CHAPTER 1

Abrasive Jet Machining

ABSTRACT

Abrasive jet machining (AJM) is a process used for cutting of hard and brittle materials such as germanium, silicon, glass, ceramics, and mica. In this process, a jet of air and abrasives travels at a very high velocity strikes the workpiece surface, and the material is removed due to brittle fracture. In this chapter, the working principle of AJM is explained which is followed by the description of the machining setup used in the process. Different process parameters and their influence on the process performance are discussed. In the last part of this chapter, the process capabilities and the associated advantages as well as disadvantages are presented.

1.1 INTRODUCTION

In AJM, a high-velocity jet containing abrasive particles is aimed at the workpiece surface under controlled conditions. The abrasive jet at a high velocity strikes the workpiece surface and the material is removed by impact erosion. The impact of the particles develops a sufficiently concentrated force to perform operations such as cutting, the material is removed by the erosion of work material with abrasive grits at a speed of 150–300 m/s. The abrasive grits are carried out in a high-velocity gas stream.

1.2 WORKING PRINCIPLE

In AJM, air is compressed in an air compressor and compressed air at a pressure of around 5 bar is used as the carrier gas. Gases like CO_2, N_2 can also be used. Generally oxygen is not used as a carrier gas. Carrier gas is first passed through a pressure regulator to obtain the desired working pressure. Gas is then passed through an air dryer to remove any residual water vapour. To remove any oil vapour or particulate contaminant, the same is passed through a series of filters. Then the carrier gas enters a closed chamber known as the mixing chamber. Abrasive particles enter the chamber from a hopper through a metallic sieve. Sieve is constantly vibrated by an electromagnetic shaker. The abrasive particles are then carried by the carrier gas to the machining chamber via an electromagnetic on-off valve. The machining is carried out as high velocity (300 m/s) abrasive particles coming out from the nozzle impact on to a workpiece.

1.3 DESCRIPTION OF AJM SETUP

The AJM setup consists of gas propulsion system, abrasive feeder, machining chamber, AJM nozzle, and abrasives. A schematic of the machining setup is shown in Fig. 1.1.

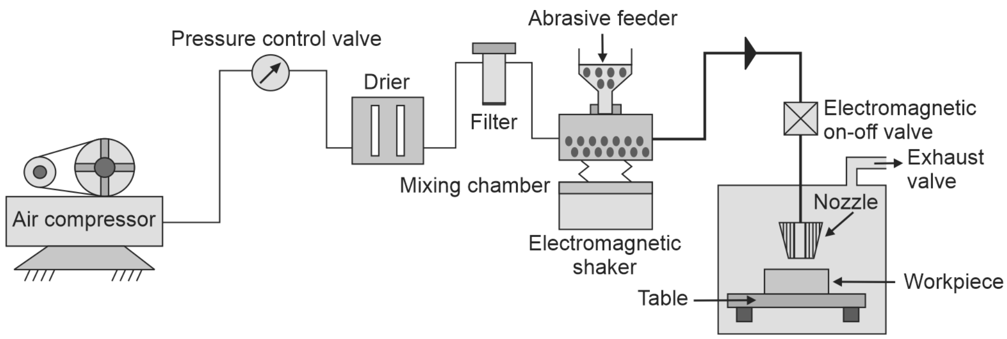

Fig. 1.1: Schematic showing the construction of AJM setup (Jain VK 2008)

1.3.1 Gas Propulsion System

It supplies clean and dry air for machining. Air, nitrogen, and carbon dioxide can be used to propel the abrasive particles. Gas may be supplied either from a compressor or a cylinder. In case a compressor is used, air filter cum drier should be used to avoid water or oil contamination of abrasives. The supplied gas must be non-toxic, cheap, and easily available and should not spread excessively when it is discharged from the nozzle into the atmosphere.

1.3.2 Abrasive Feeder

Abrasive feeder supplies the required quantity of abrasive particles for the jet. Filleted propellant is fed into the mixing chamber and the abrasive particles are fed through a sieve. Particles are propelled by carrier gas to a mixing chamber and air-abrasive mixture moves further to the nozzle. Nozzle imparts high velocity to the mixture before directing it at the workpiece surface.

1.3.3 Machining Chamber

Machining chamber is a closed region around the working chamber, equipped with the vacuum dust collector, used to contain the air-abrasives mixture within it. The dust collection system becomes very important when machining toxic materials such as beryllium.

