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REGRESSION ANALYSIS OF THE PLASMA ARC CUTTING PROCESS

Derzija Begic-Hajdarevic
Mechanical Engineering Faculty
University of Sarajevo
Vilsonovo setaliste 9, Sarajevo
Bosnia and Herzegovina

Mugdim Pasic
Mechanical Engineering Faculty
University of Sarajevo
Vilsonovo setaliste 9, Sarajevo
Bosnia and Herzegovina

Ahmet Cekic
Mechanical Engineering Faculty
University of Sarajevo
Vilsonovo setaliste 9, Sarajevo
Bosnia and Herzegovina

Dino Muhedin
ED.EN. d.o.o.
Dobrinje 129, Visoko
Bosnia and Herzegovina

ABSTRACT

Plasma cutting is important thermal cutting process and has been used successfully in the cutting of various materials. In this paper a regression model is developed for analysis and prediction of top kerf width during plasma arc cutting of high tensile steel plate based on experimental observations. Dependent variables in the model is top kerf width, while independent variables are cutting speed and plasma gas pressure. To evaluate results, analysis of variance (ANOVA) method is performed. Obtained regression model results suggest that regression modelling can be useful tool for analyzing top kerf width in plasma arc cutting process.

Keywords: plasma arc cutting, kerf width, cutting parameters, regression analysis

1. INTRODUCTION

Plasma cutting process is a thermal nontraditional machining process that was adopted in the early 1950s as an alternative method for flame cutting of stainless steel, aluminum, and other nonferrous metals. During that time the process limitations regarding the low cutting speed, poor machining quality, and the unreliable equipment were clear. Recently, cutting of conductive and nonconductive materials by plasma cutting has become much more attractive [1]. In the machine manufacturing industry, the plasma, as a tool, is used especially in cutting operations, coating, welding, melting, and assistance of the mechanical processing operations such as turning, threading, drilling, grooving etc., in order to improve the machinability of various materials.

Of particular interest to manufacturers using plasma cutting process are the productivity and the quality of components made by plasma cutting. Both aspects are managed by the selection of appropriate cutting parameters, which are unique for each material and thickness. Consequently, investigation into the affecting parameters in plasma cutting process is necessary to improve the final product quality. No general model was established because of the many process parameters and very different physical processes which are present during the plasma cutting process. Artificial neural network, regression are common for the production of machining models [2, 3, 4].

There are many researchers who have studied plasma cutting process. The effect of oxy-fuel cutting, plasma cutting and laser cutting on the fatigue behavior of cut straight edges performed on four different steels was analyzed in [5]. Grey relation analysis was used for optimization of process parameters in plasma arc cutting of EN 31 steel based on material removal rate and multiple roughness characteristics [6]. The regression analysis has been used in [7] for the development of empirical models able to describe the effect of the process parameters such as the cutting power, scanning speed, cutting height and plasma gas pressure on the cut quality during plasma arc cutting of mild steel. It was found that the surface roughness and the kerf taper angle are mainly affected by the cutting height, whereas the heat affected zone is mainly influenced by the cutting current.

Thus, it is necessary to have a deeper knowledge about the optimum cutting parameters, which will assure the good cut quality with a minimum of the kerf width. For this reason, in the present study regression analysis, including an analysis of variance (ANOVA), has been applied for prediction of the kerf width in plasma arc cutting of 5 mm thick high tensile strength steel plate S355J2+N.

2. EXPERIMENTAL SETUP

The experiments are conducted on the CNC Hyperterm 130XD plasma cutting system. The cuts are performed on 5 mm thickness S355J2+N high tensile strength steel plates, with use of oxygen as plasma (primary) gas and air as shielding (secondary) gas. The arc current of 80 A during of exaction of all experiments is kept constant. Usually a standoff is maintained between the torch tip and work piece for best cut quality. The specimens are made up of a linear cut 250 mm in length, as shown in figure 1.

