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Analysis and Optimization of Kerf Width in Fiber Laser Cutting of S235 Steel

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Abstract

This paper is focused on the analysis and optimization of kerf width obtained in fiber laser cutting of 3mm thick S235 steel plate using oxygen as assist gas. Focus position, cutting speed and assist gas pressure were considered as important input parameters, and were systematically varied at 3 levels during experimentation, in accordance with Box-Behnken experimental design. A second order non-linear mathematical model for the prediction of kerf width was developed and analyzed with respect to three selected parameters. The unknown coefficients of the mathematical model were found by the method of least squares. The conducted analysis showed dominant effects of focus position and cutting speed with positive and negative correlation with kerf width, respectively. Focus position of 1 mm, cutting speed of 3.6 m/min and assist gas pressure of 0.75 bar should be used in order to achieve the smallest value of kerf width. To determine laser cutting parameters to obtain target kerf width value of 0.4 mm, and at the same time maximize material removal rate, laser cutting optimization model was defined and solved using genetic algorithm. It is shown that the combination of fiber laser cutting parameters: focus position f=1.4mm, cutting speed v=3.6m/min and assist gas pressure p=0.89 bar ensures maximum productivity of 4320 mm^3/min, while ensuring the targeted kerf width value of 0.4mm.

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Keywords: fiber laser cutting, kerf width, mathematical model, optimization, genetic algorithm.

1. Introduction

Laser cutting is a technology that uses a laser beam to heat, melt and/or vaporize the workpiece material to produce a cut. To ensure dross free cutting coaxial to the laser beam, the flow of auxiliary assist gas, typically oxygen or nitrogen, is used. In the context of processing metallic materials, an assisting gas is employed to mitigate oxidation reactions within the cutting region. These reactions precipitate elevated temperatures through exothermic processes, thereby inducing excessive heating in the cutting zone. Consequently, the affected area exhibits cutting irregularities such as lateral burning, adhesion of dross, and thermal degradation[1]. Laser cutting produces a high-quality cut surface. However, in general, numerous cut quality characteristics are determined by choice of laser, beam quality, delivered power, cutting speed, assist gas properties, etc. [2]. Bulk material is usually not significantly heated and affected by laser cutting for non-small features. Total deposited energy on workpiece material (0.1-10 J/cm^2) is not high enough to significantly change the temperature of the bulk material, but it is enough to enable near-surface region of the workpiece to be processed under extreme conditions. The interaction between laser and matter in the near-surface region of the workpiece material results in extremely rapid heating and cooling rates [3]. Optical and thermal properties of the material to be cut have larger influence on the laser cutting effectiveness than mechanical properties of the material. High reflectivity and thermal conductivity of material have negative influence on laser cutting process. High reflectivity reduces the amount of energy absorbed by the workpiece material and reduces the amount of energy available for the cutting process, while the high thermal conductivity leads to high energy loses via heat conduction in the bulk material, away from the cutting zone[4]. Lasers can be used for cutting of complex shapes with high efficiency, high precision and in different materials while maintaining high productivity, reduced material waste and low operating costs[5].

Because of their good characteristics, applicability and versatility lasers are widely used in industry today. The main types of lasers based on distribution in the industry are CO_2, Neodymium Nd, Neodymium yttrium-aluminum-garnet Nd: YAG and fiber lasers. Fiber lasers have many advantages over mentioned types of lasers, some of them are lower operational cost[6], better accuracy and faster cutting speed[7], [8]. Apart from metal cutting, fiber lasers can be used for cutting different materials, such as wood [9], [10], plastic composites and laminates [11], carbon fiber composites [12], transparent glass [13], nanocomposites[14]. Fiber lasers are more accurate than Nd: YAG and CO_2 lasers because of their smaller focus spot size[7]. Smaller focus spot size and smaller wavelength,

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enables fiber laser to efficiently cut more reflective materials [15].Fiber lasers can achieve better surface roughness and higher repeatability of surface roughness over several cuts with significantly higher dimensional accuracy than CO_2 lasers [16].

