International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 17 (2015) pp 38543-38549
© Research India Publications. http://www.ripublication.com

Optimizing Abrasive Particle Speed and Size on Machining Performance in SAFBM of Brass

N.K. Francis
Research Scholar, Karpagam University, Coimbatore. francisnk123@gmail.com

Dr. K. G. Viswanadhan
Principal, CEMP, Alappuzha, Kerala. kgv1964@yahoo.co.in

Nair Jayish. S
S, NSS Engineering College, Palakkad, Kerala. nair505jayish@gmail.com

Vivek. M.S
METS School of Engineering, Mala, Kerala. royalmexjec@gmail.com

Sathyamoorthy. D
SPCET, Chennai. dsmsathiya@gmail.com

Abstract

Swirling Abrasive Fluidized Bed Machining (SAFBM) is a non-traditional method of abrasive flow machining as well as a novel variant of Fluidized Bed Machining (FBM) which is used to machine complex shape and size of work piece that are difficult to machine with conventional method. Owing to its ability to perform machining and generate polished surface from a roughness value of Ra 1.2µ to 0.2 µ within 8 hours of processing, this new method offers greater scope in the surface modification of rough machined surfaces with complex geometry such as component with ducts and grooves. The effects of various process parameters like machining time, abrasive grain size and particle impact speed have been investigated to reveal their impact on metal removal rate using Taguchi methodology on brass specimen. The experimental layout was designed based on the Taguchi's L^9 (3^4) Orthogonal array technique and analysis of variance (ANOVA) was performed to identify the effect of the cutting parameters on the response variables. The optimum set of process parameters has also been predicted to maximize the MRR.

Key words: SFBM, Distributor, Fluidization, Roughness, Swirling, ANOVA.

Introduction

Francis N. K. et. al [1], conducted experiments on Swirling Abrasive Fluidized Bed Machining (SAFBM) as an alternative form of Fluidized Bed Machining (FBM) using porous air distributer with inclined holes. The investigation focused on the comparative study with the FBM and testing the effectiveness as a non-traditional surface finishing process. The process parameters such as machining time, superficial velocity of air, abrasive grain size, work-piece material properties, location and geometry of the work piece and abrasive shape and type play major role in determining the degree of the roughness achieved and the metal removal. The research investigated the influence of abrasive impact speed and abrasive mesh size on copper (HV 49) specimen. The results proved that SAFBM is more effective as far as rate of surface modification is concerned and the surfaces finish that can be achieved (R_a). The flexibility and effectiveness was further demonstrated on an axi-symmetric complex-shaped machined component.

Various process parameters like processing time, particle grade, particle velocity, material properties, work piece positioning, abrasive type, particle bed weight and shape factor play major role on determining the machining performance in terms of *Ra* value and metal removal rate in FBM as observed by Barletta et al. [2]. R. K. Jain and V. K. Jain observed that the metal removal is maximized at an impact angle close to 20^0 at which the micro-cutting mechanisms plays major role [3]. R. Balasubramanian et al. [4], F. Quadrini et al. [5], Ravishankar et al.[6] observed that as the effect of micro-cutting mechanism plays less significant role during the rolling impact, MRR can be optimized when the work piece is positioned normal to the particle flow. B. Sreenivasan and V. R. Raghavan [8] studied the Hydrodynamic behavior of the swirling fluidized bed on an annular spiral distributor of blade angle 12°. Kumar et. al [8] observed that there exists an upper limit of static bed depth beyond which stable swirling of entire bed is not possible. The minimum swirl velocities are found to be 1.2–1.3 times the minimum fluidization velocities predicted for conventional fluidized beds. Mohideen et. al [9] investigated the effect of number of blades and blade inclination in radial plane. Muhammad Faizal et. al [10] conducted numerical investigation of airflow in a swirling fluidized bed. Galvin et. al [11] studied the nature and extent of inhomogeneous microstructure under various conditions in the simulation study.

