Introduction to Abrasive Jet Machining (AJM): A Review

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Abstract : This paper presents a review on abrasive jet machining (AJM). A number of researchers has investigated different process parameters in AJM. Experimental and semi experimental study has been carried out for different parameters like material removal rate (MRR), stand of distance (SOD), nozzle tip distance (NTD). In this review paper the scope of each experiment for the further investigation is to be identified. Lot of research is necessary to design a robust setup and to control the process parameter such a way that required result can be obtained effectively. This paper gives possibility of further research on AJM.

Index Terms - **Abrasive jet machining, MRR, SOD, NTD.**

I. INTRODUCTION

AJM is one of the unconventional machining process in which material is removed by high velocity stream of gas/air and abrasive mixture. It is used for machining brittle material and heat sensitive materials like sapphire, glass, quartz, mica, semiconductor materials and ceramics for which conventional process causes practical difficulties. AJM is used for deburring, shallow machining and etching (Ramchandran et al,1993). It is also used in thin sections, cutting slot, countering, drilling and for producing integrates shapes. It is often used for cleaning and polishing of plastics nylon and Teflon components. Delicate polishing and cleaning such as removal of smudges from antique documents, is also possible with AJM. Worldwide researchers are engaged in research work on AJM to achieve effective use of this process (Cheang et al, 1982) and (Venkatesh et al, 1983). In this paper review of major research work done by various researchers on AJM is presented.

II. LITERATURE REVIEW ON AJM

Perhaps Cheang and Cheang (1982-83) are first who designed and developed the AJM unit for machining of glass and found the effect of process parameters on machining. The material removal rate (MRR) increases with pressures and increase in the abrasive grit size increase MRR but eventually the rate decrease feed rate. Venkatesh (1984) studied that at high pressure and feed-rates MRR is more with improved surface finish having increased grit size. He also found that micro-chipping of the glass appears to be most effective with an incident angle of Chia and ong (1983-84) concluded that maximum wear occurs in the exit nozzle. Verma and Lal (1984) have worked on some other parameter and concluded that the penetration rate increases with velocity, while the increase in MRR occurs due to both particle velocity and impingement area and varies linearly with mixture ratio. Increase in mixture ratio (MR) increases MRR and penetration rate. Maximum value of MRR at the same value of stand-off distance (SOD) for various MR, but for the maximum penetration rate occurs at different values of SOD for the same condition. The size of abrasive particles affects the value of SOD but do not affect MRR for maximum penetration rate. It appears from the result that deburring and finishing should be carried out at larger SOD and whereas for micro-drilling smaller SOD is preferable. Ray and Paul (1987) carried out experimental study on AJM with vortex type mixing chamber and found that material removal factor (MRF) and MRR are more at higher SOD. However, in precision work a higher pressure and a lower SOD may be adopted to attain a higher accuracy and penetration rate. Venkatesh et al. (1989) found that wear takes place at the nozzle and the nozzle holder both. For the glass material most important parameter governing MRR is the nozzle tip distance. The orange yellow glow conditions occurs only when silicon carbide abrasives are used and MRR is high. Balasubramaniam et al. (1998) reported their statistical and experimental work. Through a Taguchi experimental design and analysis they found that the process of removal of burr and the generation of a convex edge were found to vary as a function of the parameters like jet height and impingement angle, with a fixed SOD. The size of the edge radius generated was found to be limited to the burr root thickness and vary linearly with SOD. Later on they also performed experimental work for deburring of cross drilled hole (1999) and concluded that the abrasive particles reflected by the stopper remove burrs by secondary erosion. At lower MR, the deburring time increases with the SOD. At higher MR, the deburring time initially decreases and on reaching at an optimum value it increases with the SOD. Coarser grit abrasives are effective in deburring. For any value of burr root to stopper distance (BSD), the velocities and the effective particles hitting the burr surface decrease. Later on Balasubramaniam et al. (2002) developed a semi empirical equation. They concluded that as the particle size and the centre line velocity of jet increases, the MRR at the centre line of jet drastically increases. Wakuda et al. (2002, 2003) studied the effect of work piece's property on machinability in AJM. They concluded that the fracture toughness and hardness of target materials are significant parameters affecting the MRR in AJM. Further, they used 3 abrasive materials to work on alumina ceramic and concluded that $Al2O3$ abrasive has no much effect for AJM of alumina ceramics, SiC abrasive can produce smooth-faced dimples and synthetic diamond abrasive can reveal a relatively rough appearance as a result of large-scale intergranular cracking and subsequent crushing. Jianxin et al. (2007) carried out research on special type of gradient ceramic composite for nozzle material. Results shows that (W,Ti)C/SiC ceramic nozzle produced by hotpressing has more erosion wear resistance than conventional ceramic nozzle. Fan et al. (2008) found that the erosion rate is proportional to air pressure, SOD, and nozzle diameter and inversely proportional to abrasive mass flow rate. They also concluded that for hole machining, the erosion rate is inversely proportional to machining time, while in channel machining it is proportional to traverse speed. Later on, Fan et al. (2009) also carried out mathematical modelling for erosion rate, in hole and channel machining on glasses. They also carried out done experimental study of particle velocity using particle imaging velocimetry (PIV) technique (Fan et al., 2011). They found that for radial velocity profiles flat shape was observed at a jet cross-section near the nozzle exit and at downstream profiles changed to a crescent shape with a local maximum at the centre line of the jet. This study was helpful to understand the kerf characteristics and formation process in AJM. Ghobeity et al. (2008) developed the model for surface evolution. They found that the velocity decreases linearly from centre line of jet to periphery and erosion rates are a function of the nominal impact angle. The masked channel profiles cause reduction of incident particle energy flux by mask edge scattering. Chandra and Singh (2011) reported various results of their experiments which were conducted by changing pressure and NTD on different thickness of glass plates. They observed that NTD increases with top surface diameter and bottom surface diameter of hole and pressure increases with the MRR. A summary of reviewed literature is given in table 1.

