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Temperature and Surface Roughness in Magnetic Abrasive Finishing Process for CuZn28 Brass Alloy

Shakir M. Mousa and Kamil J. Kadhim
Technical Institute of Al-Mussaib, Al-Furat Al-Awsat Technical University, Babil, Iraq

Abstract: The effect of Magnetic Abrasive Finishing (MAF) method on the Temperature rise (Tr) and the surface Roughness (Ra) has been investigated in this research by determining the optimum temperature through the optimum surface roughness to improve the quality of surface layer for CuZn28 brass alloy plates. Sixteen runs were done in order to determine the optimum temperature in the contact area (between the abrasive powder and surface of workpiece) and the change in the surface Roughness (ΔRa) according to Taguchi Orthogonal Array (OA). Four technological parameters (cutting speed, finishing time, working gap and the current in the inductor) with four levels for each parameter have been used, the matrix known as a L16 (4^4) OA. The Signal to Noise (S/N) ratio and Analysis of Variance (ANOVA) techniques were performed for analysing results of Tr and ΔRa using the statistical software (MINITAB17), to establish the best optimum condition and identify the significant parameters affecting on the temperature rise and surface roughness. The modern and powerful technique IR camera was used to measure the temperature while scanning electron microscopy was utilized to study the texture of finishing surface. The results showed that the optimum temperature in contact area of workpiece is (55.1°C) and the most significant factor for CuZn28 brass effect on ΔRa for MAF process was the cutting speed followed by current in the inductor, finishing time and working gap.

Key words: MAF, temperature rise, change in surface roughness, MINITAB 17, time, inductor

INTRODUCTION

Surface finish has a vital influence on functional properties such as wear resistance and power loss due to friction on the most of the engineering components. Magnetic Abrasive Finishing (MAF) is one of the advanced finishing process in which a surface is finished by removing the material in the form of microchips by abrasive particles in the presence of magnetic field in the finishing zone (Mulik and Pandey, 2011). Magnetic abrasive technique applied to machine building, radio industries, aerospace, electro industry and other industries.

An experimental study was conducted for measuring the surface roughness in MAF technique on brass alloy plate which is very difficult to be polish by a conventional machining process where the cost is high and much more susceptible to surface damage as compared to other materials (Moosa, 2017).

The interface temperature between workpiece material and abrasive material is an important parameter in finishing processes. The subsurface damage and alteration in the metallurgical structure in the machined/finished surface is mostly dependent on the interface temperature (Komanduri and Hou, 2001).

MAF process has several advantages over the commonly used finishing process such as low cost, high surface quality and it is well suited for finishing magnetic and nonmagnetic, hard and soft materials. It has been successfully used for finishing of internal as well as external surfaces of complicated designs (Kumar *et al*., 2013).

Taguchi technique involves greatly the reduction of variation in a process through robust design of experiment. The objective of Taguchi technique is to produce high product at low cost for both design and production and increasing the profit by finding the most influential parameters. Taguchi suggests two different methods for analysing results; Signal to Noise (S/N) ratio and ANOVA for carrying out the complete analysis of the obtained data from the runs to optimize the process parameters that give good quality with a saving cost and time (Vidal *et al*., 2013).

Temperatures of MAF process is less studied than other micro-cutting processes. There are many sources of heat generation in the working zone which include the current in the conductor and the friction generated between surface of workpiece and grain of abrasive powder. The total amount of heat generated depends on many cutting parameters like speed, time, gap and current.

Corresponding Author: Shakir M. Mousa, Technical Institute of Al- Mussaib, Al-Furat Al-Awsat Technical University, Babil, Iraq

Shinmura *et al*. (1985, 1990) studied the pressure acting on the workpiece surface which is a function of magnetic flux density, number of abrasive particles and the permeability of abrasive medium. It was found that magnetic pressure on the abrasive particles causes penetration of the abrasive particles on the workpiece surface. Due to micro cutting operation, temperature on the surface of the workpiece increases. Very high increase in temperature may deteriorate the surface quality of the workpiece.

