RESEARCH ARTICLE OPEN ACCESS

Process Parameters of Abrasive Jet Machining

Subhash.R.Bharadwaj*V.S.Adithya*, S.SuryaSathvik*,Rahul.D.B*,Ujwal.N.Changappa*,Mohan Krishna.G*, Dr T S Nanjundeswaraswamy**

[*] *Students,* [**]*Associate Professor*
Department of Mechanical Engineering
JSS Academy of Technical Education, Bangalore- 560060, India
Corresponding Author; Subhash.R.Bharadwaj

ABSTRACT
This paper provides a review on numerous research activities carried out on process variables of Abrasive Jet Machining. Operation, applications and a few limitations of AJM are briefly explained in the introduction section of the paper. The core of the paper identifies and explains process variables of AJM as researched by various scholars. The last part of the paper gives the conclusion drawn by us after reviewing research papers on process variables of AJM.
Keywords: Abrasive Jet Machining, Material Remove rate, Non traditional Machining, Stand off distance

---

Date Of Submission: 10-11-2019 Date Of Acceptance: 30-11-2019

I. INTRODUCTION

Machining is the process if removal of excess material from a workpiece to obtain the desired shape and size. It is classified into 2 types - Traditional and Non-Traditional Machining. Abrasive Jet Machining is a non-traditional machining process which uses kinetic energy of water instead of a cutting tool in order to remove the excess material from the workpiece.The principle of Abrasive Jet Machining is that material can be removed from the workpiece when a stream of abrasive particles carried in a gas medium is made to impinge on the surface of the workpiece at a high velocity from a nozzle.

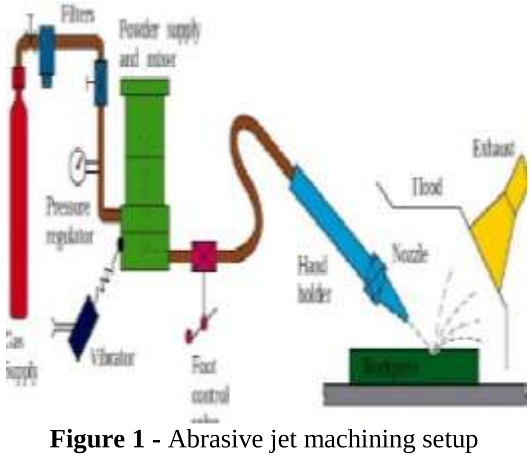

Figure 1 - Abrasive jet machining setup

In operation, filtered gas is supplied into the mixing chamber containing abrasive particles. The abrasive particles enter the gas stream due to vibrating action. The abrasive jet emerging from the nozzle at a high velocity is directed onto the surface of the workpiece that is to be machined. The removal of material of the workpiece occurs due to erosion or chipping caused by the abrasive particles impacting the workpiece surface at high speeds.

There exist a few critical parameters that affect the material removal rate(MRR), accuracy, surface finish in AJM and are called Process Variables of AJM. They are abrasive velocity, stand-off distance(SOD), type of abrasives and type of workpiece material.AJM is one of the most modern machining processes used in the industry. Heat sensitive materials, materials with intricate shapes, hard and brittle materials, materials which produce chips easily and materials inaccessible to traditional methods can be efficiently machined using AJM. AJM requires low capital cost and low power consumption. During machining using AJM, workpiece vibrations and chatter can be avoided, Heat Affected Zone(HAZ) is not produced on the workpiece. High speed and multidirectional cutting capacity, ability to effectively cut complex shapes at close tolerances, minimal heat build-up, low deformation stresses, etc., are a few advantages of AJM. Due to its versatility, AJM finds applications in not just cutting operations but also in drilling, turning, threading, trimming and removing oxides and other surface films on workpiece, removing glue and paint from leather objects etc., Few limitations include low MRR, non re-useable abrasives, embedding of abrasive particles in workpiece due to high speeds, nozzle damage etc.,

II. LITERATURE REVIEW

1. WORK MATERIAL:

Work piece materials for AJM are selected based on their mechanical properties and allowable stresses. Based on the workpiece material the abrasives, nozzle material, stand-off distance are also selected.

