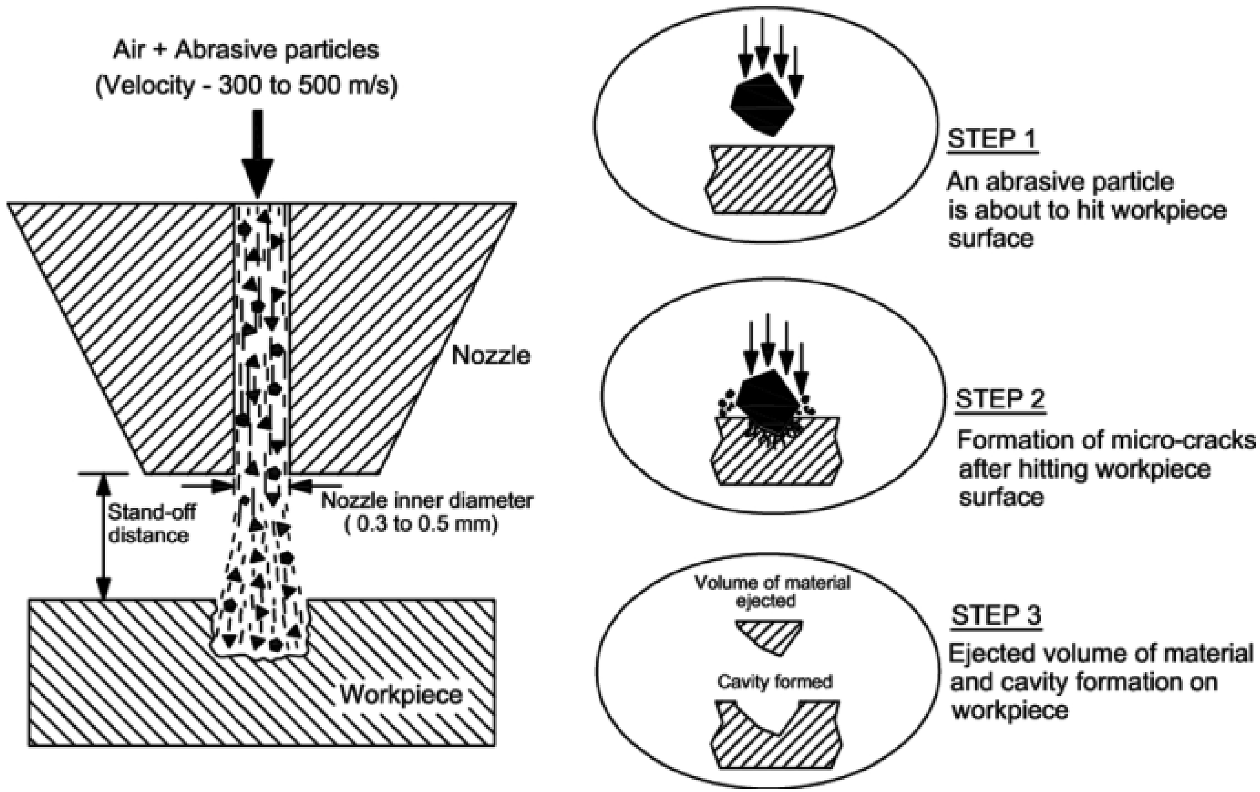
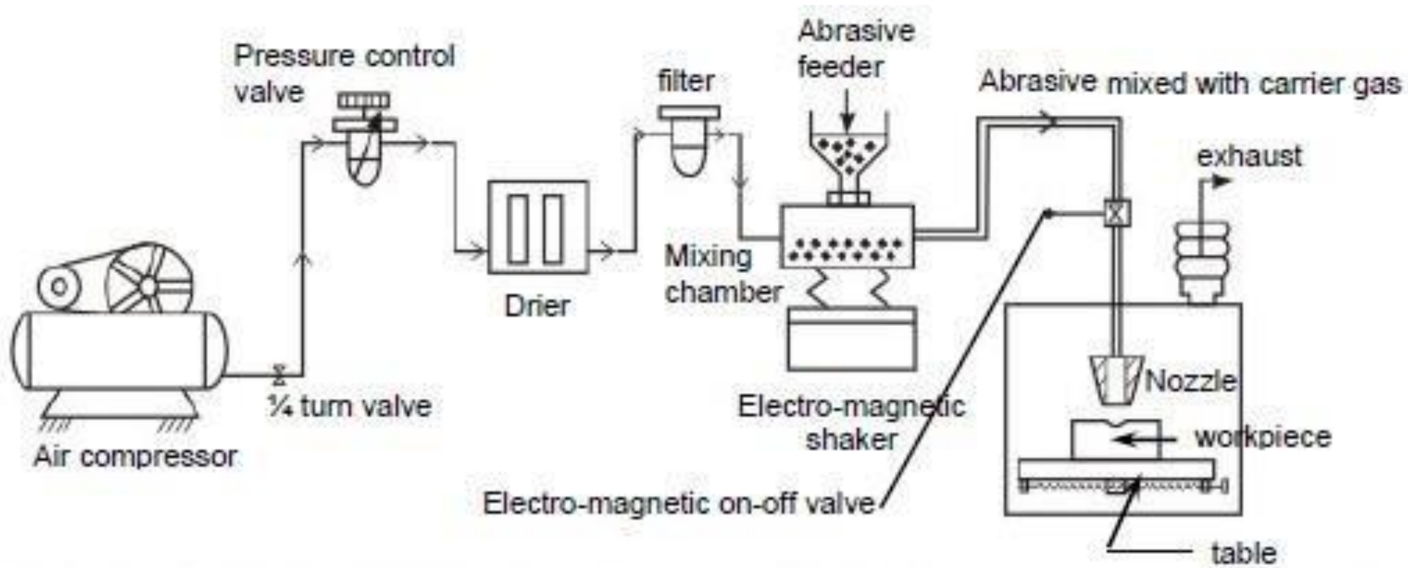
Abrasive Jet Machining