The process of fiber laser cutting is characterized by large amount of process parameters such as cutting speed, laser power, focus position, nozzle standoff distance, assist gas pressure, nozzle diameter cutting regime etc. which all have influence on laser cut quality characteristics. Some of the laser cut quality characteristics that are often investigated are kerf width, kerf taper, surface roughness, size of the heat affected zone, dross formation etc. Considering the complexity of fiber laser cutting process and large amount of input parameters which affect larger number of process performances, to achieve a better understanding of fiber laser cutting process, different analytical, experimental, and empirical modelling and optimization approaches are used. The most investigated surface quality characteristics for laser cutting of titanium alloys, steel alloys and aluminum alloys are surface roughness alongside kerf width. Beside this two surface quality characteristics, kerf tapper and HAZ are also investigated [17]. Regarding the analysis of kerf width of fiber laser cutting, the recent review is as follows:

Turkkanet al. [18],investigated the influence of fiber laser cutting parameters, i.e., cutting speed, focus position frequency and duty cycle on fiber laser cutting quality characteristics (kerf width and surface roughness). Kerf width size and surface roughness were mostly influenced by duty cycle and frequency. Alsaadawy et al. [17], investigated the influence of laser cutting parameters i.e.,laser power, cutting speed, assist gas pressure, standoff distance, pulse frequency, pulse width, nozzle diameter and assist gas for fiber laser, CO_2 and ND: YAG laser cutting of steel, titanium and aluminum alloys. Laser cutting output performances considered important in this experimental investigation were kerf width, surface roughness, HAZ and kerf angle. Kharche and Patil [19], evaluated the effects of fiber laser cutting parameters, i.e., laser power, cutting speed and assist gas pressure on kerf width and kerf taper angle. They concluded that the kerf width decreases with an increase in the cutting speed remarkably. While the increase in laser power and assist gas pressure causes slight increase in kerf width. Vora et al.[20], analyzed the influence of fiber laser power, cutting speed and assist gas pressure on kerf width, surface roughness, dross formation and material removal rate. Optimal solutions for each one of the responses were obtained via a heat transfer search algorithm. Nguyen et al. [21], successfully developed the seven layered convolutional neural network (CNN) for the assessment of kerf width in fiber laser cutting of thin non-oriented electrical steel sheets based on fiber laser cutting parameters, i.e., laser power, pulse frequency and cutting speed. The developed CNN model was compared with deep neural network (DNN) model and an extreme learning machine (ELM) model. Sharma and Kumar [22],investigated the influence of laser power, assist gas pressure, pulse frequency and cutting speed on kerf width, kerf deviation and material removal rate in fiber laser cutting of A653 galvanized steel sheets. The input parameter with highest influence on fiber laser cutting output performances in this case was cutting speed. Yilbas et al.[23],investigated the kerf width, kerf width variation and environmental impact of laser cutting for different materials, i.e., (titanium alloy Ti6Al4V, stainless steel A304, Inconel 625 and aluminum). Laser power and cutting speed were selected as input parameters for experimental investigation. Mullick et al. [24], investigated the effects of cutting speed, assist gas pressure and incidence angle on cut quality characteristics for fiber laser cutting of stainless-steel sheets. Fiber laser cut quality characteristics were assessed as ratio of kerf width and striations depth. Kerf width and kerf geometry characteristics, as cut quality characteristic, are of great importance for cutting non-metallic materials such aspolylactic acid (PLA) plates [25],carbon fiber reinforced composites (CFRP) [26-27], glass fiber reinforced plastics (GFRP) [28], printed circuit boards (PCBs)[29] and polymethyl methacrylate (PMMA) [30].

The literature review underscores the significance of kerf width in laser cutting and machining processes across various materials and applications. Experimental investigations into kerf width and kerf width quality characteristics are often accompanied by single or multi-objective optimization to achieve specific objectives. Machine learning methods, alongside with artificial neural networks are extensively used for prediction of production process outcomes and process modelling and optimization[31-32].Genetic algorithm (GA) was proposed by J.H. Holland as the algorithm that mimics the process of evolution and the survival of fittest[33], along with derivative algorithms such as differential evolution algorithm[34], these algorithms are particularly effective tools for addressing single or multi-objective optimization challenges[35]. Multi objective optimization problems can be successfully solved via new developed methods such as MOAHA and ANN-s based on k-fold cross validation approach [36].

