NTM: ABRASIVE WATER JET MACHINING

ME 270 MANUFACTURING TECHNOLOGY

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INSTRUCTIONAL OBJECTIVE

- Identify the characteristics of conventional machining
- Identify the characteristics of non conventional machining
- Differentiate between conventional and non traditional machining
- Classify different non traditional machining process
- Identify the need for non traditional machining processes
- Describe the basic mechanism of material removal in AJM
- Identify major components of AJM equipment

INSTRUCTIONAL OBJECTIVE

- State the working principle of AJM equipment
- Draw schematically the AJM equipment
- Identify the machining characteristics of AJM
- Analyse the effect of process parameters on MRR
- Draw variation in MRR with different process parameters
- Develop mathematical model relating MRR with AJM parameters
- List three applications and limitations of AJM

MANUFACTURING – Classifications

Primary Manufacturing

To impact basic shape and size

- Liquid stage forming processes-casting
- Solid stage forming processes
  - All metal working processes- forging, rolling, extrusion, etc.
- Power stage forming processes- power metallurgy

Secondary Manufacturing

- To impart final shape and size with tight control on dimension and shape
  - Mostly material removal processes

CONVENTIONAL MACHINING PROCESSES (milling, turning, broaching etc.)

- Material removal due to application of cutting forces
- Energy domain- mechanical
- Macroscopic chip
- Chip formation due to shear deformation
- Cutting tool is harder

