

Modelling and fabrication of Abrasive Jet Machine

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Abstract - With the development of technology, more and more challenging problems faced by the scientists and technologists in the field of manufacturing. The many new materials and alloys that have been developed for specific uses possess a very low machinability. Producing complicated geometries in such materials becomes extremely difficult with the usual methods. To tackle such difficult jobs two approaches are possible, viz., (i) a modification of the traditional processes and (ii) the development of new processes. This paper presents the modelling of Abrasive Jet Machine. The individual parts are fabricated and assembled in the workshop.

Key Words: AJM, Modelling, Fabrication, Catia, Assembly, Small Scale Industry.

1. INTRODUCTION

Abrasive Jet machining is nontraditional manufacturing process that can make complex shapes on the surface of the hard and brittle material. It is a process of material removal through the action of a focused stream of fluid with abrasive particles. It is especially used for machining super alloys, ceramics, glass and refractory materials. Here, the material removals are mainly due to the impingement of the fine abrasive particles on the work surface. The metal cutting occurs due to erosion caused by the abrasive particles impacting the work surface at a high speed. As a result of repeated impact, small bits of material get loosened and separated from the workpiece surface, exposing a fresh surface to the jet. The AJM is different from conventional sand blasting as the latter is a surface cleaning process and AJM is a metal cutting process. The process is used mainly to cut complex shapes in hard and brittle materials which are heat sensitive and have a tendency to chip easily. AJM is also used for removing burrs and cleaning operations. AJM is free from vibration and chatter problems. As the carrier gas itself serves as a coolant, the cutting action is cool [1].

1.1 Concept of AJM

A schematic layout of AJM is shown in Figure 1.1 In AJM air is compressed in an air compressor at a pressure 5 bar, which is used as carrier gas. Gases, like CO₂, N₂, etc., which may be directly issued from a cylinder can also be used as carrier gas. The carrier gas first passes through a pressure regulator

to obtain the required working pressure. The gas is then passed through an air filter regulator to remove any residual water vapour. To remove any oil vapour or particulate contaminant the same is passed through a series of filters. After that carrier gas enters a closed chamber known as the mixing chamber. The abrasive particles enter the chamber from a hopper through a metallic sieve. The sieve is constantly vibrated by an electromagnetic shaker. The mass flow rate of abrasive (16 gm/min) entering the chamber depends on the frequency and amplitude of vibration of the sieve. The abrasive particles are then carried by the carrier gas to the machining chamber via an electromagnetic on-off valve. The machining chamber is essential to contain the machined particles and abrasives in a safe and eco-friendly manner. The machining is carried out at high velocity (200-300 m/s) abrasive particles are issued from the nozzle onto a work surface traversing under the jet.

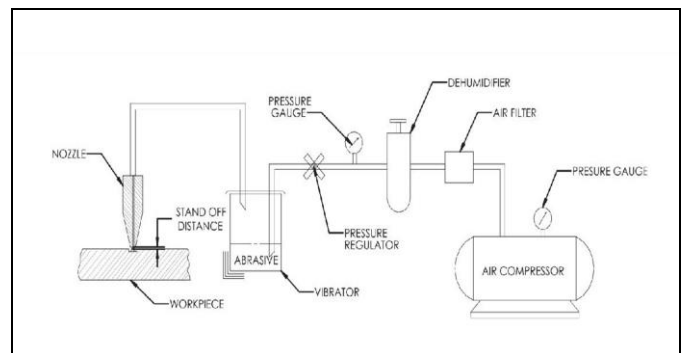


Fig -1: Schematic Layout of AJM

The components are: -

1. Air compressor
2. Air filter
3. Dehumidifier
4. Pressure gauge
5. Mixing chamber
6. Pressure regulator
7. Nozzle
8. Machining chamber
9. Vibrator
10. Work holding device

1.2 Advantages of AJM

- It is able to cut brittle, fragile or glass and heat sensitive material without damage.
- It is able to cut intricate shape or complex profile in hard or brittle materials.
- As the machining action is cool, so in this process, no heat is generated.
- No tool change required.
- High-quality surface finish.
- The surface of the work piece is cleaned automatically.
- Capital cost is low.

