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Recent Trends in Abrasive Jet Machining

Mayur S. Aware

Department of Mechanical Engineering, Pimpri Chinchwad College of Engineering and Research, Maharashtra, India

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Abstract - Abrasive jet machining (AJM) is one of the non-conventional machining process used to remove unwanted material from a given workpiece. The process parameters which are mainly influence the quality of machining in AJM are air/gas pressure, stand-off distance, nozzle diameter, traverse speed, abrasive flow rate and abrasive size. This is an inexpensive process with reasonably high material removal rate. The quality parameters considered in AJM are kerf Characteristics, Surface Roughness (SR), Material Removal Rate (MRR), Nozzle wear and Depth of Cut. Various mathematical models and modern approaches are applied to optimize process parameters there by improve the performance characteristics. deburring, machining and dimensional accuracy. Some special sorts of operations like micro-machining, polishing of micro-channels are the present issues in research and development. The dimensional accuracy is increased by using LAVAL nozzle.

Keywords-Abrasive Jet Machining, Surface roughness, Material removal rate, Nozzle

1. INTRODUCTION

Abrasive jet machining (AJM), also referred to as abrasive micro-blasting, pencil blasting and micro-abrasive blasting, is an abrasive blasting machining process that uses abrasives propelled by a high velocity gas to erode material from the workpiece. Common uses include cutting heat-sensitive, brittle, thin, or hard materials. Specifically, it's wont to cut intricate shapes or form specific edge shapes. Abrasive jet machining (AJM) is an unconventional machining method. In this method material removed by the impact of abrasive particles of the slurry on hard and brittle material. This process is used to cut the material and make the holes or cavities and kerfs. In this machining process there is no change in physical and mechanical properties since this is a non-electrical and non-chemical and non-thermal. Abrasive water jet machining contains abrasive particles like alumina carbide to chop the hard materials like ceramics, glass, metals, advanced composite materials and soft metals. This process is especially suitable for warmth sensitive materials that can't be machined by processes that produce heat while machining. The key advantages of AJM technique making it more effective than the rest of the micro-machining techniques for machining holes are high MRR, effective machining of hard and brittle materials, low process forces, no chatter and vibration, easy to machine heat sensitive material due to negligible heat affected zone and low capital and operation cost. However, it also has a disadvantage requiring an additional operation for fabricating a mask necessary to obtain micro features. The mask ascertains only the size range of the micro features produced and not its shape. The side walls of the machined holes are inherently tapered which limits the process to produce cylindrical shaped holes. This problem has not been addressed by researchers till date. Therefore the current work presents a novel approach to extend the capabilities of the process for machining cylindrical shaped holes. Adequate amount of research has been reported on different facets such as process parameters effect, machining micro features for micro devices, shape of the machined profiles, etc. Abrasive jet machining are often advantageously utilized for multifarious purposes including surface cleaning, deburring, abrading and even making holes. Common applications of abrasive jet machining process are provided below. It is to be noted that, regardless of the aim, abrasive jet machining (AJM) is useful just for hard and brittle materials. AJM should be avoided if work material is soft and ductile; otherwise quality of machined surface are going to be poor.

1.2 System Description

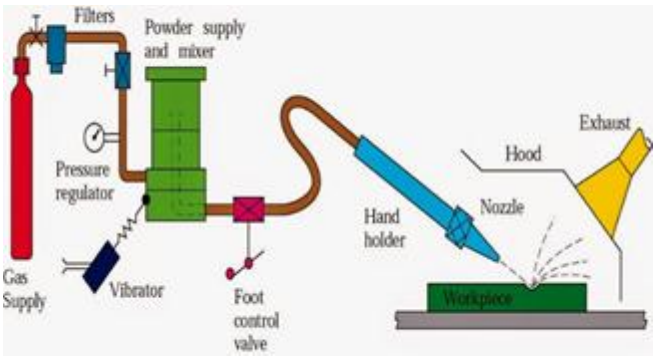

Fig1.1 Schematic diagram of Abrasive Jet Machining [7]