- The nozzle directs the abrasive jet in a controlled manner onto the work material, so that the distance between the nozzle and the work piece and the impingement angle can be set as desired.
- The high velocity abrasive particles remove the material by micro-cutting action as well as brittle fracture of the work material.



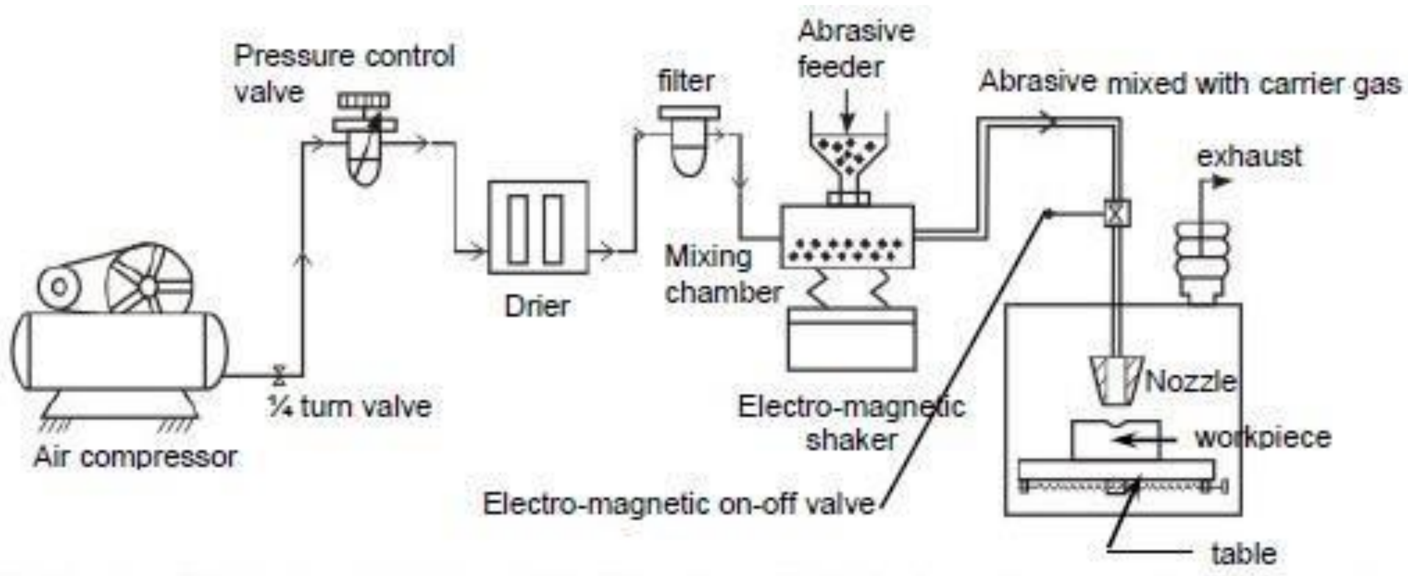
Abrasive Jet Machining

- In AJM, air is compressed in an air compressor and compressed air at a pressure of around 5 bar.
- Gases like CO_2, N_2 can also be used as carrier gas which may directly be issued from a gas cylinder. Generally oxygen is not used as a carrier gas
- The gas is 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.



Abrasive Jet Machining

- Then the 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 abrasive particles are then carried by the carrier gas to the machining chamber via an electro-magnetic on-off valve.
- The machining enclosure is essential to contain the abrasive and machined particles in a safe and eco-friendly manner.



NOZZEL