1.3 Disadvantages of AJM

- Very low material removal rate. Hence the application of AJM is limited.
- The process produces a taper cut always.
- In certain substances, abrasive particles might settle over the work piece.
- Nozzle life is less.
- It can't be used machining soft materials.
- It can't be used to drill blind holes.

1.4 Applications of AJM

- Used in cutting slots, thin sections, contouring, drilling.
- It can be also used for etching and deburring process.
- It is sometimes used for cleaning and polishing of Teflon and plastics components.
- It is used for paint removal.
- It is used mainly in textile and leather industries.
- It is used in nuclear plant dismantling.

2. Literature review

R. Balasubramaniam et al. [2] investigated the abrasive jet deburring process parameters and the edge quality of Abrasive Jet deburred components. Experimental design based on Taguchi Orthogonal array was used to systematically measure the influence of the major cutting parameters on abrasive jet deburred specimens. The experimental specimens used were 1.5mm thick, 25mm square grade AISI304 stainless-steel sheets. Burrs were generated by the face milling operations. ANOVA method was used for the visual inspection of edge quality. It was found that the deburring process is significantly affected by 'height of the jet' and 'impingement angle'. It was concluded that Abrasive Jet deburring process advantageous than manual deburring process. The quality of deburred component mainly increases by the generation of edge radius.

Y. Yamauchi et al. [3] investigated the effect of work piece properties on machinability in abrasive jet machining of ceramic materials. Three kinds of common abrasives viz. Aluminium Oxide, Silicon Carbide, and synthetic diamond were employed for conducting the experiment. The target materials used were four kinds of ceramics viz. ZrO₂, Si₃N₄, Al₂O₃, SiC. A laser scanning microscope was used to measure the volume that was removed by abrasive jet machining. The machinability of the AJM process was compared with the established models of solid particle erosion, in which the material removal is assumed to originate in the ideal crack formation system. Further, it was found that the AJM test results did not depend on the erosion models, because the relative hardness of the abrasive against the target material, which has not taken into account in the models, is critical in the machining process. It was also concluded that AJM process had high potential micro-machining method as damage free for many materials because the radial cracks did not extend downwards by the impact of the particle during the machining process.

S. Ally et al. [4] used surface evolved models to predict Abrasive jet machining of metallic substrates. The abrasive jet inclination angle of erosion rate was measured. The material is Aluminum 6061-T6, Ti-6Al-4V Titanium alloy and 316L stainless steel. The jet inclination angle was measured using 50 micrometers Al₂O₃ abrasive powder launched at an average velocity of 110m/s. The peak erosion rate was found to occur 200 to 350 relative to the surface for all three systems. It was found that Aluminum has a high volumetric erosion rate than Titanium alloy which is higher than the stainless steel erosion rate on a volumetric basis, which in turn is significantly lower than a brittle material such as glass and polymers. It was also found that where a high degree of control etches is desired; AJM of metals is best suited for etching of relatively shallow features. It was concluded that scanning electron micrograph and EDX analysis of the eroded surface of 316L stainless give a significant amount of particle adhering with a less amount in the Titanium alloy.

N. S. Pawar et al. [5] investigated abrasive material sea sand in vibrating chamber. The tungsten carbide nozzle was used in the abrasive jet micro machining process. The sand of 100-150 micron was used for the experiment. The work piece used was a glass of thickness 4 mm. The evaluated performances were material removal rate and flow rate. It was found that the impact through nozzle caused severe erosion on the material work piece. It was demonstrated that the erosion of material surface depended on velocity, direction and brittleness of the material. The experiment was performed by using the combination of two different parameters viz. Standoff distance and pressure. From the result, it was concluded that material removal rate and flow rate were similar to actually abrasive used like aluminum oxide, silicon carbide, etc. It was noticed that by increasing feed rate width of the cut was also increased. It was also found that at greater stand-off distance and feed rate, taper cut was found to be a higher slot.

