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Abrasive Jet Drilling Of Glass using Normal-bed and Fluidized-bed AJM Setup

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Abstract*: *Abrasive Jet Machining (AJM) is a promising unconventional modern machining process used to machine hard and brittle materials. This paper focuses on machining of borosilicate-glass work piece with various grits of zircon abrasives using normal and fluidised bed mixing chamber based AJM setups.The normal AJM setup is first designed and fabricated to conduct the experiments according to the Box-Behnken design of response surface methodology. Again, some modifications are made in the existing normal mixed chamber to fabricate the fluidized bed mixing chamber based AJM setup and experiments are carried out with the same input parameters on both the AJM setups. The SEM micrograph analysis is performed to study the impact-mechanism and crack-propagation due to AJM.

Keywords* : *Normal AJM, FB-AJM, RSM, Borosilicate Glass, SEM.

I. INTRODUCTION

Nontraditional machining covers a wide range of machining with less material removal and high accuracy which are difficult and uneconomical in the conventional methods. Abrasive Jet Machining (AJM) is treated as one of the efficacious non-conventional method that has paid more attention to the researchers because of its wide application in economical machining of complex, intricate parts of the brittle materials like ceramics, glass, quartz, sapphire, mica, and refractory materials with high cutting efficiency and accuracy. The repeated bombardment of the tiny solid abrasives on the target surface at high momentum creates micro cracks which are then expanded and propagated in lateral and longitudinal directions to produce fractures. AJM is free from any chatter and vibration problems. This contactless cutting action occurs in a cool atmosphere because the compressed air acts as the coolant. Proper utilization of the process parameters, operator's experience and proper design of the machine setup affect a lot towards the machining process.

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Proper combination of the input parameters and their optimization is required for economic utilization otherwise the elaborate experimentation will be costly. Different machining parameter like carrier gas, pressure, grain sizes, work piece material, and nozzle-tip distance influence the working efficiency of AJM process. Researchers have proposed different methods with certain design of experiments (DOE) to find many suitable combinations of process parameters for achieving better machining efficiency. The effects of different input quantities like abrasive size, nozzle specification, stand-off-distance and workpiece specification upon the output quantities was experimentally investigated by Balasubramaniam et al.[1] using the Taguchi design for the stainless steel burr specimens. Wakuda et al.[2] investigated the responses of AJM of alumina ceramics with three types of grains for smoothing and creating fragmentations. Ally et al.[3] considered the surface evolution models to study the abrasive jet micro machining in glass polymer for predicting the profile of micro-channels. Routara et al.[4] considered the Grey Taguchi analysis for finding the optimal machining parameters of AJM on the glass work piece. Embedding of erodent particles was examined by Getu et al.[5] by impacting angular garnet grains on materials like acrylonitrile butadiene styrene polymethyl-methacrylate and polyethylene. Domiaty et al. [6] verified the results of experiments with the mathematical models for drilling of glass pieces with AJM. Park et al. [7] performed the micro-grooving of glass, deburring of ceramics and semiconductor using masking technique. Saragih et al.[8] performed the micro AJM of glass material by implementing thick layers of SU-8 erosion resistant masks. AJM of the planar areas with oscillating target material and fixed nozzle was carried out by Ghobeity et al. [9] using both masked and unmasked methods. Abrasive hot air jet machining of soda lime glass was successfully implemented by Jagannatha et al. [10] to study the impact of air temperature on the responses using Taguchi method.

Hence the machining process on AJM is still in the developing stage and a lot of research can be done upon it. One such effective development is the homogeneous mixing of abrasives inside the mixing chamber.Then the new concept of fluidised bed abrasive jet machining (FB-AJM) is designed, fabricated and implemented. Barletta et al. [11-12] first developed this hybrid concept of FB-AJM to finish the internal surfaces of long tubes of stainless steel and aluminium alloy to achieve smooth surfaces. B. K Nanda et al. [13-14] performed experiments on FB-AJM of alumina ceramic and glass fibre reinforced polymer (GFRP) using SiC abrasives to analyze the influence of process parameters on the different responses and applied the particle swarm optimization technique for predicting optimal combinations. The present research work has reported on the design and development of normal AJM.