Mishra *et al*. (2014) determined work-brush interface temperature in magnetic abrasive finishing process. Transient thermal analysis of workpiece domain has been performed to predict the temperature rise due to frictional heat flux. The predicted temperature on work-brush interface was found in the range of 34-51°C.

The temperature rise is important in contact area during MAF process, the surface roughness is a function of temperature rise and the temperature affects the performance of workpiece to be finished, so, multi regression model has been developed. The finishing process can be controllable because the temperature is controlled by change in the technological parameters.

MATERIALS AND METHODS

Design of experiments for MAF process

Selection the technological parameters, ranges and their levels: In the present work, four variable technological parameters (cutting speed, finishing time, working gap and the current in the inductor) with four levels for each parameter are used to study the effect of technological parameters on temperature rise and the change in the surface roughness in MAF process for CuZn28 brass alloy plates. The invariable parameters of MAF process (i.e., abrasive powder, grain size, amount of abrasive powder) are selected by carrying out trial MAF process to find the best invariable technological parameters. The selected technological parameters for the MAF process, ranges and their levels according to large range of parameters are listed in Table 1.

Determining OA of experimental design: Knowing the number of parameters and their levels, the Orthogonal Array (OA) can be determined. Using the software through DOE-Taguchi-Create Taguchi Design, the levels and the number of factor, OA can be found. Therefore, an OA L16 (4^4) for the four parameters with the four levels is used in the current work to perform the most effective experiments (16 test) and (Lakshminarayanan and Balasubramanian, 2008). Sixteen tests with different details of experimental MAF array will be conducted according to OA are represented in Table 2.

Table 1: The technological parameter's values and their levels

Technological parameters		Levels			
Parameters	Code	1	2	3	4
Cutting speed (rpm)	A	240.0	550.0	860.0	1150.0
Finishing time (min)	B	3.0	6.0	9.0	12.0
Working gap (mm)	C	0.5	1.0	1.5	2.0
Current in the inductor (amp)	D	1.0	1.5	2.0	2.5

Table 2: Experimental design of technological parameters based on the OA L16(4^4)

Exp.	Cod	A	Cod	B	Cod	C	Cod	D
1	1	240	1	3	1	0.5	1	1.0
2	1	240	2	6	2	1.0	2	1.5
3	1	240	3	9	3	1.5	3	2.0
4	1	240	4	12	4	2.0	4	2.5
5	2	550	1	3	2	1.0	3	2.0
6	2	550	2	6	1	0.5	4	2.5
7	2	550	3	9	4	2.0	1	1.0
8	2	550	4	12	3	1.5	2	1.5
9	3	860	1	3	3	1.5	4	2.5
10	3	860	2	6	4	2.0	3	2.0
11	3	860	3	9	1	0.5	2	1.5
12	3	860	4	12	2	1.0	1	1.0
13	4	1150	1	3	4	2.0	2	1.0
14	4	1150	2	6	3	1.5	1	1.5
15	4	1150	3	9	2	1.0	4	2.5
16	4	1150	4	12	1	0.5	3	2.0

Table 3: The mechanical properties of test specimens (Brass alloy CuZn28)

Material	Tensile strength (kg/mm^2)	Vickers hardness	Density (kg/mm^3)	Shear strength (kg/mm^2)
CuZn28	38-39	89-105	84	28

Experimental prosedure of MAF process: In this research, sixteen different tests is designed based on the Taguchi OA L16 are listed in Table 2. The dimensions of the flat workpiece were (100×50×3). The mechanical properties of the flat workpiece from CuZn28 Brass alloy are listed in Table 3.