Optimization plays a pivotal role in the machining industry, where achieving the highest efficiency and quality is paramount. This importance is further accentuated in the context of multi-objective optimization, which involves simultaneously optimizing multiple conflicting objectives. In machining, these objectives typically include minimizing production time, reducing operational costs, and enhancing surface finish [36-39].

Ding et al. [40]proposed a non-dominated sorting genetic algorithm with elite strategy for optimization of generalized neural network used for prediction of fiber laser cutting parameters i.e. laser power, cutting speed, gas pressure, and defocus. Material used in this experimental study was stainless steel, while kerf width and surface roughness are selected as performance evaluation parameters. H.J. Hao et al. [41]used improved pareto genetic algorithm for prediction of laser cutting quality kerf width and material removal rate. Among the combined parameters, two specific combinations gas pressure with cutting speed and gas pressure with pulse width exert a more pronounced effect on kerf width. Conversely, the combinations of gas pressure with pulse frequency and gas pressure with cutting speed have a more significant impact on the material removal rate. Shrivastava K. P. and Pandey A. K. [42]used hybrid approach of multiple regression analysis and genetic algorithm for parametric optimization. They investigated the influence of gas pressure, standoff distance, cutting speed and laser power on kerf width, kerf taper and kerf deviation for laser cutting of Inconel - 718. Regression models have been utilized as objective functions for multi-objective optimization, employing a hybrid approach that integrates multiple regression analysis and genetic algorithms.

Response Surface Methodology (RSM) comprises a suite of statistical and mathematical techniques aimed at process optimization and product quality enhancement. RSM serves as a robust tool for systematically investigating the effects of multiple variables and their interactions, thereby facilitating improved decision-making and performance across diverse domains. RSM is often used in combination with Taguchi method [43], [44], and fuzzy logic [45]. Besides RSM and other optimization techniques, in multi criteria environment, multi criteria decision making method such as COPRAS [46], CRITIC , EDAS [47] and TOPSIS [48] are often employed.

Given in mind the multiple significances of kerf width in laser cutting, the present study are focused on the analysis and optimization of kerf width in fiber laser cutting of S235 steel. The study uses Box-Behnken experimental design with fifteen trials of which three trials are in central point, for assessment of three factors on three levels with respect to selected fiber laser cutting performance characteristic i.e., kerf width. After development of mathematical model, which depicts relationship between input parameter and considered output parameter, optimization model was formulated and solved with genetic algorithm to maximize material removal rate while simultaneously ensure desired value of kerf width.

2. Experimental setup and details

The workpiece material used in this experimental study was 3mm thick non-alloyed structural steel S235. The low yield strength of S235 steel makes it ideal for general construction purposes. The tensile strength of S235 steel typically ranges from 360 to 510 MPa. S235 steel offers moderate tensile strength, allowing it to withstand the applied loads in structural applications. S235 steel exhibits good ductility and is known for its excellent weldability. S235 steel is easy to machine, making it suitable for applications that require machining processes such as drilling, milling, and turning [49].Table 1. gives main components of chemical composition of S235 steel.

Table 1. Chemical composition of S235 steel [49]

Label	*C*	*Mn*	*P*	*S*	*Si*
S235	0.22% max	1.6% max	0.05% max	0.05% max	0.05% max

While conducting the experimental study, the following conditions were constant: maximum laser power of 2 kW, standoff distance of 1mm, assist gas type (Oxygen), nozzle diameter of 1.2 mm and laser head. For assessment of parameters effect on kerf width, three laser cutting parameters such as: focus position (*f*), cutting speed (*v*) and assist gas pressure (*p*) were varied in accordance with the Box-Behnken experimental design and the response surface methodology (RSM). Box-Behnken experimental designs are alongside central composition face centered designs and full factorial designs most used experimental designs for creating of second order empirical polynomial mathematical models. This type of experimental design is often used when it is necessary to evaluate the effects of parameters on three levels, while upper and lower level have same distance from middle level. Box-Behnken experimental design can be geometrically represented as depicted on Figure 1.