Components of Abrasive Jet Machining

1) Gas Propulsion System

2) Mixing Chamber

3) Nozzle

- Gas Propulsion System

The main purpose of gas system is to supply clean and dry, high velocity air or gas for machining. Mostly air, carbon dioxide, Nitrogen etc. are used as gas in gas propulsion system. This system consists, compressor, air filter and drier. The gas utilized in this technique should easily available. First gas is compressed into a compressor. This gas sends to filler and drier where all dust and unwanted particle along side moisture remove from it. Now these clean air is send to mixing chamber. [1,2]

- Mixing Chamber

The fabrication of mixing chamber is done such that the carrier gas would enter from three different inlets at 120(degree) angle and abrasive particles would enter from the top of the mixing chamber. This would result in cyclone formation inside the mixing chamber and homogeneous mixture of abrasive particles and carrier gas will be obtained. The thickness of the blending chamber is additionally kept 5 mm. The converging section of the mixing chamber will ensure the increase in velocity of the mixture. Further increase in velocity is completed in nozzle to realize cutting velocity. [2]

- Nozzle

Nozzles are the devices which increases the kinetic energy of the fluid in exchange to the pressure drop. Nozzles create high velocity jet which is impinged on the fabric to be machined. As the nozzle wear may be a big issue in AJM, tungsten carbide or sapphire material nozzle is employed. Tungsten carbide nozzle can cut square, rectangular and circular section but sapphire nozzles can only cut circular sections. Average lifetime of nozzle made from tungsten carbide is 12 to twenty hr whereas nozzle made from sapphire has a mean lifetime of 300 hr.

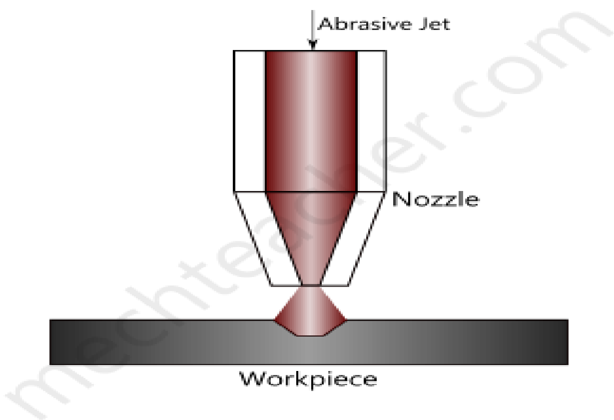

Fig1.2 nozzle [8]

4.1 2. EFFECT OF PROCESS PARAMETERS ON (AJM)

- Effect of abrasives on AJM performance

The parameters like shape, size, strength, material and flow rate of abrasive can influence machining performance. Irregular shape abrasives having sharp edges tend to supply higher MRR as compared to spherical grits. Smaller size grits produce highly finished surface but reduce material removal rate (MRR) and thus productivity descends. Larger grits can again create trouble while mixing and flowing through the pipeline. However, variation in size within the entire volume should be low otherwise estimation or assessment won't be accurate. Abrasive materials have varying strength or hardness. The harder is that the abrasive with reference to surface hardness, the larger are going to be the quantity removal rate. It is basically the relative hardness between abrasives and workpiece that determines machining capability and productivity.[5]

- Effect of carrier gas on AJM performance

Carrier pressure and its flow are two paramount factors that determine performance and machining capability. Higher pressure reduces jet spreading and thus helps in cutting deeper slots accurately. However, various accessories including pipeline must be capable enough to handle such high without failure. Moreover, increased gas flow gives the supply for utilizing higher abrasive flow, which may improve productivity.[5]