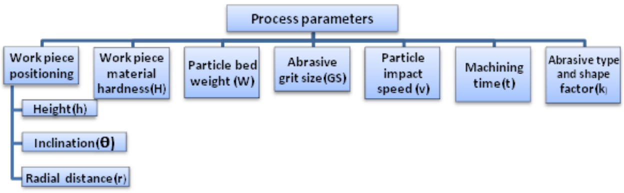


Figure 1. Process parameters affecting machining performance in SAFBM

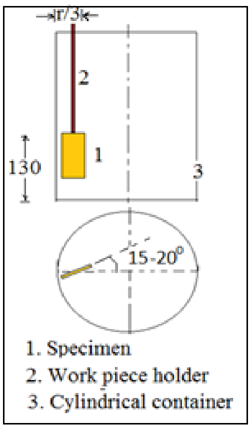
Various process parameters which determine the machining performance in terms of metal removal rate (MRR) and surface roughness (Ra) are schematically represented in Fig. 1. Work piece positioning depends on three parameters, namely height (h), radial distance (r), and inclination (ϴ) within the cylindrical container. The role played by material properties like hardness (H) the abrasive weight in the fluidized bed (W), abrasive type and shape factor (k) is also significant for the effectiveness of surface modification. Investigation on abrasive mesh size (MS), particle impact speed (v) and machining time (t) have already conducted in the previous works [1, 2].The present study focus on optimization of three most relevant process parameters such as abrasive mesh size (MS), superficial velocity (V) and machining time (t) on surface finish and material removal rate in SAFBM of softer materials like brass by using Taguchi methodology. The results of analysis of variance (ANOVA) indicate the ranking of relevance of the process parameters to maximize the MRR and minimize the surface roughness.

Materials and Methods

Swirling Fluidized Bed Machining (SAFBM) is a variant of conventional FBM in which the blower generates sufficient air supply to the porous distributor with evenly placed angular openings (Fig.2) through the plenum chamber. Compressed air surging out of the distributer with horizontal and vertical components of velocity due to the inclination of the holes fluidizes the silicon carbide grits lying settled on the distributer plate. The particles in fluidized state hence moves up in the container, swirls vigorously and hit on the metallic specimen surface causing wear and surface finish (Fig. 2-3).

The SAFBM is performed in a vertical fluidization column made up of plexi-glass as indicated in Figure 2. It also shows the distributor with angular openings of inclination 15^0 (hole diameter 3 mm). The evaluation of the findings of the tests were carried out by estimating the MRR from the work piece after machining, by means of a digital scale (resolution of 0.001g) and roughness (R_a value) with the help of Taylor Hobson instrument.

Fig. 2. SAFBM experiment setup and porus distributer



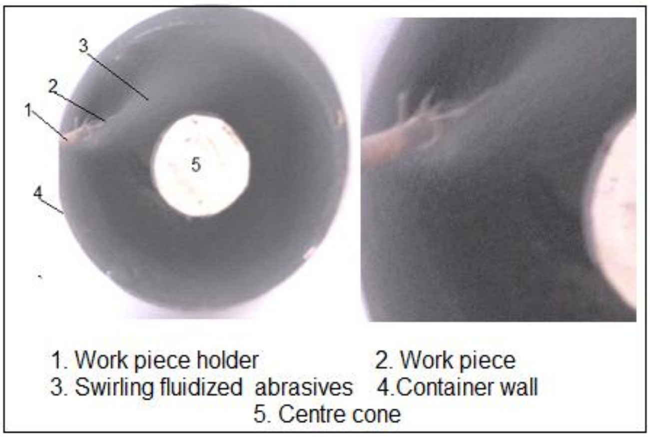


Fig. 3. Work piece positioning within the container and the top view of container while machining

During the first experimental plan three specimens of brass named as A, B, & C were treated with "grade 80" sand paper and rough surface was generated with *Ra* value 1.2μ each and then subjected to SAFBM under the operating conditions as shown in the Table 1 to investigate the effect of superficial velocity of abrasive particles on surface finish and metal removal rate. The second experiment investigates the effects of grain size, on metal removal and surface finish, using three different types of abrasive grain sizes namely MS: 8, MS: 16 and MS: 24 at constant superficial velocity as indicated in the Table 1.