The model of the conventional Turret vertical Milling Machine is MDM 4VS/4HS/4S. Its spindle is used to fix the Magnetic inductor. The electromagnetic coil was calculated and implemented in the following specifications, the number of wire turns equals to 4000, material of core is C15 low carbon and diameter of wire is 0.9 mm. There are two power supplies, one for control the current and the other to control the velocity of spindle. The general view is shown in Fig. 1.

Experimental tests for all samples begun with the measured Ra for the workpiece, before experiments at (three random points) for each sample. The workpiece is fixed on the table of the machine, the working gap was filled with magnetic abrasive powder (tungsten carbide with iron, mesh 250 μm) with amount of volume (4 cm^3) and then the other condition of the process was adjusted according to OA. After machining, the area of finishing the Ra was measured by profile meter at three random

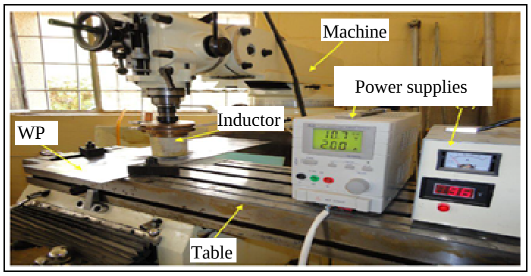

Fig. 1: Experimental setup of the MAF process

points, to reduce experimental error then the average values were computed. The procedure was repeated all the above for sixteen different test. IR camera was used to measure the temperature in the contact region, measured during finishing of workpiece at the last two second by using IR camera after proper calibration. The fringe pattern readily changes with the change in any technological parameters which affect cutting temperature.

RESULTS AND DISCUSSION

S/N ratio technique: The signal-to-noise ratio measures how the response varies relative to the nominal or target value under different noise conditions. The appropriate S/N ratio was chosen depending on the goal of experiment and according to the criterion (larger is better) to maximize the response or the criterion (nominal is best) to target the response, the S/N ratio is based on means and standard deviations for static designs. The Mean Squared Deviation (MSD) and the S/N ratio for (large is better and nominal is best) are calculated by using the statistical software (MINITAB 17) (Roy, 1990) and MINITAB™. Mean squared deviation (Anonymous, 2018):

$$\text{MSD} = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{y_{ij}^{2}}\right) \tag{1}$$

Larger is better:

$$\frac{S}{N} = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{yi^{2}}\right] \tag{2}$$

Nominal is best:

$$S/N=10\times\log_{10}\left(\bar{y}^{2}-\sigma^{2}/n\right)/\sigma^{2} \tag{3}$$

Where:

n = The total number of experiments and y_i represents the value of the response in that run

$\bar{y}^2$, σ = Mean value of response and the standard deviation

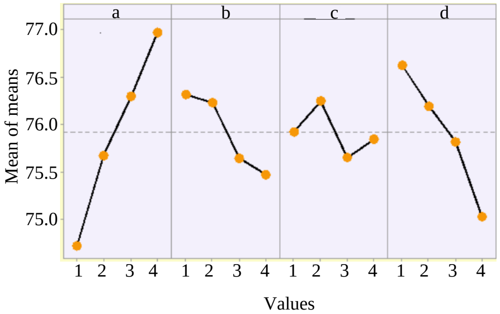

Fig. 2: Main effects plot of means for Δra

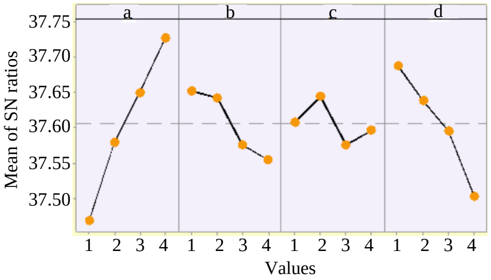

Fig. 3: Main effects plot of SN ratios for ΔRa

Table 4: Experimental results of surface roughness, mean, SNR and temperature rise for MAF process