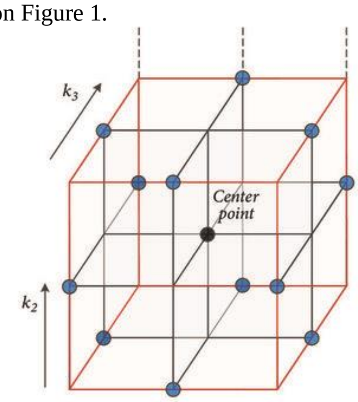

Figure 1. *Box-Behnken experimental design*

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Due to its robustness and efficiency, the Box-Behnken Design (BBD) methodology is extensively employed in numerous optimization case studies [39], [50], [51]. This design is particularly advantageous for its ability to efficiently explore quadratic response surfaces. The most widely utilized experimental BBD array involves three independent variables and a total of 15 experiments, including three replications at the central point. This configuration provides a comprehensive and statistically significant assessment of the interactions and quadratic effects of the variables, facilitating precise optimization and reliable conclusions in complex experimental setups. The parameter levels used in this experiment are given in Table 2.

Table 2. Parameters and parameter levels

Level	*f*(mm)	*v*(m/min)	*p*(bar)
-1	1	1.8	0.75
0	1.5	2.7	0.85
+1	2	3.6	0.95

In the experiment, fifteen experimental trials were conducted with 3 experimental trials in the center point. To eliminate any kind of subjectivity and minimize effects of unknown or uncontrolled variables, experimental trials were conducted in randomized order, while effects of all external factors were held constant. Experimental trials were conducted in the manufacturing environment with Gweike fiber laser LF3015CNR 2000W. Gweike fiber lasers are fiber lasers of the latest generation with power range from 1000W to 3000W, with the possibility of processing flat sheets of different sizes with a maximum size of 3000x1500mm, maximum speed of 100m/min, maximum acceleration of 1.5G and a maximum load of

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700kg. They can achieve high productivity and the required accuracy, all while ensuring a minimum labor cost [52]. Used fiber laser in manufacturing environment is shown in Figure 2., cutting process of experimental specimen is shown on Figure 3.

Figure 2. Gweike fiber laser LF3015CNR 2000W

Figure 3. Experimental setup

Kerf width (K_w) was selected as the process response because it is important for maintaining the desired geometry of machined part. The value of kerf width was measured with combined measuring system DeMeet 443-Combo. It is a combined measuring system consisting of an optical sensor and contact measuring elements. It is used for measuring parts of medium dimensions with a maximum weight of 50 kg[53]. The averaged value of three measurements taken along the straight cut was recorded for each experimental specimen (Figure 4.).

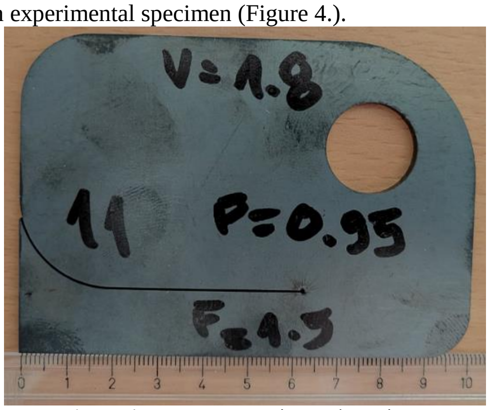

Figure 4. Laser cut experimental specimen

3. Results and discussion

3.1. Experimental results

After conducting the experimental trials, the kerf width value (K_w) was measured. Values of kerf width and combinations of input parameters in accordance with Box-Behnken experimental design with 12 trials and 3 trials in center point are shown in Table 3.

3.2. Analysis of parameter effects on kerf width

To perform comprehensive analysis of the obtained experimental results, i.e., the effect of considered laser cutting parameters on kerf width, an empirical mathematical model was developed. The quadratic model is easily the most commonly used model for RSM and this is because it is very flexible, and the unknown model parameters can easily be estimated using the least squares method algorithm[54].

This mathematical model, relating the laser cutting parameters and kerf width (K_w), was developed in the form of the second order polynomial equation:

$$K_w = 0.629 + 0.123 * f + 0.0286 * v - 0.93 * \mathrm{p} - 0.0283 * f^2 - 0.00998 * v^2 + 0.517 * p^2 + 0.0078 * fv + 0.065 * fp - 0.0083 * vp \quad (1)$$

The ANOVA table corresponding to the regression model for kerf width is presented in Table 4. The P-value quantifies the likelihood that an observed F-value greater than the calculated F-value arises solely due to random variability (noise) within the data. A low p-value, specifically less than 0.05, indicates that there is strong evidence against the null hypothesis, suggesting that the associated term is statistically significant. In other words, the term has a meaningful impact, and the observed effect is unlikely to be due to chance. This threshold ($p < 0.05$) is commonly used in scientific research to establish the significance of results, thereby specifying the importance of the related term in the context of the model's explanatory power.

