Abrasive Jet Machine

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Abstract

Advance machining processes are used where higher accuracy and surface finish is required. One of them, Abrasive jet machining is a non-traditional machining process in which a high-pressure air stream and abrasive particles impinge on a work surface through a nozzle. Abrasive jet machining (AJM) removes material through the action of a focused beam of abrasive jet directed at the work piece the resulting erosion can be used for cutting, drilling and debarring etc. With the increase of needs for machining of ceramics, semiconductors, electronic devices and L.C.D., AJM has become a useful technique for micromachining. It is more useful in industries for precision work. Material removal rate during this process affected by different parameters like abrasive particle size, the velocity of abrasive flow rate, gas pressure, standoff distance etc.

Keywords: Abrasive jet machine (AJM), Material removal rate (MRR), Stand-off distance (SOD), Abrasive mass flow rate, Erosion rate.

Introduction

Abrasive jet machining (AJM) is a processing nontraditional machine which operators on no physical contact between tool and work piece so there is no thermal stresses and shocks developed. AJM is applied for many applications like cutting, cleaning, polishing, deburring, etching, drilling and finishing operation. In Abrasive jet machining, abrasive particles are made to impinge on work material at high velocity. A jet of abrasive particles is carried by carrier gas or air. The high-velocity stream of abrasives is generated by converting pressure energy of carrier gas or air to its Kinetic energy and hence high-velocity jet. Nozzles direct abrasive jet in a controlled manner onto work material. The high-velocity abrasive particles remove the material by micro-cutting action as *well* as a brittle fracture of the work material.

Literature survey:

The literature study of Abrasive Jet Machine reveals that the Machining process was started a few decades ago. Till date there has been a through and detailed experiment and theoretical study on the process. Most of the studies argue over the hydrodynamic characteristics of abrasive jets, hence ascertaining the influence of all operational variables on the process effectiveness including abrasive type, size and concentration, impact speed and angle of impingement. Other papers found new problems concerning carrier gas typologies, nozzle shape, size and wear, jet velocity and pressure, stand-off-distance (SOD), or nozzle-tip-distance (NTD). These papers express the overall process performance in terms of material removal rate, geometrical tolerances and surface finishing of work pieces, as well as in terms of nozzle wear rate. Finally, there are several significant and important papers which focus on either leading process mechanisms in machining of both ductile and brittle materials, or on the development of systematic experimental-statistical approaches and artificial neural networks to predict the relationship between the settings of operational variables and the machining rate and accuracy in surface finishing. The erosion of brittle materials by solid micro-particles is a complex process in which material is removed from the target surface by brittle fractures. The rate of material removal is one of the most important quantities for a machining process. Predictive mathematical models for the erosion rates in micro-hole drilling and micro-channel cutting on glasses with an abrasive air jet are developed. A dimensional analysis technique is used to formulate the models as functions of the particle impact parameters, target material properties and the major process parameters that are known to affect the erosion process of brittle materials. The effect of various parameters like abrasive mass flow rate, air pressure and stand off distance on erosion rate is shown by following graphical presentation.

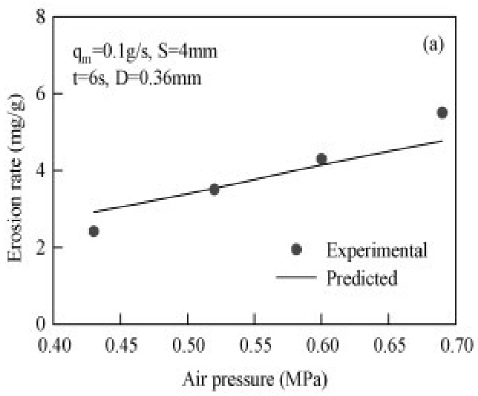

Fig 1. Ericson rate vs. pressure

Abrasive Jet Machining Process

A. Components:-

1) ***Air/gas supply cylinder/compressor***

Cylinder basically used for the storage of air/gas at certain high pressure & this pressurized gas/air is supplied forward to the system. Same way, Air compressors collect and store air in a pressurized tank, and use pistons and valves to achieve the appropriate pressure levels within an air storage tank that are attached to the system.

2) ***Filter***

The main purpose of using a filter is to purify the air/gas passed through it by removing an unnecessary or unwanted particle from air/gas flow.

3) ***Pressure Regulator***

The line pressure is regulated by a pressure regulator. A pressure regulator's primary function is to match the flow of gas through the regulator of gas place upon the system. A pressure regulator includes a restricting element, a loading element, and a measuring element.

4) ***Vibrator***

The main function of the vibrator in this is to proper mixing of two different materials by vibration mechanism.

