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A Literature Review on Parameters Influencing Abrasive Jet Machining and Abrasive Water Jet Machining

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ABSTRACT
Abrasive Jet Machining (AJM) especially Abrasive Water Jet Machining (AWJM) is widely used in the manufacturing sector. Every organization tries to sustain in the competitive business market by reducing the cost of the production without reducing the quality of the product. From the literature it is identified that by combining the manufacturing process and optimization technique, the process parameters can be controlled. This paper gives an overview of previously carried research on process parameters of Abrasive Jet Machining and Abrasive Water Jet Machining. Study reveals that following are the important process parameters effects on the accuracy of machining process such as Nozzle design and Stand-off Distance (SOD), Effect of fluid and flow properties, Effect of particle type, size, shape and hardness, Effect of velocity and jet angle, Effect of Traverse Speed on Surface Profile and Geometry

KEY WORDS: Abrasive jet machining, Abrasive Water Jet Machining, Nozzle tip distance, Material Removal Rate (MRR), Stand-off distance (SOD)

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I. INTRODUCTION

Abrasive Jet Machining (AJM) is a non-traditional machining process which uses mechanical energy to remove unwanted material from a given workpiece. Though abrasives may be expensive, the process requires low capital and operational costs compared to other Non-Traditional Machining processes. A high velocity abrasive jet is used to remove material and provide a satisfactory surface finish to workpiece. An abrasive jet consists of a mixture of abrasive particles such as aluminum oxide, silicon carbide and carrier gas like carbon dioxide, nitrogen and compressed air, which are previously mixed in a chamber. The carrier gas is filtered and compressed before it is fed into the mixing chamber. A hopper is used to feed abrasive particles to the same chamber. Pressure gauges and flow regulators are used to regulate the abrasive jet. A nozzle, which is made of a hard and resistant material like synthetic sapphire or tungsten carbide further, increases the velocity of the jet.

In Water Jet Machining (WJM) water is used in place of abrasive grits and is made to impinge on the workpiece at a high velocity. Its kinetic energy gets converted into pressure energy, which induces stress on the workpiece, causing it to undergo failure and removes the unwanted materials.

In Abrasive Water Jet Machining (AWJM) is a hybrid of abrasive jet machining and water jet machining processes, where the mechanical energy of water and abrasive particles are used to achieve material removal. Various parameters influencing these processes are discussed in the literature review section

II. LITERATURE REVIEW

Literature review was conducted by considering the following parameters: Nozzle design, Stand Off Distance, effect of fluid and flow properties, effect of particle size, shape and hardness, Effect of velocity, jet angle, effect of traverse speed on surface Profile and geometry. The review also highlights other notable approaches in AJM parametric analysis, process hybridizations and optimization.

Nozzle design and Stand Off Distance (SOD)

Venkatesh, (1984) carried out Parametric Studies on Abrasive Jet Machining using experimental approach and studied the effects of feed rate, spray angle, pressure, abrasive grain grit size, SOD and material removal rate. Ordinary optical and toughened glass specimens were machined using aluminium oxide and silicon carbide powder. These specimens were easily machined using AJM, but in case of toughened glass, only compressive layers could be machined, i.e. drilling a hole was not possible. Severe wear was observed at the exit nozzle, whereas wear was considerable in the mixing chamber and almost negligible in the inlet nozzle.

Srikanth and Sreenivasa Rao (2014) conducted an experiment on ceramic material to study the influence of process parameters on Material Removal Rate (MRR) and kerf width. A direct proportionality was observed between the nozzle diameter and MRR. It was also observed that with a decrease in the nozzle tip distance from the work piece, divergence of the hole produced was reduced.

Park et al., (2004) considered parameters like Stand Off Distance (SOD) and nozzle diameter and noted the effect of these parameters on the shape of the groove. By performing SEM analysis, U shapes of the grooves were observed on the workpiece. Difficulty in machining the square type grooves accurately due to the basic characteristics of micro-AJM. Khan and Haque (2007) conducted a performance test on different abrasive materials in Abrasive Water Jet Machining of glass. Experiment reveals that width of cut increases as the SOD is increased. This is due to the divergent shape of the abrasive water-jet.

Jurisevic et al.,(2004) performed monitoring of abrasive water jet cutting using sound detection with a set objective of process control. It is claimed that this objective can be achieved by the detection of SOD during cutting. In order to monitor the SOD, the sound signals emitted during AWJ straight cut operations were analyzed with respect to time and frequency. This directly emphasizes on the significance of SOD in process control.

