Fuzzy Logic Modelling of Dross Height in Plasma Jet Cutting of Shipbuilding Aluminium Alloy 5083

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Abstract

In this paper experimentations were made on shipbuilding aluminium alloy EN AW 5083 thickness of 8 mm in order to investigate influence of variable plasma jet cutting process parameters such as gas pressure, cutting speed, arc current and cutting height on formation of dross on the exit of the plasma jet from the workpiece material. Dross is significant cut quality response in plasma jet cutting process. It can be defined as blown molten metal concentrated on the bottom side of the sheet. Artificial intelligence method fuzzy logic was applied to model relations between input parameters and analysed response. Prediction accuracy of developed fuzzy logic model was checked by comparison between experimental and predicted data. Mean absolute percentage error (MAPE) and coefficient of determination (R^2) were used as prediction accuracy measures. After prediction accuracy was proved it was concluded that such defined fuzzy logic model represents good basis for further more detailed experimental research in this area. Furtherly, it allows creation of fuzzy expert system that will enable deeper understanding of process parameters effects on dross formation and quite better response prediction.

Keywords: Plasma jet cutting, shipbuilding aluminium, dross height, fuzzy logic modelling

1. INTRODUCTION

Plasma jet cutting process is nonconventional manufacturing process that is very present in shipbuilding and metal industry especially as pre-processing technique for welding of metal sheets. In order to minimize post processing actions such as cleaning and grinding before welding it is very important to reach the best possible cut quality. Aluminium alloy 5083 is a high magnesium alloy with a good strength, excellent corrosion resistance and weldability. Excellent corrosion resistance makes this alloy very acceptable for applications in shipbuilding industry as well as in automotive and aircraft industry. Regarding cut quality responses in plasma jet cutting process of aluminium some authors have already investigated influence of variable process parameters on different quality responses and applied various mathematical techniques in order to find out optimal cutting conditions that result with best possible cut quality. Peko et al. [1] analysed the influence of cutting speed, arc current and cutting height in plasma jet cutting process of aluminium 5083 thickness 3 mm. Cut quality responses that were analysed are: kerf width, bevel angle, surface roughness *Ra* and *Rz* and material removal rate (MRR). Regression analysis and ANOVA (Analysis of variance) were applied to define mathematical models for responses and to determine the significance of influence of process parameters and their interactions on each response. Multi-objective optimization was performed using Desirability analysis and optimal cutting region where all analysed cut quality responses have optimal values was defined. Peko et al. [2] applied fuzzy logic technique for modelling dross height as cut quality response in plasma jet cutting process of aluminium alloy 5083 thickness 3 mm. Experimentations were made by varying three process parameters: cutting speed, arc current and cutting height. Fuzzy expert system created in this paper was validated and effectively used for prediction of dross height depending of various input parameters values as well as for determination of optimal cutting areas. Peko et al. [3] defined artificial neural network (ANN) model to predict influence of cutting speed, arc current and cutting height on kerf width in plasma jet cutting process of aluminium alloy 5083 thickness 3 mm. Developed mathematical model was tested and validated on two different datasets. After prediction accuracy of developed model was checked 2D and 3D plots were created to analyse the influence of process parameters on kerf width response and to define optimal cutting conditions. Peko at al. [4] conducted optimization of bevel angle in plasma jet cutting process of aluminium alloy 5083 thickness 3 mm using Taguchi method. Process parameters that were varied in experimentations were cutting speed, arc current and cutting height. Main and interactions effects plots were generated to determine optimal cutting conditions. ANOVA was performed to check significance of the influence of each parameter and their interactions on bevel angle response. Kadirgama et al. [5] defined mathematical model by using response surface method in order to predict influence of current, standoff gap and pressure on heat affected zone (HAZ) in plasma cutting of aluminium alloy 6061. Partial swarm optimization algorithm was applied to find out process parameters values that lead to minimal HAZ. Patel et al. [6] investigated influence of arc current, standoff distance, gas pressure and cutting speed on MRR, top and bottom kerf width and bevel angle in plasma jet cutting process of aluminium alloy 6082 thickness 5 mm. In order to discuss the influence of process parameters, main effects plots for each cut quality response were generated. ANOVA was performed to check process parameters contributions on analysed responses. Hamid et al. [7] conducted experimentations on aluminium alloy 5083 thickness 10 mm in order to analyse the influence of process parameters such as arc current, feed rate, gas pressure and cutting distance on surface roughness and conicity responses. Grey relational analysis combined with ANOVA was applied to define parameters values that lead to minimal surface roughness and conicity as well as to define parameters significance for analysed process responses.