5) ***Mixing chamber***

A mixing chamber is a small compartment in which proper mixing of gas/air abrasive particle takes place with help of vibrator attached to it.

6) ***Foot control valve***

It is used to maintain required pressure at the tip of the nozzle for material removal from the work piece by controlling valve.

7) ***Nozzle***

The abrasive particles are directed into the work surface at high velocity through nozzles. The rate of material removal and the size of machined area are influenced by the distance of the nozzle from the work piece.

8) ***Piping system***

The piping systems are required for carrying the compressed air from the compressor to the mixing chamber and from the mixing chamber to the nozzle orifice via the regulator. It is required to maintain the pressure in the line without eroding the pipe.

9) ***Guide ways(x-y table)***

The x-y table is the most important part of the AJM over which the work piece has to be kept and machined. The main function of the guide-way is to make sure that the machine tool operative element moves along the predetermined path. The guide way provides a smooth and linear motion in machine tool due to which higher accuracy and precision can be obtained. Guide way has a mechanism to bear the load and to guide their linear motion simultaneously.

*10) **Abrasives***

An abrasive is a material that is used to shape or finish a work piece through rubbing which leads to part of the work piece being worn away. While finishing a material often means polishing it to gain a smooth surface. Various abrasives used are Silicon oxide ($SiO2$), Silicon carbide (SiC), Aluminum oxide ($Al2O3$) of different sizes for cutting and drilling operation.

B. Design Methodology:-

An abrasive machine was fabricated in the institute workshop with required raw materials and procured components. Before that a detailed design of the functional subsystems were made using computer aided design tools. For this CATIA software was used which is very good in product design and analysis. The components that were designed include the machining chamber, work-holding device, nozzle and its holder, abrasive container and vibrating unit, cam and total piping system. Care was taken so to optimally use the material and space in the production engineering lab along with ease in using. The final components were fabricated in the workshop using the available materials like mild steel sheets bars and pipes, Aluminum sheets, rubber sheets, glass fiber, standard nuts and bolts etc. For fabrication purpose the welding machine, grinding machine, the hand-drill, sheet-bending machine, and shearing machines were used.

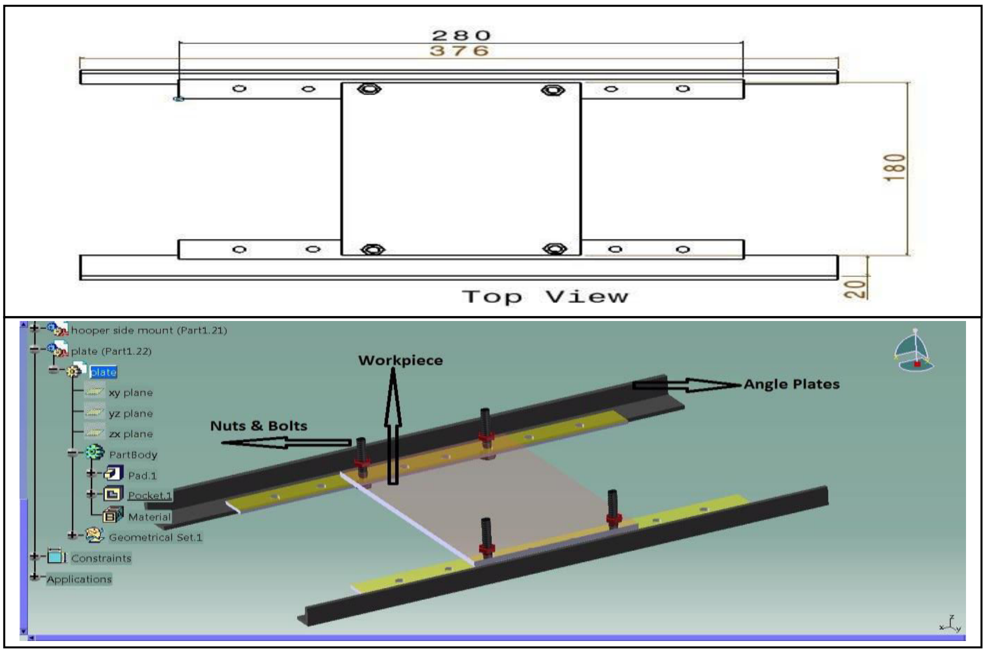

Fig 2 . Schematic design on CATIA *Fig 3. Process Setup*

C. Working Process:-

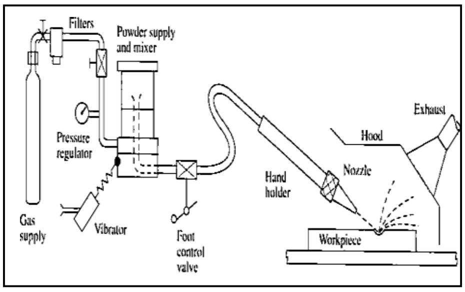

Fig 4. AJM Mechanism

1. First, Gas /dry air is supply from the cylinder/compressor & reaches to a filter.

2. After the filtration, air/gas move towards pressure regulator, which indicate the pressure of the air/gas flow.

3. Then this air/gas is mixed with abrasive particle powder in the mixing chamber with the help of vibrator attached to it.