II. EXPERIMENTATION

A. Normal bed mixing chamber-AJM setup

The indigenously designed and fabricated abrasive jet machining (AJM) setup with different components and its CATIA model are shown in Fig.1and Fig.2. The single cylinder air compressor with maximum working pressure of 12 bar is used to supply the compressed air at the required machining pressure. Then, the pressurized air is allowed to flow through the dehumidifier or Filter Regulator Lubricator (FRL) to supply dry air. Proper mixing of air and abrasive occurs inside the designed mixing chamber. A seamless mild steel pipe is joined with two circular plates, at its top and bottom ends. Fine grained abrasive particles of different grades are made to pass into the chamber through the drilled hole on the top, the hole on the surface of the pipe allows compressed air to flow into the chamber from the dehumidifier, and finally the uniform air-abrasive mixture is taken out from the mixing chamber though another hole on the opposite side of the pipe surface to feed to the nozzle.

B. Fluidized bed mixing chamber-AJM setup

In the fluidized bed abrasive jet machining (FB-AJM) system, the high pressure compressed air coming out of the dehumidifier triplicates to make the flow in upward, downward, and horizontal directions. All these three three streams proceed through the abrasives inside the mixing chamber to make it fluidized bed for creating a cloud of suspended particles close to the nozzle area to produce the uniform and homogeneous air-abrasive mixture. The FB-AJM setup with different fixtures are indigenously designed and fabricated as shown in Fig. 3. The high pressure, clean, and dry air is used to prevent the agglomeration and clogging of abrasives inside the nozzle duct. High wear and abrasion resistance D2 steel material is used to manufacture the nozzle.

Fig.1. Normal AJM setup

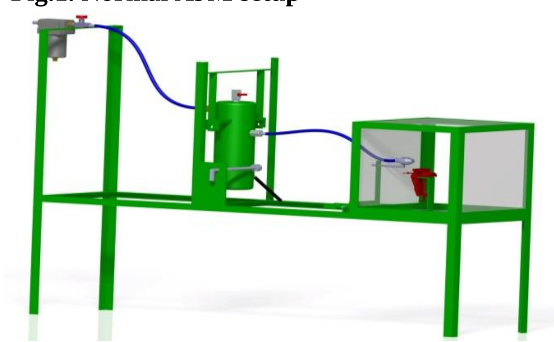

Fig. 2. CATIA model of Normal AJM setup.

Fig. 3. FB-AJM setup.

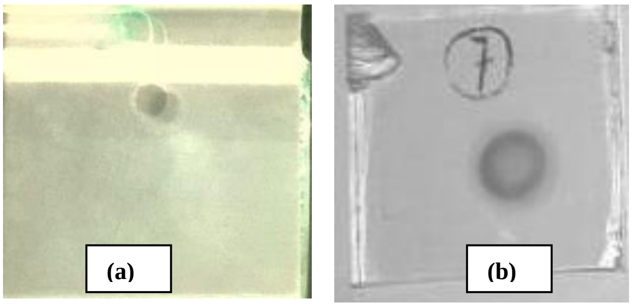

Fig. 4. Machined surface with (a) Normal AJM (b) FB-AJM.

C. Specification of work piece and abrasive particle

Borosilicate glass material is selected as the work-piece for experimentation with specification of 25mm x 25mm x 4mm (with ±1% dimensional accuracy) as given in Fig. 4. The nature of abrasive material depends on the shape, size, nature of the work piece, and surface finish. So, zircon sand of three grain sizes, 260, 525, and 745µm are considered as the abrasive material for experimentation as shown in Fig.4. Zircon sand particles of irregular shapes with sharp cutting edges are shown in Fig.5 in their SEM micrograph, but their average sizes are considered here.

D. Selection of input and output parameters

The selected three input process parameters influencing the responses of both the normal and the FB-AJM processes are: pressure (P), nozzle tip distance (Z) and grain size (G) .They are used to measure the two responses: material removal rate (MRR) and average surface roughness (Ra).

E. Measurement of Output quantities

Material removal rate (MRR) is the amount of material removed from the glass surface per unit time.