2. ABRASIVE PARTICLES:

Abrasives are hard materials that are used for polishing, smoothening and grinding surface of other materials. Abrasives are usually in block or powdered form. The block forms are pieces cut in suitable shapes from abrasive materials. In powdered form, the materials are crushed into different grades and sizes. Abrasives of different types are used in AJM like garnet, olivine, aluminum oxide (Al2O3), silica-sand, glass bead, silicon carbide (SiC), zirconium, etc. SiC is usually preferred only when the workpiece material is very hard. Size of abrasive ranges from 10-50µm. Abrasives should have excellent flow characteristics and should also be fine enough to remain suspended in carrier-gas. As discussed, shape, size, material, strength and flow rate of abrasives will influence machining performance. Higher MRR is achieved by machining using irregular shape abrasives having sharp edges when compared with spherical grits. Smaller size grits produce highly finished surface but reduce material removal rate (MRR) and thus productivity descends. Larger grits lead to unsteady flow through pipeline and create trouble while mixing. However, variation in size in the entire volume should be low otherwise estimation or assessment will not be accurate. Abrasive materials have varying strength or hardness. The larger the abrasive hardness is with respect to work surface hardness; the larger will be the volume removal rate. Machining capability and productivity is basically dependent on the relative hardness between abrasives and workpiece.

Khan et al., (2007) conducted an experiment using glass as workpiece material. There were three types of abrasives used in his study which were garnet, Al2O3 and SiC. Their hardness of the abrasives was 1350, 2100 and 2500 knoops, respectively. They concluded that garnet abrasive particles produced larger taper of cut when compared to Al2O3 and SiC particles. Thus, they concluded that abrasive particles of higher hardness like SiC provide lesser taper angle resulting in better MRR.

Manabu Wakuda et al., (2003) conducted experiment using 3 abrasives namely Al2O3, SiC and synthetic diamond (SD) on 4 types of alumina ceramics as workpiece material. They concluded that Al2O3 abrasive has insufficient hardness to dimple the alumina ceramics. AJM with SiC abrasive can successfully produce smooth-faced dimples, although it exhibits relatively low MRR. SD abrasive is used if high machining efficiency is desired. They showed depressions on workpiece when machined with different abrasives and also variation of MRR.