TABLE 1. Operating conditions for the experiments

Specimen details -Material: brass Size: 80mmX60mm						
Thickness:1mm Weight: 80 g Type of Abrasive : SiC						
Experimental plan		Specimen	Initial *Ra* (μ)	Superficial velocity (m/s)	Abrasive grain size	Machining time (hours)
No	Details					
1	Effect of superficial velocity on roughness and wear	A	1.2	4.1	20	8
		B	1.2	3.8	20	8
		C	1.2	3.4	20	8
2	Effect of abrasive particle size on roughness and wear	D	1.2	4.1	8	8
		E	1.2	4.1	12	8
		A	1.2	4.1	20	8

TABLE 2: Process parameters and their values at different levels

Symbol	Cutting Parameter	Level 1	Level 2	Level 3
A	Machining time (t hours)	3	5	7
B	Mesh size (MS)	8	16	24
C	Superficial velocity (V m/s)	4.11	3.8	3.4

Results and Discussion

In the experiment to study the effect of machining time on metal removal and surface finish, a significant non-linear behaviour in both the metal removal and the Ra value trends were observed with the increase in machining time. It is already established in the previous works [1] that the metal removal and surface finish curves follow a linear approach in the initial stages and thereafter, a nonlinear approach. An accelerated metal removal tendency in the initial stages is due to the super imposition of metal removal actions of rolling impact and sliding impact by the abrasive particles and various cutting mechanisms such as ploughing, micro cutting, fatigue and cracking while the abrasive media strikes on the metal surface of specimen as reported in the literature survey. Typical rough surface texture generated after applying emery paper also contributed considerably towards the fast rate of metal removal in the initial stages. Nevertheless on processing further when the unique surface texture vanishes, the surface roughness attains a standard value for each metal alloy which remains constant thereafter. The trends of roughness curves, as depicted in Fig.4 (a-b) underline that larger the abrasive grit size and higher the velocity of impact faster will be the pace of surface modification to achieve the asymptotic value (0.84μ in 3 hours with MS: 8 and 0.42μ in 8 hours with MS: 20 at maximum velocity of 4.11m/s) and the non- linear characteristics. At the lowest speed of 3.43 m/s all the roughness curves continue to follow linear approach but with different slopes as both the surface modification and MR follow much lower pace owing to the low kinetic energy of abrasive particles at low speeds as depicted in Fig. 5c. Fig. 5(d-f) emphasis that machining with larger abrasives generate surface with high Ra value (0.84μ with MS: 8, 0.65μ with MS: 16 and 0.42μ with MS: 24) but with different machining times such as 2, 5 and 7 hours respectively. Further from Fig. 5a it is evident that at higher speeds, machining with high grades of abrasives on softer metals like copper for long will damage the surface due to sudden increase of Ra value. Optical microscopic images observed on brass specimen machining with SAFBM at different superficial velocity H(high)-4.11m/s, M(medium)-3.83 m/s and L(low)-3.43 m/s after intervals of 0, 3, 5, 7 and 10 hours are depicted in Fig. 4. It is quite evident that at high velocity surface modification quite faster as a result of which the stripes featuring in the initial stage (H0) vanished easily. Metal removal that follows a linear trend initially and thereafter non-linear trend is clearly explained in the figure as remarkable difference in surface morphology is visible between H0 and H3 but not among H5, H7 and H10. Processing for long on softer materials at higher velocities may damage the surface texture which is evident from H7 and H10. Slow pace of surface modification at lower speeds is explained in M0-M10 and L0-L10.