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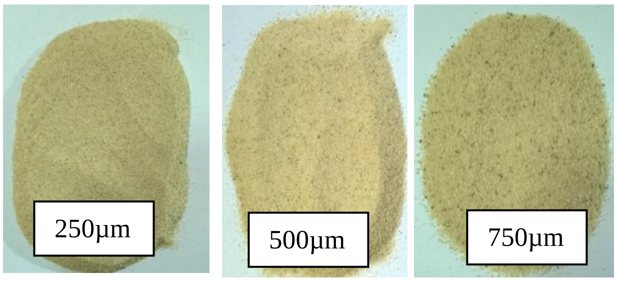
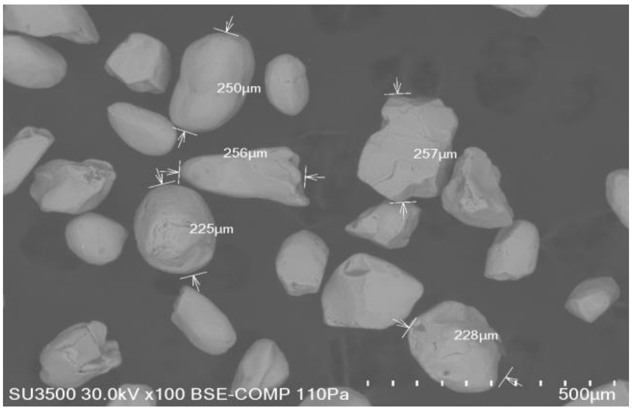
If m_1 and m_2 are the mass of the work material before and after AJM for Δt seconds, then the material removal rate is $MRR = \frac{(m_1 - m_2)}{\Delta t}$, where m_1 and m_2 are measured by the weighing machine with least count 0.0001.

The surface roughness (Ra) of the machined surface are measured with MITUTOYO roughness tester.



(a)



(b)

Fig. 5. (a) Different grades of zircon sand abrasives; and (b) SEM of abrasives of APS 250 µm.

F. Experimental Planning

Box-Behnken Design (BBD) of response surface methodology (RSM) of the design of experiment (DOE) is used to perform the experiments with the selected three inputs, each with three levels: low, mid and high, along with three centre points to find the fifteen number of runs. The design matrix and surface plots are obtained by using Design Expert 8 software. Table-I shows the selected input parameters with levels.

Table I: Input parameters at different levels

Sl. No.	Input quantities with unit	Lower (-1)	Middle (0)	Higher (+1)
1	Pressure(P), kg/cm^2	3	4	5
2	Nozzle Tip Distance (D), mm	4	5	6
3	Grain Size (Gs), µm	200	350	500

III. RESULTS AND DISCUSSION

The 15 number of experiments with BBD design matrix are conducted on both the Normal AJM (N-AJM) and FB-AJM setups. Table-II shows the input values at different levels and the corresponding results therein. Design expert software is used for further analysis.

A. Surface Plot analysis of Responses of FB-AJM

The surface plot of MRR with combinations of the input parameters pressure (P), nozzle tip distance (Z) and grain size(G) are shown in Fig.6(a) to study the variations. It is found that MRR remains constant with P up to the mid-values of P but after that it decreases slightly due to certain amount of flaring. Further MRR increases with NTD due to acceleration of abrasives after leaving the nozzle. Initially MRR increases with GS and after that it decreases because of less impulse action on the work piece. The 3-D plot analysis of Ra with pressure , nozzle tip distance, and grain size are given in Fig.6(a). It is seen that Ra increases with pressure, nozzle tip distance, but decreases with the grain size.

Table II: Observations

Sl. No.	P	Z	G	FB-MRR	FB-Ra	N-MRR	N-Ra
1	3	6	500	0.02072	1.712	0.01862	3.28
2	4	6	750	0.02071	1.712	0.01644	2.48
3	4	5	500	0.02115	1.64	0.01784	2.54
4	4	5	500	0.01782	1.83	0.01512	3.7
5	5	5	750	0.02011	2.115	0.01675	2.48
6	4	4	250	0.01633	1.586	0.01521	2.98
7	4	5	500	0.01911	1.89	0.01405	3.12
8	3	4	500	0.0211	1.456	0.01731	3.04
9	3	5	750	0.01794	1.709	0.0136	2.16
10	4	4	750	0.01713	1.634	0.01232	3.54
11	4	6	250	0.02108	1.909	0.0129	2.72
12	5	5	250	0.01725	2.275	0.0121	3.18
13	5	4	500	0.01621	2.21	0.01507	3.6
14	3	5	250	0.01766	1.513	0.01512	2.64
15	5	6	500	0.01773	1.822	0.01325	3.12

