ISSN 2812-9717
https://doi.org/10.46793/tribomat.2022.011

Determination of the optimal mode of laser surface marking of aluminium composite panels with CO_2 laser

Emil YANKOV [1],*, Roussi MINEV [1], Nikolay TONCHEV [2], Lyubomir LAZOV [3]

[1] University of Ruse "Angel Kanchev", Ruse, Bulgaria
[2] University of Transport, Sofia, Bulgaria
[3] Rezekne Academy of Technologies, Rēzekne, Latvia
*Corresponding author: eyankov@uni-ruse.bg

Keywords

aluminium composite panel
CO_2 laser
surface
optimisation model
laser marking

History

Received: 27-07-2022
Revised: 15-08-2022
Accepted: 19-08-2022

Abstract

This research examines an approach for finding the optimal modes of laser treatment with CO_2 laser on advertisement boards made of aluminium composite panels. To achieve the optimal area of the processing mode, an experimental methodology has been developed and an experiment has been planned for finding the limits at the given parameters of the speed and power to obtain an optimisation model. The optimal results are obtained at speeds from 100 to 200 mm/s along the *x* and *y* operative axes, as well as the power limits from 5 to 7.5 W to obtain a clear and well-defined image. The defined theoretical mode, obtained because of multicriteria optimisation, is implemented in practice. It is defined as having the relatively best quality image obtained in the shortest time.

1. Introduction

In recent years, composite materials combined with various technological and physicomechanical properties are widely used in mechanical engineering, construction, production of information panels, signs and more. Materials that are applied or glued to the information boards are often used to present information. This, of course, is associated with additional costs of materials and technological modes. Most of them are obtained from chemical technologies – chemical dyes. Such are, for example, inks and paints, which are difficult to degrade, and their extractive waste is harmful to the environment. Therefore, in recent years, solutions are being sought for new technologies and processes that can replace existing ones. In recent years, the application of lasers in various industries is increasing, such as mechanical engineering, energy and electronics [1,2]. Now, it has been widely used in research in the field of laser printing of metallic and non-metallic materials [3-9]. This will create a strong development of laser technology in the next few years in the field of billboards and materials, replacing classic production technologies. Like any new technology, it is necessary to assess productivity and the necessary resources such as capacity equipment for the quality of the product, which is directly related to the economic effect of each company or industry.

In the 90s of the previous century in metallurgical practice [10], there has been approved the use of the model experiment on the specific physicochemical formulation of the target process. In the development of a multicomponent alloy, the optimisation problem is formulated by determining the optimal technological mode, ensuring the specified quality.

Regardless of the universality of the considered methods, each specific problem requires its own effective methods, in which case there is a need to develop new algorithms and modification of existing ones, which eliminates the observed shortcomings [11-13].

Because the experimental approach does not use information about the mechanism of ongoing phenomena [14,15], the numerical procedure used as a tool in this article turns out to be very universal. Each case under consideration can be described with the same structure, but with different coefficients. They form the mathematical model of the examined phenomenon (process), which can be examined from different points of view: technological, informational, organisational, etc. [16]. The aim of this research is to determine, after an analysis of controlled magnitudes, a mode corresponding to an optimal compromise solution in a case study, similar to multi-criteria support for decision-making by shifting restrictions [17,18].

2. Problem statement

To form a quality image, it is necessary to vary the technological parameters of the laser system [19-22]. For the purposes of the research, a CO_2 laser with technical capabilities of a speed of movement of 500 mm/s along the *x* and *y* axes, and regulated laser power up to 50 W in step 0.05 W was used. This is a previous technological procedure for the implementation of new equipment with unidentified processes. Image quality is determined by an experiment, most often planned. Based on the experiment, the technological capabilities of the CO_2 laser are determined compared to the controlled magnitudes: speed, power and constant focus of the spot 50.8 mm. The necessary information for the analysis of the selected technological process is contained in the experimentally obtained values indicated in Table 1.