4. Then this mixer of abrasive particle & air/gas reaches to foot control valve, which uses for maintaining the required pressure of mixer at the tip of the nozzle.

5. Mixer with sufficient pressure reaches to the nozzle, nozzle increases the velocity of the mixer and strike the work piece at very high velocity, say about 300m/s.

6. So due to the high velocity of air-abrasive mixer strike at the work surface, material removal can take place & machining can do.

D. Typical Parameters of AJM:-

1) Abrasive

Material: - Al oxide, brass, silicon carbide

Shape: - irregular / spherical

Size: - 10 to 50 micron

Mass flow rate: – 2 to 20 gm/min

2) Carrier gas

Composition - dry air, nitrogen (N_2), carbon dioxide (CO_2)

Pressure – 2 to 10 bar

Flow rate – 5 to 30 L/min

3) Abrasive Jet

Velocity – 100 to 300 m/s(⌟1000 km/hr)

Standoff distance – 0.5 to 15 mm

Impingement angle – 60° to 90°

Mixing ratio – Volume flow rate of abrasives/Volume flow rate of gas

4) Nozzle

Material – tungsten carbide (WC)/ Sapphire

Diameter – (internal) 0.2 to 0.8 mm

Life – 300 hours for sapphire, 20 to 30 hours for WC.

E. Advantages & Disadvantages of AJM:-

1) Advantages:-

- ✓ Capital cost is low and it is easy to operate and maintain AJM.
- ✓ The process is free from chatter and vibration as there is no contact between the tool and work piece.
- ✓ The Higher surface finish can be obtained.
- ✓ Ability to cut fragile, brittle hard & heat sensitive material without damage.
- ✓ Thin sections of hard brittle materials like germanium, mica, silicon, glass, and ceramics can be machined It provides cool cutting action, so it can machine delicate and heat sensitive Material.
- ✓ It has the capability to cut intricate shape holes of any hardness and brittleness material.

2) Disadvantages:-

- ✓ Limited capacity due to low MRR. MRR for glass is 40 gm/minute.
- ✓ Abrasive powders cannot be reused as the sharp edges are worn and smaller Particles can clog the nozzle.
- ✓ Short standoff distances when used for cutting, damages the nozzle.
- ✓ A dust collection system is a basic requirement to prevent atmospheric pollution and health hazards.
- ✓ Nozzle life is limited (300 hours).
- ✓ Abrasive jet machining cannot applicable for a ductile material.
- ✓ Stray cutting is difficult to avoid.

F. Application of AJM:-

- ✓ This is used for abrading and frosting glass more economically as compared to
- ✓ Etching or grinding.
- ✓ Cleaning of metallic smears on ceramics, oxides

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on metals, resistive coating etc.

- ✓ AJM is useful in the manufacture of electronic devices, drilling of glass wafers, deburring of plastics, making of nylon and Teflon parts permanent marking on rubber stencils, cutting titanium foils.
- ✓ Used for cutting thin fragile components like germanium, silicon etc.
- ✓ Used for drilling, cutting, deburring etching and polishing of hard and brittle materials.
- ✓ Most suitable for machining brittle and heat sensitive materials like glass, quartz, sapphire, mica, ceramics germanium, silicon, and gallium.

G. Effective Process Parameters:-

The followings are some of the important parameters of abrasive jet machining which directly or indirectly affect the material removal rate (MRR) during the process.