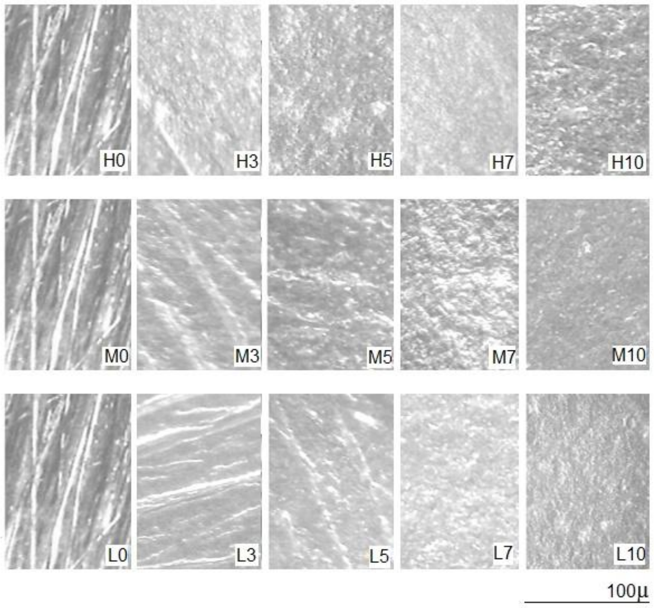
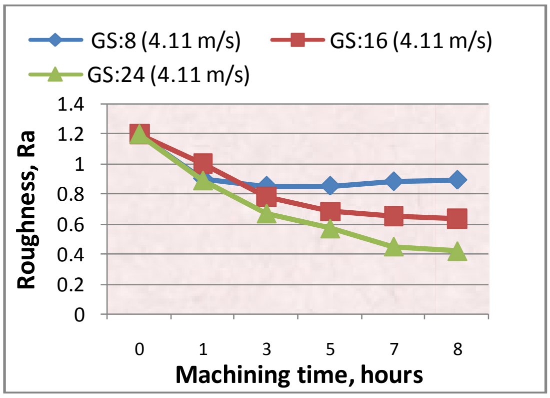
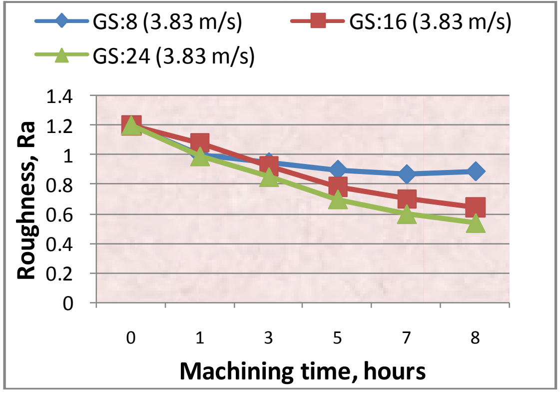


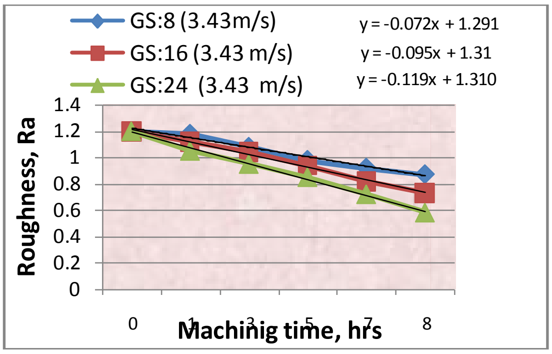
Fig. 4. Optical microscopic images on brass specimen machining with SAFBM varying superficial velocity. H(high)-4.11m/s, M(medium)-3.83 m/s and L(low)-3.43 m/s after intervals of 0, 3, 5, 7 and 10 hours.



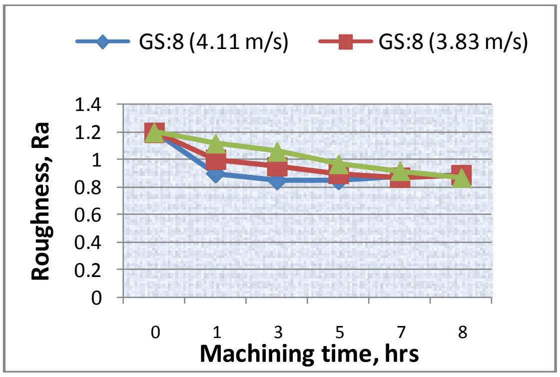
a)



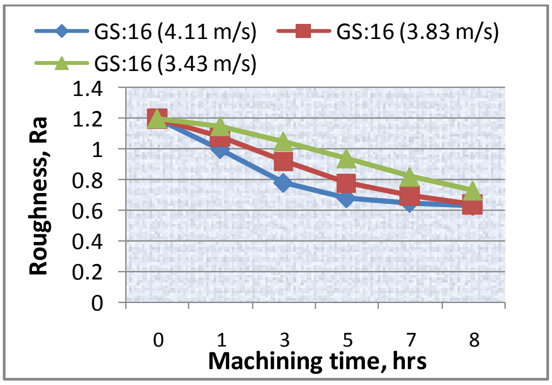
b)