Nozzle

- Material – WC / sapphire
- Diameter – (Internal) 0.2 ~ 0.8 mm
- Life – 10 ~ 300 hours

ABRASIVES

Abrasive

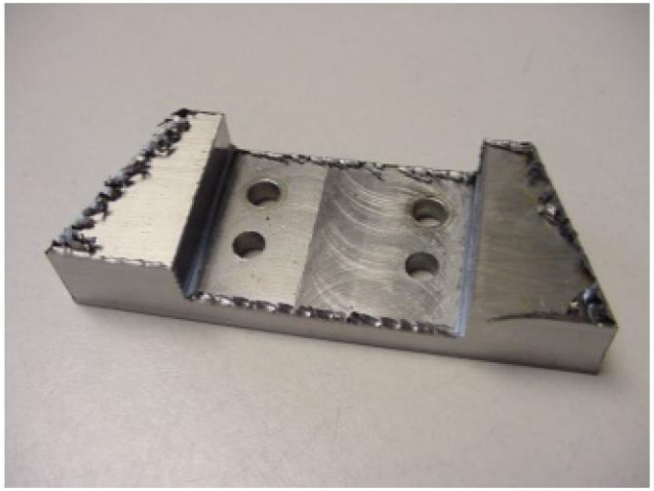
- Material – Al_2O_3 / SiC / glass beads
- Shape – irregular / spherical
- Size – 10 ~ 50 μm
- Mass flow rate – 2 ~ 20 gm/min

ABRASIVE MEDIA/ CARRIER GAS

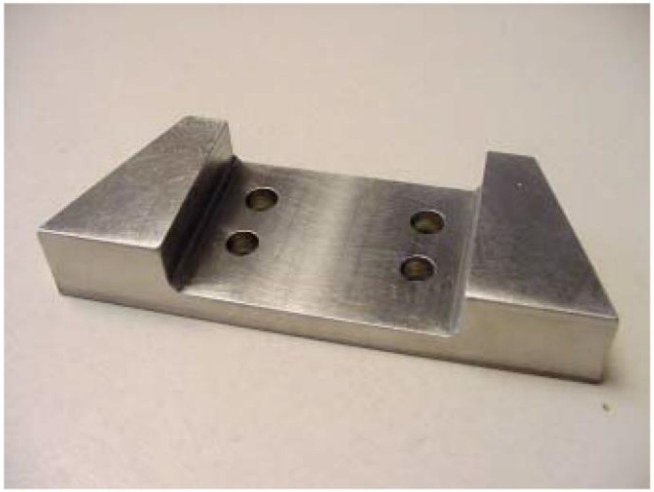
- Composition – Air, CO_2, N_2
- Density – Air ~ 1.3 kg/m^3
- Velocity – 500 ~ 700 m/s
- Pressure – 2 ~ 10 bar
- Flow rate – 5 ~ 30 lpm

APPLICATIONS

- For drilling holes of intricate shapes in hard and brittle materials
- For machining fragile, brittle and heat sensitive materials
- AJM can be used for drilling, cutting, deburring, cleaning and etching.
- Micro-machining of brittle materials



(a) Before deburring



(b) After deburring

DISADVANTAGES

- MRR is rather low (around ~ 15 mm3/min for machining glass)
- Abrasive particles tend to get embedded, particularly if the work material is ductile
- Tapering occurs due to flaring of the jet
- Environmental load is rather high.