- ✓ Abrasive mass flow rate
- ✓ Velocity of abrasive particles
- ✓ Mixing ratio
- ✓ Gas pressure
- ✓ Standoff distance

1) Effect of Abrasive mass flow rate and grain size on MRR:-

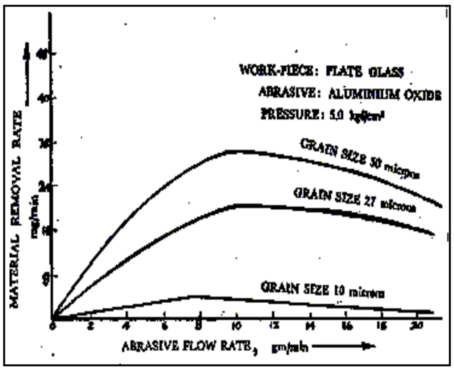

Fig 5. variation in MRR with abrasive grain size

It is clear from the figure that at a particular pressure MRR increase with the increase of abrasive flow rate and is influenced by the size of abrasive particles. But after reaching optimum value, MRR decreases with further increase of abrasive flow rate. This is owing to the fact that Mass flow rate of gas decreases with the increase of abrasive flow rate and hence mixing ratio increases causing a decrease in material removal rate because of decreasing energy available for erosion.

2) *Effect of exit gas velocity and abrasive particle density*

This graph shows variation in exit gas velocity with respect to abrasive particle density. The velocity of carrier gas conveying the abrasive particles changes considerably with the change of abrasive particle density as indicated in the figure.

The exit velocity of gas can be increased to critical velocity when the internal gas pressure is near twice the pressure at the exit of the nozzle for the abrasive particle density is zero. If the density of abrasive particles is gradually increased exit velocity will go on decreasing for the same pressure condition. It is due to fact that Kinetic energy of gas is utilized for transporting the abrasive particle.

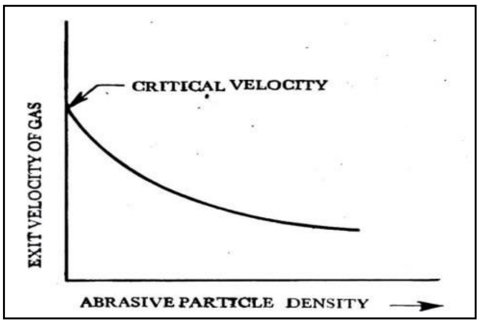

Fig 6. Effect of Critical velocity & Abrasive particles density

3) *Effect of mixing ratio on MRR*

The increased mass flow rate of abrasive will result in a decreased velocity of the fluid and will thereby decrease the available energy for erosion and ultimately the MRR. It is convenient to explain to this fact by term "Mixing Ratio".

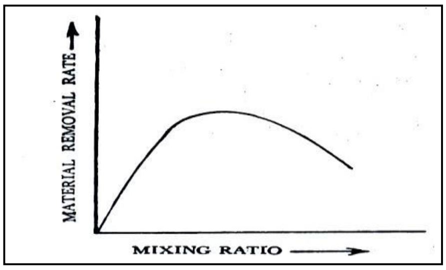

Fig 7 . Effect of mixing ratio in MRR

4) Effect of Nozzle Pressure on MRR

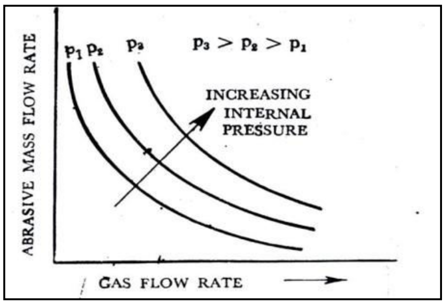

Fig 8. nozzle pressure vs. MRR

The abrasive flow rate can be increased by increasing the flow rate of the carrier gas. This is only possible by increasing the internal gas pressure as shown in the figure. As the internal gas pressure increases abrasive mass flow rate increase and thus MRR increases.

As a matter of fact, the material removal rate will increase with the increase in gas pressure Kinetic energy of the abrasive particles is responsible for the removal of material by erosion process. The abrasive must impinge on the work surface with minimum velocity for machining glass by SIC particle is found to be around 150m/s.

5) Effect of Standoff distance

Standoff distance is defined as the distance between the face of the nozzle and the work surface of the workpiece.SOD has been found to have a considerable effect on the work material and accuracy. A large SOD results in flaring of the jet which leads to poor accuracy.

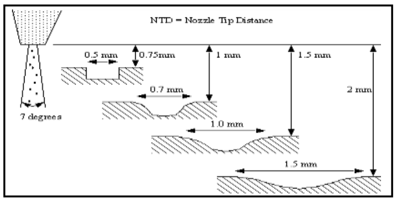

Fig 9. NTD variation

Conclusion

- ✓ For Higher precision work higher pressure and lower standoff distance are adopted to attain a higher accuracy and penetration rate for AJM.
- ✓ The Higher standoff distance is preferable where material removal is prime importance.
- ✓ MRR increase with an increase in abrasive jet flow rate, mixing ratio, internal pressure, standoff distance under certain condition.

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