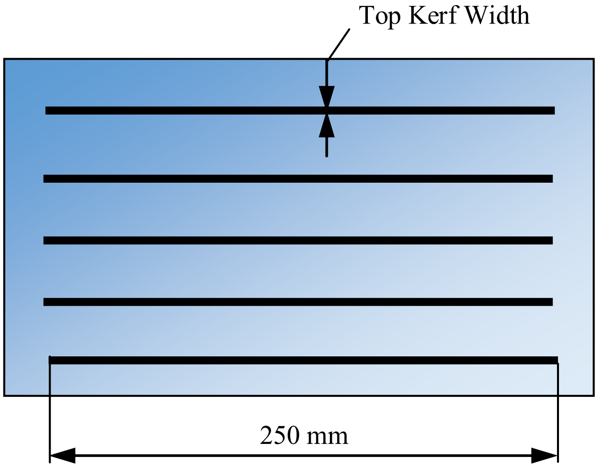

Figure 1. Schematic view of the cut specimen

Figure 2. Measuring of top kerf width using a ZKM universal microscope

In this study, the experimental plan has two controllable variables, namely, cutting speed and plasma gas pressure. These parameters are varied within the range: the cutting speed from 2670 mm/min to 5170 mm/min, and the plasma gas pressure from 4.37 bar to 6.37 bar. Testing the effect of one parameter on the kerf width requires the variation of one parameter while keeping the second parameter at the pre-selected value.

The controlled parameter has been the top surface kerf width. A visual inspection of each cut was carried that no pitting and burrs are present in the cut area. The kerf width was measured using a ZKM universal two-coordinate microscope, figure 2. It was measured in the each specimen at four different places along of the cut.

3. REGRESSION ANALYSIS AND DISCUSSION

As described above there were 72 measurements of the kerf width as dependent variable for different plasma gas pressures and cutting speeds as independent variables. Results of regression analysis are given in table 1.

F test, referred to as ANOVA test as well (analysis of variance) is calculated as ratio of (*MSR/MSE*), and equals 343,05318. Since *F* ratio is large, one can conclude the explained variability is large relative to the unexplained variability, and there is evidence that the regression equation provides strong explanatory power. Associated *p-value* of *F* ratio, or significance *F* equals zero which is less than significance level for this test α=0,05. It means that hypothesis test conclusion for *F* test is to reject the null hypothesis that all coefficients are equal zero. So, one can conclude that the model has the explanatory power.

Table 1. Output of Regression Analysis

	df	*SS*	*MS*	*F*	*Sig F*
Regression	2	5,95565	2,97783	343,05318	0,00000
Residual	69	0,59895	0,00868		
Total	71	6,55460			

	Coefficients	*Standard Error*	*t-stat*	*p-value*	*Lower 95%*	*Upper 95%*
Intercept	1,71862	0,08875	19,36523	0,00000	1,54157	1,89566
Cutting Speed (mm/min)	-0,00033	0,00001	-25,35664	0,00000	-0,00035	-0,00030
Plasma Gas Pressure (bar)	0,08833	0,01345	6,56865	0,00000	0,06151	0,11516

Coefficient of determination R^2 is 0,95321which means that 95,321% of variability of the kerf width is explained by the variability of these two independent variables (plasma gas pressure and cutting speed). Since R^2 is the square of correlation coefficient between observed and fitted values of dependent variables, multiple R value is 0,95322.

Figure 3 depicts a scatterplot of a correlation of predicted versus observed kerf width. Since the points on the scatterplot are very close to be on the line that creates angle of 45° with the horizontal axes, one can conclude that there is good prediction of the kerf width, which is shown by R^2 and multiple R (or square root of R^2). Figure 4 depicts histogram of residuals. This histogram shows that residuals are approximately normally distributed with the mean value equals zero.

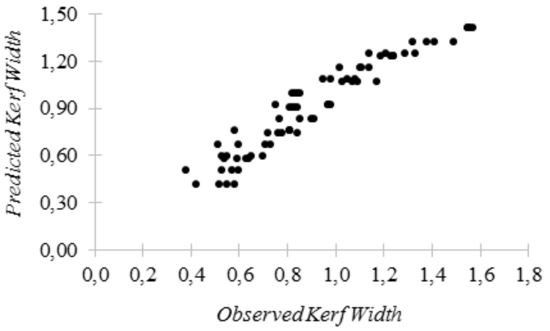

Figure 3. Predicted versus Observed Kerf Width

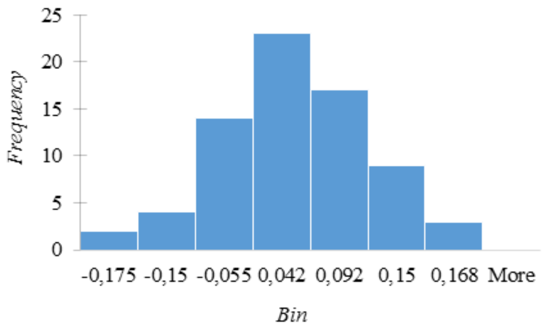

Figure 4. Histogram of Residuals

Figure 5 depicts that the constant error variance condition is satisfied for all values of explanatory variables, while Figure 6 shows that all standardized values of residuals are within +/- two standard deviations from the corresponding mean value. It can be concluded that the variability of the kerf width is the same about regression line for small as well as for large values of plasma gas pressures and cutting speeds.