Mathematical Modeling of AJM

- Abrasives are spherical in shape and rigid. The particles are characterized by the mean grit diameter
- The kinetic energy of the abrasives are fully utilized in removing material
- Brittle materials are considered to fail due to brittle fracture and the fracture volume is considered to be hemispherical with diameter equal to chordal length of the indentation
- For ductile material, removal volume is assumed to be equal to the indentation volume due to particulate impact.

Calculation of MRR for AJM

- Interaction of abrasive particles with workpiece

From the geometry of the indentation

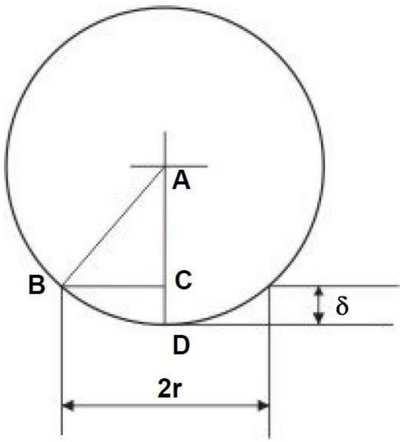
$$AB^2 = AC^2 + BC^2$$

$$BC^2 = r^2 = AB^2 - AC^2$$

$$r^2 = \left(\frac{d_g}{2}\right)^2 - \left\{\frac{d_g}{2} - \delta\right\}^2$$

$$r^2 = -\delta^2 + d_g\delta \cong d_g\delta$$

$$r = \sqrt{d_g\delta}$$



Kinetic energy of a single abrasive particle is given by

$$K.E._g = \frac{1}{2}m_g v^2 = \frac{1}{2}\left\{\frac{\pi}{6}d_g^{\ 3}\rho_g\right\}v^2 = \frac{\pi}{12}d_g^{\ 3}\rho_g v^2$$

where, v = velocity of the abrasive particle
m_g = mass of a single abrasive grit
d_g = diameter of the grit
ρ_g = density of the grit

Calculation of MRR for AJM

- On impact, the work material would be subjected to a maximum force F which would lead to an indentation of ‘δ’. Thus the work done during such indentation is given by

$$W = 0.5F\delta$$

- Now considering H as the hardness or the flow strength of the work material, the impact force (F) can be expressed as:

F = indentation area x hardness

$$\therefore W = \frac{1}{2}F\delta = \frac{1}{2}\pi r^2 H \delta$$

- Now, as it is assumed that the K.E. of the abrasive is fully used for material removal, then the work done is equated to the energy

$$W = K.E.$$

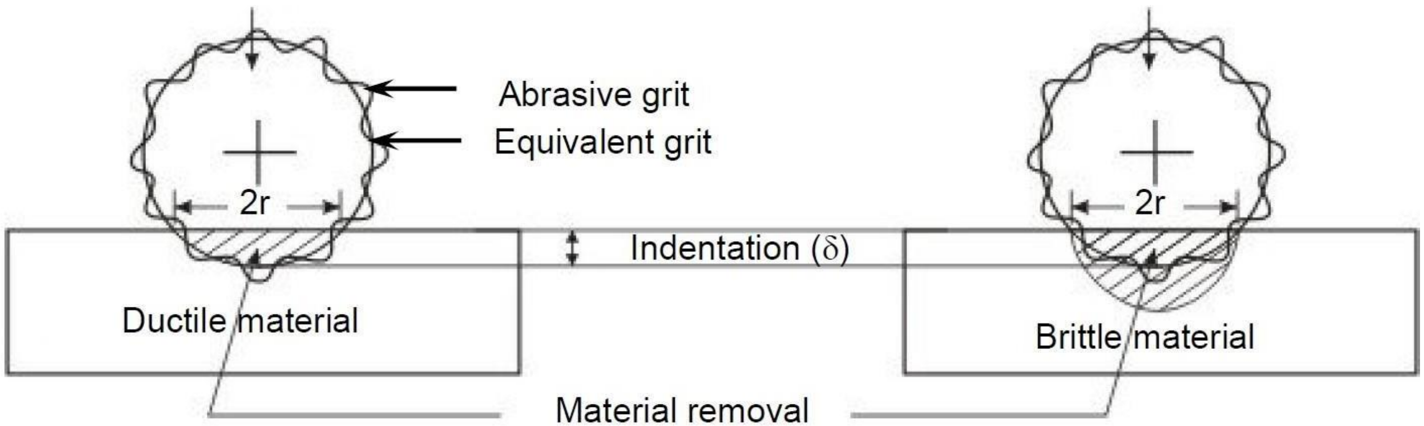
$$\frac{1}{2}\pi r^2 \delta H = \frac{\pi}{12} d_g^3 \rho_g v^2$$

