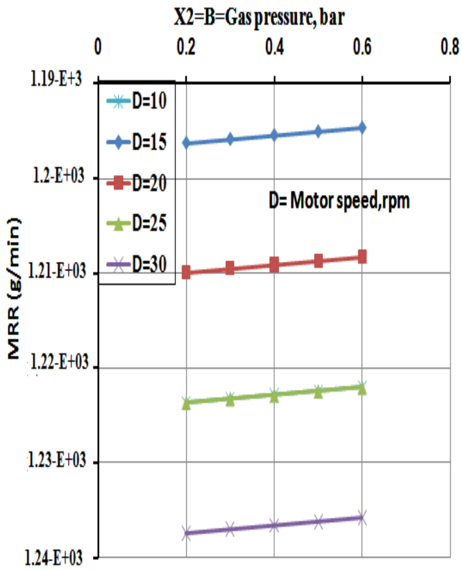

Fig. 4 (b)

Fig. (4) Effect of gas pressure on the MRR at a various (a) feed rate, (b) motor speed.

Table (4) shows the constraints parameters and optimum parameters.

Table 4: Constraints parameters and Predicted optimum parameters for specimens machined by Laser turning process.

Parameter	Constraints parameters	Optimum parameters
Power, (P), Watt	1000 – 3000	3000
Gas Pressure, (*GP*), bar	0.2 – 0.6	0.6
Feed rate (*F*)mm/min	200 – 400	200
Motor Speed(*S*), r.p.m	10 – 30	10

5. Confirmation Experiments

(Table.5) indicates the predicted optimum responses, experimental responses and error (%).

Table 5: Experimental validations of the developed models with optimal parameter for specimens machined by Laser turning process.

Response	Predicted optimum responses	Experimental responses	Error (%)
MRR , (g/min)	0.97717	0.91539	4.7
DC , (mm)	0.7857	0.8391	6.8
UC , (mm)	0.6186	0.6335	2.4
LC , (mm)	0.3099	0.3103	1.3
RE, (µm)	10.3273	10.7301	3.9

6- Conclusions

1-The Laser turning process has proved its adequacy to machine armored steel under acceptable responses and (error %) was not more than 6.8%.

2-The metal removal rate, depth of cut, upper width of cut lower width of cut and roundness error increases with the increase parameters as Laser power and gas pressure, but MRR decrease with the increase of feed rate, while The motor speed has a moderate effect.

3-The optimal process parameters are Laser power 3000 watt, gas pressure 0.6 bar, feed rate 200 mm/min and speed rate 10 rpm for achieving acceptable metal removal rate and of the depth of cut, upper width cut, lower width cut and round error.

REFERENCES

1. EL- Hofy, H., "Advanced machining process, nontraditional and hybrid machining processes", PP 8-12, 2005.

2. Davima, P., Barricasa, N., and Oliveira, C., "Some experimental studies on CO_2 laser cutting quality of polymeric materials", journal of materials processing technology, Vol 1 9 8, PP 99–104, 2008.

3. Nagels , E.," The influence of sulphur content on the quality of laser cutting of steel", Journal of Materials Processing Technology, Vol 194, PP 159–162, 2007.

4. De Keuster , J.," Monitoring of high-power CO_2 laser cutting by means of an acoustic microphone and photodiodes" Int. J. Adv Manuf. Techno, Vol 35, PP 115–126, 2007.
5. Ho ,C.Y. and Wen, M.Y., " Temperature history for cutting of ceramics preheated by a CO_2 laser" Journal of Materials Processing Technology 192–193, PP 525–531, 2007.
6. Yilbas, B.S. and Arif ,A.F., " Cemented carbide cutting tool: Laser processing and thermal stress analysis" Applied Surface Science, Vol 253, PP 5544–5552, 2007.
7. Chwan-Huei , T. and Bor-Chang Lin," Laser cutting with controlled fracture and pre-bending applied to LCD glass separation",Int. J. Adv Manuf. Technology, Vol 32, pp 1155–43, 2007.
8. Dhupal, D., Doloi, B. and Bhattacharyya, B.," Pulsed Nd: YAG laser turning of micro-groove on aluminum oxide ceramic (Al_2O_3)", International Journal of Machine Tools & Manufacture, Vol 48, PP 236–248, 2008.
9. Montgomery, D.C., "Design and analysis of experiments". John Wiley, New York. 2001.

NOMENCLATURES

RSM	Response Surface Methodology
ANOVA	Analysis of Variance
MRR	Metal Removal Rate
DC	Depth of Cut
UC	Upper Cut
LC	Lower Cut
RE	Roundness Error
SEM	Scanning Electron Microscope
HAZ	Heat Affected Zone
LBM	Laser Beam Machining
LCD	Liquid Crystal Display

عملية التشغيل الامثل باشعة ليزر ثانى اكسيد الكربون للصلب المدرج

تحت إشراف

الأستاذ الدكتور / وجيه وديع مرزوق – أستاذ متفرغ بقسم هندسة الإنتاج والتصميم – كلية الهندسة–جامعة المنيا

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الدكتور / وسام محمد فاروق – مدرس بقسم الهندسة الميكانيكية بهندسة بنها

الملخص العربى

يقدم هذا البحث دراسة عن اختيار ظروف التشغيل المثلى باستخدام اشعة الليزر لسبيكة الصلب المدرج ذات الصلادة العالية والتى تبلغ٥٠٠ برنل. استخدم نسق الاستجابة السطحى لتحليل وتحديدالظروف المثلى لخراطة هذه السبيكة باشعة الليزر . تم تقييم معايير اداء العملية بتحديد كلا من العرض العلوى والعرض السفلى للقطع وعمق القطع ومعدل ازالة الصلب ونسبة الخطا فى الاستدارة.تم توظيف نسق الاستجابة السطحى لاستنتاج نماذج رياضة للربط بين معايير الاداء ومتغيرات التشغيل المختلفة مثل طاقة الليزر وضغط الغاز ومعدل التغذية وسرعة الموتور.اختبرت مصداقية النماذج الرياضية باستخدام التحليل التابينى. تم تصميم تجهيزة معملية لاجراءالتجارب على ماكينة القطع بالليزر، وبعد تشغيل العينات باستخدام ماكينة الليزر تم وزن العينات قبل وبعد التشغيل لتحديد معدل ازالة الصلب.كما تم دراسة ابعاد القطع بواسطة الميكرسكوب الالكترونى لقياس ابعاد االقطع (العرض والعمق)، وتم قياس نسبة الخطا فى الاستدارة. اثبتت عملية التشغيل باشعة الليزر انها طريقة كافية لتشغيل الصلب المدرج بحيث تحقق نسبة مقبولة من معدل ازالة الصلب وابعاد قطع مقبولة و نسبة استدارة جيدة للسطح المشغل. معدل ازالة السبيكة يزداد بصورة عامة بازدياد قيمة كل من طاقة الليزر، ضغط الغاز ، معدل التغذية وكذلك سرعة الموتور لها تاثير متوسط على معدل ازالة السبيكة. صممت الدراسة للحصول على اقصى معدل ازالة واقصى عمق قطع واقصى عرض للقطع واقل نسبة خطا فى الاستدارة تحت ظروف تشغيل مختلف.