Rajkamal Shukla and Dinesh Singh [6] used Taguchi method for experimental investigation of abrasive water jet machining parameters. The material used is AA6351 aluminum alloy. Parameters such as transverse speed, stand off distance and mass flow rate are considered to obtain the influence of these parameters on kerf top width and taper angle. Regression models have been developed to correlate the data generated using experimental results. The percentage contribution of standoff distance in kerf top width and taper angle is found to be 77.642% and 81.774% respectively.

A. Ghobeity et al. [7] predicted models of abrasive jet micro machining for masked and unmasked borosilicate glass channels by using 25 micro meter aluminum oxide. A novel technique is used for the velocity distribution of the particles in the jet of an abrasive jet micro machining. It was found that the velocity decreased linearly from the centre line of the jet to the periphery, Weibull distribution followed by the probability of a particle arriving at the surface a given radial distance from the centre of the impacting jet. To predict the cross sectional profile of unmasked channels this Weibull distribution was used with an extension of the already existing model. Time-dependent particle mass flux and velocity distribution were used for modeling of the effect of the nozzle. Further, it was demonstrated that the distribution of net erosive power over the cross section passing through the round nozzle had the same form as the distribution along the diameter of the stationary nozzle. By measuring the particle velocity across the cross section of the jet, it was found that the velocity decreased linearly from the centre to the periphery. It was concluded that by reducing the incident particle energy flux caused by mask edge scattering the prediction of masked channel profiles is affected.

Manabu Wakuda et al. [8] investigated the material response of alumina ceramics to the abrasive particle impact in the AJM process. Three types of abrasive grains, viz. Aluminum Oxide, Silicon Carbide and Synthetic diamond were used for the impact on alumina ceramics. AJM equipment with Micro-Blaster (MB2-ML-001, Sintoblator, Japan) was used which is capable of shooting fine abrasives along with a pressurized nitrogen gas stream through a small jet nozzle. It was found that the softest abrasive aluminum Oxide leads to roughening of the alumina surface, but causes no mark, due to the lack of the hardness of the abrasive against that of the work piece. It was also found that by employing Silicon Carbide, a relatively smooth face could be produced as a result of ductile behaviour under the elevated temperature caused by the abrasive impacts. By the impingement of Synthetic Diamond abrasive, a large-scale fragmentation was observed and therefore the surface became rough.

Dong-Sam Park et al. [9] improved micro-machining using the machining ceramics, semiconductors, electronic devices and LCD. For micro grooving of glass, he checked the performance of micro-AJM. Process parameters for micro-

AJM were pressure, velocity and time, stand-off distance, material properties number of nozzle scanning times. Micro-grooving consisted of masking process, abrasive jet machining process and a mask removing and cleaning process. White Alundum was used for machining whose main ingredients were Al₂O₃. The results showed that when the heat amount was 160mJ at 1050°C, then the masking results were considerable and otherwise were poor. In the same way, grooving results showed that when the heat amount was 150mJ the hole type was not well generated, but when the amount was 160mJ the machined grooves were in generally in good condition.

3. Modelling of AJM

The whole 3D modelling was done in CATIA. Following articles cover the modelling of different components of AJM.