B. Surface Plot analysis of Responses of FB-AJM

The surface plot of MRR with combinations of the input parameters pressure (P), nozzle tip distance (Z) and grain size(G) are shown in Fig.6(a) to study the variations. It is found that MRR remains constant with P up to the mid-values of P but after that it decreases slightly due to certain amount of flaring. Further MRR increases with NTD due to acceleration of abrasives after leaving the nozzle. Initially MRR increases with GS and after that it decreases because of less impulse action on the work piece. The 3-D plot analysis of Ra with pressure , nozzle tip distance, and grain size are given in Fig.6(a). It is seen that Ra increases with pressure, nozzle tip distance, but decreases with the grain size.

C. Surface Plot analysis of Responses of N-AJM

The surface plot of MRR with combinations of the input parameters pressure (P), stand off distance (Z) and grain size(G) are shown in Fig.6 (b) to study the influence of these inputs. It is found that MRR remains constant with P up to the mid-values of P but after that it increases slightly due to high velocity of the abrasives. Further MRR increases with NTD due to acceleration of abrasives after leaving the nozzle. Initially MRR increases with GS and after that it decreases because of less impulse action on the work piece.

The surface plot analysis of surface roughness (Ra) with pressure, stand off distance, and grain size are given in Fig.6(b).

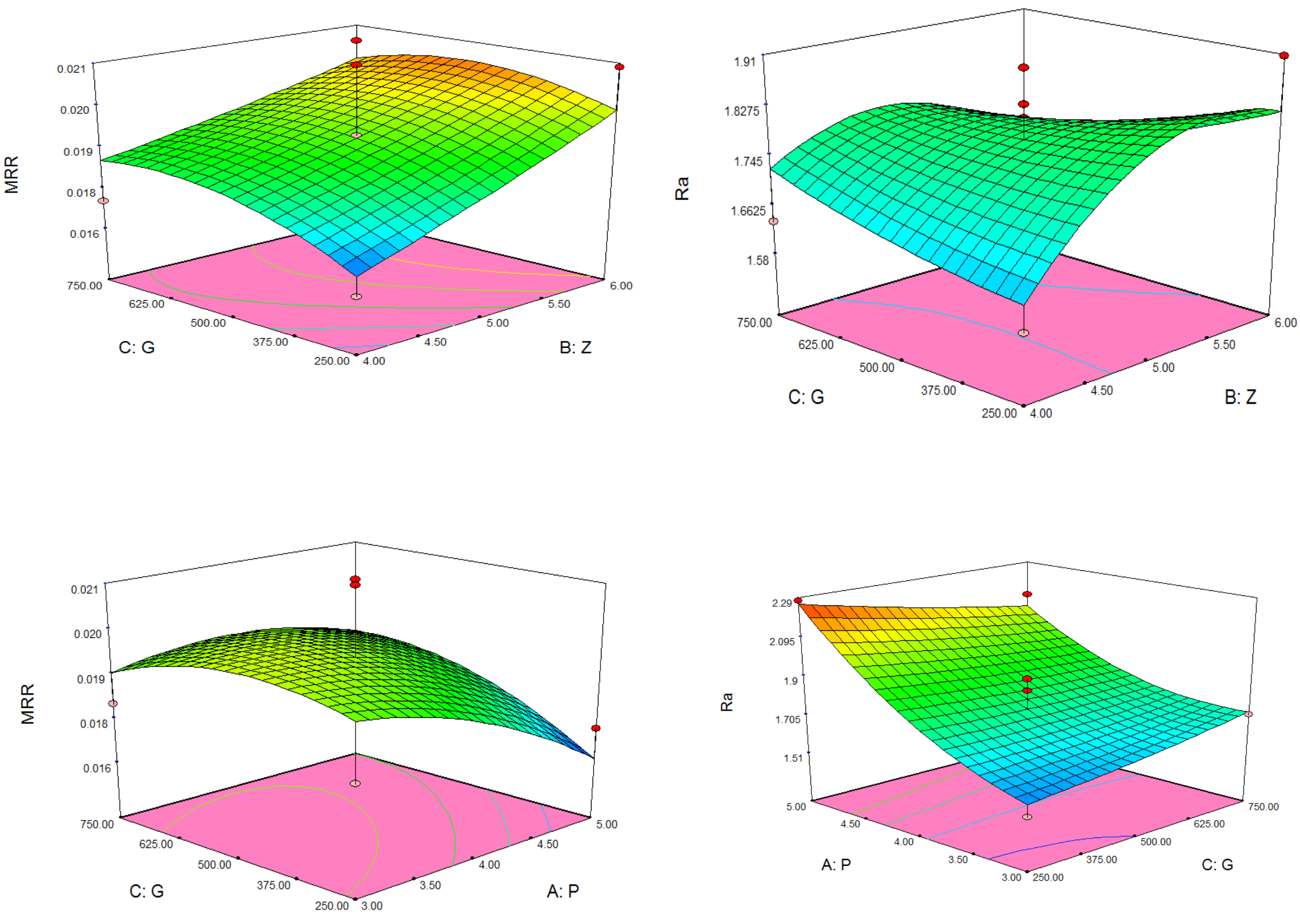


Fig. 6. (a) Surface Plots of MRR and Ra of machined work-piece during FB-AJM.

It is seen that surface roughness is less at lower pressure, but increases later with P to make the surface rough because of more impact on the surface. Initially, Ra slightly decreases with nozzle tip distance due to less MRR, and then it slightly increases. Again Ra increases with GS up to the mid-values and then decreases.