					Surface roughness Δra			
Exp.	A	B	C	D	$\Delta Ra\times10^{-2}$	SNRA1	$MEAN1\times10^{-2}$	Temp. C°
1	1	1	1	1	76.30	37.6505	76.30	44.5
2	1	2	2	2	75.90	37.6048	75.90	38.4
3	1	3	3	3	74.00	37.3846	74.00	65.1
4	1	4	4	4	72.70	37.2307	72.70	68.4
5	2	1	2	3	75.70	37.5819	75.70	37.7
6	2	2	1	4	75.02	37.5035	75.02	35.3
7	2	3	4	1	76.30	37.6505	76.30	61.7
8	2	4	3	2	75.70	37.5819	75.70	58.4
9	3	1	3	4	75.80	37.5934	75.80	35.2
10	3	2	4	3	76.90	37.7185	76.90	42.8
11	3	3	1	2	75.70	37.5819	75.70	42.0
12	3	4	2	1	76.81	37.7084	76.81	39.9
13	4	1	4	2	77.50	37.7860	77.50	51.6
14	4	2	3	1	77.13	37.7445	77.13	45.9
15	4	3	2	4	76.60	37.6846	76.60	39.9
16	4	4	1	3	76.70	37.6959	76.70	43.4

Analysis of ΔRa test

First step: Analysis of experiment is done to determine the optimum condition that give optimum surface roughness and the temperature rise in the contact zone to describe the quality of the surface roughness in MAF process.

Results of the S/N ratio technique give the optimal level of ΔRa for each parameter according to the larger S/N ratio are given in Table 4 and to ensure the maximum value of ΔRa in MAF process (the values for ΔRa indicate the improvement in the surface quality). The S/N ratio and mean are calculated and given in Table 5. The main effects plot of means and S/N ratio for ΔRa are shown in Fig. 2 and 3, respectively.

Table 5: The main effects table of mean and (S/N) ratio for ΔRa

	Means for ΔRa Response					(S/N)Ratio for ΔRa Response			
Levels	A	B	C	D	Levels	A	B	C	D
1	74.72	76.33	75.93	76.63	1	37.47	37.65	37.61	37.69
2	75.68	76.24	76.25	76.20	2	37.58	37.64	37.64	37.64
3	76.30	75.65	75.66	75.83	3	37.65	37.58	37.58	37.60
4	76.98	75.48	75.85	75.03	4	37.73	37.55	37.60	37.50
Delta	2.26	0.85	0.59	1.60	Delta	0.26	0.10	0.07	0.19
Rank	1.00	3.00	4.00	2.00	Rank	1.00	3.00	4.00	2.00

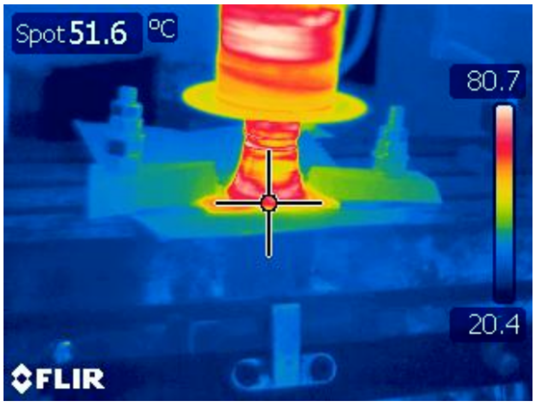

Fig. 4: Infrared photography for experiment number 13 in levels (A4, B1, C4 and D2)