3.1 Mixing Chamber

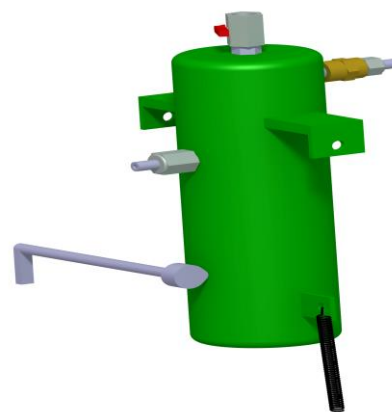


Fig -2: 3D Model of Mixing Chamber

3.2 Nozzle

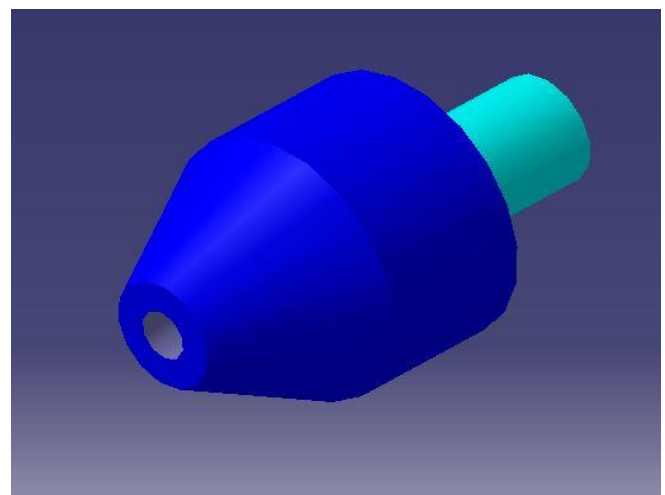


Fig -3: 3D Model of Nozzle

3.3 Assembly for X-Y Movement of Nozzle

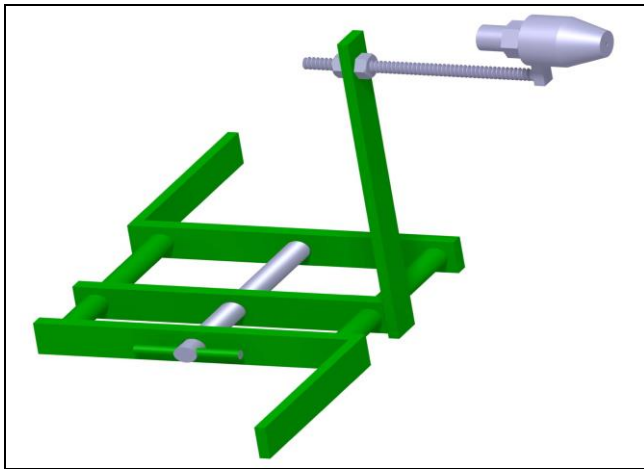


Fig -4: 3D Model of Nozzle Stand Assembly

3.4 Machining Chamber

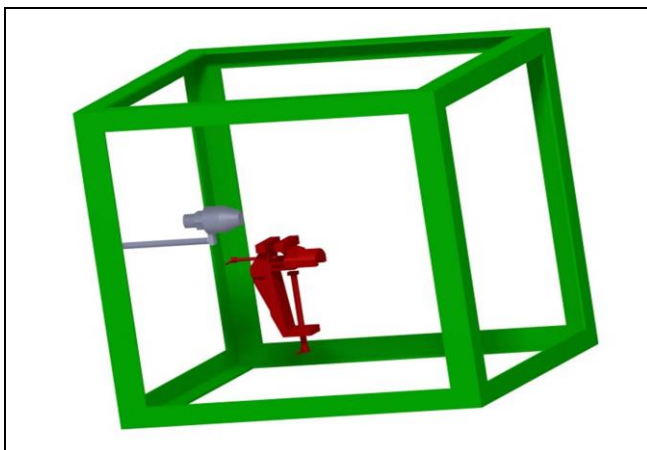


Fig -5: 3D Model of Machining Chamber

3.5 Complete Assembly

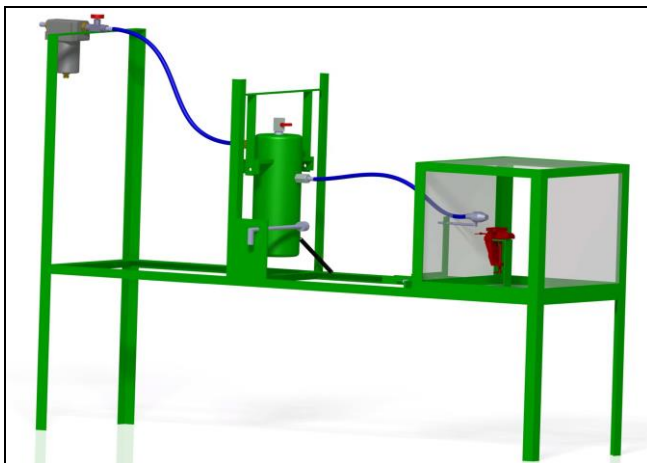


Fig -6: 3D model of AJM

4. Fabrication of AJM

The systems were developed as per modelling and then assembled.