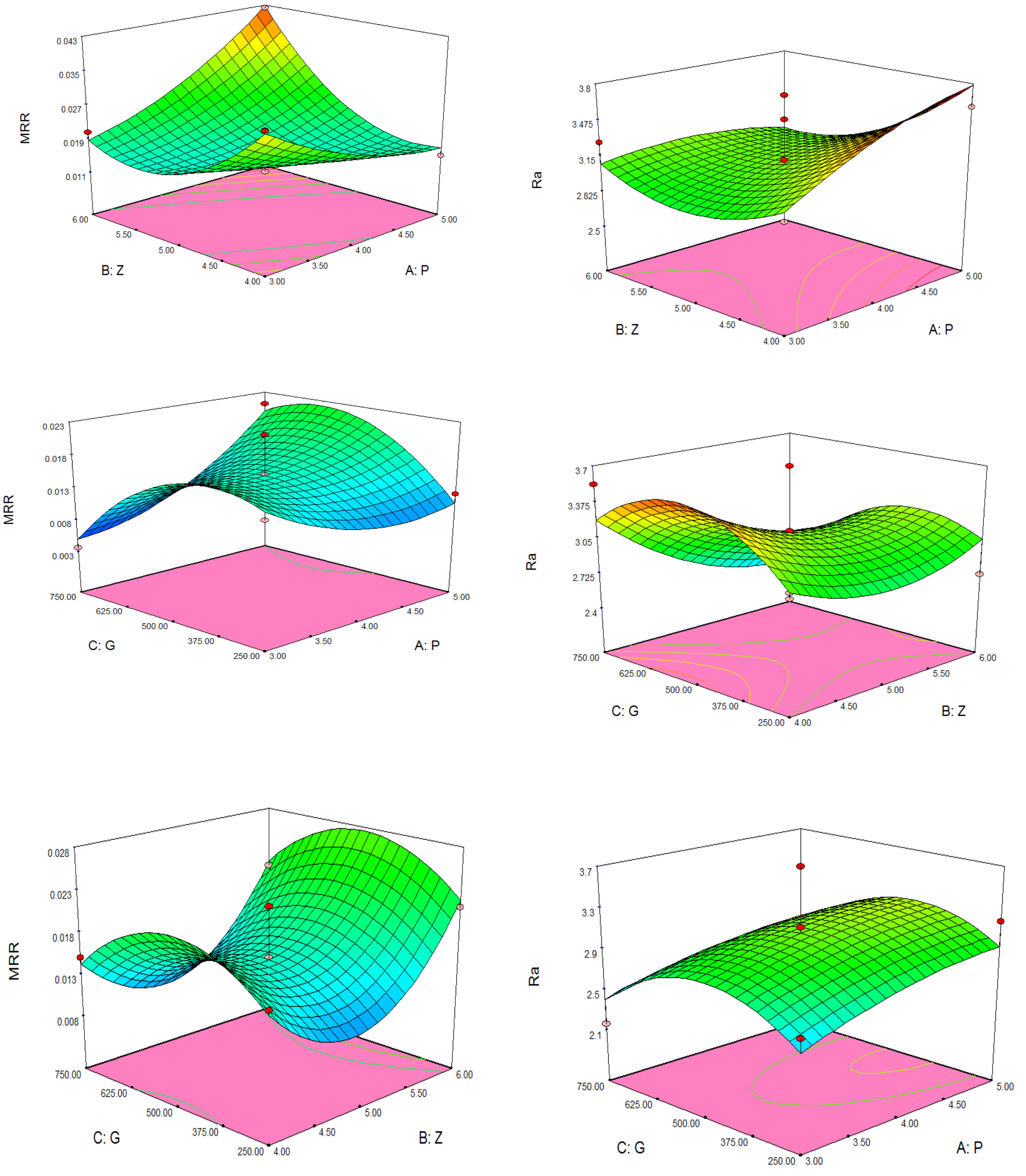


Fig. 6. (b) Surface Plots of MRR and Ra of machined work piece during N-AJM.

D. Comparison between FB-AJM and Normal AJM

The comparison plots of FB-AJM and Normal-AJM are given in Fig.7(a) and 7(b) for the MRR and Ra. It is clear from the plots that MRR is more in FB-AJM as compared to Normal AJM for the same input parameters, indicating that more material is removed from the work piece in the fluidized bed mixing from the work piece in the fluidised bed mixing chamber. Similarly, it observed that surface roughness is lesser in FB-AJM as compared to Normal AJM, implying that surface is more smooth in FB-AJM.