Table 3. Experimental matrix and kerf width results

Trial	*f (mm)*	*v (m/min)*	*p (bar)*	*K_w (mm)*
1	1	1.8	0.85	0.385
2	2	1.8	0.85	0.506
3	1	3.6	0.85	0.330
4	2	3.6	0.85	0.465
5	1	2.7	0.75	0.384
6	2	2.7	0.75	0.479
7	1	2.7	0.95	0.384
8	2	2.7	0.95	0.492
9	1.5	1.8	0.75	0.444
10	1.5	3.6	0.75	0.419
11	1.5	1.8	0.95	0.450
12	1.5	3.6	0.95	0.422
13	1.5	2.7	0.85	0.434
14	1.5	2.7	0.85	0.432
15	1.5	2.7	0.85	0.444

From the ANOVA table, model as source of variability have F-value that is 24.83, which indicates that the model is highly significant, at the same time, P-value is 0.001 which is a lot smaller than threshold value of 0.05. With that in mind, one can conclude that the model is statistically significant at the significance level of 95%. ANOVA also indicates that quadratic model is suitable for the prediction of kerf width with contribution of 97.81%.

Table 4. ANOVA table

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.02981	0.003312	24.83	0.001
f	1	0.02634	0.026335	197.44	0
v	1	0.00278	0.002775	20.81	0.007
p	1	0.00006	0.00006	0.45	0.531
f * f	1	0.00019	0.000185	1.39	0.292
v * v	1	0.00054	0.000542	4.03	0.115
p * p	1	0.000099	0.000099	0.74	0.429

Table 5. ANOVA table – Second part

f * v	1	0.000045	0.000045	0.33	0.571
f * p	1	0.000041	0.000041	0.32	0.598
v * p	1	0.000008	0.000008	0.02	0.889
Error	5	0.000667	0.000133		
Lack-of-Fit	3	0.000584	0.000195	4.71	0.18
Pure Error	2	0.000083	0.000041		
Total	14				
R^2					97.81%
S					0.012

The influence of considered parameters on resulting kerf width was analyzed via surface diagrams (Figs. 6-8) showing the combined effects of two parameters at a time, while the third parameter was kept constant at the central level. Based on the surface diagram in Figure 6, it can be seen that with an increase in value of focus position, there is an increase in the width of the cut, i.e., kerf width, while the pressure of the assist gas does not significantly affect the increase in the width of the cut for small values of the focus positions. Assist gas pressure affects the kerf width at larger values of the focus position where the maximum value of the kerf width can be obtained as a combination of the maximum gas pressure and the maximum focus position. Figure 5. represents the main effects plot of focus position, assist gas pressure and cutting speed on kerf width.

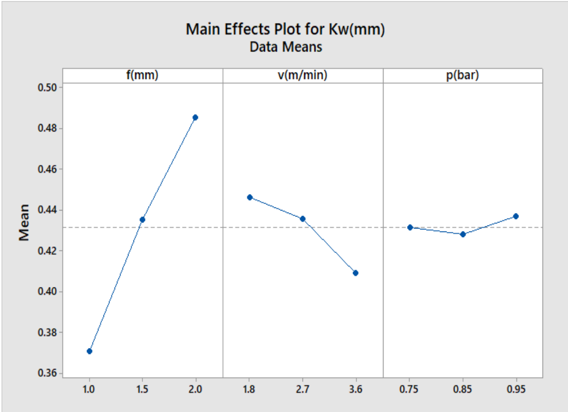

Figure 5. Main effects plot

Hossain et al. [30] concluded that kerf width increases with decrease of cutting speed and increase of laser power, they have also found out that kerf width value increases with increase of assist gas pressure.