4.1 Mixing Chamber

The designing of the mixing chamber was done specially for proper mixing of the compressed air and abrasives. For this purpose, we used a seamless mild steel pipe and joined a circular plate, both at top and bottom ends. Three holes were drilled on the structure, the first at the top; the other two were on the surface. The top hole was used to pass on the abrasives into the chamber. From the two holes on the surface, one was used to pass the compressed air from the dehumidifier and the other brought out the mixture of compressed air with abrasive to the nozzle.



Fig -7: Actual view of mixing chamber

4.2 Nozzle

The nozzle was used for the general purpose of increasing the velocity of the mixture of compressed air and abrasives. Owing to this purpose it was tapered in shape. The nozzle was prepared from a cylindrical block which underwent plain turning in the beginning. The nozzle was then tapered for the required use. Inside tapering was done using different drill bits in continuation. The nozzle was fabricated using EDM. The material used was D-2 steel.



Fig -8: Actual view of nozzle

4.3 Assembly for X-Y Movement of Nozzle

The nozzle was connected to a nut and bolt assembly. The assembly consisted of two nuts one of which was fixed while the other was moving. While rotating the moving nut by 360° the nozzle moved a distance of 1 pitch which equals to 1.5mm in the X direction.

In Y direction, the end of the nut was attached to a working table which also consisted of a nut for the movement of the nozzle. The purpose for moving the nozzle in Y direction was to make a slot in the work piece.



Fig -9: 3D Model of Complete Assembly

4.4 Machining Chamber

It was cubical in shape. It was basically made up of glass structure. The entire structure was closed so as to prevent the abrasives from spreading around. It housed the nozzle assembly and the bench vice. The bench vice was used for holding the work piece. The used abrasives were removed by opening the bottom glass of the working chamber. One of the side glass was closed in such a way that it can be removed by removing the threaded bolt. It was done so to load and unload the work- piece.

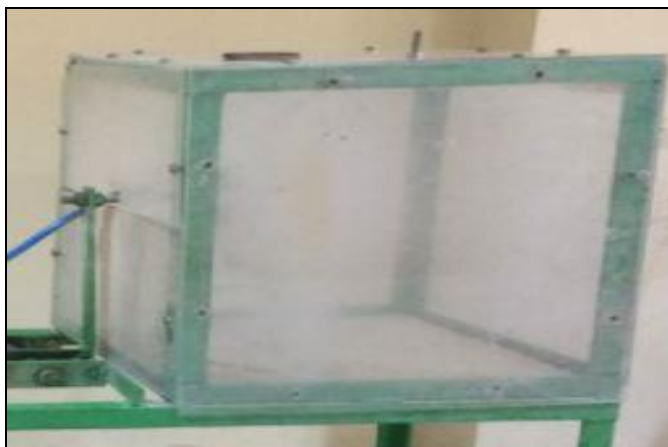


Fig -10: Actual view of machining chamber

4.5 Complete Assembly

After fabricating different components of abrasive jet machining, a frame like structure was designed and fabricated which supports all the major components of abrasive jet machining. The figure shows the assembly design of abrasive jet machining. All the above components, including dehumidifier, carrier gas supply line and pressure gauge were mounted on the frame, which gives the overall experimental setup.

The material used for manufacturing the above frame is mild steel. The carrier gas supply pipe is made up of pneumatic material which has high strength. The purpose of using pneumatic material instead of general pipe was to prevent the pipe from being eroded due to the flow of abrasive grit under high pressure.



Fig -11: Actual view of AJM

5. Result and conclusion

In AJM, a focused jet or stream of abrasive particles carried by high-pressure gas (carrier) is made to impinge on the work surface through a nozzle. The metal cutting occurs due to erosion caused by the abrasive particles impacting the work surface at high speed. As a result of the impact, small bits of materials get loosened and separated from the workpiece surface, exposing a fresh surface to the jet. This process is capable of cutting intricate holes and shapes in materials of any hardness and brittleness.

Some of the remarks on the present work:

- Each part is modelled in CATIA software.
- Each part is fabricated in the workshop.
- Each part is assembled to make a complete AJM setup.

6. Future Scope

- Manual nut assembly has been used to vary the nozzle tip distance. This process can be done automatically.
- For shaking of the mixing chamber, we have used handle manually. This can be done automatically by using a motor.

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