Effect of fluid and flow properties

Williams and Rajurkar (1989) analyzed surface finish characteristics in abrasive flow machining by carrying experiments to study the effect of pressure and viscosity on material removal rate and surface finish. The material of the workpiece was also found to be an important factor determining the amount of metal removal. Using scanning electron microscopy, it was revealed that there was a significant improvement in surface finish within the first few cycles. Wavelength decomposition provided a detailed surface profile, which led to a better understanding of the mechanism of surface generation.

Loveless et al.,(1994) performed a study on various machining process such as turning, milling, grinding and wire electrical discharge machining to identify the effects of abrasive flow on surface finish. It is observed that the viscosity of the medium significantly affects the surface improvement, whereas extrusion pressure did not have a significant role. The initial surface condition of the workpiece also affected the amount of material removal.

Khan and Haque (2007) on their performance evaluation test on glass, demonstrated that the taper of cut decreases with increase in jet pressure for all the types of abrasives used. Nguyen et al.,(2008) studied the effect of liquid properties on the stability of an abrasive water jet. It was noted that a jet's stability increases with the addition of polymeric additives, as a consequence of increased fluid viscosity. Experimental model was devised and analyzed to develop a parametric model using dimensional analysis. From this model, the length of the jet-stable region was predicted.

Effect of particle type, size, shape and hardness

Wakuda et al.,(2003) conducted a study on material response to particle impact during abrasive jet machining of alumina ceramics. Study revealed that the employed abrasive grit properties have a crucial impact on the material response upon impact. Experiment showed that aluminium oxide abrasive led to roughening of the surface, whereas silicon carbide produced a relatively smooth surface. Synthetic diamond abrasive was found to induce more roughness upon impact. The underlying mechanisms influencing surface roughness is highlighted in this paper.

Balasubramaniam et al., (2002) conducted a study on the shape of the surface generated by AJM. Analytical approach was used to generate a semi-empirical equation to obtain the shape of the surface generated by AJM. Changes in the entry side diameter were observed as input parameters were varied. Particle size was found to have a crucial impact on the normalized erosion profile, which is also influenced by SOD, central and peripheral line velocities.

Fowler et al., (2009) studied the effect of particle hardness and shape during the abrasive water jet milling process on titanium alloy Ti6Al4V. With an increase in abrasive particle hardness, the MRR and surface roughness was found to increase. However, there was no significant effect of shape factor and particle factor on surface waviness. Li et al., (2014) adopted Discrete Element Method – Computational Fluid Dynamics (DEM-CFD) approach to compare simulations of high speed micro-abrasive air jet machining with experimental investigations of the same for various inlet pressures and nozzle diameters. It was found that the results predicted by simulations were in good agreement with experimental findings with particle shape factors of 0.6 and 0.8, which correspond to “edged” and “round” abrasive grits. It is claimed that the particle sphericity plays a crucial role in affecting the aerodynamic behaviour of abrasive grits.

Effect of velocity and jet angle

Li et al.,(2009) Conducted an analysis and modelling of particle velocities in micro-abrasive air jet. Based on the models developed, the particle velocities at the nozzle exit can be determined based on the nozzle length, particle mean diameter, particle density, air density and air flow velocity. Also, mathematical approach is adopted to determine a numerical solution to these models. Particle Image Velocimetry (PIV) is used to effectively measure the velocity distribution in the jets. It is noted that the model predictions are in good agreement with experimental results, with less than 4% average errors.

Yan et al.,(2014) studied processing characteristics of constrained abrasive jet polishing operation. In their experiment on K9 optical glass, properties such as velocity, jet angle and average Roughness surfaces were considered for analysis. Results demonstrated that an increase in abrasive jet velocity more than the experimental range decreases glass surface roughness value. Wang (1999) Performed abrasive water jet machining of polymer matrix composites and studied the effect of jet forward impact angle on the cutting performance. Variations in the kerf width, kerf taper angle, depth of cut, roughness with respect to jet impact angle are plotted for three different water pressures.

Matsumura et al., (2011) used CFD analysis to present crack-free abrasive water jet machining of micro grooves and fluid polishing of micro channels in glass material. Stagnation under the jet and the horizontal flow on the machining area were controlled to generate crack-free surfaces by the mask shape. Flow velocity was found to be high enough to polish the surface by restricting the direction of water flow. At low flow velocity, polishing performance was observed to be low because of the spreading action of the abrasive jet.

