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ABRASIVE JET MACHINING AND ITS APPLICATIONS

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ABSTRACT

Abrasive jet machining is a material removal process in which abrasive particles (like 〖Al〗_2 O_3, SiC, glass beads, etc.) mixed with highly pressurized carrier gas jet (such as air, N_2, 〖CO〗_2), which acts as a coolant, is impinged on surface of a material by a nozzle. This machining process is useful in many applications like abrading, frosting, deflashing, cleaning, etc. which removes the surface material by micro cutting or brittle fracture. It has an advantage over the traditional machining that vibration, chatter, and stresses in work piece are very low. Moreover, intricate shapes of heat sensitive and brittle materials can be well produced using this process. In this research paper the basic theory of abrasive jet machining and its possible applications have been discussed.

1. INTRODUCTION

In abrasive jet machining (AJM), highly pressurized carrier gas (mainly air) mixed with abrasive particles is impinged on workpiece through nozzle with high velocity. The material is removed by brittle fracture and micro-cutting action. AJM is different from sand blasting in a way that very fine particles are used as abrasive particles and parameters are controlled more effectively. Abrasive particles of size 0.025 mm are impinged with nozzle of inner diameter 0.3-0.8 mm maintaining the stand-off distance (SOD) around 2mm and the velocity of jet is around 300 m/s.

2. PROCESS

AJM consist of different units i.e. gas propulsion system, abrasive feeder, machining chamber, AJM nozzle and abrasives. Figure 1 shows the schematic representation of the set-up for AJM. Gas propulsion system consists of compressor, air filter, drier and carrier gas (air, nitrogen and carbon dioxide). Compressor pressurizes the carrier gas up to 12 bar. Air filter and drier are used to remove moisture and oil contents to avoid contamination of abrasive particles. Abrasive flow rate of 2 to 4 gm/min is used for finishing operations and 10 to 20 gm/min for cutting operation. Abrasive feeder supplies a particular quantity of abrasive particles. The propellant and abrasive particles are fed in mixing chamber. An electro-magnetic shaker vibrates the mixing chamber at certain frequency and provides homogenous mixture of abrasive particles and propellant. This mixture is impinged on a workpiece at very high velocity through a nozzle. Machining chamber is a well closed so that machining does not reach harmful limits. AJM nozzle mainly used is made of tungsten carbide and sapphire which resistance to wear. Different abrasive particles, like aluminum oxide, silicon carbide, glass beads, dolomite, sodium bicarbonate etc., are used on the basis of machining accuracy, type of material and material removal rate (MRR). Abrasive particles cannot be used again for machining as the edges are worn out and particles can clog the nozzle.

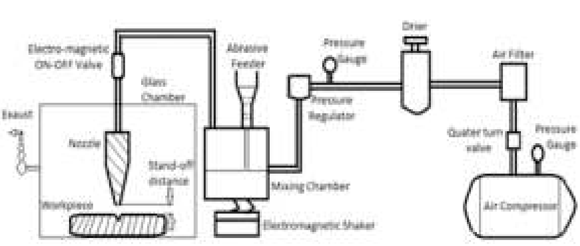

Figure 1: Schematic representation of AJM

Governing parameters of AJM are carrier gas composition and pressure; abrasive material, shape, size, flow rate and mixing ratio; nozzle material and design; jet velocity and impingement angle; SOD; workpiece material and shape of cut. These parameters are adjusted to obtain desired machining accuracy, MRR and surface finish. As per the theory, MRR of brittle and ductile materials is determined by mathematical models as in equation (1) and (2).

$$MRR = \left[\frac{M_a V^{3/2}}{(\rho_g)^{1/4}(\sigma_w)^{3/4}}\right] \quad \text{(For brittle materials)} \qquad (1)$$

$$MRR = \left[\frac{M_a V^2}{2\sigma_w}\right] \quad \text{(For ductile materials)} \qquad (2)$$

Where 'M_a' is mass flow rate of abrasives in kg/s, 'V' is velocity of jet in mm/s, ρ_g is abrasive grain density in kg/mm^3 and 'σ_w' is flow strength of work material in N/mm^3.