In this paper influence of gas pressure, cutting speed, arc current and cutting height on dross height in plasma jet cutting process of aluminium alloy 5083 thickness 8 mm was examined. According to experimental trials constraints regarding process parameters values that do not allow cutting process were defined. Due to width of experimental space and nature of analysed process and response values fuzzy logic technique was applied to describe relations between input parameters and output. Such defined fuzzy logic model enables good base for further design of fuzzy logic expert system that would be upgraded with more detailed experimentations and that will enable even better prediction of dross formation on the plasma jet exit side.

2. EXPERIMENTAL PROCEDURE

All experimentations were conducted on shipbuilding aluminium alloy EN AW 5083 thickness 8 mm. CNC machine FlameCut 2513 (Arpel Automation) was used for cutting. As arc current source an LG 100 IGBT Inverter Air

Plasma Cutting Machine was used. For preparing compressed air as plasma gas compressor SCK5 200 PLUS (ALUP Kompresoren Gmbh) was applied. A purifier and air-drying system are integrated in the compressor. Experimental plan was created according to Taguchi L_{27} orthogonal array where gas pressure, cutting speed, arc current and cutting height were varied on three levels. Constant parameter was outlet nozzle diameter: 1.2 mm. Due to complexity of manufacturing process on the one side and aim to cover as wider experimental space as possible there are some cutting constraints regarding process parameters levels that do not allow cutting of the workpiece material. These process parameters levels are marked in Fig. 1. with bold blue lines. According to these statements there are 9 experimental points where cutting is not possible.

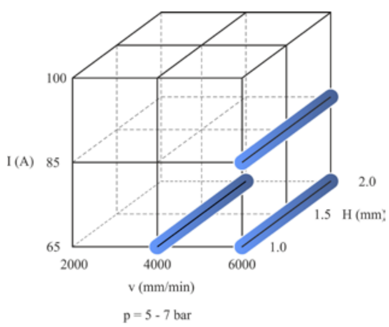


Fig. 1. Cutting process constraints

Experimental trials were made of straight cuts length 80 mm. Universal optical microscope was used to measure dross height on the bottom side of the workpiece material. Each measurement was done on three equidistant places in the middle of the cut. Mean value of all three measurements was taken as experimental result (Fig. 2.). Experimental results as well as variable process parameters values are shown in Table 1.

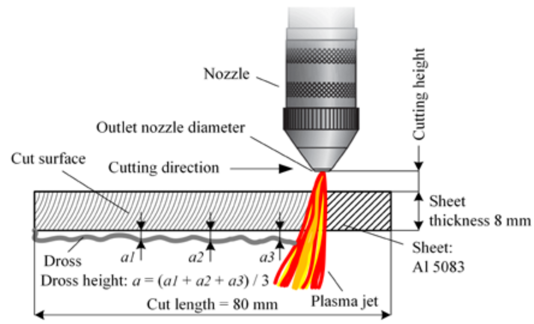


Fig. 2. Experimental setup and dross height measurements

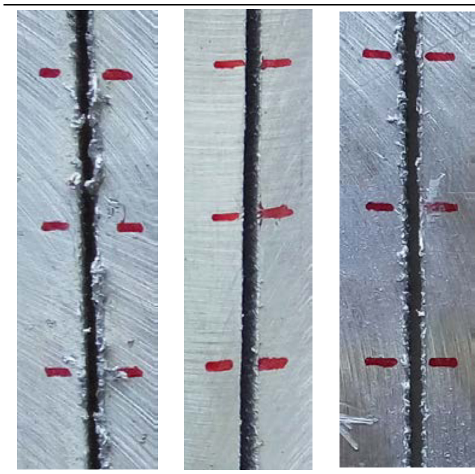
In Table 2. are given examples of dross formation on the bottom side of the workpiece depending on different process parameters values.

