Effect of Various Process Parameters on Different Materials by Abrasive Jet Machine – A Review

Gaurav P Bandhania[1], Prashant Singh R. Tomar[2], Tejas Vyas[3]

Department of Mechanical Engineering

Parul Institute of Technology (PIT), Parul University, India

Email: *gaurav.bandhania@paruluniversity.ac.in[1], prashantsingh.tomar@paruluniversityac.in[2], tejas.vyas@paruluniversityac.in[3]*

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Abstract

Abrasive jet machining offers a solution to the expanding need for machining of brittle materials like single crystals, glasses and polycrystalline ceramics and to perform critical machining to provide complex shapes and workpiece profiles. This machining process is non-thermal, non-chemical, creates no change in the workpiece's microstructure and chemical or physical properties and offers virtually stress-free machined surfaces. Due to that, it is used extensively in machining hard and brittle materials, which are difficult to cut by other traditional methods. There are many process parameters like Abrasive mass flow rate (AMFR), Stand of Distance (SOD), Nozzle diameter, Pressure, abrasive grain size, and traverse speed that affect the performance of the abrasive jet machine. Due to all these process parameters, we can obtain many response parameters like Material Removal Rate (MRR), surface roughness, depth of cut, Radial over cut, taper angle. This paper discusses the individual effect of those parameters on different materials like Alumina ceramic, Glass fibre, Nickel 233 alloys, Kevlar epoxy composites, porcelain tiles, and soda lime glass. This paper presents a literature review to understand the effect of different process parameters like Abrasive grain size, Pressure, SOD on different materials to improve quality and accuracy on an abrasive jet machine.

Keywords: - *Abrasive mass flow rate (AMFR), Stand of Distance (SOD), Pressure, MRR;*

INTRODUCTION

More than twenty different non-conventional manufacturing processes had been invented and successfully implemented in manufacturing engineering during the last six decades. Among them, abrasive jet machining is a constructive non-conventional method for machinings hard and brittle materials like glass, ceramics, quartz, GFRP composites and other engineering materials. The abrasive particles are made to influence the work material at a high velocity.[I] The kinetic energy of the high-speed abrasive particles creates brittle fractures on the target material that propagate both in lateral and longitudinal directions to cause material removal. Althoughmany attempts have been made by the researchers in different parts of the globe to search out the machining characteristics and related process parameters to control the requirements of abrasive jet machining, still further research is required for analysing the effects of various abrasive jet machining parameters to increase the effectiveness of the material.[II]

Many factors affect the cutting process behaviour in AJM, such as gas pressure, nozzle diameter, abrasive variables (mass flow rate, grain size), standoff distance, etc. The appropriate combination and proper utilisation of pre-cited machining process parameters are of prime importance for acquiring good grades and the circularity of holes, which generally consumes precious time and effort due to the abrasive jet machining process[III]. Various researchers have been employed methods including statistical as well as computational approaches using RSM (response surface Methodology), ANN (Artificial Neural networks) for mathematical modelling to predict the responses and the Taguchi method [XI] GA (genetic algorithm) for multi-response optimisation to control the process parameters of AJM process. [X]

This literature review has been done to understand the effect of different process parameters on different materials to get good quality and accuracy by abrasive jet machine.

OBJECTIVES AND SCOPE OF THE STUDY

The study's main aim is to investigate experimentally the effect of process parameters like pressure, abrasive grain size, standoff distance and workpiece material thickness on the material removal rate, taper angle, kerf, and overcut in drilling.

a. To analyse the effect of these parameters on the material removal rate and dimensional accuracy in terms of radial overcut and taper.
b. To develop a mathematical model based on the experimental data to express the relationship between the control parameters – pressure, standoff distance, Abrasive grain size and response parameters – material removal rate, overcut and taper.

LITERATURE REVIEW

Prasad et al. [I] analysed the modified air abrasive jet machining (MAAJM). In their work new approach was developed to produce holes within measurements on nickel 233 alloys. The taper angle was uniformly produced compared to the stationary work table, which was observed to maintain proper parameters to achieve desired cylindricity. They obtained values of output parameters such as maximum MRR 0.046, minimum surface roughness 0.92 and taper angle 7.47°.

Dhanawade et al. [II] explained that abrasive water jet machining was used on carbon epoxy composite material. The effect of process parameters on surface roughness was investigated based on an analysis of variance. It was found that surface roughness decreases up to 11-32 % with an increase in hydraulic pressure and AMFR (Abrasive mass flow rate) and a decrease in TR(Traverse rate) and SOD(Standoff Distance).