- Effects of mixing ratio on AJM performance

Mixing ratio (M) is that the ratio between mass flow of abrasive particles and mass flow of carrier gas. It basically determines concentration of abrasives within the jet. Mixing ratio can be increased by increasing abrasive percentage and in such case an increasing trend in MRR can be noticed because larger number of abrasives participates in micro-cutting action per unit time. However, excessive concentration of abrasive in the jet can significantly reduce MRR because of lower jet velocity (as gas pressure is constant) and unavoidable collision (thus loss of kinetic energy). MRR are often enhanced by proportionally increasing both the abrasive flow and gas flow at same rate in order that mixing ratio remains constant. In such case, higher pressure of the carrier gas has got to be utilized. This necessitates thicker and stronger pipelines and other accessories to smoothly handle such high pressure without leakage and rupture. Indefinite increase in MRR isn't practically feasible due to limited capability of kit and accessories.[5]

- Effect of stand-off distance on AJM performance

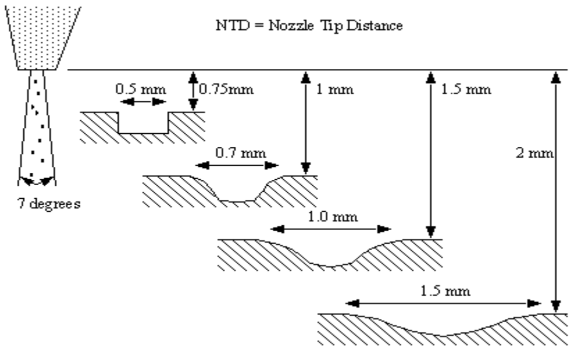

Fig2.1 Stand-off distance [12]

Distance from the surface to the tip of nozzle in abrasive jet machining set-up is named Stand-Off Distance, abbreviated as SOD. Higher SOD causes spreading of jet and thus its cross-sectional area increases with the sacrifice of jet velocity. As a consequent, machining deeper slots or hole becomes difficult; instead a wider area is cut. Alternatively smaller SOD can cut a deeper but narrow slot or hole. It also enhances MRR. Thus an optimum value of stand-off distance is required to line for obtaining satisfactory performance in abrasive jet machining.[5]

- Material removal rate and its estimation

Knowledge of fabric removal rate (MRR) is useful for choosing process parameters and selecting feed rate of the nozzle. It also facilitates accurate estimation of productivity, delivery time also as cost. Since only kinetic energy of abrasive grits is utilized for erosion, the analytical formula for MRR can be established by equating available kinetic energy with the work done required for creating an indentation of certain cord length on a specific work material. However, ductile and brittle materials behave differently in indent formation, and thus size of indentation created by the impact of single abrasive grit is different for ductile and brittle materials.[3]

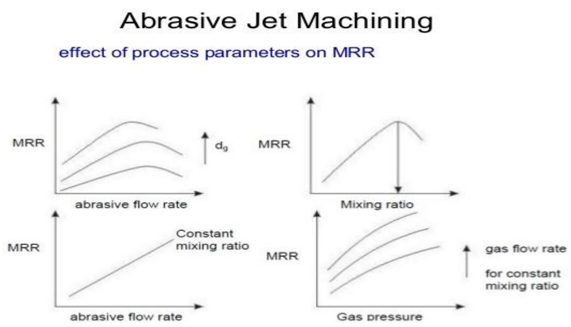

Fig4.2 Effect of Process Parameters on MRR [4]