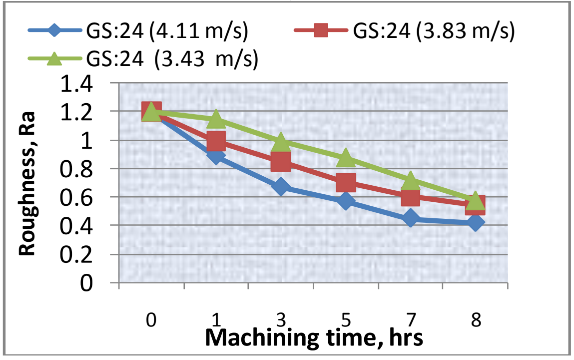
c)



d)



e)



f)

Fig. 5. Characteristic curves representing roughness v/s machining time with (a-c) impact velocity constant and (d-f) mesh size constant. H(high)-4.11m/s, M(medium)-3.83 m/s and L(low)-3.43 m/s after intervals of 0, 3, 5, 7 and 10 hours.

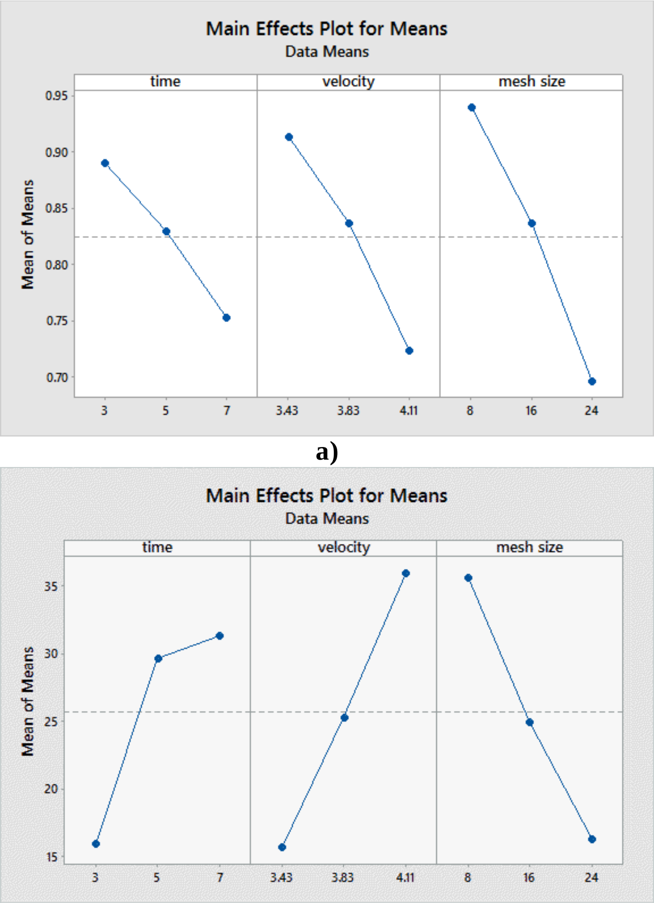
TABLE 3. Taguchi's experimental plan

Experimental levels	Experimental factors			Mesh Size (mm^3)	Exp. responses	
	Time	Velocity	Mesh size		Roughness	MRR
1	3	3.43	8	0.001953	1.08	14
2	3	3.83	16	0.000244	0.92	16
3	3	4.11	24	0.000072	0.67	18
4	5	3.43	16	0.000244	0.94	20
5	5	3.83	24	0.000072	0.7	18
6	5	4.11	8	0.001953	0.85	51
7	7	3.43	24	0.000072	0.72	13
8	7	3.83	8	0.001953	0.89	42
9	7	4.11	16	0.000244	0.65	39

Discussing experimental design strategy, Taguchi recommends orthogonal array (OA) for laying out experiments. For the present study L9 OA is selected in which three factors at three levels (3^3). Minitab software is used for Design of Experiment (DOE) in analysis of SFABM. Three process parameters, three at three levels have been decided. It is desirable to have three minimum levels of process parameters to reflect the true behavior of output parameters of study. The levels for each process parameters were entered in the Minitab window as a new design. The operating parameters such as abrasive mesh size (MS), superficial velocity(V) and machining time(t) were varied to determine their effects on machining characteristics of surface finish(in terms of reduction in Ra value) and MRR. The experiments were designed to study the effect of these on response characteristics of SAFBM process. Table 2 shows various levels of process parameters and values of other fixed parameters.