Table 1. Experimentally results and experimental plan

Experimentally obtained values for the regulated control parameters				Experimental plan	
Power, % (X_1)	Speed, mm/s (X_2)	Time, s (y_1)	Quality, % (y_2)	Mp =	
10	100	494.4	96.63	−1	−1
20	100	508.2	86.21	1	−1
30	100	514.8	74.37	−1	1
10	200	454.8	62.56	1	1
20	200	497.4	68.95	1	0
30	200	509.4	72.11	−1	0
10	300	454.8	54.05	0	1
20	300	513.6	56.34	0	−1
30	300	546.0	58.44	0	0

In the specified interval with the two variables, an experimental plan is drawn up, as described in Table 1. As can be seen from Table 1, the variable power is 10 % (5 W), 20 % (10 W) and 30 % (15 W), and the variable speed of operation on the *x* and *y* axes is 100 mm/s, 200 mm/s and 300 mm/s. Parameter Mp = is the encoding of the experimental plan, with the left vertical column corresponding to the power data in the encoded form – 1, 0 and 1. The right column is the speed data in the encoded form – 1, 0 and 1. For each experimental combination of control parameters in Figure 1 two of the controlled quantities are defined. As a result of the conducted experiment for y_1, the reporting time for manufacturing was chosen, and for y_2 the quality of the obtained trace was evaluated by comparative analysis of the digital image with the obtained image from the laser marking in %.

Figure 1. Results of test experimental modes

The experimental plan (Table 1) is embedded in an information matrix in a way that is expected to obtain the coefficients of the regression model. Since we determine the structure of the model:

$$F(X_1, X_2) = B_0 + B_1 X_1 + B_2 X_2 + \\ + B_3 X_1 X_2 + B_4 X_1^2 + B_5 X_2^2, \qquad (1)$$

the cited plan Mp occupies the second and third columns in the information matrix **F**.

For the methodical purpose of obtaining the coefficients of the regression model, an information matrix related to Equation (1) is indicated. The information matrix based on the experimental plan from Table 1 has the form:

$$\mathbf{F} = \begin{pmatrix} 1 & -1 & -1 & 1 & 1 & 1 \\ 1 & 1 & -1 & 1 & 1 & -1 \\ 1 & -1 & 1 & 1 & 1 & -1 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & -1 & 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 & 1 & 1 \\ 1 & 0 & -1 & 0 & 1 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}.$$

The first column of the information matrix is composed of ones, because the value of the free member of the model is unknown. The remaining columns are calculated based on the values of X_1 and X_2 according to the selected structure. According to the performed Mp plan for each combination of the variables X_1 and X_2, the experimental value of the studied quantity is determined. This is how the vector **Fst** is formed. The **Fst** vectors are two, one is for quality and the other is for operation time. The values of these vectors are indicated in Table 1. Each experimental combination of the control parameters from Table 1 corresponds to each of the quality indicators. The information matrix has 9 rows and accordingly the vector of experimental values **Fst** also consists of nine values. $\mathbf{F}^T$ is a transposed information matrix **F**. The coefficients of the regression model are determined based on the following matrix calculation:

$$\mathbf{C} = (\mathbf{F}^T\,\mathbf{F})^{-1}\,\mathbf{F}^T\,\mathbf{Fst}. \qquad (2)$$

To conduct a planned experiment, a series of experiments were conducted in which a specific image was selected related to the face of the famous Bulgarian scientist Prof. Lyubomir Kalev on pieces of aluminium composite panel.

From the obtained results of different modes, shown in Figure 1, it can be seen how the changed parameters of power and speed affect the quality image during marking. The resulting images are captured with a digital camera. The resulting digital images are compared to the original photo using the Adobe Photoshop software product. It compares the power of contrast and the power of black and white. The difference is reported in percentages (%) and filled in Table 1. The bounds of the planned experiment were determined experimentally: speed from 100 to 300 mm/s, power from 10 to 30 % at a constant frequency of 20 kHz and a resolution of 600 dpi. The material consists of 7075 aluminium alloy foil with a thickness of 0.25 mm on both outer sides. The intermediate layer is made of sheet polyethylene with a thickness of 2.5 mm. The chemical composition of 7075 aluminium alloy roughly includes 5.6 – 6.1 % zinc, 2.1 – 2.5 % magnesium, 1.2 – 1.6 % copper, and less than a half percentage of silicon, iron, manganese, titanium, chromium and other metals.