There are many advantages of AJM. High surface finish and low depth of damage is obtained. AJM can machine delicate, intricate and heat sensitive materials free from vibrations and chatter. It is successful in cutting holes of complex shapes and machine thin sections of hard and brittle materials. In spite of several advantages, there are many limitations which hinder the machining capability of AJM. Main disadvantages are low MRR and embedment of abrasives in work piece. Machining accuracy becomes difficult to achieve due to unavoidable flares of abrasive jet which results in tapering of holes.

AJM is used in many applications. It is used in abrading and frosting of glass. Cleaning processes, manufacturing of electronic devices, drilling of glass, deburring of plastics are successfully done with AJM. AJM is most suitable for drilling, cutting, deburring, etching and polishing of hard and brittle materials. Different materials suitable for machining are mica, germanium, gallium, ceramics, silicon, glass, quartz, sapphire etc.

3. PROCESS PARAMETERS

Process AJM is based on various parameters on which material removal rate and surface finish depends. With experimentations, researchers found that MRR was the function of abrasive velocity, abrasive diameter, abrasive density, workpiece toughness, and workpiece hardness. Kumar [1] carried out experiments using parameters such as nozzle length, diameter and entrance angle; mixing ratio; and abrasive size and found that wear rate of nozzle increases with increase in nozzle length, decrease in nozzle diameter, and decrease in angle of impingement. Venkatesh [2] added two more parameters, feed rate and impingement angle, to above parameters for further research. However, these studies were not sufficient for the prediction of effects of various parameters. Wide range of materials and abrasive particles were used to establish erosion models based on these parameters. Results showed that as the SOD increases, MRR increases, reach optimum value and decreases further. The other parameter on which MRR depends is nozzle pressure. As increase in nozzle pressure, above the threshold pressure, help in increasing the MRR. Achtsnick et al. [3] noticed that abrasive particles coming out from nozzle had lower velocity than carrier gas velocity. Wensink and Elwenspoek [4] studied the effects of abrasive size and impact angle. Results demonstrated that machinability was improved with smaller abrasive size and less impact angle. Kandpal et al. [5] conducted experiments with various abrasive particles, by changing pressure and SOD, on glass plates and ceramic plates of different thickness and compared it with theoretical results. It was concluded that MRR first increases and then decreases with increase in SOD.

4. REVIEW OF AJM AND ITS APPLICATIONS

In 1931, first study of particle impact by the mixture of smoke and dust on different shapes of material was carried out in Germany, reported by Finnie [6]. Burwell [7] investigated on wear mechanism which was the loss of material when two surfaces were in contact. This study and other various studies accomplish that abrasive wear and adhesive wear were of great importance. In year 1960 Finnie [6] noticed that, during AJM the material removal mechanism of ductile and brittle material was affected upon by the prevalent flow conditions. Removal of material during AJM was predictable for ductile materials, with change in direction and velocity of abrasive particles. However it was very difficult to predict the same in case of brittle materials.

Ray and Paul [8] conducted experiments on abrasive jet drilling.It was reported that SiC particles were suitable for machining hard and brittle material like porcelain. For high MRR, SOD was kept high; for precision work SOD was kept low and for accuracy high pressure is maintained.

Tsai et al. emphasized on surface polishing rather than bulk material removal. Abrasive jet polishing (AJP) is a technique in which rather than abrasive particles, either pure water or pure water with machining oil is use. AJP effects were perceived on EDM machined SKD 61 mold steel surfaces with different abrasive particles type and size. Results were obtained with help of Taguchi technique. Gas pressure and impact angle had greatest effect on surface roughness. 1:1 ratio of pure water and machining oil had reduced cutting forces on workpiece due to abrasive particles. Taguchi analyses results that the gas pressure and impingement angle had greatest effects on surface roughness. It was determined that for best optimum results abrasive to additive ratio must be 1:2, impact angle be 〖30〗^o, SOD be 10mm, gas pressure be 4kg/〖cm〗^2 and platform rotational velocity and travel speed be 200 rpm and 150 mm/s respectively.