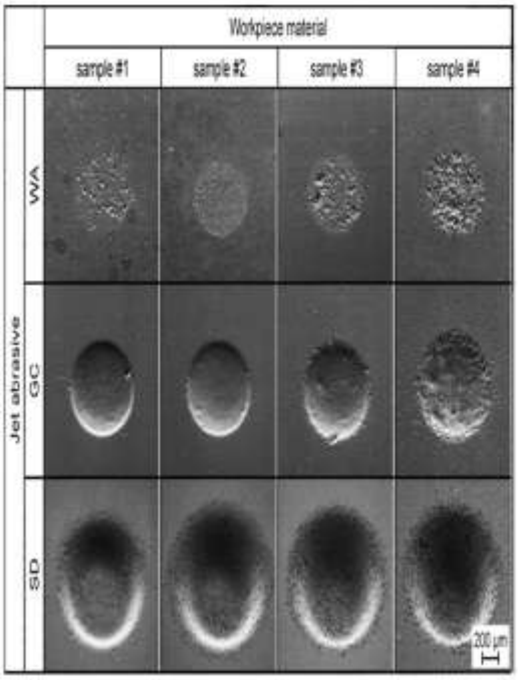

Figure 2 - Appearance of sample surface following AJM test

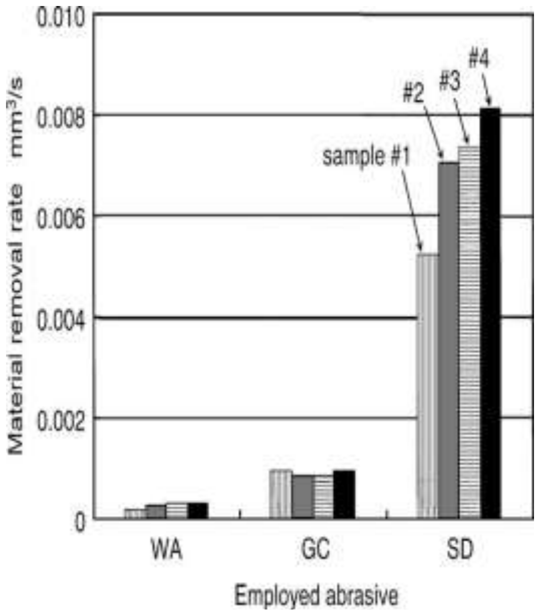

Figure 3 - Comparison of the material removal rate for various combination of abrasives and workpiece material.

Kantha Babu et al., (2003) conducted experiments on recycling abrasives in AJM and its effect on surface finish and arrived at the following conclusion. The reusability of abrasives of test sample with more than 90m will be 81, 49, 26 and 15% after the first, second, third, and fourth cut respectively. They concluded that MRR and penetration rates increase as the abrasive particle size increases.Mixing ratio is the ratio that determinesquality of the air-abrasivemixture in AJM. It is the ratio between the mass flow rate of abrasive particles and the mass flow rate of air (or gas).

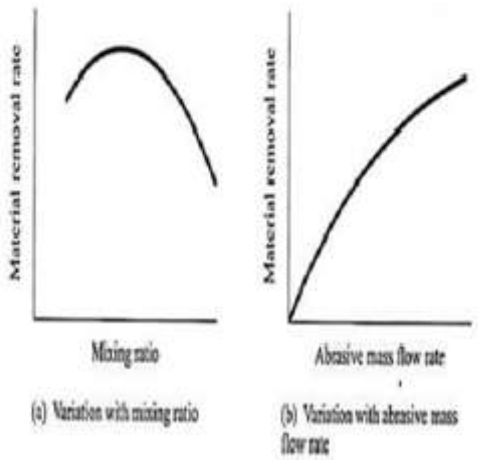

Figure 4 - Material Removal Rate Characteristics in AJM

3. CARRIER GAS:

In AJM, fine abrasive particles, accelerated by dry pressurized gas, are allowed to strike the work surface in the form of a jet with the help of a nozzle. The gas with which the abrasive particles are mixed is called carrier gas and the mixing is done in suitable proportions. Carrier gas must be dehumidified and made dust free. The machining capability and performance are determined by carrier gas pressure and its flow rate. Higher gas pressure reduces jet spreading and thus helps in cutting deeper slots accurately. However, to avoid failure during operation various accessories including pipeline must be capable enough to handle such high pressure. Moreover, increased gas flow rate results in higher abrasive flow rate, which can improve productivity. Air is commonly used in AJM as it is abundantly available at free of cost. Sometimes commercially pure carbon di-oxide and nitrogen are also used to harness better performance. Carrier gas accelerates the tiny abrasive particles, helping in formation of abrasive jet which blows away eroded metal particles and used grits from machining zone.

Miller et al., (1994) concluded that the carrier functions to support the abrasive mixture in a storage form as well as deliver it to the intended surface and further the carrier maintains fluid in a manner that facilitates material removal once in contact with surface. They also concluded that carrier may be aqueous, organic or any mixtures.Ramachandranet al., (1992) reviewed paper of Kamada et al., (1985) and said thatexperimental works using loose abrasives mixed in an aqueous solution of sodium nitrate has been found to be surprisingly successful in mirror finishing to very close tolerances in stainless steel.

Dried and dust free carrier gas is firstly compressed to high pressures of 15-20 bar using an air compressor. Abrasives are then mixed with this compressed gas in a mixing chamberat constant pressure according to mixing ratio. A nozzle then converts the hydraulic energy or pressure energy of the gas-abrasive mixture to kinetic energy by substantially increasing velocity. This high velocity jet ranging between 100–300m/s is allowed to strike the work surface for material erosion. Therefore, ultimate jet velocity depends directly on carrier gas pressure. So higher gas pressure indicates high velocity jet and thus higher erosion rate or MRR. However, carrier gas pressure cannot be increased indefinitely to enhance MRR. The machine set-up must be capable of withstanding such high pressure. Every machine setup has its own certain rated capacity. Malfunctioning of machines, leakages and bursts may occur if parameters exceed the maximum limit. Along with carrier gas pressure, its flow rate also influences machining capability in abrasive jet machining.