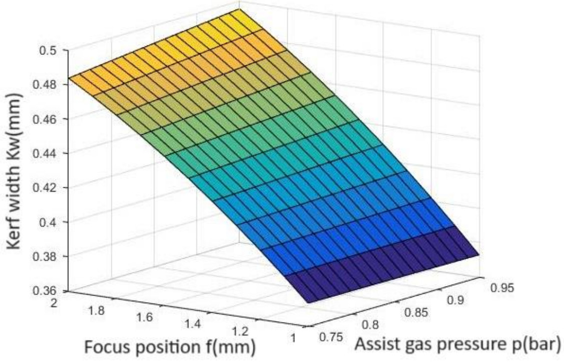

Figure 6. Surface diagram: interaction effect of Focus position f(mm) and Assist gas pressure p(bar)

Based on the surface diagram in Figure 7, it can be seen that with an increase in the focus position, the value of the kerf width also increases, while with an increase in the cutting speed, the value of the kerf width decreases. To obtain the maximum value of the cutting kerf width, it is necessary to reduce the cutting speed and increase the focus position, while to obtain the minimum value of the cutting kerf width, it is necessary to increase the cutting speed and lower the focus position. Based on the surface diagrams, one can observe, in certain areas, a potential non-linear dependence of the kerf width of the cut in relation to the focus position and the cutting speed.

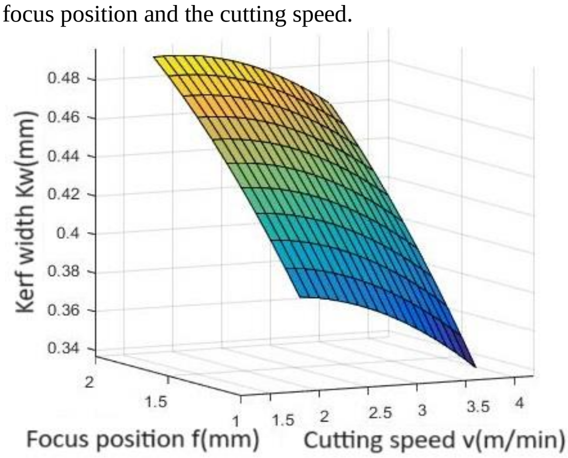

Figure 7. Surface diagram: interaction effect of Focus position f(mm) and Cutting speed V(mm/min)

Based on the surface diagram in Figure 8, one can see that with an increase in the cutting speed, the value of the kerf width nonlinearly decreases, while with an increase in the pressure of the auxiliary gas, the kerf width of the cut slightly increases. The maximum kerf width of the cut can be expected for the maximum assist gas pressure and the minimum cutting speed, while the minimum value of the kerf width can be expected for the maximum value of the speed and the minimum value of the assist gas pressure. Yilbas et al. [55] found that increasing laser power or reducing laser cutting speed results in increased kerf width size. In addition, the kerf width size variations also increase.

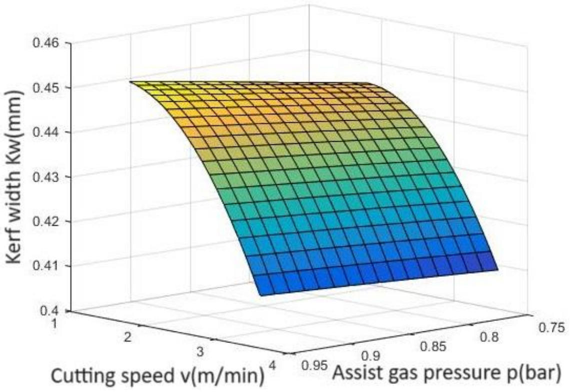

Figure 8. Surface diagram: interaction effect of Cutting speed V(mm/min) and Assist gas pressure p(bar)

3.3. Optimization model

To maintain the constancy of the dimensions of the cut part during laser cutting, it is necessary that the value of the kerf width is always within narrow limits. Varying the kerf width can significantly affect the dimensional accuracy of the parts, the influence of the kerf width on the dimensions decreases with the increase in their size, i.e., the larger the dimensions, the less important is the occurrence of deviations caused by improper changes in the width of the cut during cutting.