Table 1. Experimental results

Exp. Trial	Gas pressure p / bar	Cutting speed v / mm/min	Arc current I / A	Cutting height H / mm	Dross height a / mm
1	5	2000	65	1	1.63
2	5	2000	85	1.5	0.32
3	5	2000	100	2	0.36
4	5	4000	85	2	2.00
5	5	4000	100	1	0.66
6	5	6000	100	1.5	4.12
7	6	2000	65	1	0.50
8	6	2000	85	1.5	0.19
9	6	2000	100	2	0.18
10	6	4000	85	2	0.61
11	6	4000	100	1	0.42
12	6	6000	100	1.5	1.11
13	7	2000	65	1	3.34
14	7	2000	85	1.5	0.36
15	7	2000	100	2	0.24

16	7	4000	85	2	1.11
17	7	4000	100	1	0.63
18	7	6000	100	1.5	1.08

Table 2. Dross formation depending on different cutting conditions



p = 5 bar v = 2000 mm/min I = 65 A H = 1 mm	p = 6 bar v = 2000 mm/min I = 85 A H = 1.5 mm	p = 7 bar v = 4000 mm/min I = 85 A H = 2 mm

3. FUZZY LOGIC MODELLING

Fuzzy logic is one of the artificial intelligence (AI) methods that is quite useful in describing manufacturing processes and systems with imprecise and incomplete measurements data and where greater presence of ambiguity and noises is usual. Also, it is very convenient for modelling of complex manufacturing processes where because of their nature it is not possible to develop mathematical models by using conventional methods such as regression analysis. Aim of this paper is to create functional relations between plasma cutting process parameters and dross height response by using fuzzy logic technique. Created fuzzy logic model will be base for fuzzy expert system that will be updated furtherly with new and more detailed experimental findings.

In order to define relations between process inputs and output fuzzy logic technique uses few modules: fuzzification module, fuzzy inference module and defuzzification module [8, 9]. Fuzzification module converts analysed process inputs and outputs real data into fuzzy linguistic variables using different membership functions such as: Gaussian, trapezoidal, triangular etc. Membership function defines for each value of inputs and outputs degree of membership between 0 and 1. Fuzzy inference module applies knowledge base of fuzzy IF-THEN rules and membership functions to perform fuzzy reasoning and create relations between inputs and outputs. Two most popular fuzzy inference systems are Mamdani and Sugeno. Mamdani is more widely used because of its relatively simple structure and intuitive and interpretable fuzzy IF-THEN rules base. Finally, defuzzification module converts fuzzy outputs into a real values [9-11].

In this paper, in order to develop fuzzy logic model of dross height and to define functional relations between process input parameters and analysed cut quality response Mamdani fuzzy inference system was applied. Applied settings of the Mamdani fuzzy inference system are: and method: min, or method: max, implication: min, aggregation: max, defuzzification method: centroid. Plasma cutting process parameters: gas pressure, cutting speed, arc current and cutting height are taken as inputs and dross height as output of developed fuzzy logic system (Fig. 3.).

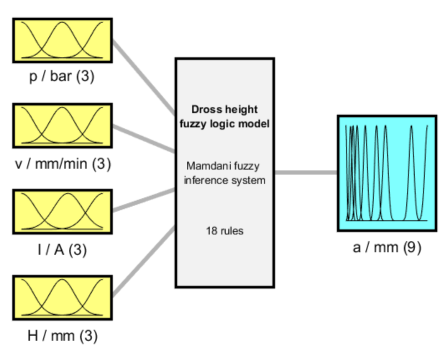
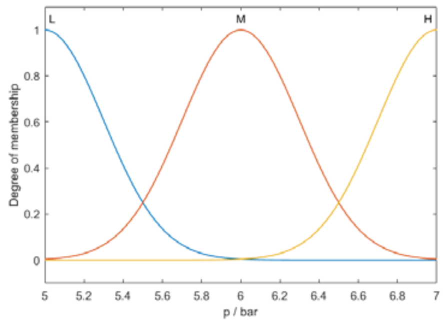


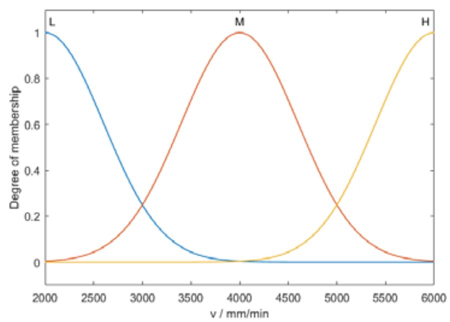
Fig. 3. Fuzzy logic system for dross height modelling

For each of input parameters three Gaussian membership functions were defined: low (L), medium (M), high (H), Fig. 4. a), b) c), d)).