Effect of Traverse Speed on Surface Profile and Geometry

Hascalik et al., (2007) studied the effect of traverse speed on abrasive waterjet machining of Ti6 Al4 V alloy. Ti6Al 4V alloy, which is regarded as one of the most difficult alloys to machine using traditional methods was machined under varying traverse speeds by AWJM. The microstructure, kerf geometry, and other surface morphologies were examined using surface profilometry and Scanning Electron Microscopy (SEM). Experimental findings indicated a great significance of traverse speed on the machined surface profile.

Fowler et al., (2005) performed abrasive water-jet controlled depth milling of Ti6Al4V alloy. Investigations were done on the effects of jet–work piece traverse speed, number of passes of the jet and abrasive grit size on the MRR, surface waviness and surface roughness. Traverse speed is found to govern the material removal rate. An inverse proportionality between traverse speed and surface waviness was shown. However, as number of passes of the jet increases over the workpiece, waviness increases. Study reveals that roughness was not strongly influenced by traverse speed.

Gupta et al., (2014) while conducting AWJM experiments on marble for the minimization of kerf taper angle and kerf width noted that the nozzle traverse speed was the most significant factor affecting the top kerf width and the kerf taper angle. Wang et al.,(1999) conducted a study on abrasive water jet cutting process of metallic coated steel sheet noted using SEM analysis that micromachining and plastic deformation are the dominant cutting phenomena. An optimum water pressure with a small SOD was used while the traverse speed was selected as high as possible for through cuts, as it was noted that the traverse speed had a direct effect on the cutting rate. Based on the above considered optimizations, empirical models for kerf geometry and total quality were established for the prediction of AWJ cutting performance.

Other Notable Approaches in AJM parametric analysis

Nouhi et al., (2015) dealt with the effect of particle size and SOD using the newly developed Shadow Mask Technology. Experimental data were collected using shadow mask and clamped mask technologies and the cross sectional profiles of channels were compared for various number of jet passes. Effect of mask thickness on the striking of abrasive particle on the work surface, effect of mask standoff were studied, whose data can be used in designing an appropriate mask according to the shape required to be cut.

Paul, et al., (1998) performed Analytical modelling of the total depth of cut in the abrasive water jet machining of polycrystalline brittle material. The mechanism of cutting seemed to be micro-cutting and intergranular fracture at shallow impact angles. Experimental verification showed good agreement of analytical model-derived value to actual observed total depth of cut. Hlaváč et al., (2009) discussed an experimental method for the investigation of the abrasive water jet cutting quality. Declination angle was chosen as an important parameter for the prediction and control of AWJ quality. The data values predicted from the theoretical model is verified experimentally over selected samples and it was demonstrated that it is usable for the calculation of cutting head tilting respective to traverse speed changes.

Process Optimization

Rao and Kalyankar (2013) developed a teaching-learning based optimization algorithm for the process optimization of selected non-traditional machining processes. Decision variables used in previously prescribed mathematical models were considered in this process for the parametric optimization of abrasive jet machining of brittle and ductile workpiece materials separately.

Jain et al., (2007) used genetic algorithms for the optimization of abrasive jet machining. Normal impact angle was kept constant throughout the machining process, and ranges of optimum values for material removal rate, mean radius of abrasive particles and their average velocity were suggested differently for ductile and brittle workpieces.

Parikh and Lam (2009) conducted an experiment on abrasive water jet machining process using neural networks to identify the process parameters. In this study "Back propagation" and "radial basis function networks" was the two neural network approaches proposed, result indicates that a better estimation of parameters for AWJM compared to earlier linear and non-linear regression models. A scope for a better estimation of parameters was identified, which requires collection of a larger set of input-output data values.

Jagannatha et al., (2012) used modified Taguchi method for parametric optimization of abrasive hot air jet machining of glass. Analysis of Variance (ANOVA) revealed that the temperature of carrier media was the most significant on material removal rate and surface roughness (Ra).Empirical equations are derived which can be employed to figure out a feasible range of parameters such as MRR and Ra. Reddy et al., (2018) proposed the use of trained Artificial Neural Networks (ANN) model for the optimization of AJM process. Four different control parameters were chosen, namely MRR, flow rate of abrasives, SOD and traverse speed. Input-output parametric combinations were varied to generate numerous optimum points and the best among those are graphically highlighted.

Çaydaş and Hascalık (2008) scrutinized abrasive waterjet machining process using artificial neural networks and regression analysis. From experimental data values, mathematical models were developed to predict surface roughness (Ra). Using machining parameters like traverse speed, water pressure, stand-off distance (SOD) and abrasive flow rate, a revised final empirical model was formulated for the prediction of surface roughness. Vijayaraghavan et al., (2015), addressed the need of energy consumption in abrasive machining in their study. They conducted an analysis of input process parameters on energy consumed in machining. A technique combining Multi-Adaptive Regression Splines (MARS) and Genetic Programming (GP) was used for computational modeling and it was verified experimentally. It was highlighted that the selection of optimum machining time and the appropriate type of abrasive is essential for achieving better environmental performance.