Table 1. Summary of reviewed literature on the influence of process parameters in AJM.

Researchers	Process parameters	Remark
Verma et al. (1983)	Work material = glass. Abrasive: Al2O3. Size = 25, 30, 38 and 48 micron Nozzle: tungsten carbide Nozzle Diameter = 0.712 mm Pressure = 0.98 - 2.9 bar Mixture ratio = 0.095 -0.30	Determination of two phase flow problem can be the scope of future for study of erosion phenomena.
Venkatesh et al. (1984)	Work piece: glass Abrasive: Al2O3,SiC Nozzle : aluminium , steel and brass Nozzle diameter = 0.15 - 2mm. NTD=2 - 4mm Feed rate = 0.33-18mm/s Pressure = 4 - 6.5 bars Grit size = 40 - 90 microns	Capable for glass. Modification can be done for drilling which is not possible in this experiment
Ray et al. (1987)	Work piece: porcelain Nozzle : S.S Nozzle diameter =1.83 mm. Abrasive: SiC Pressure = 1.96-2.96 bar Grit size = 60-120 microns SOD = 2,3,5mm	Further experiment for pressure more than 3 bars is required.
Venkatesh et al. (1989)	Work piece: glass ,ceramic and EDM machined die. Abrasive: Al2O3,SiC Nozzle: tungsten carbide, sapphire Nozzle Diameter = 0.46-0.65 mm. Pressure=5-7 bar, NTD=5-10 mm	Experiments for deburring process on AJM can be done.
Balasubramani et al. (1998)	Work material =S.S Abrasive: Al2O3 Grit Size = 46-60 micron Nozzle: tungsten carbide SOD=2-5mm Pressure = 2.96-5.8 bar	For different material, this experiment can be done.
Balasubramani et al. (1999)	Work material = burr specimen Abrasive: Al2O3 Grit Size = 30-60 micron Nozzle: tungsten carbide SOD=10-40mm Pressure = 2.96-5.8 bar Mixture ratio = 0.2-0.6	Burr model for other than 90^0 cross drilled can be studied further.
Balasubramani et al. (2000)	Work material = Plaster-of- Paris,S.S Abrasive: Al2O3 Grit Size = 30-60 micron Nozzle: Steel hardened Nozzle diameter=4-8mm	The control of edge radius that can enhance the utility of progress can be studied further.