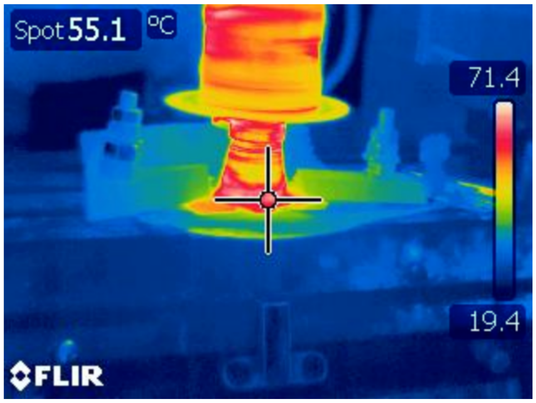

Fig. 5: Infrared photography for the optimum value of temperature = 55.1 CO after conformation test at the level (A4, B1, C2 and D1) when the predicted mean = 78.427×10-2 µm and predicted S/N ratio = 37.895

There are two conditions, the first is based on the mean and the second is based on the S/N ratio. From Table 5 the optimum level of parameters that corresponds to large value for mean and S/N ratio (A_4, B_1, C_2 and D_1) is compatible and the temperature rise in this condition Tr = 51.6 C° as show in Fig 4. It is obvious that the optimum condition (A_4, B_1, C_2, and D_1) is not found among the sixteen experiments.

The conformation test at the level (A_4, B_1, C_2 and D_1), gives the predicted value for mean = 78.427×10^{-2} µm and predicted value for (S/N) ratio = 37.8950 are computed by Eq. 1 in the contact region of MAF process while the actual value of mean = 77.50×10^{-3} µm and the actual value for S/N ratio = 37.7860. The conformation test gives the Tr = 55.1C° as shown in Fig. 5.

$$\Delta Ra_{\text{Predicted}} = \bar{A}_{\text{Nop}} + \bar{B}_{\text{Nop}} + \bar{C}_{\text{Nop}} + \bar{D}_{\text{Nop}} - 3\bar{T} \quad (4)$$

$\bar{T}$ = The overall mean of response ΔRa
$\bar{A}_{Nop}+\bar{B}_{Nop}+$ = The average of response at the optimum
$\bar{C}_{Nop}+\bar{D}_{Nop}$ = level of cutting speed, finishing time, working gap and the current, respectively

Based on the largest S/N ratio, the optimum condition is found at cutting speed A_4 = 1150 rpm, finishing time B_1 = 3 min, working gap C_2 = 1mm and the current in the inductor D_1 = 1 A. Delta is determined by calculating the difference between the higher and lower value of level for each value. The most significant factor on ΔRa for MAF process is cutting speed (A) followed by (D) current in the inductor, (B) finishing time and (C) working gap as shown in Table 5.

Second step: In the step, the optimum temperature according to optimal predicted levels was determined. The additional experiment (conformation test) showed that the optimal condition at level (A_4, B_1, C_2 and D_1) gives the maximum optimum value for ΔRa = 78.427×10^{-2} µm and in this optimum level, the optimum value of temperature was 55.1°C after conformation test as shown in Fig. 5.

Third step: In this step, we determine the optimal parameters (cutting speed, finishing time, working gap, and the current in the inductor) according to (Nominal is best) Eq. 3. Based on the S/N ratio on means and standard deviations and depending on the target value of temperature rise (55.1°C) after confirmatory test in the contact zone of MAF process. The solution for the optimal parameters obtained the values (A = 700 rpm, B = 7.5 min, C = 1.84 mm, D = 1 A) as shown in Fig. 6 where the dash lines show optimal setting and the black