Hybridized AJM Innovations for MRR enhancement:

Singh and Shan (2002) applied magnetic field around the workpiece being machined using abrasive flow machining (AFM) and noted an increase in material removal rate (compared with normal AFM). Empirical modelling revealed that the applied magnetic field significantly affects material removal and average roughness after machining at high flow rates. Lin et al., (2012) conducted studies and developed a novel hybrid process combining AJM and EDM. Experimental result showed that this hybrid approach is superior to the dry EDM in terms of material removal rate and fine surface integrities.

III. CONCLUSIONS:

A substantial review of the research and development in AJM spanning many years is presented in this paper. There is a scope for the improvement in nozzle design, which would greatly help in optimizing the machining process for lower cost and faster production. Study on material behavior needs more attention in order to determine optimum values of crucial governing parameters like stand-off distance spray angle, pressure and feed rate for a variety of materials. Wide experimental investigations are required to get a better understanding of the relationship between various parameters influencing abrasive jet machining.

There is much scope of research in AJM to study the effect of abrasive particle size, shape and hardness through computational modeling. Flow visualization techniques can be effectively used to understand the underlying mechanisms. Integration of one or more non-conventional approaches with AJM (hybrid approach) appears to be very promising for industrial purposes. Further research is required in this regard. Attempts can be made to extend the range of constraints of mathematical models aiding optimization problems.

REFERENCES

[1]. Balasubramaniam, R., Krishnan, J., & Ramakrishnan, N. (2002). A study on the shape of the surface generated by abrasive

jet machining. Journal of Materials Processing Technology, 121(1), 102-106.
[2]. Çaydaş, U., & Hascalık, A. (2008). A study on surface roughness in abrasive waterjet machining process using artificial neural networks and regression analysis method. Journal of materials processing technology, 202(1-3), 574-582.
[3]. Fowler, G., Pashby, I. R., & Shipway, P. H. (2009). The effect of particle hardness and shape when abrasive water jet milling titanium alloy Ti6Al4V. Wear, 266(7-8), 613-620.
[4]. Fowler, G., Shipway, P. H., & Pashby, I. R. (2005). Abrasive water-jet controlled depth milling of Ti6Al4V alloy–an investigation of the role of jet–workpiece traverse speed and abrasive grit size on the characteristics of the milled material. Journal of materials processing technology, 161(3), 407-414
[5]. Gupta, V., Pandey, P. M., Garg, M. P., Khanna, R., & Batra, N. K. (2014). Minimization of kerf taper angle and kerf width using Taguchi's method in abrasive water jet machining of marble. Procedia materials science, 6, 140-149.
[6]. Hascalik, A., Çaydaş, U., & Gürün, H. (2007). Effect of traverse speed on abrasive waterjet machining of Ti–6Al–4V alloy. Materials & Design, 28(6), 1953-1957.
[7]. Hlaváč, L. M., Hlaváčová, I. M., Gembalová, L., Kaličinský, J., Fabian, S., Měšťánek, J., ... & Mádr, V. (2009). Experimental method for the investigation of the abrasive water jet cutting quality. Journal of Materials Processing Technology, 209(20), 6190-6195.
[8]. Jagannatha, N., Hiremath, S. S., & Sadashivappa, K. (2012). Analysis and parametric optimization of abrasive hot air jet machining for glass using Taguchi method and utility concept. International Journal of Mechanical and materials engineering, 7(1), 9-15.
[9]. Jain, N. K., Jain, V. K., & Deb, K. (2007). Optimization of process parameters of mechanical type advanced machining processes using genetic algorithms. International Journal of Machine Tools and Manufacture, 47(6), 900-919.
[10]. Jurisevic, B., Brissaud, D., & Junkar, M. (2004). Monitoring of abrasive water jet (AWJ) cutting using sound detection. The International Journal of Advanced Manufacturing Technology, 24(9-10), 733-737.
[11]. Khan, A. A., & Haque, M. M. (2007). Performance of different abrasive materials during abrasive water jet machining of glass. Journal of materials processing technology, 191(1-3), 404-407.
[12]. Li, H. Z., Wang, J., & Fan, J. M. (2009). Analysis and modelling of particle velocities in micro-abrasive air jet. International Journal of Machine Tools and Manufacture, 49(11), 850-858.
[13]. Li, H., Lee, A., Fan, J., Yeoh, G. H., & Wang, J. (2014). On DEM–CFD study of the dynamic characteristics of high speed micro-abrasive air jet. Powder Technology, 267, 161-179.
[14]. Lin, Y. C., Chen, Y. F., WANG, A. C., & Sei, W. L. (2012). Machining performance on hybrid process of abrasive jet machining and electrical discharge machining. Transactions of Nonferrous Metals Society of China, 22, s775-s780.
[15]. Loveless, T. R., Williams, R. E., & Rajurkar, K. P. (1994). A study of the effects of abrasive-flow finishing on various machined surfaces. Journal of Materials Processing Technology, 47(1-2), 133-151.
[16]. Matsumura, T., Muramatsu, T., & Fueki, S. (2011). Abrasive water jet machining of glass with stagnation effect. CIRP Annals-Manufacturing Technology, 60(1), 355-358.
[17]. N., S., Tirumala, D., Gajjela, R & Das, R. (2018). ANN and RSM approach for modelling and multi objective optimization of abrasive water jet machining process.Decision Science Letters , 7(4), 535-548.
[18]. Nguyen, T., Shanmugam, D. K., & Wang, J. (2008). Effect of liquid properties on the stability of an abrasive waterjet. International Journal of Machine Tools and Manufacture, 48(10), 1138-1147.
[19]. Nouhi, A., Lari, M. S., Spelt, J. K., & Papini, M. (2015). Implementation of a shadow mask for direct writing in abrasive jet micro-machining. Journal of materials processing technology, 223, 232-239.
[20]. Parikh, P. J., & Lam, S. S. (2009). Parameter estimation for abrasive water jet machining process using neural networks. The International Journal of Advanced Manufacturing Technology, 40(5-6), 497-502.
[21]. Park, D. S., Cho, M. W., Lee, H., & Cho, W. S. (2004). Micro-grooving of glass using micro-abrasive jet machining. Journal of materials processing technology, 146(2), 234-240.