E. SEM Analysis

The SEM images in Fig.8(a) and Fig.(b) reveal the smoothness of the eroded surfaces with presence of some craters to indicate that some particles are flared beyond the cutting zone creating over cut . It is also cutting zone that produces over cut . It is also seen that this flaring is more in Normal AJM making the surface rough with less MRR as compared to FB- AJM. Again, direct plastic deformation on the material is seen by the appearance of white marks.

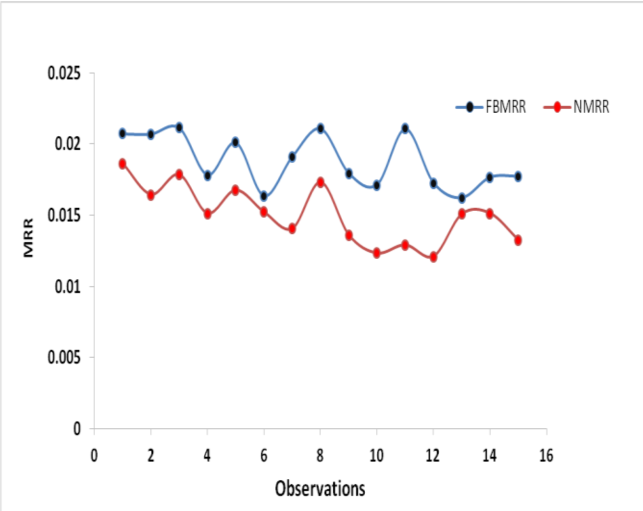


Fig. 7. (a) Comparison of MRR of FB-AJM and Normal AJM.

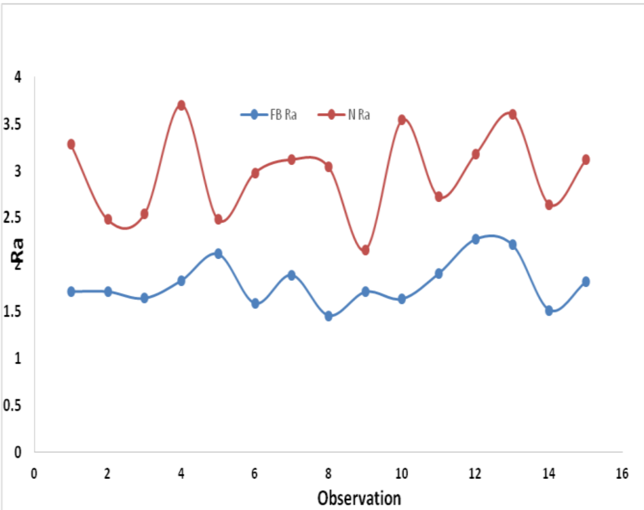


Fig. 7. (b) Comparison of Ra of FB-AJM and Normal AJM.