Dross height as output was described with nine Gaussian membership functions: extreme low (EL), very low (VL), low (L), medium low (ML), medium (M), medium high (MH), high (H), very high (VH), extreme high (EH) (Fig. 5.).



a)



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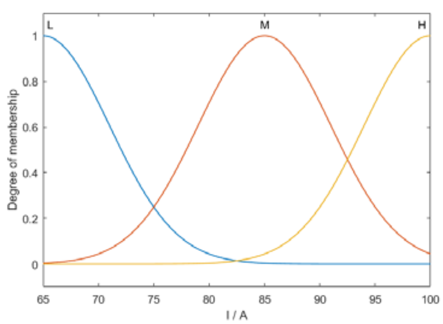

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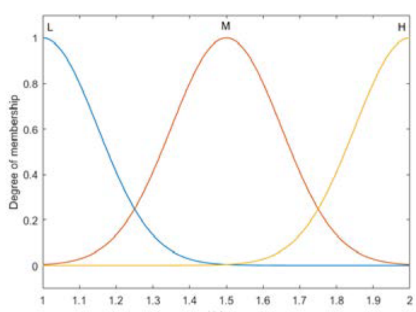

d)

Fig. 4. Membership functions for: a) gas pressure, b) cutting speed, c) arc current, d) cutting height

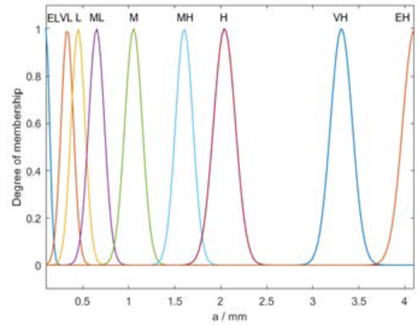

Fig. 5. Membership functions for dross height

In order to define relations between cutting process parameters and dross height set of 18 fuzzy IF-THEN rules was created. Graphical representation of defined rules is shown in Fig. 6.

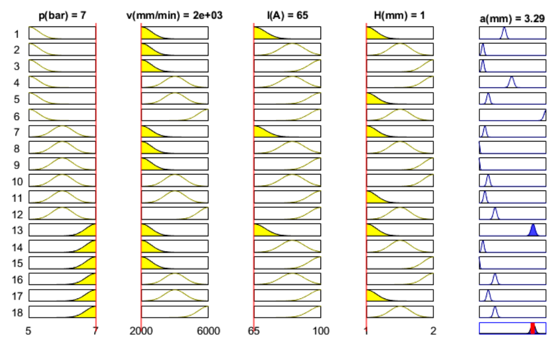

Fig. 6. Graphical representation of fuzzy IF-THEN rules

Converting dross height fuzzy values into non-fuzzy numerical values was performed by using MatlabR2015 defuzzification module toolbox. In order to check prediction accuracy of developed fuzzy logic model comparison between experimental dross heights and those predicted by created fuzzy logic model was conducted. As prediction accuracy measures mean absolute percentage error (MAPE) and coefficient of determination (R^2) were used. Comparison results are shown in Fig. 7 and Fig. 8. MAPE of 14.89% and R^2 of 0.99 present good prediction accuracy of developed fuzzy logic model.

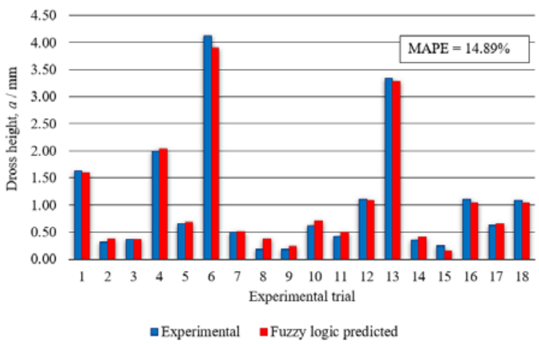

Fig. 7. Comparison of experimental and fuzzy logic predicted dross height with MAPE

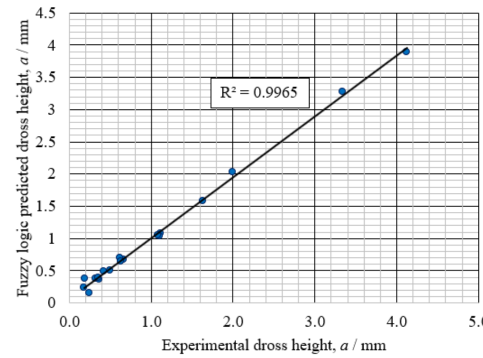

Fig. 8. Comparison of experimental and fuzzy logic predicted dross height with R^2

4. RESULTS

After the prediction accuracy of developed fuzzy logic model was proved the model was furtherly used to generate surface plots to discuss the influence of process parameters values on the dross formation. These plots are shown in Figure 9.