Tomy et al. [III] conducted machining of holes in fabricated multidirectional HFRC (Hybrid fibre Reinforced composite) has been carried out using a set of input machining parameters –air pressure, abrasive grit size, and standoff distance. The output responses selected for the experiment were material removal rate(58.7µg/s), Taper Angle (TA) (1), and Surface Roughness (Ra) (4.95 µm). Also, they obtained results indicating the absence of defects like delamination, burr formation, heat-affected zones in the machined samples.

Kumar UA et al. [IV] presented the cutting of glass fibre reinforced polymer on an abrasive water jet machine where the machining parameters are standoff distance, water jet pressure, abrasive mass flow rate and traverse rate were considered for the machining operation. The experiment outcomes were material removal rate increased from 12.789 to18.664 mm3/s., kerf width from 1.164 to 1.181 mm. and kerf taper angle 0.037° to 0.085°.

Ceritbinmez F et al. [V] presented cutting multi-walled carbon nanotubes (MWCNTs)-doped composite sheets by abrasive water jet machining with parameters such as cutting speed, fixed nozzle diameter, cutting pressure and abrasive garnet. It was determined that the composite materials produced with 0.1 wt.% of MWCNTs additive were stronger than the pure samples. As the cutting speed increased, the hole circularity deteriorated, and the cutting surface was indented. Due to the increased cutting speed, the speedy movement of the water jet resulted in an increase in the kerf taper angle and increased hole diameter.

Paul et al. [VI] presented Silicon Carbide (SiC) with grit sizes of 60 µm, and 120 µm has been chosen to find out the effect of grit size on process parameters(nozzle diameter, Stand-off distance and pressure) while making holes on ceramic tiles on an abrasive jet machine. Maximum MRR value of 0.019 gm/sec was obtained at optimum parametric conditions such as gas pressure of 4.2 kgf/cm2, SOD of 9 mm and Nozzle Diameter of 2.5 mm and minimum taper value of 0.02 mm was obtained at optimum parametric conditions such as the pressure of 4.2 kgf/cm2, SOD of 5 mm and Nozzle Diameter of 2 mm by using an abrasive size of 120 µm during AJM process. So if the size of abrasive particles increases, MRR increases and Taper decreases.

Jessi et al. [VII] analysed that the mechanical properties such as flexural strength were evaluated, and abrasive jet machining was performed for plain glass (G), carbon(C), and hybrid composite ([CG2CG]S) in dry and seawater aged condition. The material removal rate (MRR), surface roughness (Ra) and depth of cut (DOC) were determined. The flexural strength of dry hybrid composite [CG2CG]S was higher by 22.9% than seawater aged composites. The material removal rate for seawater aged composites is higher than in dry conditions.

Kumar, Puneet et al. [VIII], analysed abrasive water jet machining used Kevlar Epoxy Composite Influence of process parameters, namely standoff distance, traverse speed and abrasive mass flow rate surface roughness and kerf taper was investigated. It was found that a smooth surface was obtained with high water pressure and low traverse speed, having less kerf taper.

Behera et al. [IX] focused on the experimental investigation of hot, abrasive jet machining (HAJM)and precision drilling operation on flat surfaces of K-60 alumina ceramic material using different grades of silicon carbide abrasives. The experiments were performed with four parameters pressure, standoff distance, abrasive temperature and grain size. The investigation outcomes were that the material removal rate increased up to 0.005 gm/s, and flaring diameter increased to 6.382 mm.

Prasad et al. [X] presented a multi-objective optimisation technique based on the WASPS method toward optimising the machining parameters in abrasive jet machining (AJM) process: pressure, nozzle to tip distance (NTD), an average grain diameter on NICKEL 233 alloy. Three conflicting objectives, Material Removal Rate (MRR), surface roughness (Ra) and taper angle (Ta), were simultaneously considered.

Anjaneyulu et al. [XI] used a new technique of investigating (Taguchi Technique) the P, AFR(abrasive flow rate), SOD(standoff distance) and T(Thickness) on abrasive air-jet machining of Al2O3 work material. They conclude that percentage contributions of Pressure, Stand of Distance, Time and Abrasive Flow Rate were about 87.1%, 6.79%, 3.75 and 2.8% on the Surface Roughness, respectively.

Potom et al. [XII] analysed that variable abrasive water jet parameters considered here include water pressure, nozzle diameter, standoff distance and abrasive flow rate. Experiments were conducted on carbon fibre reinforced polymer composites by varying these parameters. This work concluded that maximum abrasive jet pressure increases the material removal rate up to 6.7 gm/min, and minimum standoff distance (SOD) will decrease the kerf angle in carbon fibre composites.

Jadav et al. [XIII] discussed amount of material removed by AJM depends on various process parameters such as nozzle bore diameter, operating pressure, standoff distance, etc. While drilling a micro-hole, getting the required amountof bore diameter on the workpiece is very kin. The outcomes of the experiment were material removal rate, kerf width and kerf taper angle.