$$\delta = \frac{d_g^3 \rho_g v^2}{6r^2 H} \qquad now\ r = \sqrt{d_g \delta} \quad \Rightarrow r^2 = d_g \delta$$

$$\delta^2 = \frac{d_g^2 \rho_g v^2}{6H}$$

$$\boxed{\delta = d_g v \left(\frac{\rho_g}{6H}\right)^{1/2}}$$

Calculation of MRR for AJM



- Volume of material removal in brittle material is the volume of the hemispherical impact crater and is given by:

$$\Gamma_B = \frac{2}{3}\pi r^3 = \frac{2\pi}{3}(d_g\delta)^{3/2}$$

- For ductile material, volume of material removal in single impact is equal to the volume of the indentation and is expressed as:

$$\Gamma_D = \pi\delta^2\left[\frac{d_g}{2} - \frac{\delta}{3}\right] = \frac{\pi\delta^2 d_g}{2}$$

Calculation of MRR for AJM

- **Now MRR in AJM of brittle materials can be expressed as:**

$$MRR_B = \Gamma_B x \text{ Number of impacts by abrasive grits per second } = \Gamma_B N$$

$$MRR_B = \Gamma_B \frac{m_a}{\text{mass of a grit}} = \frac{\dot{m}_a}{\frac{\pi}{6} d_g^{\ 3} \rho_g} = \frac{6\Gamma_B \dot{m}_a}{\pi d_g^{\ 3} \rho_g} \quad as\ \Gamma_B = \frac{2\pi}{3}(d_g \delta)^{3/2}$$

$$= \frac{6x\frac{2\pi}{3}(d_g \delta)^{3/2} \dot{m}_a}{\pi d_g^{\ 3} \rho_g} = \frac{4\dot{m}_a}{\rho_g}\left(\frac{\delta}{d_g}\right)^{3/2}$$

$$MRR_B = \left(\frac{4\dot{m}_a}{\rho_g}\right)\left(\frac{\delta}{d_g}\right)^{3/2}$$

$$as \quad \delta = d_g v \left(\frac{\rho_g}{6H}\right)^{1/2}$$

$$MRR_B = \frac{4\dot{m}_a}{\rho_g} \cdot \left(\frac{d_g v}{d_g}\right)^{3/2} \left(\frac{\rho_g}{6H}\right)^{3/4}$$

$$\boxed{MRR_B = \frac{4\dot{m}_a v^{3/2}}{6^{3/4} \rho_g^{\ 1/4} H^{3/4}} \approx \frac{\dot{m}_a v^{3/2}}{\rho_g^{\ 1/4} H^{3/4}}}$$

Calculation of MRR for AJM

- **Now MRR in AJM of ductile materials can be expressed as:**

$$\Gamma_D = \frac{\pi\delta^2 d_g}{2}$$ MRR for ductile material can be simplified as:

$$MRR_D = \Gamma_D N = \Gamma_D \frac{6\dot{m}_a}{\pi d_g^{\,3}\rho_g} = \frac{\pi\delta^2 d_g 6\dot{m}_a}{2\pi d_g^{\,3}\rho_g}$$

$$MRR_D = \frac{6\pi\delta^2 \dot{m}_a}{2\pi d_g^{\,2}\rho_g}$$

$$as \quad \delta = d_g v\left(\frac{\rho_g}{6H}\right)^{1/2}$$

$$MRR_D = \frac{6\dot{m}_a d_g^{\,2} v^2}{2 d_g^{\,2}\rho_g}\left(\frac{\rho_g}{6H}\right)$$

$$MRR_D = \frac{1}{2}\frac{\dot{m}_a v^2}{H}$$

Process Parameters and Their Effects