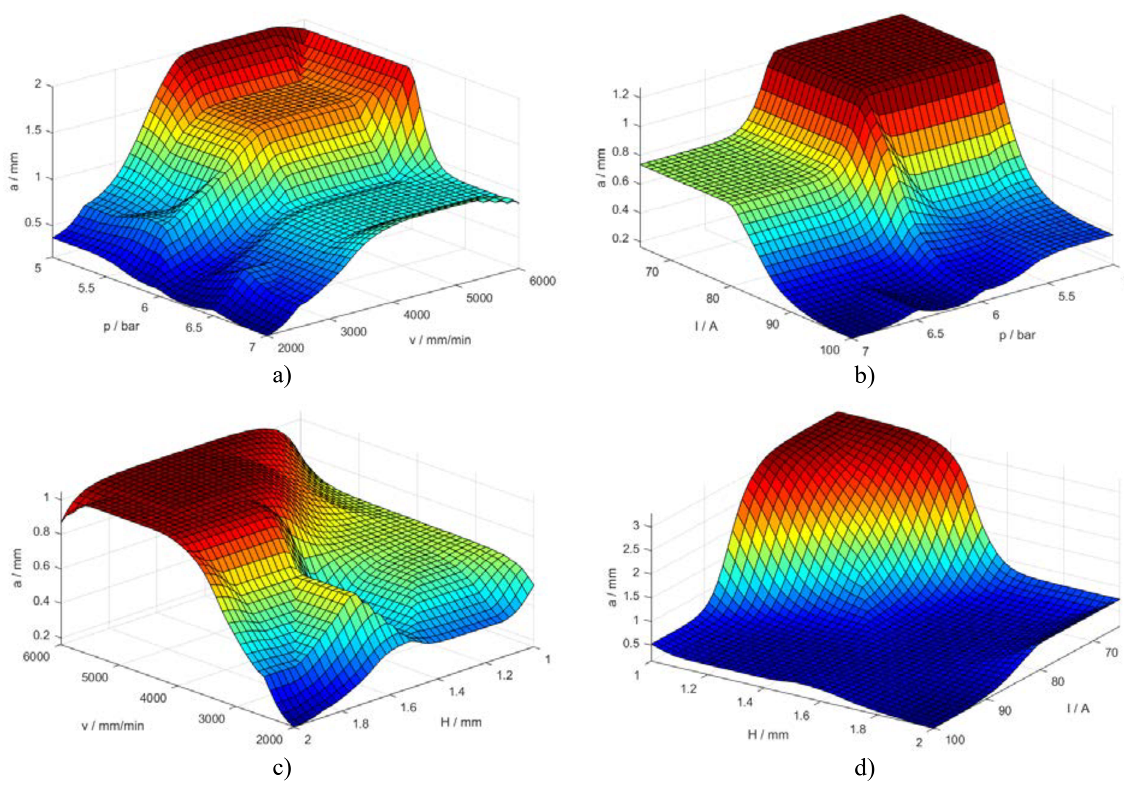

Fig. 9. Effects of process parameters values on dross height when: a) I = 100 A, H = 2 mm, b) v = 2000 mm/min, H = 2 mm, c) p = 7 bar, I = 100 A, d) p = 7 bar, v = 2000 mm/min

From Figure 9 it can be observed that process parameters differently affect dross formation in plasma jet cutting process of aluminium alloy 5083 thickness 8 mm. Figure 9a) shows that higher cutting speed and lower gas pressure when arc current is 100 A result with higher dross on the bottom side of the workpiece. High cutting speed (v: 6000 mm/min) and high arc current (I: 100 A) lead to the high energy input in the workpiece material combined with strong disturbance of the melt flow, consequently to the higher dross. These parameters values request higher gas pressure to blow molten material from the cutting zone and to achieve lower dross. From Figure 9b) it can be concluded that plasma cutting process is less stable at lower arc currents such as 65 A and due to that dross formation is more noticeable at parameters levels p: 5 bar, v: 2000 mm/min, I: 65 A. Figure 9c) and 9d) confirm earlier mentioned statements regarding cutting speed and arc current values and their influence on dross formation. Regarding cutting height, it can be affirmed that it doesn't have a significant influence on dross formation. It is also stated in [2].

These findings were derived from conducted experimental trials and generated fuzzy logic model. In order to discuss more precisely process parameters effects on dross formation in cutting aluminium sheet 5083 thickness 8 mm it is desirable to conduct additional experimentations and to upgrade presented fuzzy logic model.