4. 3. NOZZLE WEAR ISSUE

Like most of the other machining technologies, all AJM methods are related to the issue of tool wear. The nozzle is the most vulnerable component of any abrasive jet system. High pressured energy carrier moves through the orifice to the inner chamber, where it is mixed with abrasive particles. Then, the mixture enters the nozzle tube, obtaining a directed motion and exits in a form of an abrasive jet. The wall of the mixing tube is multiply impacted by particles during the process that leads to internal nozzle erosion and changes in the tube profile. Continuous increase of nozzle hole diameter leads to process instability due to rise in air flow rate, jet divergence, and footprint size. Such circumstances affect the MRR, surface waviness and preciseness in general. Therefore, the nozzle wear mechanism became an important technological topic in the improvement of AJM economic indicators. During blasting, abrasive particles collide with the entrance edge and inner cylindrical surface of the nozzle. It leads to erosion and geometry changes both on the nozzle entrance and exit. A common nozzle life indicator is nozzle weight loss rate (NWLR) in g/min. Depending on impact angles, both ductile cutting and brittle fracturing may proceed simultaneously. It was shown that the central and exit sector of the nozzle undergoes mainly the ploughing with a linear wear rate, meanwhile, there is a brittle fracturing at the nozzle entrance. Boron carbide nozzle has shown the rapid wear for the first 10 h of operational time and then slow progressive wear for the next 50 h. Alumina nozzle with the same geometry undergoes rapid wear for the first 4 h [19]. Both cases demonstrate the same NWLR character which makes relevant the conclusion that the sliding erosion mechanism after some operational time starts to dominate over the fracture produced by the direct particles impact. The nature and rate of nozzle wear is affected by a number of factors, which could be separated into three groups: nozzle material, geometry, properties of abrasive particles and influence of process parameters, which are discussed below.[4]

- **Influence of nozzle material**

A variety of ceramics, especially silicon carbide (SiC), alumina oxide (Al_2O_3), zirconia dioxide (ZrO_2), boron carbide (B_4C) and silicon nitride (Si_3N_4) have got an extensive application in nozzle manufacturing due to its universal mechanical properties. In comparison to metals, ceramics have a higher hardness and melting point, but lower thermal shock resistance. Lastly, significant thermal stress during the blasting process results in intensive brittle fracturing at the nozzle exit. Nevertheless, for instance, alumina ceramic nozzles are able to work for around 30 times longer compared to stainless and carbon steel nozzles. Thus, hardness was claimed as one of the most important contributors to the nozzle life. The hardness and abrasive resistance of boron carbide are inferior only to diamond and its relative cubic boron nitride structure. Monolithic B4C coating shows a reduction of NWLR for around 30% in contrast with Al2O3/(W,Ti)C coating [19]. Sapphire orifice was used for ultrasonic CAFJP and for the creation of "hydraulic flip" effect. In studies, functionally graded materials (FGMs) in a range of two ceramics were applied to nozzle design. FGMs is an approach to design parts with gradually changing properties by means of a sequential combination of different materials. Comparing to sintered (W,Ti)C, SiC has a low coefficient of thermal expansion and high thermal conductivity. To reduce tensile stress and wear, (W,Ti)C nozzle was gradually modified to SiC from the nozzle exit to nozzle entrance. FG nozzle has shown almost 4 times less NWLR than the conventional one.[4]

3.1 HOW MATERIAL REMOVAL RATE (MRR) CAN BE IMPROVED IN AJM

In abrasive jet machining, kinetic energy of high velocity abrasive grits is utilized to erode material in solid form. The carrier gas accelerates these fine abrasives and also assists to blow away eroded particles from machining zone. Although AJM is used mainly to get a smooth surface (instead of bulk material removal) by removing a thin layer of material from work surface, erosion rate or material removal rate (MRR) is one of the crucial factors (other factors are nozzle life and machining accuracy) to assess the performance of process. Improved MRR without sacrificing product quality and nozzle life is highly advantageous from economic point of view as it considerably enhances productivity. This indirectly helps industry in acquiring goodwill (an important asset for any company) by delivering products in timely manner. However, improving MRR is not an easy task as many controllable and uncontrollable parameters affect the erosion capability in AJM. Various possible ways of improving material removal rate in abrasive jet machining along with limitations are discussed in the following sections.[4]