When planning the technological procedure of laser cutting for programming the path of the laser beam, it is of foremost importance to know what the resulting width of the cut will be in all parts of programmed path. The aim of the manufacturer is to cut the given contour in the shortest time and achieve the best possible cut quality characteristics, i.e., to achieve the highest productivity for desired quality characteristics of the workpiece. Various formulas can be found in the literature to quantitatively describe the productivity of the laser cutting process. In laser cutting, achieving the maximum MRR is crucial for enhancing productivity. However, it must be balanced with other quality parameters, such as the kerf width and the surface finish of the cut. The kerf width is particularly important because it affects the precision of the cut and the material waste. A narrower kerf width generally indicates higher precision and less material loss. The thickness of the material is a critical factor that influences the MRR. Thicker materials result in a higher volume of material removal per unit length of cut, thereby increasing the MRR. However, cutting thicker materials may require adjustments in other parameters, such as laser power and cutting speed, to maintain cut quality and prevent defects.

Productivity in laser cutting can be defined by volumetric material removal rate (*MRR*) as given by the following equation:

$$MRR = h * Kw * v \tag{2}$$

Where:

h – thickness of the workpiece material (mm)

K_w – kerf width (mm)

v – cutting speed (mm/min)

MRR – material removal rate (mm³/min)

Todetermine the laser cutting parameter values which would ensure maximal MRR while achieving desired value of the kerf width one can formulate and solve the following optimization model:

$$Maximize\ MRR = h * Kw * v \tag{3}$$

Subjected to constraints:

$$1 \leq f \leq 2\ (mm) \tag{4}$$

$$1.8 \leq v \leq 3.6\ (m/min) \tag{5}$$

$$0.75 \leq p \leq 0.95\ (bar) \tag{6}$$

$$Kw = 0.4\ mm \tag{7}$$

The optimization problem previously defined by Equations (3-7) in the context of fiber laser cutting is formulated as a single-objective optimization problem, characterized by a single non-linear equality constraint. The simplicity inherent in this single-objective optimization problem facilitated the successful application of a basic variant of the genetic algorithm. This straightforward approach obviated the necessity for employing more advanced optimization algorithms, which are typically required for more complex or multi-objective problems. The genetic algorithm (GA) employed here is a heuristic search and optimization technique inspired by the process of natural selection. It is particularly well-suited for problems where the search space is large and complex, but the objective and constraint functions are relatively simple to evaluate. In this specific application to fiber laser cutting, the basic GA variant was sufficient due to the manageable complexity of the optimization landscape defined by the single-objective and single non-linear constraint. By applying the genetic algorithm with the default hyper-parameter values, and solving the defined optimization problem, it can be shown that the combination of fiber laser cutting parameters: focus position *f*=1.4mm, cutting speed *v*=3.6m/min and assist gas pressure *p*=0.89 bar ensures maximum productivity of 4320 mm^3/min, while ensuring the targeted kerf width value of 0.4mm.

4. Conclusion

The present study dealt with the analysis and optimization of kerf width in fiber laser oxygen cutting of S235 structural steel by combining design of experiments, empirical mathematical modelling, and artificial intelligence methods. The main conclusions drawn from the study can be summarized as follows:

- Kerf width is mostly affected by the focus position followed by the cutting speed while the effect of assist gas pressure is least pronounced. The most significant influence of the focus position can be explained given it significantly affects the focused beam diameter and the resulting spot size. By moving away from the upper surface of the workpiece, i.e., by increasing the focus position, kerf width significantly increases.

- There are no significant interaction effects of considered parameters on the kerf width.
- To get minimal value of kerf width, laser beam should be focused closer to the upper surface of the workpiece while using the combination of highest cutting speed and lowest assist gas pressure. In relation to the recommended values of laser cutting parameters one can achieve narrower kerf width without sacrificing other important quality characteristics such as dross, pitting, roughness, etc.
- To consider two important performances in the present study, a single objective optimization problem with nonlinear constraint was proposed and solved using the genetic algorithm. This metaheuristic algorithm proved efficient in determining optimal combination of laser cutting parameters for maximization of MRR and achievement of desired kerf width value.

The developed kerf width prediction model can be used to estimate kerf width for arbitrarily chosen values of laser cutting. It can also be used in combination with other models for formulation of different laser cutting optimization models and this may be future research scope. In order to increase the range of possible applications of this model, some more experimental data should be collected. In the subsequent experimental investigations, more input and output parameters of laser cutting could be employed for more complex investigation. With that in mind, more complex multi-objective optimization problems could be defined and solved with some newer metaheuristic's methods or other optimization tools.

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