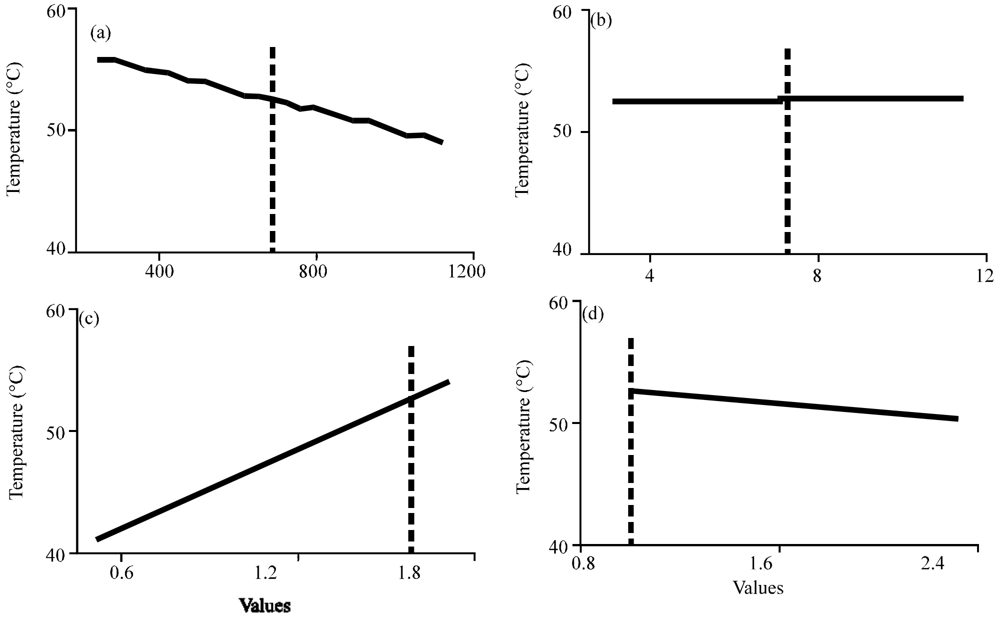

Fig. 6: Setting the optimum solution according to target temperature 55.1C°. Blue lines show optimal setting: a) rpm; b) min; c) mm and d) A

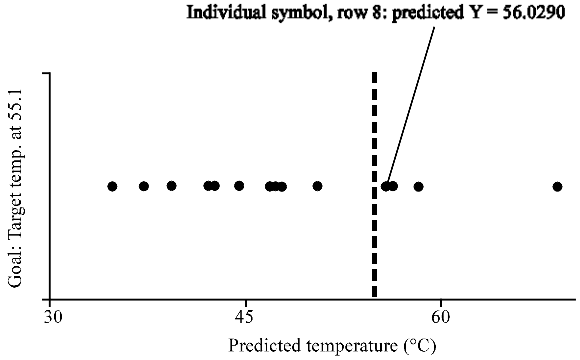

Fig. 7: Predicted y for all sample points

lines show the predicted response (y-temperature rise) at different settings. Figure 7 shows predicted (y) for all sample points.

SEM micrograph and photography for surfaces: The condition of finished surfaces before and after magnetic abrasive finishing process for brass alloy were observed using SEM images of the surface polished as shown in Fig. 8. Obviously, the cutting traces were eliminated when the optimum temperature rise and surface roughness. It is obvious that the surface for brass after polishing was smoother than before polishing and Ra decreased from 0.985-0.215 and ΔRa = 0.77 μm.

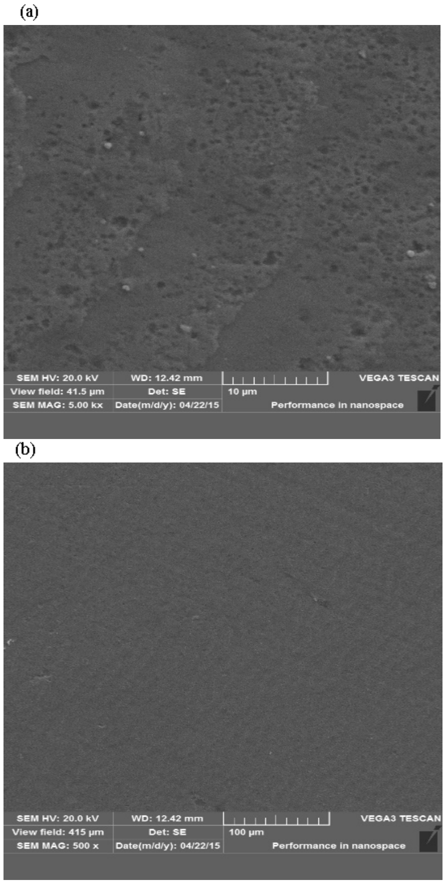

Fig. 8: SEM images of brass: a) Before MAF process and b) After MAF process

CONCLUSION

The effect of Magnetic Abrasive Finishing (MAF) method on the Temperature rise (Tr) andthe surface Roughness (Ra) has been investigated in this current work and the following conclusions can be deduced.