- Various ways of improving MRR in abrasive jet machining

a) Enhancing abrasive flow rate

It is evident from analytical model of material removal rate in AJM for ductile or brittle materials that MRR is proportional to abrasive flow rate. As usual, increased abrasive flow rate can lead to palpable improvement in erosion rate as more number of abrasives will impinge the work surface per unit time. However, final velocity of jet reduces since carrier gas flow rate and pressure are kept unchanged. Consequently, jet quickly losses its kinetic energy because of spreading while moving through stand-off distance (SOD), and ultimately erosion capability degrades. A steady enhancement in MRR can be noticed if gas flow rate and pressure are also increased with abrasive flow rate; however, such actions depend greatly on set-up capability as tight joints, thicker pipelines, strong structures, etc. are absolutely necessary to withstand high pressure without failure.[1,2]

b) Using high carrier gas pressure and flow rate

As discussed earlier, a high gas flow rate gives provision of utilizing high abrasive flow rate and thus enhancing material removal rate without sacrificing machining quality and nozzle life. For same mixing ratio and nozzle diameter, velocity of abrasive jet also can be increased by increasing carrier pressure. However, every set-up has certain limitation and rated capability beyond which pressure can't be increased.[1,2]

c) Reducing stand-off distance (SOD)

When gas-abrasive mixture jet moves through SOD (gap between nozzle tip and work surface) it experiences substantially lower surrounding pressure and consequently it starts spreading leading to increase in diameter and loss of velocity. When jet strikes workpiece after passing though longer SOD, it lacks kinetic energy to efficiently erode material. On the contrary, when SOD becomes very small, abrasives don't get sufficient passage to leave machining zone and thus fresh abrasives collide with used abrasive that leads to loss of velocity, lower erosion rate and also machining inaccuracy. Thus an optimum SOD can fetch better MRR.[1,2]

d) Using proper impingement angle

In most of the cases a vertical jet (impingement angle = 90º) provides better result; however, in many instances it was observed that 70º – 80ºangle gives maximum MRR. Although it depends on many other factors, in general any deviation in impingement angle from 90ºcan lead to machining inaccuracy. Also an angle of below 60º can considerably degrad e material removal rate. There exist many other factors that can influence erosion rate in AJM, for example, size and strength of abrasives, mechanical properties of work surface including strain hardening and residual stress, diameter and wear rate of nozzle, type of cutting, type of carrier gas, etc. Therefore it is been observed that enhancing material removal rate (MRR) in abrasive jet machining (AJM) is one challenging task because of its dependency on many controllable and uncontrollable factors. An optimization considering various constraints arising from machine set-up, process parameters, requirements, work material and abrasive properties, etc. can provide a better solution for a specific scenario.[3]

4. DEVELOPMENT OF LAVAL NOZZLE

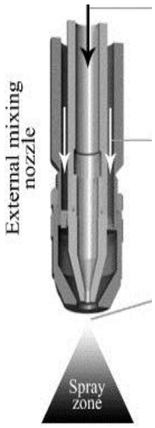

Fig5.1 Laval Nozzle

4.1 EXPERIMENTATION

Experiments are carry out for micro hole on stainless steel ANSI 316 plate and the compressed air of set pressure is passed through air conditioning unit i.e. Filter-Regulator unit which removes the moister and sends dry air to the abrasive feeder through solenoid valve which is employed to possess an instantaneous on-off control of the method. This dry compressed gas imparts momentum to abrasive particles stored within the abrasive feeder. The air-abrasive mixture comes out of the cylinder with sufficient kinetic energy. High energy air-abrasive mixture is skilled the nozzle which produces a high velocity jet of the air-abrasive mixture. The high velocity jet of air-abrasive mixture impact on a piece surface and take away the fabric through erosion phenomena. Silicon Carbide (SiC) of mesh sizes 50 micron is employed. The Laval nozzle is formed of tungsten Carbide and features a diameter of 500 micron. The machining time is kept constant together minute. There is various important process parameters of micro-AJM out of which atmospheric pressure (P1) and guiding atmospheric pressure (P2), stand-off distance are chosen for the study. In the present work, stainless steel ANSI 316 plate of dimension (70 mm×50mm×0.6mm) is taken a s work piece sample for machining holes was used as the work material. With Dino-Lite Premier Digital Microscope (AM3713TB) is used for measuring the Micro holes and flow patterns of jet. At high jet flow isn't visible during this camera so effect of guiding pressure P2 on P1 are often measured. For this experiment Air-abrasive mixture pressure (bar) P1 is kept constant as 3 bar and experimental condition.[9]