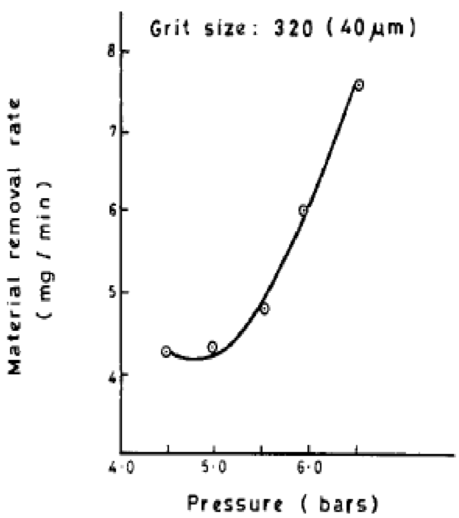

Figure 5 - MRR variation with pressure of carrier gas

4. NOZZLE MATERIAL:

Nozzle can be defined as an isentropic steady flow device which converts hydraulic or pressure energyof the gas-abrasive mixtureto the kinetic energy and thus high velocity jet is obtained. Nozzle also directs high velocity jet towards work surface from a specific distance (called Stand-off Distance) and at a particular predefined angle, called impingement angle. Inner diameter of the nozzle is an important parameter as it determines the final velocity and cross-sectional area of the jet. As flow rate and compressor delivery pressure are constant, the jet velocity will be inversely proportional to the jet cross-sectional area. Choosing of the nozzle material is another decisive factor from economic point of view. Usually in industrial applications tungsten carbide (WC) or sapphire nozzles are used. WC nozzles are cheaper but have limited life (20–30hr); while sapphire nozzles have extended life (150–200hr) but are costlier. Frequent changing of nozzle is associated with idle time during machining. Nozzles in AJM are eithercircular or rectangular in cross-section.

Madhu (2015) has said that Tungsten carbide, sapphire, HCHCr steel, aluminum nozzles for mixing stage, brass and steel nozzles at the exit stage, Stainless steel, Tool Steel , deep reactive ion etching (DRIE), Alloy steel (EN38) heat treated of hardness 50 HRC was used for nozzles are used as nozzle materials for research purpose.

Figure 6 - Stainless Steel Nozzles

Madhu (2015) on reviewing paper by Lei Zhang et al., (2005) who had worked with the nozzle material and design wrote in his paper that the abrasive particles are directed onto the work surface at high velocity with the help of nozzle. Thus, the nozzle material is subjected to a great degree of abrasion wear and hence these are to be made of hard materials such as tungsten carbide or synthetic sapphire. Tungsten carbide nozzles are used for circular cross-sections in the range of 0.12-0.8mm diameter, for rectangular sections of size 0.08x0.05 to 0.18 x 3.8 mm and for square sections of size up to 0.7 mm. Sapphire nozzles are only made for circular cross-sections. The diameter varies from 0.2 to 0.7 mm. In order to minimize the secondary effects due to ricocheting of the high-speed abrasive particles, nozzles are made with an external taper.