While performing AJM, nozzle wear was a big issue. As for continuous machining, nozzle has to be changed after certain interval of time. Sychuk et al. [9] introduced and developed a new design of nozzle for AJM. Wear resistance of internal surface of nozzle was in main concentration. Many materials such as hard alloys, ceramics, carbides, and artificial diamonds were practiced to produce internal surface of nozzle. Boron carbide nozzle, made with powder metallurgy, was most popular and was fit for this application.

Srikanth and Rao [10] optimized process parameters of AJM on glass by Taguchi methodology and compared the results with analysis of variance. Many experiments were conducted using L_9 orthogonal array for MRR and kerf. MRR was best for 8 kg/cm2 air pressure, 10mm SOD and 4 mm nozzle diameter kerf for 6 kg/cm2 air pressure, 9 mm SOD and 3 mm nozzle diameter. Results obtained by Taguchi method was in agreement with analysis of variance. Lee et al. [11] recently examined the characteristics of SAE1045 medium carbon steel. Steel was processed by milling machine and AJM by varying load and friction distance. Results showed that micro craters formed on the surface of steel during AJM can hold the lubricant providing the smooth sliding motion. This decreases the friction coefficient and reduces machine wear. Amount of wear during AJM was less than that of milling machine for same friction distance. Many researchers had been working for the enhancement in the lubrication effect and wear resistance of workpiece and obtained satisfactory results. Micro craters on the surface of workpiece need to be retained, not only for lubrication enhancement and wear reduction efficiency, but also their rapid loss may lead pollution to the environment. Quality of craters had been examined in prior academic investigations but no research was done on lubricant storage. Lee et al. [11] recently in 2014 conducted experiments on lubricant storage in micro craters and found its contribution against friction.

Latest investigations by Lin et al. [12] intend to explore the effect of hybrid process AJM and EDM on surface modification. This results an increase in efficiency of metal removal and reduction in surface roughness. This hybrid process fulfills the requirements of modern manufacturing applications.

As the particle embedding can be undesirable in numerous of applications Getu el al. [13] identified two criteria for particle embedment in erosion process. Firstly, the contiguous contact between the particle and the target be maintained throughout the impact. Second was that the magnitude of the static friction forces reach a critical value. Particle orientation was defined as the angle between the particle linear velocity vector and the line connecting the center of mass to the furthest downstream particle vertex. It was observed that certain particle orientation were more favorable to particle embedment. Hadavi et al. [14] worked on finding the process parameters which are dependent on particle orientation. A model capable of predicting the instantaneous particle orientation and velocity within and downstream of nozzle was presented and shown to agree well with measurements.

Bellman and Levy [15] reported that material removal of ductilematerial was due to platelets mechanism. SiC particles- (~100 μm dia) mixed in air, moving at velocity 100 ft/s, was used as abrasive stream for eroding the target materials (Al 1100-0 metal and Al 7075-T6). It was established that due to forging and extrusion mechanism, platelets were formed on target materials. Platelets so formed were blown off by next impacting particle. Platelets were only formed in thin layer surface which was heated up to annealed temperature. This causes the hard subsurface layer to form beneath the soft layer because of cold working. This sub layer formation enhanced the formation of platelets and increases the efficiency of erosion to a constant level.

Tilly [16] examined mechanism of fragmentation and surface topology for different particle sizes against type 66 nylon, 11% chromium steel and fiberglass. It was concluded that there was a minimum size of the particles below which material did not break. Material was removed by formation of lip initially and then the lip was detached as fragment particles.Stephen Wan et al. [17] presented simple deterministic process models for the prediction of the evolution of the cross-sectional profile of glass channels generated by erosive wear in micro air abrasive jet machining using a round nozzle. Experiments were carried out on soda lime and borosilicate glass to verify the process models. Predicted model results show fairly good agreement with experimental results.

5. CONCLUSION

AJM is used for cutting small holes or slots, polishing, de-burring, trimming and removing oxide layers from surface of the material. Main parameters on which AJM depends are the abrasive type and movement of jet in relation to the workpiece. Processing time for AJM is subject to nozzle material and nozzle wear rate. Different experiments can be conducted to optimize the hybrid machining processes, like abrasive electrical discharge machining, abrasive electro-chemical machining, abrasive electro-chemical-discharge machining, abrasive discharge grinding and ultrasonic electrochemical Machining, for more precise and accurate machining.

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