1.3.4 AJM Nozzle

An AJM nozzle is usually made of either tungsten carbide or sapphire. It is one of the most vital elements controlling the process characteristics. An average life of a nozzle is around 30 hours for tungsten carbide and around 300 hours for sapphire. The cross-section of a nozzle can be either rectangular or circular in shape. It is designed such that the loss of pressure due to the bends and friction is minimum. As the wear of a nozzle increases, the divergence of jet stream increases which results in stray cutting and inhomogeneity in the kerf width. Nozzle diameter usually varies between 0.2 to 1 mm.

1.3.5 Abrasives

In AJM, the selection of abrasives depends upon the required material removal rate, type of workpiece material to be machined, and the machining accuracy. The type of abrasive used also depends upon the application. Aluminium oxide is used cleaning, cutting and deburring operations. Silicon carbide is also used for similar applications as those of aluminium oxide, but, for harder materials. Glass beads are used to obtain a matted finish on the workpiece surface. Dolomite is commonly used for the purpose of etching and polishing. $NaHCO_3$ is used for the cutting of soft materials. Grain size of abrasive particles generally varies from 12 μ to 50 μ. It is upto 1 mm for glass beads.

1.4 PARAMETRIC ANALYSIS

Volumetric material removal rate (MRR_V) in AJM is affected predominantly by the three parameters, namely: stand-off distance (the distance between nozzle tip and workpiece surface), abrasive flow rate, nozzle pressure, and mixing ratio. The effects of these parameters on the performance of AJM are discussed as follows:

- *Stand-off distance:* It is also known as the nozzle tip distance (NTD) and has an influence on the MRR_V and the shape and size of the machined cavity. As this distance increases, the velocity of abrasive particles impinging on the work surface increases because of their acceleration after leaving the nozzle and results in an increase in MRR_V. As this distance increases further, the velocity reduces due to the drag of atmosphere which stops the increment of MRR_V and further leads to its decrement. A decrease in NTD improves accuracy, decreases kerf width, and reduces taper in the machined groove (Fig. 1.2). For operations such as cleaning and frosting, NTD is kept large (in the range of 12.5 to 75 mm).

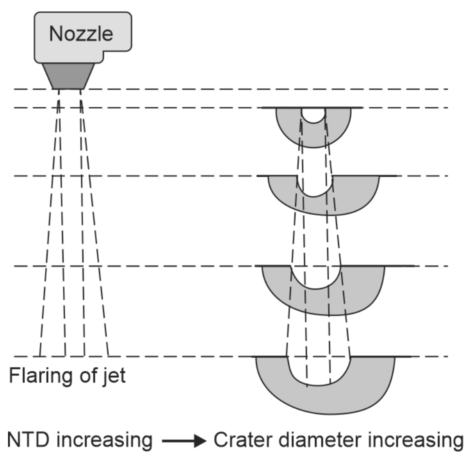

Fig. 1.2: Schematic showing the influence of NTD on the shape and dimension of the machined crater (Ghosh and Mallik, 2010)

- *Abrasive flow rate:* With an increase in the value of abrasive flow rate, the MRR_V increases upto a certain value and then starts decreasing. With an initial increase in the value of abrasive flow rate, the number of particles hitting the workpiece increases, thereby, increasing the MRR_V (Fig. 1.3). However, as the flow rate increases further, the velocity of abrasive particles decreases and this reduces the MRR_V.

- *Nozzle pressure:* It is observed that with an increase in nozzle pressure, the MRR_V increases. As the kinetic energy of the abrasive particles is responsible for the removal of material by erosion, the abrasives must impinge on the workpiece surface with a certain minimum velocity such that the material removal can take place.
- *Mixing ratio:* It is defined as the ratio of the volume flow rate of the abrasive particles and the volume flow rate of carrier gas. MRR_V is observed to increase with an increase in the value of mixing ratio. However, as this ratio increases beyond a certain limit, the jet velocity decreases. This results in a decrease in the value of MRR_V and may further lead to blockage in the nozzle.