The optimum temperature for brass is obtained at 55.1C° which gives the highest value of $\Delta Ra = 78.427\times10^{-2}$ μm. The optimum parameters for brass are obtained at the following values (A = 700 rpm, B = 7.5 min, C = 1.84 mm and D = 1 A) which gives the highest value of ΔRa the most significant factor that has an effect on the surface roughness and temperature rise is the cutting speed followed by current, finishing time and the working gap.

NOMENCLATURE

$\bar{A}_{Nop}$ = The average of response at the optimum level of cutting speed
$\bar{B}_{Nop}$ = The average of response at the optimum level of finishing time
$\bar{C}_{Nop}$ = The average of response at the optimum level of working gap
$\bar{D}_{Nop}$ = The average of response at the optimum level of current
MAF = Magnetic Abrasive Finishing
MSD = Mean Squared Deviation
n = The total number of experiments
Ra = Surface Roughness
S/N = Signal to Noise ratio
$\bar{T}$ = The overall mean ofresponse ΔRa
Tr = Temperature rise
yi = The value of the response in that run
$\bar{y}^2$ = Mean value of response
σ = Standard deviation
ΔRa = The change in surface Roughness

REFERENCES

Anonymous, 2018. Discover companion: Tools and reporting to ensure process and product excellence. Minitab Inc., Pennsylvania, USA. http://www.minitab.com/en-us/.

Komanduri, R. and Z.B. Hou, 2001. A review of the experimental techniques for the measurement of heat and temperatures generated in some manufacturing processes and tribology. Tribol. Int., 34: 653-682.

Kumar, H., S. Singh, G. Nanak and P. Kumar, 2013. Magnetic abrasive finishing: A review. Intl. J. Eng. Res. Technol., 2: 1-9.

Lakshminarayanan, A.K. and V. Balasubramanian, 2008. Process parameters optimization for friction stir welding of RDE-40 aluminium alloy using Taguchi technique. Trans. Nonferrous Met. Soc. China, 18: 548-554.

Mishra, V., H. Goel, R.S. Mulik and P.M. Pandey, 2014. Determining work-brush interface temperature in magnetic abrasive finishing process. J. Manuf. Processes, 16: 248-256.

Moosa, A.A., 2017. Utilizing a Magnetic Abrasive Finishing technique (MAF) via, Adaptive Nero Fuzzy (ANFIS). Al Khwarizmi Eng. J., 10: 49-56.

Mulik, R.S. and P.M. Pandey, 2011. Magnetic abrasive finishing of hardened AISI 52100 steel. Intl. J. Adv. Manuf. Technol., 55: 501-515.

Roy, K.R., 1990. A Primer on the Taguchi Method. Van Nostrand Reinholds, New York.

Shinmura, T., K. Takazawa, E. Hatano and T. Aizawa, 1985. Study on magnetic abrasive process- process principles and finishing possibility. Bull. Japan. Soc. Precis. Eng., 19: 54-55.

Shinmura, T., K. Takazawa, E. Hatano and T. Matsunaga, 1990. Study on magnetic abrasive finishing. Ann. CIRP, 39: 325-328.

Vidal, C., V. Infante, P. Pecas and P. Vilaca, 2013. Application of taguchi method in the optimization of friction stir welding parameters of an aeronautic aluminium alloy. Adv. Mater. Manuf. Charact., 3: 21-26.