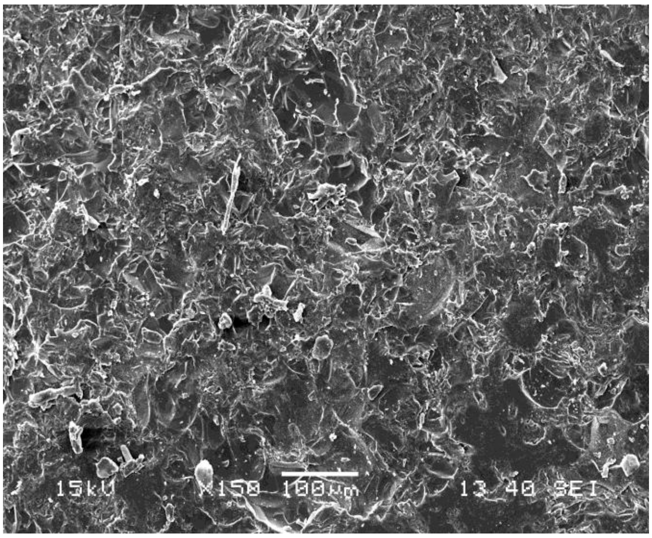


Fig. 8 (a) SEM of machined work piece on FB-AJM.

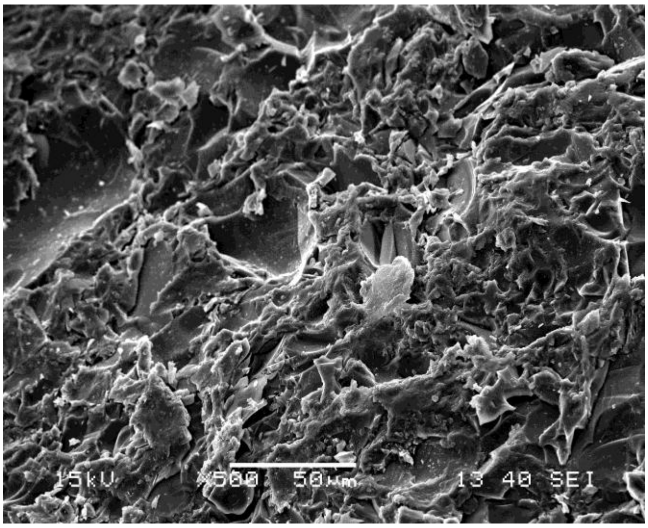


Fig. 8. (b) SEM of machined work piece on Normal AJM.

F. SEM Analysis

The SEM images in Fig.8(a) and Fig.(b) reveal the smoothness of the eroded surfaces with presence of some craters to indicate that some particles are flared beyond the cutting zone creating over cut . It is cutting zone creating over cut . It is also seen that this flaring is more in Normal AJM making the surface rough with less MRR as compared to FB-AJM. Again, direct plastic deformation on the material is seen by the appearance of white marks.

IV. CONCLUSIONS

All the designed experiments are conducted sucessfully to produce the required machining on borosilicate glass work piece by the indigenously designed and developed fluidized bed abrasive jet machining (FB-AJM) and Normal abrasive jet machining (N-AJM) setup using zircon sand abrasives of three different grades. The following inferences can be drawn:

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(i). From the surface plot it is observed that better material removal rate (MRR) is achieved for the FB-AJM setup as compared to the Normal AJM at the same parametric combinations on the same work-piece material.
(ii). Similarly, it observed that surface roughness is lesser in FB-AJM as compared to Normal AJM, implying that surface is more smooth in FB-AJM.
(iii). From the analysis of individual responses at different input factors it is seen that FB-AJM is more suitable than the normal AJM giving more MRR and Ra. It is due to the fact that more homogeneous mixture of the abrasive and air mixture impinge on the work surface.
(iv). The SEM micrograph depicts that plastic deformations of material are generated at the impingement area and propagated. The flaring area is more in Normal AJM as compared to FB-AJM.