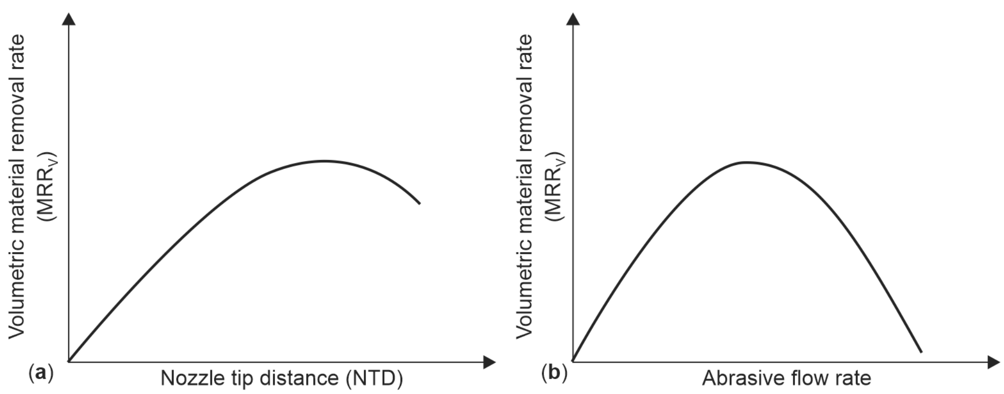

Fig. 1.3: Graph showing the variation of volumetric material removal rate with (a) nozzle tip distance and (b) abrasive flow rate (Verma and Lal, 1984)

1.5 PROCESS CAPABILITIES AND APPLICATIONS

AJM process is suitable for producing intricate details in hard and brittle materials. Kerfs with width in the range of 0.12 mm to 0.25 mm can be easily machined with reasonably low tolerance (± 0.2 mm) (Balasubramaniam *et al* 2002). Surfaces with roughness value in the range of 0.25 µm and 1.25 µm can be obtained with sharp corners on the machined edge.

This process is commonly used for abrading and frosting glass more economically as compared to etching or grinding. AJM also finds application in manufacturing is useful in 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, deflashing small castings and engraving registration numbers on toughened glass used for car windows. AJM is also suitable for deburring small hole like that found in hypodermic needles and for small milled slots in hard metallic components.

1.6 ADVANTAGES AND DISADVANTAGES

The advantages and disadvantages of AJM are as follows (Melentiev and Fang, 2018):

- **Advantages**
  1. High surface finish can be obtained depending upon the grain size.
  2. It provides cool cutting action, so it can machine delicate and heat sensitive material.

3. Process is free from chatter and vibration as there is no contact between the tool and workpiece.
4. Capital cost is low and it is easy to operate and maintain.
5. Thin sections of hard brittle materials like germanium, mica, silicon, glass and ceramics can be machined.
6. It has the capability of cutting holes of intricate shape in hard materials.

- **Disadvantages**

1. Material removal rate is relatively low.
2. When machining soft materials using AJM, abrasive may get embedded into it.
3. Machining accuracy of the process gets hampered by the flaring of abrasive jet.
4. Abrasive powder cannot be reused as the sharp edges of the particles gets worn out after their first use.
5. Small NTD, necessary for achieving high accuracy, often damages the nozzle.
6. Life of the nozzle is limited (around 300 hours for the nozzle made of sapphire).

SUMMARY

In AJM, the mechanism of material removal is brittle fracture of workpiece material by the impingement of abrasive particles at a high velocity. The velocity of abrasive jet ranges between 150–300 m/s and jet pressure ranges between 2–10 atm. Nozzles of tungsten carbide and sapphire are generally used in this process. This process is most suited for the machining of hard and brittle materials such as germanium, silicon, glass, ceramics, and mica. AJM is commonly used for operations such as drilling, cutting, deburring, etching, and cleaning. Stand-off distance, abrasive flow rate, nozzle pressure, and the mixing ratio are the most important parameters in the process which directly influences the material removal rate.

Acronyms

AJM	Abrasive jet machining
MRR	Material removal rate
NTD	Nozzle tip distance

PRACTICE QUESTIONS

1. **Draw a schematic of AJM system and label its components.**
2. **In AJM, what will be the effect of increasing the mass flow rate of abrasive particles on mixing ratio?**
3. **In AJM, what will be the effect of decreasing the NTD on material removal rate?**
4. **Discuss the effect of carrier gas pressure on the material removal rate and nozzle life in AJM.**
5. **What are the different important process parameters in AJM process? Discuss them in brief.**
6. **Write the applications of different types of abrasive used in AJM process.**
7. **Discuss the role of gas propulsion system in AJM process.**

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