3. Results of the research and determination of the compromise solution

To form the image it is necessary to vary the technological marking parameters. The image quality is determined based on an experiment which determines the technological capabilities of the equipment. In Table 2 the results from the coefficients and the respective checks obtained for the two examined quantities are given.

Table 2. Coefficients of the regression models for the studied quantities

Parameter coefficient	Quality	Operation time
B_0	+67.9	+493.889
$B_1\,X_1$	−1.4	+27.667
$B_2\,X_2$	−14.74	−0.5
$B_3\,X_1\,X_2$	+6.625	+17.5
$B_4\,X_1^2$	–	−10.33
$B_5\,X_2^2$	+3.099	+18.1667
R	0.9638	0.9963
$F_{calc} > F_{table}$	13.0521 > 6.3883	80.1359 > 9.0135

The last two lines of Table 2 show the model checks. The multiple correlation coefficient *R* for both models is extremely high, which is proof of the adequacy of the models. Scanning the regression models with structure and coefficients shown in Table 2 is performed in the interval (– 1; 1) with a certain step. In this case, a bi-dimensional space formed by the two technological parameters of variation and the two studied quantities is the object of research.

The values in Table 2 are obtained by performing the matrix calculations from Equation (2). The determined values of the tested quantity as a result of this calculation form a corresponding array (y_M) at the respective (set) sampling. The optimisation problem for determining y_{Mmax} and y_{Mmin} is solved followed by the transformation of the calculated values into a uniform percentage distribution. The transformation is performed via the equation:

$$y_N = \frac{y_M - y_{Mmin}}{y_{Mmax} - y_{Mmin}}\,100\ \%. \qquad (3)$$

When scanning the investigated quantities in the defined area (– 1; 1) with a certain step, their minimum and maximum value can be determined (Equation (3)). Through these values, each normalised value at the respective discretisation is obtained. The value Y_M from Equation (3) is the current value of the studied quantity, the one at which the normalised value is located.

Figure 2 shows the scanned normalised values of the two examined quantities. The intervals for the individual colours of the very ranking direct the decision maker to the preferred values of the examined quantity. The selected value is defined as an even percentage distribution based on the colour ranking. For it, the real value of the examined quantity in the respective dimension and the specific combination of the factors of the technological regime can be determined. After scanning the controlled quantities, it is possible to create a composite image of Figure 2, built according to the requirements of the user. In this case, maximal quality is required in minimal time.