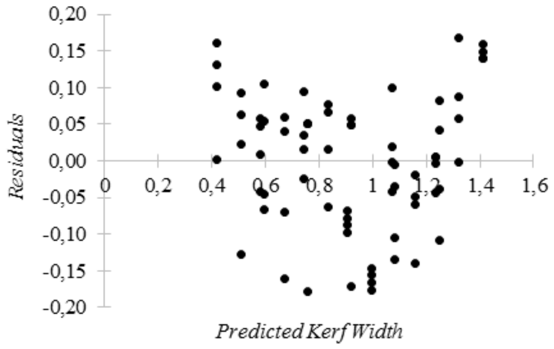

Figure 5. Residuals versus Predicted Kerf Width

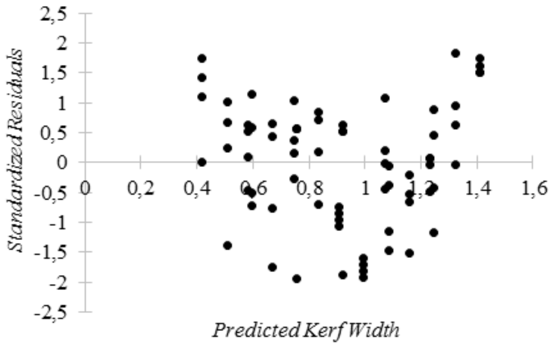

Figure 6. Standardized Residuals versus Predicted Kerf Width

Regarding the inference about the regression coefficients, it can be seen from table 1 that *p-value* and *t-stat* value show that both coefficients for cutting speed as well as for plasma gas pressure are significantly different from zero, with emphasis that two-tailed test is used for this hypothesis testing with α=0,05. Finally, the regression equation is given by equation 1.

$$Kerf\ Width = 1{,}71862 - 0{,}00033 \cdot Cutting\ Speed + 0{,}08833 \cdot Plasma\ Gas\ Pressure \quad ...\ (1)$$

From the regression equation it can be seen that increase in cutting speed decreases the kerf width (holding plasma gas pressure constant), while increase in plasma gas pressure increases the kerf width (holding cutting speed constant).

4. CONCLUSION

Top kerf width measurements as results of experiments of cutting of 5 mm thick high tensile strength steel S355J2+N using plasma arc cutting process are presented. Multiple regression analysis appears to be acceptable approach to develop model to predict kerf width as independent variable with respect to cutting speed and plasma gas pressure as independent variables. Future work might include testing of cutting of plates made from different materials as well as influence of other cutting parameters on performances of the cutting process.

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5. REFERENCES

[1] Helmi A. Y., Hassan El-H.: Machining Technology:Machine Tools and Operations, CRC Press, Egypt, 2008.
[2] Mocnik D., Paulic M., Klancnik S., Balic J.: Prediction of dimensional deviation of workpiece using regression, ANN and PSO models in turning operation. Tehnički vjesnik, vol. 21 (1), pp. 55-62, 2014.
[3] Klancnik S., Begic-Hajdarevic D., Paulic M., Ficko M., Cekic A., Cohodar Husic M.: Prediction of laser cut quality for tungsten alloy using neural network method, Strojniški vestnik, vol. 61 (12), pp.714-720, 2015.
[4] Begic-Hajdarevic D., Pasic M., Bijelonja I., Cekic, A.: Regression analysis of the surface roughness in abrasive water jet cutting, 19th International Research/Expert Conference “Trends in the Development of Machinery and Associated Technology TMT2015, pp.21-24, Barcelona, 2015.
[5] Cicero S., Garcia T., Alvarez J.A., Bannister A., Klimpel A., Martin-Meizoso A., Aldazabal J.: Fatigue behaviour of structural steels with oxy-fuel, plasma and laser cut straight edges. Definition of Eurocode 3 FAT classes, Engineering Structures, vol. 111, pp.152-161, 2016.
[6] Kumar Das M., Kumar K., Barman T., Sahoo P.: Optimization of process parameters in plasma arc cutting of EN 31 steel on MRR and multiple roughness characteristics using grey relational analysis, Procedia Materials Science, vol. 5, pp.1150-1559, 2014.
[7] Salonitis K., Vatousianos S.: Experimental Investigation of the Plasma Arc Cutting Process, Procedia CIRP, vol. 3, pp.287-292, 2012.