Madhu et al. [XIV] presented abrasive jet machining of glass fibre reinforced polymer laminates that were experimentally investigated for the various parameters in terms of average surface roughness (Ra). This work deals with making holes on glass fibre reinforced polymer composite material using a newly designed nozzle with and without internal thread. Machining GFRP laminates with an internally threaded nozzle resulted in surface roughness (Ra) of 0.531 µm, and it was 0.802 µm with the unthreaded nozzle. The whirling effect of abrasive particles due to the internal threads presented inside the nozzle increases the surface quality of glass fibre reinforced polymer composites more than the unthreaded nozzle.

Ghara et al. [XV] explain Experimental investigations on abrasive jet machining performance on cutting various materials like glass and tiles with machining parameters like abrasive carrier gas pressure, flow rate, SOD on machined holes. The result was found that SiC abrasive has more cutting ability than silica sand. The machined hole diameters have an increasing trend with the increasing of SOD in a particular pressure.

Kumar et al. [XVI] analysed the details of the developed micro-abrasive jet machine prototype and the experimental investigations on the influence of mixing chamber design on material removal rate in the machining of borosilicate glass. Pressure, stand-off-distance, nozzle diameter, abrasive type (Al2O3 and SiC) and abrasive size were used as control factors. Experiments were conducted based on the L16 orthogonal array and optimised with Taguchi's method. The spread of abrasive particles was more with a fixed mixing chamber compared to an oscillating mixing chamber. The depth of penetration of abrasive particles was more with an oscillating mixing chamber than a fixed mixing chamber.

Abhishek et al. [XVII] focused on a novel approach for machining holes on brittle material quartz, using the in-house developed micro-abrasive jet machine. The nozzle was given a feed rate equal to the average rate of change of the workpiece thickness. The experiments were conducted to study the effect of this novel approach on the shape of the machined hole by measuring the entrance diameter and exit diameter and hence calculated the taper angle. The obtained experimental results reveal that the Entrance diameter of the hole reduces approximately by 29 %, whereas the taper angle is reduced by approximately 58 %, which results in improved cylindricity.

Srikanth et al. [XVIII] presented a study highlighting the influence of different parameters of Abrasive jet machining like Pressure, SOD, Abrasive Flow Rate on the Metal removal, and Kerf width on Ceramic Tiles, the type of abrasive particle used for this experiment was Al2O3. The experiments were conducted according to the TAGUCHI method of L9 orthogonal array and RSM, later compared with the Results of ANOVA using STATGRAPHICS. The Optimum Range of machining of Stat graphics ANOVA was similar to the results obtained by Taguchi as well as RSM.

Router et al. [XIX] presented the Taguchi method to optimise the machining parameters for machining glass workpieces in abrasive jet machining (AJM) for individual responses such as material removal rate and surface roughness. Multi-response performance characteristic was used to optimise process parameters like (pressure: nozzle-tip-distance, abrasive grain size with the application of grey relational analysis. The response parameters like material removal rate (MRR) was increased, and surface roughness was decreased.

Chandra et al. [XX] discussed various results of experiments conducted by changing pressure and nozzle tip distance on different thicknesses of glass plates on an Abrasive jet machine. The effect of their process parameters on the material removal rate (MRR), top surface diameter and bottom surface diameter of hole obtained were measured and obtained that nozzle tip distance increases, the top surface diameter and bottom surface diameter of hole increases and also As the pressure increases material removal rate (MRR) was also increased.

RESEARCH GAP

From the review of the published work related to Effect of Various Process Parameters on Various Materials by Abrasive Jet Machine-A Review, it is observed that many parameters are responsible for research, such as:

- Type of abrasive grain size selection for the required application.
- Selecting the suitable diameter of the nozzle.
- Better dimension use as a Standoff distance or Nozzle tip distance for a good Metal removal rate.
- Proper Selection of cutting speed to increase the size of the kerf.

CONCLUSIONS

The following major conclusions are drawn from Effect of Various Process Parameters on Various Materials by Abrasive Jet Machine-A Review.

- The statistical method and computational approaches used RSM (response surface Methodology), ANN (Artificial Neural networks) for mathematical modelling to predict the responses.
- Taguchimethod, GA(genetic algorithm), is used for multi-response optimisation to control the process parameters during the AJM process.
- In the abrasive jet machining process, we can attain the dimensional tolerance of 0.05 mm with a surface finish of 0.5 to 1.2 µm.
- This abrasive jet get machining process is also used to clean and machine semiconductors such as silicon, gallium or germanium, making holes and slots in glass, quartz, mica and ceramics.