The stress distribution in nozzles as calculated by FEM is as shown

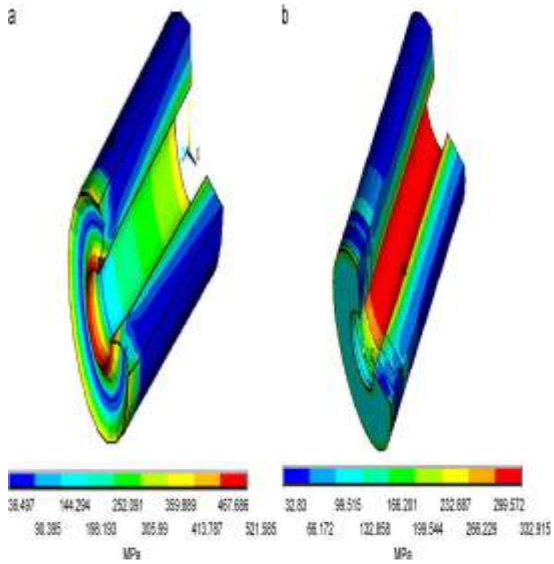

Figure 7 - (a) CN-2 conventional nozzle (b) GN-2 gradient nozzle

Using the above analysis Madhu(2015) concluded that the tensile stresses at the entry region of GN-2 gradient nozzle arereduced greatly when compared with that of CN-2 conventional nozzle. This effect may lead to increase in resistance to fracture, and thus may increase the erosion wear resistance of the gradient nozzle.

V. C. Venkatesh et al., (1988) conducted experiments using tungsten carbide or sapphire as nozzle materials. The parameters investigated are shown in the table below -

Table 1 - Machining Parameters And Their Variations

Notation	Parameter	Level	
		-	+
X1	Nozzle Tip Distance	5mm	10mm
X2	Spray Angle	60	90
X3	Pressure	5 bar	7 bar
X4	Abrasive Material	Silicon Carbide	Aluminium Oxide
X5	Nozzle Material	Tungsten Carbide	Sapphire
X6	Nozzle Size (Internal Diameter)	0.46mm	0.65mm

Table 2 - Summary of effects of machining parameters

Response	Material	Nozzle Tip Distance X1	Spray Angle X2	Pressure X3	Powder Material X4	Nozzle Material X5	Nozzle Size X6
Material Removal Rate	Glass EDM Ceramic	+ 0 +	0 0 0	+ + +	0 - -	0 + 0	+ + +
Spray Dimension	Glass EDM	+ +	- -	0 +	0 0	+ 0	+ +
Cavity Dimension	Glass Ceramic	+ +	- -	+ 0	0 -	+ 0	+ +

He explained that wear not only takes place in nozzle but also in nozzle holder. The material of the nozzle holder - Brass, wore out rapidly though not as fast as the nozzle material - tungsten carbide or sapphire.

4. STAND-OFF DISTANCE(SOD):

Stand-off distance is defined as the distance between the work surface of the workpiece and the face of the nozzle. SOD has been found to have considerable effect on the work material and accuracy.

A.P. Verma et al., (1983) reported in his paper after reviewing papers of C.N.Ingulli(1967), A.Bhattacharya(1977), M.L.Neema et al., (1977) and P.C.Pandey et al., (1976)the effects of abrasive flow rate and stand-off distance on the MRR in abrasive jet machining. They have found that MRR increases with increase in abrasive flow rate and stand-off distance and after a certain point it decreases with further increase in these parameters, giving optimum values.

A.P. Verma et al (1983) conducted experiments from which the effects of stand-off distance on volumetric material removal rate and penetration rate are shown below.

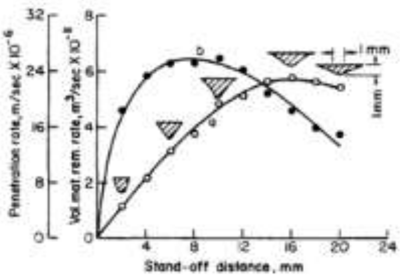

Figure 8-Variation of material removal rate and penetration rate with stand-off distance(a) Volumetric material removal rate and(b)Penetration rate. Particle size= 30 ~ nozzle pressure= 14.715 × 104 N/m z (gauge); mixture ratio = 0.148; cutting time = 60 sec.

From his experiment, he concluded that both material removal rate as well as penetration rate are dependent on stand-off distance, mixture ratio, carrier gas pressure and grain size. The maximum values of material removal rate and penetration rate are obtained at different values of stand-off distance.