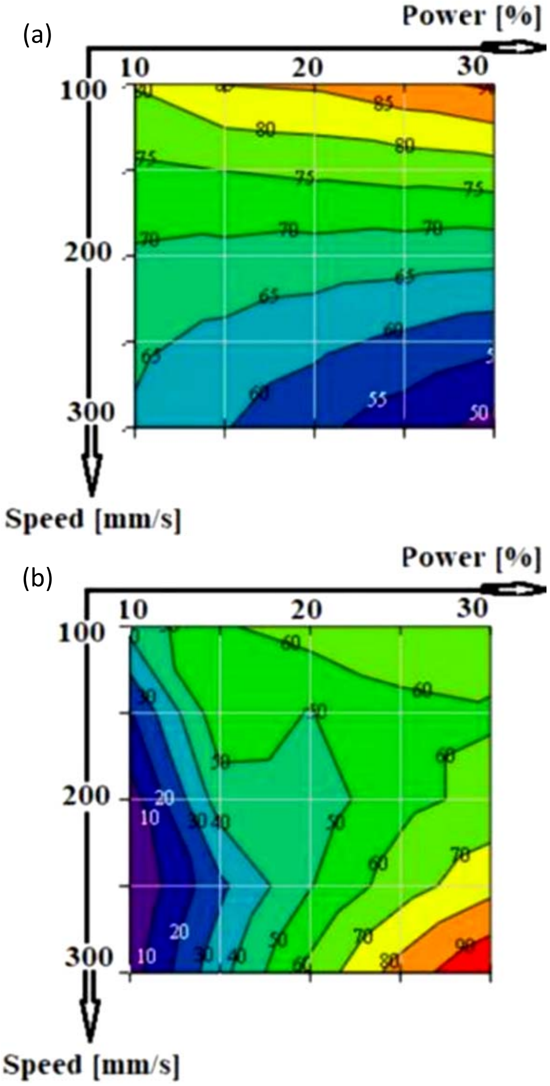

Figure 2. Normalised values as a percentage of: (a) image quality and (b) operation time

This summary image of Figures 2a and 2b is shown in Figure 3. From Figure 3, the optimal solution can be defined as relatively good, obtained in the shortest time. A colour map representing the solutions in colour code was also built. The optimal mode is obtained in the area of the yellow borders shown in Figure 3a, where the speeds can be from 100 to 200 mm/s and laser beam power from 10 % (5 W) to 12.5 % (7.5 W). In this area, the clearest image is obtained by laser marking.

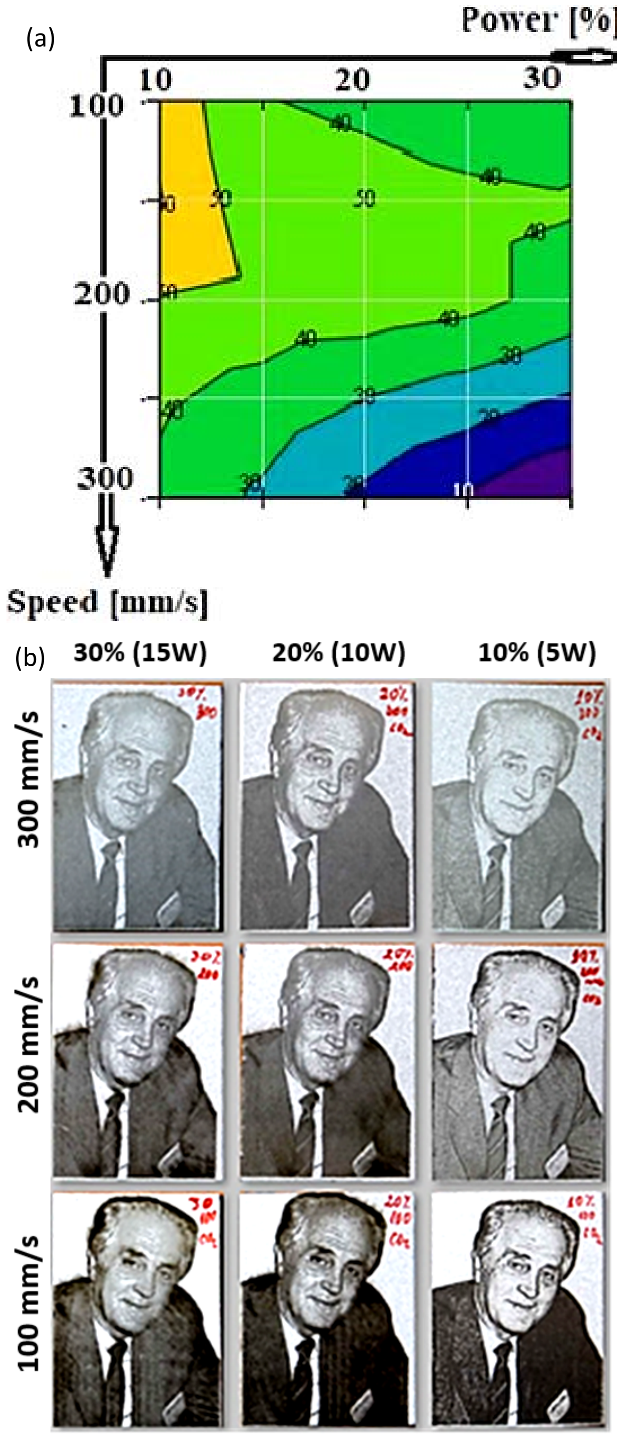

Figure 3. Result of: (a) optimal solution of the planned experiment and (b) control check by a real experiment