REFERENCES

1. Prasad, S. Rajendra, K. Ravindranath, and M. L. S. Devakumar. "Experimental investigation on modified air abrasive jet machining (MAAJM)." Production & Manufacturing Research 8, no. 1 (2020): 101-114.
2. Dhanawade, Ajit, Puneet Kumar, and Shailendra Kumar. "Experimental study on abrasive water jet machining of carbon epoxy composite." Advances in Materials and Processing Technologies 6, no. 1 (2020): 40-53.
3. Tomy, A., &Hiremath, S. S. Machining and Characterization of Multidirectional Hybrid Silica Glass Fiber Reinforced Composite Laminates Using Abrasive Jet Machining.Springer,28 April-2020
4. Kumar UA, Alam SM, Laxminarayana P. Influence of abrasive water jet cutting on glass fibre reinforced polymer (GFRP) composites. Materials Today: Proceedings. 2020 Apr 23
5. Ceritbinmez F, Yapici A. An Investigation on Cutting of the MWCNTs-Doped Composite Plates by AWJ. Arabian Journal for Science and Engineering. 2020 Jan 29:1-3.
6. Paul, Thia, and IndranilMandal. "Development and Parametric Optimisation of Abrasive Jet Machining Setup." Materials Today: Proceedings 22 (2020): 2306-2315.
7. Jesthi, D. K., R. K. Nayak, B. K. Nanda, and Diptikanta Das. "Assessment of Abrasive Jet Machining of Carbon and Glass Fiber Reinforced Polymer Hybrid Composites." Materials Today: Proceedings 18 (2019): 3116-3121.
8. Kumar, Puneet, and Ravi Kant. "Experimental study of abrasive water jet machining of Kevlar epoxy composite." Journal of Manufacturing Engineering 14, no. 1 (2019): 026-032
9. Behera, Ranjit Kumar, and Sudhansu Ranjan Das. "Modelling and optimisation of technological parameters in hot, abrasive jet machining of alumina ceramic." Matériaux& Techniques 107.6 (2019): 603.
10. Prasad, S. R., Ravindranath, K., &Devakumar, M. L. S. (2019). Experimental Investigation and Parametric Optimisation in Abrasive Jet Machining on NICKEL 233 Alloy Using WASPS. Journal of Advanced Manufacturing Systems, 18(04), 549-561
11. Anjaneyulu, B., K. Prahladharao, and G. Nagamalleswararao. "Optimisation of process parameters by using Taguchi Techniques in abrasive air-jet machining of Al2O3 ceramic material." Materials Today: Proceedings 19 (2019): 140-147.

12. Potom, B., Madhu, S., Kannan, S., &Prathap, P. (2019, July). Performance Analysis of Abrasive Water Jet Cutting Process in Carbon Fiber Epoxy Polymer Composite. IOP Conference Series: Materials Science and Engineering (Vol. 574, No. 1, p. 012014). IOP Publishing.
13. Jadav, S. M., & Lekurwale, R. R. (2019). Effect of process parameters while machining using an abrasive jet machine (AJM). In Proceedings of the international conference on intelligent manufacturing and automation (pp. 575-581). Springer, Singapore
14. Madhu, S., & Balasubramanian, M. (2018). Impact of nozzle design on surface roughness of abrasive jet machined glass fibre reinforced polymer composites. Silicon, 10(6), 2453-2462
15. Ghara, T., Desta, G., Das, S., &Haldar, B. (2018, January). Abrasive Jet Machining: Drilling of Porcelain Tiles and Soda Lime Glass. In International Conference on Mechanical Engineering (pp. 189-208). Springer, Cham
16. Kumar, HK Darshan, et al. "Experimental Investigations on the Influence of Mixing Chamber Design in Micro–Abrasive Jet Machining of Borosilicate Glass." Materials Today: Proceedings 5.11 (2018): 24075-24084
17. Abhishek, Kumar, and Somashekhar S. Hiremath. "Improvement of geometrical accuracy of micro-holes machined through micro-abrasive jet machining." Procedia Corp 46 (2016): 47-50.
18. Srikanth, D. V., and M. SreenivasaRao. "Application of Taguchi& response surface methodology in optimisation for machining ceramics with abrasive jet machining." Materials Today: Proceedings 2.4-5 (2015): 3308-3317.
19. Router, Bharat Chandra, et al. "Optimisation of multiple performance characteristics in abrasive jet machining using grey relational analysis." International journal of manufacturing technology and management 24.1-4 (2011): 4-22.
20. Chandra, Bhaskar, and Jagtar Singh. "A study of the effect of process parameters of abrasive jet machining." International Journal of Engineering Science and Technology 3.1 (2011): 504-513.