The effect of SOD on MRR is shown in the below graph-

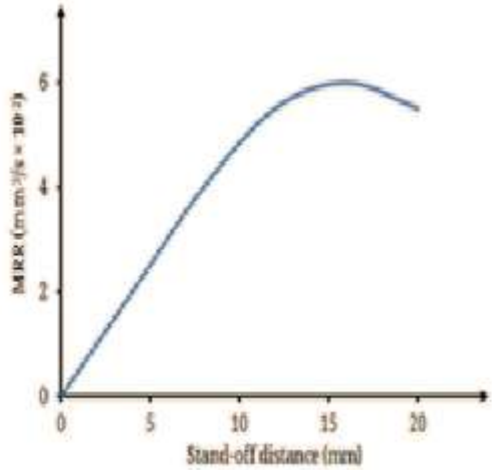

Figure 9 - MRR variation with SOD in AJM

R. Balasubramaniam et al., (2001) conducted experiments and concluded that as SOD increases, the entry side diameter and entry side edge radius also increases, thereby leading to increase in MRR. The below figure is from his experiments and it shows the normalized erosion profiles for different values of SOD-

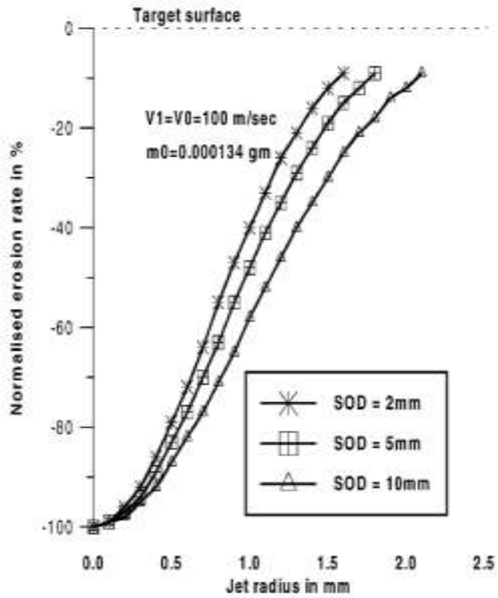

Figure 10 - Normalized erosion profiles for different stand-off distances(-ve values on Y axis indicate that erosion is along the depth)

III. CONCLUSIONS

- Work material has to have high mechanical strenghts. Based on the work material selected, the other parameters are decided.
- Abrasives usually used in AJM are Aluminium dioxide(Al2O3) and Silicon carbide(SiC). Effect of abrasives on MRR are discussed above.
- Carrier gas acts as a transfer medium for abrasive mixture and also direction of flow.
- Nozzle material has to be chosen accordingly to avoid wear of nozzle due to high velocities of abrasive mixture.
- MRR increases directly with SOD.

REFERENCES

[1]. 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.

[2]. 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.

[3]. Babu, M. K., & Chetty, O. K. (2003). A study on recycling of abrasives in abrasive water jet machining. Wear, 254(7-8), 763-773.

[4]. Ramachandran, N., & Ramakrishnan, N. (1993). A review of abrasive jet machining. Journal of Materials Processing Technology, 39(1-2), 21-31.

[5]. Kamada, H. (1982). A Study of Electrolytic Abrasive Mirror Finishing. Bull. Jap. Soc. Prec. Eng., 16, 109-110.

[6]. Madhu, S. (2015). Nozzle design and material in abrasive jet machining process–a review. Int J Appl Eng Res, 10, 25526-25526.

[7]. Zhang, L., Kuriyagawa, T., Yasutomi, Y., & Zhao, J. (2005). Investigation into micro abrasive intermittent jet machining. International Journal of Machine Tools and Manufacture, 45(7-8), 873-879.

[8]. Venkatesh, V. C., Goh, T. N., Wong, K. H., & Lim, M. J. (1989). An empirical study of parameters in abrasive jet machining. International Journal of Machine Tools and Manufacture, 29(4), 471-479.

[9]. Verma, A. P., & Lal, G. K. (1984). An experimental study of abrasive jet machining. International Journal of Machine Tool Design and Research, 24(1), 19-29.

[10]. 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.

Subhash.R.Bharadwaj "Process Parameters of Abrasive Jet Machining' International Journal of Engineering Research and Applications (IJERA), vol. 9, no. 11, 2019, pp 46-51