[22]. Paul, S., Hoogstrate, A. M., Van Luttervelt, C. A., & Kals, H. J. J. (1998). Analytical modelling of the total depth of cut in the abrasive water jet machining of polycrystalline brittle material. Journal of materials processing technology, 73(1-3), 206-212.

[23]. Rao, R. V., & Kalyankar, V. D. (2013). Parameter optimization of modern machining processes using teaching–learning-based optimization algorithm. Engineering Applications of Artificial Intelligence, 26(1), 524-531.

[24]. Singh, S., & Shan, H. S. (2002). Development of magneto abrasive flow machining process. International Journal of machine tools and manufacture, 42(8), 953-959.

[25]. Srikanth, D. V., & SreenivasaRao, M. (2014). Metal removal and kerf analysis in abrasive jet drilling of glass sheets. Procedia materials science, 6, 1303-1311.

[26]. Venkatesh, V. C. (1984). Parametric studies on abrasive jet machining. CIRP Annals-Manufacturing Technology, 33(1), 109-112.

[27]. Vijayaraghavan, R., Garg, A., Vijayaraghavan, V., & Gao, L. (2015). Development of energy consumption model of abrasive machining process by a combined evolutionary computing approach. Measurement, 75, 171-179.

[28]. Wakuda, M., Yamauchi, Y., & Kanzaki, S. (2003). Material response to particle impact during abrasive jet machining of alumina ceramics. Journal of Materials Processing Technology, 132(1-3), 177-183.

[29]. Wang, J. (1999). Abrasive waterjet machining of polymer matrix composites–cutting performance, erosive process and predictive models. The International Journal of Advanced Manufacturing Technology, 15 (10), 757-768.

[30]. Wang, J., & Wong, W. C. K. (1999). A study of abrasive waterjet cutting of metallic coated sheet steels. International Journal of Machine Tools and Manufacture, 39(6), 855-870.

[31]. Williams, R. E., & Rajurkar, K. P. (1989). Metal removal and surface finish characteristics in abrasive flow machining. In MECHANICS OF DEBURRING AND SURFACE FINISHING PROCESSES. PRESENTED AT THE WINTER ANNUAL MEET. OF THE AMERICAN SOC. MECHANICAL. New York, USA, American Society of Mechanical Engineers.

[32]. Yan, R., Liu, Z., & Zhu, H. (2014, August). Study on processing characteristics of constrained abrasive jet polishing. In Mechatronics and Automation (ICMA), 2014 IEEE International Conference on (pp. 856-861). IEEE.

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