	SOD=5-15mm Mixture ratio = 0.2-0.6	
Wakuda et al. (2002)	Work material = ceramic Abrasive: Al2O3, SiC,ZrO2,Si3N4 Grit Size = 15-25 micron Nozzle: tungsten carbide Nozzle diameter=0.6mm Pressure = 3 bar	Erosion models can be developed for other work materials also.
Balasubramani et al. (2002)	Work material = Plaster-of-Paris Abrasive: Al2O3 Grit Size = 30-60 micron Nozzle: Steel hardened Nozzle diameter=4-8mm SOD=5-15mm Mixture ratio = 0.2-0.6	To control edge radius, peripheral velocity can be varied for further work.
Wakudaa et al. (2003)	Work material = alumina ceramics Abrasive: Al2O3, SiC, synthetic diamond Grit Size = 15-25 micron Nozzle: tungsten carbide Nozzle diameter=0.6 mm Pressure = 3 bar Jet distance =0.5mm Abrasive flow rate=2 g/min Machining time=20 sec	By using these three types of commercial abrasives, study of other work material can be done.
Chastagner et al. (2007)	Work material = inconel 718 Abrasive: SiC Grit Size = 50-150 micron Nozzle: tungsten carbide. Nozzle diameter=8 mm Pressure = 4 bar	Edge generation in AJM for other work material can be done.
Deng et al. (2007)	Work material = glass Abrasive: SiC. Grit Size = 50-150 micron Nozzle: (W,Ti)C/SiC ceramic Nozzle diameter = 8 mm Pressure = 0.4 bar.	This ceramic nozzle can be implemented on other material also.
Ghobeity et al. (2008)	Work material = Borosilicate glass Abrasive: Al2O3 Grit Size = 25 micron Nozzle: tungsten carbide Nozzle diameter = 0.76 mm Pressure = 2 bar SOD = 20mm	Work material = Borosilicate glass Abrasive: Al2O3 Grit Size = 25 micron Nozzle: tungsten carbide Nozzle diameter=0.76 mm Pressure=2 bar SOD=20mm
Fan et al. (2009)	Work material = soda-lima glass Abrasive: Al2O3 Grit Size = 27 micron Nozzle diameter = 0.46,0.36 mm Pressure = 4.3,5.2,6,8 bar SOD = 1,2,3,4 mm Flow rate = 0.1,0.117,0.133.0.1 g/min Machining time = 3,2,6,8 sec hole machining	This can be essential basis for the optimisation of micromachining technique to achieve effective operation.
Fan et al. (2011)	Work material = ceramic Abrasive: Alumina Grit Size = 27 micron Nozzle: (W,Ti)C/SiC ceramic Nozzle diameter = 0.36,0.46 mm Pressure = 4.3,5.2,6,6.9 bar Flow rate = 6g/min	Experimental study is useful for velocity profile of jet.
Chandra and Singh (2011)	Work material = glass Abrasive: Alumina Grit Size = 0.15-1.25 mm Nozzle: steel NTD = 6-18mm	Experimental study can be done for the different thickness of other materials.

	Pressure = 5.3-7.25 ba	
Gradeen, et al. (2012)	Workpiece = polydimemhylsiloxane Abrasive: Al2O3 Grit Size = 25 micron Nozzle: tungsten carbide,1.5mm diameter SOD = 20mm Pressure = 2.6 - 4 bar	Experiments can be done based on independent control of temperature and velocity.

III. CONCLUSION

A review of the available literature in the area of influence of process parameters in AJM is presented in this paper. It is found that most of the work is carried out on experimental investigation for few materials like glasss, ceramics, polydimemhylsiloxane, and Plaster-of-Paris etc. Most of the experiments are performed with the e e e . Little work has been carried out on optimization of these process parameters. Therefore, further research is required to design a robust setup and to control the process parameter in such a way that required result can be obtained effectively.

REFERENCES

[1]. Balasubramaniam R, Krishnan J and Ramakrishnan N, 1998, "Investigation of AJM for deburring", Journal of Materials Processing Technology, 79, pp. 52-58.

[2]. Balasubramaniam R, Krishnan J and Ramakrishnan N, 1999, "An experimental study on the abrasive jet deburring of cross-drilled holes" Journal of Materials Processing Technology, 91, pp. 178–182.