4.2 RESULT

Table 1: Effect of Guiding Pressure P1 and P2[9]

Exp no	Parameters	Value
1)	Air-abrasive mixture pressure (bar) P1	3
	Guiding pressure(bar) P2	1
	Bottom	0.508
	Centre	0.426
	Exit	0.622
	Nozzle tip Distance	2.506
2)	Air-abrasive mixture pressure (bar) P1	3
	Guiding pressure(bar) P2	1.5
	Bottom	0.557
	Centre	0.491
	Exit	0.540
	Nozzle tip Distance	2.276
3)	Air-abrasive mixture pressure (bar) P1	3
	Guiding pressure(bar) P2	2
	Bottom	0.524
	Centre	0.491
	Exit	0.655
	Nozzle tip Distance	2.375

Experimental Result and flow visualization. Generally when jet exits from the nozzle, the flow should always divergent but with the help of Laval nozzle the flow will get convergent with some distance (approx. 1mm to 3mm) and again divergent. So here convergent flow is achieved up to nozzle tip distance. In micro AJM for convergent flow is extremely useful process parameter f or higher velocity and geometric accuracy. So the Laval nozzle is extremely useful for micro abrasive jet machining.

5. CONCLUSION

The better performance, and therefore the applications represented above statements confirm that ABRASIVE JET MACHINING can be still expand. The new software's wont to minimize time and investments, there by making it possible for more manufacturers of precision parts to install AJM centres.

REFERENCES

[1] Book: Nontraditional Manufacturing Processes by G. F. Benedict (Manufacturing Engineering and Materials Processing-19).

[2] Book: Unconventional Machining Processes by T. Jagadeesha (I. K. International Publishing House Pvt. Ltd.).

[3] Book: Advanced Machining Processes by V. K. Jain (Allied Publishers Private Limited).

[4] Book: Nonconventional Machining by P. K. Mishra (Narosa Publishing House).

[5] Paper: M. W. Chastagner and A. J. Shih, Abrasive Jet Machining for Edge Generation, Transactions of NAMRI/SME, Volume 35, 2007.

[6]http://modernmanufacturingprocesses.blogspot.com/2015/11/historical-development-of-abrasive-jet.html

[7] https://www.mech4study.com/2017/03/abrasive-jet-machining-principle-working-equipment-application-advantages-and-disadvantages.html

[8] http://mechteacher.com/process-parameters-of-abrasive-jet-machining/

[9]V.V. Vanmorea, U. A. Dabadeb, "Development of Laval Nozzle for Micro Abrasive Jet Machining [MAJM] Process", Procedia Manufacturing 20 (2018) 181–186.

[10]Huaizhong Li, Jun Wang, Ngaiming Kwok, Thai Nguyen, Guan Heng Yeoh," A study of the micro-hole geometry evolution on glass by abrasive air-jet micromachining", Journal of Manufacturing Process 31(2018) 156-161.

[11] Kumar Abhishek, Somashekhar S. Hiremath, S. Karunanidhi," A novel approach to produce holes with high degree of cylindricity through Micro-Abrasive Jet Machining (m-AJM)", CIRP Journal of Manufacturing Science and Technology (2018).

[12]https://www.slideshare.net/mohit99033/abrasive-jet-machining-58178882