5. CONCLUSIONS

In this paper application of artificial intelligence method fuzzy logic to analyse the influence of variable process parameters such as: gas pressure, cutting speed, arc current and cutting height on dross formation in plasma jet cutting process of shipbuilding aluminium alloy 5083 thickness 8 mm was presented.

Based on conducted experimentations and generated fuzzy logic model next findings can be derived:

- Artificial intelligence method fuzzy logic can be successfully implemented for modelling manufacturing processes (such as plasma jet cutting) that have imprecise, uncomplete and obscure responses data and where application of traditional mathematical modelling approaches is not convenient.

- Combination of Mamdani fuzzy inference system, Gaussian membership functions and centroid defuzzification method present good settings to model and predict dross height response.

- Variable process parameters differently affect dross formation.

- Cutting speed and arc current have the most significant effect on the dross height response.

- Process parameters levels such as v: 2000 mm/min, I: 65 A / v: 6000 mm/min, I: 100 A lead to higher dross due to the lower stability of the plasma jet cutting process, higher energy input combined with the strong disturbance of the melt flow. These parameters levels request higher gas pressure values (7 bar) to blow molten material from the cutting area and to accomplish lower dross.

- Based on conducted experimental trials and defined fuzzy logic model optimal cutting parameters that lead to minimal dross formation are: p: 7 bar, v: 2000 mm/min, I: 100 A, H: 1…2 mm.

- This research presents good base for further experimentations in this area. In order to discuss more precisely process parameters effects on dross formation it is desirable to conduct additional experimentations to cover all experimental space and to upgrade presented fuzzy logic model with new measurement results.

6. REFERENCES

[1] I. Peko; D. Marić; B. Nedić; I. Samardžić, Modeling and Optimization of Cut Quality Responses in Plasma Jet Cutting of Aluminium Alloy EN AW-5083. Materials 14 (2021), pp.5559

[2] I. Peko; B. Nedić; M. Dunđer; I. Samardžić. Modelling of Dross Height in Plasma Jet Cutting Process of Aluminium Alloy 5083 Using Fuzzy Logic Technique. Tehnički vjesnik 27 (2020), pp.1767-1773

[3] I. Peko; B. Nedić; A. Đorđević; I. Veža. Modelling of Kerf Width in plasma jet

cutting process using ANN approach. Tehnički vjesnik 25 (2018), pp.401-406

[4] I. Peko; B. Nedić; M. Dunđer; I. Samardžić. Taguchi optimization of bevel angle in plasma jet cutting process of aluminium alloy 5083. Journal of Production Engineering 23 (2020), pp.1-6

[5] K. Kadirgama; M.M. Noor; W.S.W. Harun; K.A. Aboue-El-Hossein. Optimisation of heat affected zone by partial swarm optimisation in air plasma cutting operation. Journal of Scientific & Industrial Research 69 (2010), pp.439-443

[6] S.B. Patel; T.K. Vyas. Parametric Investigation of Plasma Arc Cutting on Aluminium Alloy 6082. Proceedings of the International Conference on Ideas, Impact and Innovation in Mechanical Engineering, Pune, India, 1-2 June 2017, pp.87-93

[7] A. Hamid; O. Novareza; T. Dwi Widodo. Optimization of process parameters and quality results using plasma arc cutting in aluminium alloy. Journal of Engineering and Management in Industrial System 7 (2019), pp.7-14

[8] M. Dragičević; E. Begović; I. Peko. Optimization of dry turning process parameters using Taguchi method combined with fuzzy logic approach. Proceedings of the 16th International Conference on Tribology, Kragujevac, Serbia, 15-17 May 2019, pp.429-435

[9] M. Madić; Ž. Ćojbašić; M. Radovanović. Comparison of fuzzy logic, regression and ANN laser kerf width models. UPB Scientific Bulletin, Series D: Mechanical Engineering 78 (2016), pp.197-212

[10] M. Madić; M. Radovanović; Ž. Ćojbašić; B. Nedić; M. Gostimirović. Fuzzy Logic Approach for the Prediction of Dross Formation in CO_2 Laser Cutting of Mild Steel. Journal of Engineering Science and Technology Review, 8 (2015), pp.143-150

[11] P. Kovač; D. Rodić; V. Pucovsky; B. Savković; M. Gostimirović. Application of fuzzy logic and regression analysis for modeling surface roughness in face milling. Journal of Intelligent Manufacturing, 24 (2013), pp. 755-762