REFERENCES

1. R.Balasubramaniam, J. Krishnan,and N. Ramakrishnan,"An Experimental Study on the Abrasive Jet Deburring of Cross-Drilled Holes," Journal of Materials Processing Technology 91, no. 1 1999,pp. 178–182.
2. Manabu Wakuda, Yukihiko Yamauchi, and Shuzo Kanzaki, "Material Response to Particle Impact during Abrasive Jet Machining of Alumina Ceramics," Journal of Materials Processing Technology 132, no. 1 ,2003, pp 177–183.
3. S. Ally, J. K. Spelt, and M. Papini, "Prediction of Machined Surface Evolution in the Abrasive Jet Micro-Machining of Metals," Wear 292 ,2012 pp ,89–99.
4. Bharat Chandra Routara et al., "Optimisation of Multiple Performance Characteristics in Abrasive Jet Machining Using Grey Relational Analysis," International Journal of Manufacturing Technology and Management 24, no. 1–4 ,2011 pp,4–22.
5. H. Getu, J. K. Spelt, and M. Papini, "Conditions Leading to the Embedding of Angular and Spherical Particles during the Solid Particle Erosion of Polymers," Wear 292 ,201 pp: 159–168.
6. A. El-Domiaty, HM Abd El-Hafez, and M. A. Shaker, "Drilling of Glass Sheets by Abrasive Jet Machining," World Academy of Science, Engineering and Technology 32 (2009): 61–67.
7. Dong-Sam Park et al., "Micro-Grooving of Glass Using Micro-Abrasive Jet Machining," Journal of Materials Processing Technology 146, no. 2 (2004): 234–240.
8. Agung Shamsuddin Saragih and Tae Jo Ko, "A Thick SU-8 Mask for Microabrasive Jet Machining on Glass," The International Journal of Advanced Manufacturing Technology 41, no. 7 (2009): 734–740.
9. A. Ghobeity, M. Papini, and J. K. Spelt, "Abrasive Jet Micro-Machining of Planar Areas and Transitional Slopes in Glass Using Target Oscillation," Journal of Materials Processing Technology 209, no. 11 (2009): 5123–5132.
10. N. Jagannatha et al., "Machining of Soda Lime Glass Using Abrasive Hot Air Jet: An Experimental Study," Machining Science and Technology 16, no. 3, 2012:, pp 459–472.
11. M. Barletta et al., "Fluidized Bed Assisted Abrasive Jet Machining (FB-AJM): Precision Internal Finishing of Inconel 718 Components," Journal of Manufacturing Science and Engineering 129, no. 6 2007, pp1045–1059.
12. Massimiliano Barletta and Vincenzo Tagliaferri, "Development of an Abrasive Jet Machining System Assisted by Two Fluidized Beds for Internal Polishing of Circular Tubes," International Journal of Machine Tools and Manufacture 46, no. 3,2006, pp 271–283.
13. B. K. Nanda, A. Mishra, and D. Dhupal, "Fluidized Bed Abrasive Jet Machining (FB-AJM) of K-99 Alumina Ceramic Using SiC Abrasives," The International Journal of Advanced Manufacturing Technology 90, no. 9–12 , 2017 pp 3655–3672.
14. Nanda, B. K. Nanda., Ankan Mishra, and D. Dhupal. "Drilling of GFRP Flat Plates with Modified AJM Process using SiC Abrasives." AIMTDR-2016, December ,2016, pp 16-18.

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Dr. B.K. Nanda is working as Associate. Professor in KIIT Deemed University, India. His research interests are in non-traditional machining, micro conventional machining, optimization, He has been teaching mechanical subjects since last twenty-five years. He holds memberships of various professional bodies like Life Member Indian Society of Technical Education (ISTE) and Indian Science Congress Association (ISCA).He has guided one Ph. D scholar, seven MTech. scholars. and published about twenty research papers in different international journals .

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