The planned experiment was confirmed by conducting a series of experiments proving the capabilities of the laser system in search of quality and speed. The practical equation for solving the problem is:

$$X_1 = -1 \text{ and } X_2 = -0.25, \quad (4)$$

the better solution and:

$$2X_1 = -0.25 \text{ and } X_2 = -0.25. \quad (5)$$

4. Conclusions

As a result of the performed procedure, a mode is determined, subject to multicriteria compromise optimisation, making it possible to obtain a relatively high-quality image in the shortest time. The applied methodology helped to fully assess the regimes for the implementation of new equipment with unidentified technological impact on controlled factors. The proposed calculation procedure is a tool with which it is possible to build a complete picture of the examined process. The approach creates a prerequisite in the examined applications to look for models oriented to certain savings of time, raw materials or energy.

Acknowledgement

The research and the participation in this scientific conference were implemented with the support of the: Research Fund at the University of Ruse "Angel Kanchev" by contract project FMME 2020-01 for "Research of laser and layer-by-layer technologies for obtaining prototype models" and the Research Fund at the University of Transport "Todor Kableshkov" by contract project No. 90-05-20 for "Contribution of VTU in the analysis, modeling and optimization of simulation and experimental databases".

References

[1] M. Hoseinpour Gollo, H. Moslemi Naeini, G.H. Liaghat, M.J. Torkamany, S. Jelvani, V. Panahizade, An experimental study of sheet metal bending by pulsed Nd:YAG laser with DOE method, International Journal of Material Forming, Vol. 1, No. 1, Supplement, 2008, pp. 137-140, DOI: 10.1007/s12289-008-0010-7

[2] K. Paramasivan, S. Das, D. Misra, A study on the effect of rectangular cut out on laser forming of AISI 304 plates, The International Journal of Advanced Manufacturing Technology, Vol. 72, No. 9-12, 2014, pp. 1513-1525, DOI: 10.1007/s00170-014-5695-9

[3] I. Balchev, L. Lazov, E. Teirumnieks, Precision micromachining of metals by CuBr laser, Environment. Technology. Resources, Vol. 12, No. 3, 2019, pp. 13-17, DOI: 10.17770/etr2019vol3.4178

[4] D. Klavins, L. Lazov, A. Pacejs, R. Revalds, E. Zaicevs, Research of laser marking and engraving on brass alloy 260, Environment. Technology. Resources, Vol. 12, No. 3, 2019, pp. 119-123, DOI: 10.17770/etr2019vol3.4167

[5] M. Riahi, M.H. Gollo, S.N.A. Kalkhoran, Study the effect of Gaussian and uniform heat flux on laser forming of Bi-layer sheets, Mechanics & Industry, Vol. 16, No. 4, 2015, Paper 407, DOI: 10.1051/meca/2015014

[6] L. Lazov, N.T. Dolchinkov, J.S. Ivanov, M.N. Peneva, D.A. Bojhanova, Study of laser cutting and marking on the filt with the help of a CO_2-laser, Environment. Technology. Resources, Vol. 12, No. 3, 2019, pp. 143-147, DOI: 10.17770/etr2019vol3.4202

[7] N.T. Dolchinkov, Practical research of marking and cutting of textiles with increased resistance, using CO_2 laser, Journal of Physics: Conference Series, Vol. 1681, 2020, Paper 012014, DOI: 10.1088/1742-6596/1681/1/012014

[8] Y. Angelova, L. Lazov, S. Mezinska, Innovative laser technology in textile industry: Marking and engraving, Environment. Technology. Resources, Vol. 11, No. 3, 2017, pp. 15-21, DOI: 10.17770/etr2017vol3.2610

[9] E. Yankov, M. Nikolova, V. Zaharieva, M. Firov, Changes in the structure during laser treatment of austenitic steel, in Proceedings of the 55th Annual Science Conference of Ruse University, 28-29.10.2016, Ruse, Bulgaria, pp. 195-206.