Fig. 6 shows the main effect plots (MEPs) of MRR and Ra value according to all the process variables. Process variable mesh size (MS) was found to be the most significant factor on the experimental responses MRR and Ra values. The greater the increase in mean diameter of abrasive particles, the greater the increase in MRR and the more will be the average roughness. Each process parameter at three levels are plotted on X- axis and on Y-axis the response values. The main effect plots are used to determine the optimal design conditions to obtain the high MRR and good surface finish. The MEPs for surface finish (Ra) indicate that with the increase in machining time (7 hours at level 3), increase in velocity (4.11 m/s at level 3) and decrease in abrasive grit size(MS: 24 at level 3) there is improvement the in surface finish in terms of reduction of Ra value (Fig. 6a). Fig.6b shows the main effect plot for MRR in which maximum value in MRR is recorded with the increase in machining time (7 hours at level 3), superficial velocity (4.11 m/s at level 3) and abrasive mesh size (MS:8 at level 1).

The delta statistics involving response data for Signal to Noise Ratios to compare the relative magnitude of 'effects' is described in Table 4. The delta statistics is estimated by calculating the difference between highest and the lowest average values for each factor. Ranks are assigned based on delta values; rank 1 to the highest delta value, rank 2 to the second highest and so on. The rank indicates the relative importance of each factor to the response. The rank and delta value shows that the superficial velocity has the greatest effect on MRR followed by abrasive size whereas abrasive size has the greatest effect on surface finish followed by superficial velocity.



a)

b)

Fig. 6. ANOM on L9 mixed level Taguchi's experimental design a) Surface Roughness b) MRR

TABLE 4. Response table for Signal to Noise Ratios

	Smaller is better(Roughness)			*Larger is better(MRR)*		
Level	Time	Velocity	Mesh size	Time	Velocity	Mesh size
1	1.1781	0.9074	0.585	24.04	23.7	29.85
2	1.6824	1.6115	1.668	28.43	27.2	27.31
3	2.5358	2.8773	3.143	28.86	30.4	24.16
Delta	1.3577	1.9698	2.558	4.82	6.62	5.68
Rank	3	2	1	3	1	2

TABLE 5. ANOVA table for experimental response roughness(Ra)

Source	Degree of freedom	Sum of squares	Mean square	Calculated Fisher	Contribution
	DF	Seq SS	Adj MS	Fα=5%	P%
Time	2	0.028156	0.0141	19	16
Velocity	2	0.054822	0.0274	19	32
Mesh Size	2	0.089489	0.0447	19	52
Error	2	0.000956	0.0005		0.6
Total	8	0.173422			100
Standard deviation(S)		Coefft. of determination(R-sq)		R-sq (adj)	
0.054961		91.29%		86.07%	

The results of the ANOVA (Analysis of Variance) with surface roughness and material removal rate are shown in Tables 5 and 6. This analysis was carried out for significance level of $\alpha=0.1$ i.e. for a confidence level of 90%. The last column of the tables shows the percent contribution of significant source of the total variation indicating the degree of influence on the result. Table 5 shows the results of ANOVA for surface roughness Ra. The abrasive mesh size (51.6%) is the most significant process parameter followed by superficial velocity of air (31.61%) and machining time (16.24%). Table 6 shows results of ANOVA for metal removal rate MRR. The superficial velocity of air (38.17%) is closely followed by abrasive mesh size (34.6%) and machining time (26.12%). The reliability of the experimental procedure is confirmed as the percentage contribution of factor ‘error’ is reported very low.

TABLE 6. ANOVA table for experimental response MRR

Source	Degree of freedom	Sequential Sum of squares	Mean Square	F-Ratio	Calculated Fisher	Contribution
	DF	Seq SS	Adj MS	Test-F	Fα=5%	P%
Time	2	425	212	23.6	19	26.12%
Velocity	2	621	310	34.5	19	38.17%
Mesh Size	2	563	281	31.3	19	34.60%
Error	2	18	9			1.11%
Total	8	1626				100
Standard deviation(S)		Coefft. of determination(R-sq)			R-sq (adj)	
3		98.89%			95.57%	

Conclusion

This work is a part of the ongoing research project in the Swirling Abrasive Fluidized Bed Machining (SAFBM). Although various process parameters such as machining time, superficial velocity of air, abrasive grain size, work-piece material properties, location and geometry of the work piece and abrasive shape and type affect the machining performance, the most relevant parameters of machining time, superficial velocity and abrasive grain size were subjected to Taguchi’s design in the experimental study on copper specimens to optimize them. The analysis of variance (ANOVA) confirms the analysis of mean (ANOM) results reported. The following conclusions have been made.