[3]. Balasubramaniam R, Krishnan J and Ramakrishnan N, 2000, "An empirical study on the generation of an edge radius in abrasive jet external deburring (AJED)", Journal of Materials Processing Technology, 99 , pp. 49-53.

[4]. Balasubramaniam R, Krishnan J and Ramakrishnan N, 2002, "A study on the shape of the surface generated by abrasive jet machining", Journal of Materials Processing Technology, 121, pp. 102-106.

[5]. Cheang C S and Cheang P W, 1982-83, "Abrasive jet machining of ordinary and toughened glass", B.Eng. Project, National University of Singapore.

[6]. Chia S Y and Ong M H, 1983-84, "abrasive jet machining of ordinary and optical glass", B.Eng.project, national university of Singapore.

[7]. Chastagner Matthew W and Shih Albert J, 2007, "Abrasive Jet Machining For Generation", Transactions of NAMRI/SME Michigan, 35, pp. 359-366.

[8]. Chandra Bhaskar And Singh Jagtar, 2011, "A Study of effect of Process Parameters of Abrasive jet machining", International Journal of Engineering Science and Technology, 3 ,pp. 504-513.

[9]. Fan J M, Wang C Y, Wang J , 2008, "Study on the machining performance of micro abrasive jet machining, China Mechanical Engineering", 19.5, pp. 584–589.

[10]. Fan J M, Wang C Y, Wang J, Luo G S, 2008, "Effect of nozzle type and abrasive on machinablity in micro abrasive air jet machining of glass", Key Engineering Materials, pp. 359–360,404–408.

[11]. Fan J M, Wang C Y, and Wang J, 2009, "Modelling the erosion rate in micro abrasive air jet machining of glasses", journal of Wear, 266, pp. 968–974.

[12]. Fan J M, Li H Z , Wang J. and Wang C Y, 2011, "A study of the flow characteristics in micro-abrasive jets", Experimental Thermal and Fluid Science, 35, pp. 1097–1106.

[13]. Ghobeity A, Krajac T, Burzynski T, Papini M and Spelt J.K, 2008, "Surface evolution models in abrasive jet micromachining", journal of Wear, 264, pp. 185–19.

[14]. Gradeen A G, Spelt J K and Papini M, 2012, "Cryogenic abrasive jet machining of polydimethylsiloxane at different temperatures", journal of Wear, pp. 274– 275,335– 344.

[15]. Jianxin Deng, Fengfang Wu,and Jinlong Zhao, 2007, "Wear mechanisms of gradient ceramic nozzles in abrasive air-jet machining", International Journal of Machine Tools & Manufacture, 47, pp. 2031–2039.

[16]. Ramachandran N and Ramakrishnan N, 1993, "A review of abrasive jet machining", Journal of Materials Processing Technology,39, pp. 21-31.

[17]. Ray P K and Paul A K, 1987, "Some Studies on Abrasive Jet Machining", Journal of the Institution of Engineers (India), 68 part PE 2.

[18]. Verma A P and Lal G K, 1984, "An experimental study of abrasive jet machining" ,Journal of Mechanical Tool Des ,24.1, pp. 19-29.

[19]. Venkatesh V C, 1983, "Machining of glass by impact processes, Journal of Mechanical Working Technology, 8, pp. 247-260.

[20]. Venkatesh V C, 1984, "Parametric Studies on Abrasive Jet Machining", National University of Singapore.

[21]. Venkatesh V C , GoIJ T N ,Won K H and LIM M J, 1989, "An empirical study of parameters in abrasive jet machining", Journal of Mechanical Tools Manufacturing, 29.4, pp. 471-479.

[22]. Wakuda M, Yamauchi Y and Kanzaki S, 2002, "Effect of workpiece properties on machinability in AJM of ceramic materials", Journal of the International Societies for Precision Engineering and Nanotechnology, 26, pp. 193–198.

[23]. Wakudaa M, Yamauchi Y and Kanzaki S, 2003, "Material response to particle impact during abrasive jet machining of alumina ceramics", Journal of Materials Processing Technology,132, pp. 177–183.