[10] I. Rozhkov, S. Vlasov, G. Mulk, Mathematical Models for the Choice of Optimal Technology and Quality Control of Steel, Metallurgy, Moscow, 1990 [in Russian].

[11] A.J. Antończak, D. Kocoń, M. Nowak, P. Kozioł, K.M. Abramski, Laser-induced colour marking – Sensitivity scaling for a stainless steel, Applied Surface Science, Vol. 264, 2013, pp. 229-236, DOI: 10.1016/j.apsusc.2012.09.178

[12] M.-F. Chen, W.-T. Hsiao, W.-L. Huang, C.-W. Hu, Y.-P. Chen, Laser coding on the eggshell using pulsed-laser marking system, Journal of Materials Processing Technology, Vol. 209, No. 2, 2009, pp. 737-744, DOI: 10.1016/j.jmatprotec.2008.02.075

[13] N. Sanner, N. Huot, E. Audouard, C. Larat, J.-P. Huignard, Direct ultrafast laser micro-structuring of materials using programmable beam shaping, Optics and Lasers in Engineering, Vol. 45, No. 6, 2007, pp. 737-741, DOI: 10.1016/j.optlaseng.2006.10.009

[14] I.N. Vuchkov, L.N. Boyadjieva, Quality Improvement with Design of Experiments, Springer, Dordrecht, 2001, DOI: 10.1007/978-94-009-0009-7

[15] I.N. Vuchkov, I.I. Vuchkov, Statistical Methods of Quality Control, Robust Engineering, Planning, Modeling and Optimization, QStatLab, v5.3, 2009 [in Bulgarian].

[16] S.K. Stoyanov, Methods and Algorithms for Fast Convergence, PhD thesis, University of Chemical Technology and Metallurgy, Sofia, 1990 [in Bulgarian].
[17] N. Tonchev, E. Yankov, Multi-criteria support for decision-making by shifting restrictions, in Proceedings of the International Scientific Conference "Mathematical Modeling", 12.2017, DOI: 10.13140/RG.2.2.13458.35520
[18] N. Tontchev, Materials Science, Effective Solutions and Technological Variants, Lambert Academic Publishing, Saarbrücken, 2014.
[19] L. Lazov, E. Teirumnieks, N. Angelov, E. Teirumnieka, Methodology for automatic determination of contrast of laser marking for different materials, Environment. Technology. Resources, Vol. 12, No. 3, 2019, pp. 134-136, DOI: 10.17770/etr2019vol3.4143
[20] L. Lazov, H. Deneva, P. Narica, Factors influencing the color laser marking, Environment. Technology. Resources, Vol. 10, No. 1, 2015, pp. 102-107, DOI: 10.17770/etr2015vol1.223
[21] B. Stojanović, R. Tomović, S. Gajević, J. Petrović, S. Miladinović, Tribological behavior of aluminum composites using Taguchi design and ANN, Advanced Engineering Letters, Vol. 1, No. 1, 2022, pp. 28-34, DOI: 10.46793/adeletters.2022.1.1.5
[22] B. Stojanović, A. Vencl, I. Bobić, S. Miladinović, J. Skerlić, Experimental optimisation of the tribological behaviour of Al/SiC/Gr hybrid composites based on Taguchi's method and artificial neural network, Journal of the Brazilian Society of Mechanical Sciences and Engineering, Vol. 40, No. 6, 2018, Paper 311, DOI: 10.1007/s40430-018-1237-y