- The experimental results showed that the Taguchi parameter design is an effective way of determining the optimal process parameters for achieving high MRR and better surface finish.
- The percent contributions of abrasive grit size (51.6%) and superficial velocity of air (31.61%) in affecting the variation of surface roughness are significantly larger as compared to the contribution of the machining time (16.24%).
- The percent contributions of abrasive grit size (38.17%) and superficial velocity of air (34.6%) are found to be more or less equally significant with the former (grit size) has a slight edge in affecting the MRR. Contribution of machining time (26.12%) also is not less compared to the previous case of surface finish.
- Delta statistics ranks velocity, mesh size and machining time as 1,2 and 3 affecting MRR and mesh size, velocity and time as 1,2 and 3 affecting surface finish
- The optimal combination of process parameters for maximum MRR was obtained at 4.11m/s as superficial velocity, MS: 8 as abrasive size and 7 hours as machining time.

References

[1] Francis, N. K., Viswanadhan, K. G., Paulose, M. M. “Swirling abrasive fluidized bed machining: Effect of process parameters on machining performance”, International journal of Materials and Manufacturing Process, vol.30, no. 2, pp. 852-857, 2015.

[2] Barletta, M. “A new technology in surface finishing - fluidized bed machining (FBM) of aluminum alloys” International Journal of Material Processing Technology, vol.173, no. 2, pp. 157-165, 2006.

[3] Jain, R.K., Jain, and V.K. “Modeling of material and surface roughness in abrasive flow machining process” International Journal of Machine Tools & Manufacture, vol. 39, pp. 1903-1923, 2001.

[4] Balasubramanian, Krishnan, J, Ramakrishnan, N. “A study on the shape of the surface generated by abrasive jet machining” Journal Material Process Technology, vol. 121, pp. 102-106, 2002.

[5] F. Quadrini, V. Tagliaferri and R. Polini. “Effect of coating roughness on performance of small CVD

diamond coated tools", Machining Science and Technology, vol. 12, pp. 390-404. 2008.

[6] Ravi Sankar V. K. Jain, J. Ramkumar. "Effect of Abrasive Medium ingredients on finishing of Al alloy and Al alloy/SiC Metal Matrix Composites using Rotational Abrasive Flow Finishing", Applied Mechanics and Materials vol. 110- 116, pp. 1328 - 1335, 2012.

[7] Sreenivasan, B., Raghavan, V. R. "Hydrodynamics of a swirling fluidized bed", Chemical Engineering and Processing, vol. 41, pp. 99-106, 2002.

[8] Kumar, Harish, S. and Murthy, D. V. R. "*Minimum superficial fluid velocity in a gas–solid swirled fluidized bed,"* Chemical Engineering and Processing: Process Intensification, vol. 49, no. 10, pp. 1095-1100, 2010.

[9] Mohideen, M. F., Seri, S. M., Raghavan, V. R. "Fluidization of Geldart type-D particles in a swirling fluidized bed," Applied Mechanics and Materials, vol. 110-116, pp. 3720 – 27, 2012.

[10] Mohd. Faizal, Mohideen Batcha, Vijay. R. Raghavan. "Numerical investigation of airflow in a swirling fluidized bed," Asian Journal of Scientific Research, vol. 6, pp. 157-166, 2013.

[11] Galvin, J. V., S., Benyahia. "The effect of cohesive forces on the fluidization of aeratable powders", AIChE J, vol. 60, pp. 473-478, 2014.

[12] J. Y. Li, W. N. Liu, L. Yang, F. Sun. "Study of abrasive flow machining parameter optimization based on Taguchi method," Journal of Computational and Theoretical Nano- science, vol. 10, no. 12, pp. 2949–2954, 2013.

[13] R. K. Jain, V. K. Jain, and P. M. Dixit, "Modeling of material removal and surface roughness in abrasive flow machining process," International Journal of Machine Tools and Manufacture, vol. 39, no. 12, pp. 1903–1923, 1999.