CLASSIFICATION OF NTM PROCESSES

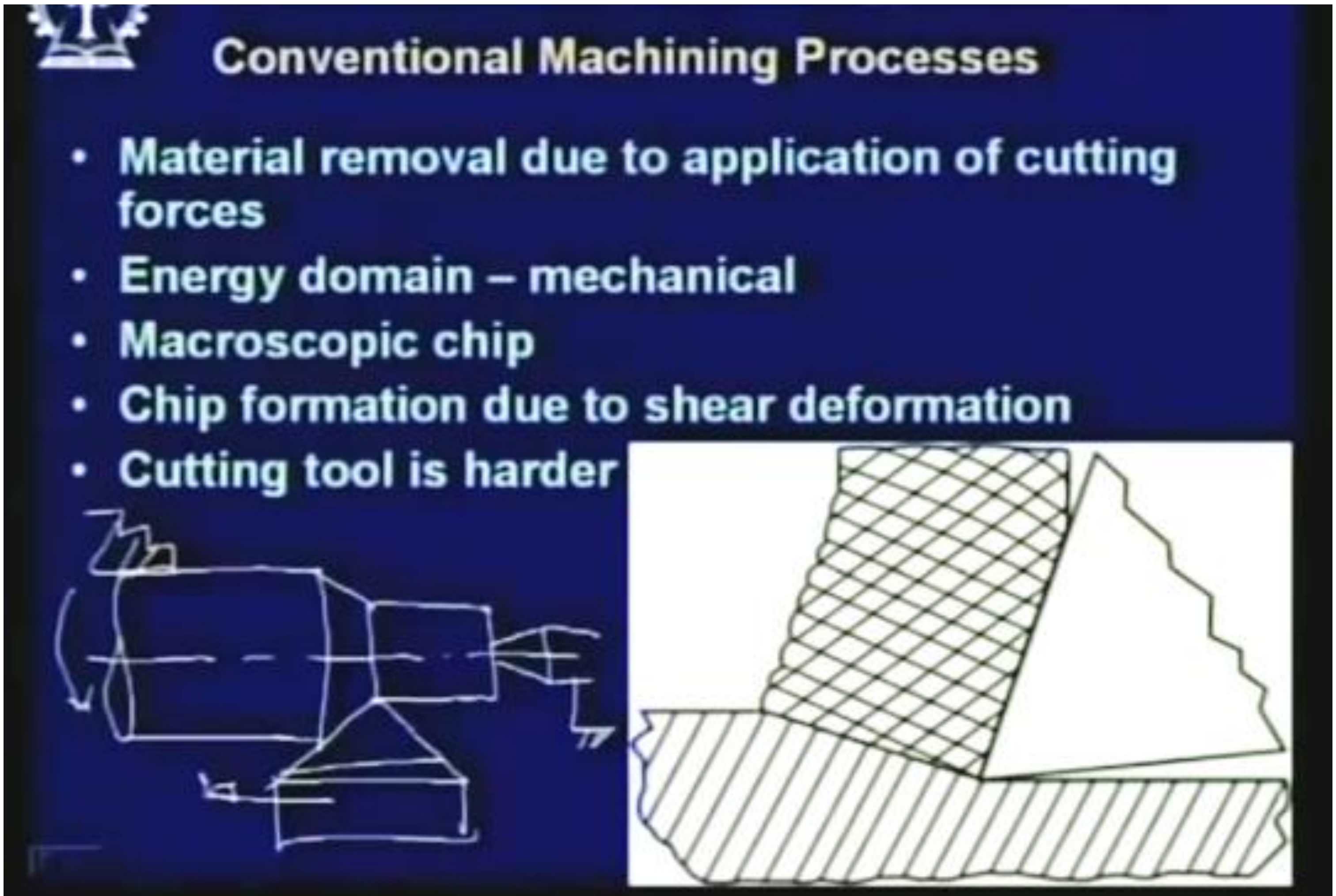
Mechanical Processes

- Abrasive Jet Machining (AJM)
- Ultrasonic Machining (USM)
- Water Jet Machining (WJM)
- Abrasive Water Jet Machining (AWJM)

Electrochemical Processes

- Electrochemical Machining (ECM)
- Electro Chemical Grinding (ECG)
- Electro Jet Drilling (EJD)

Characteristics of conventional machining



Characteristics of NON- TRADITIONAL MACHINING PROCESSES

- Material removal – chip formation or even no chip formation
  - AJM- microscopic size
  - ECM- electrochemical dissolution at atomic level
- Physical tool- may be absent
  - LBM, machining is carried out by laser beam
  - WJM, machining is done by a high pressure water jet
  - EDM, a physical tool is very much required
  - ECM, similarly requires a tool

NON- TRADITIONAL MACHINING PROCESSES

- Tool need not be harder than the work piece

  - EDM, copper is used as the tool material to machine hardened steels

- Energy domain- not necessarily mechanical

  - different energy domains for machining

  - USM,AJM,WJM mechanical energy

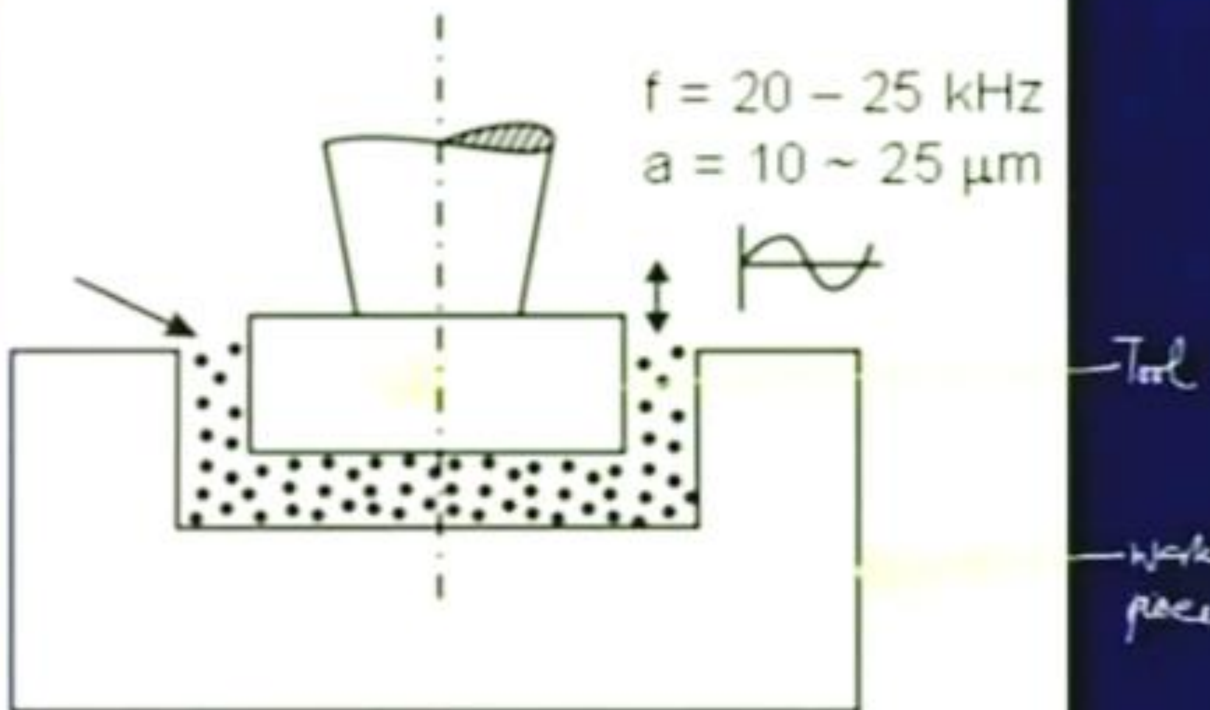
  - EDM, electro-thermal energy

- Electro-thermal
  - EDM
  - EBM
  - LJM

WHY THE NEED FOR NTM PROCESSES

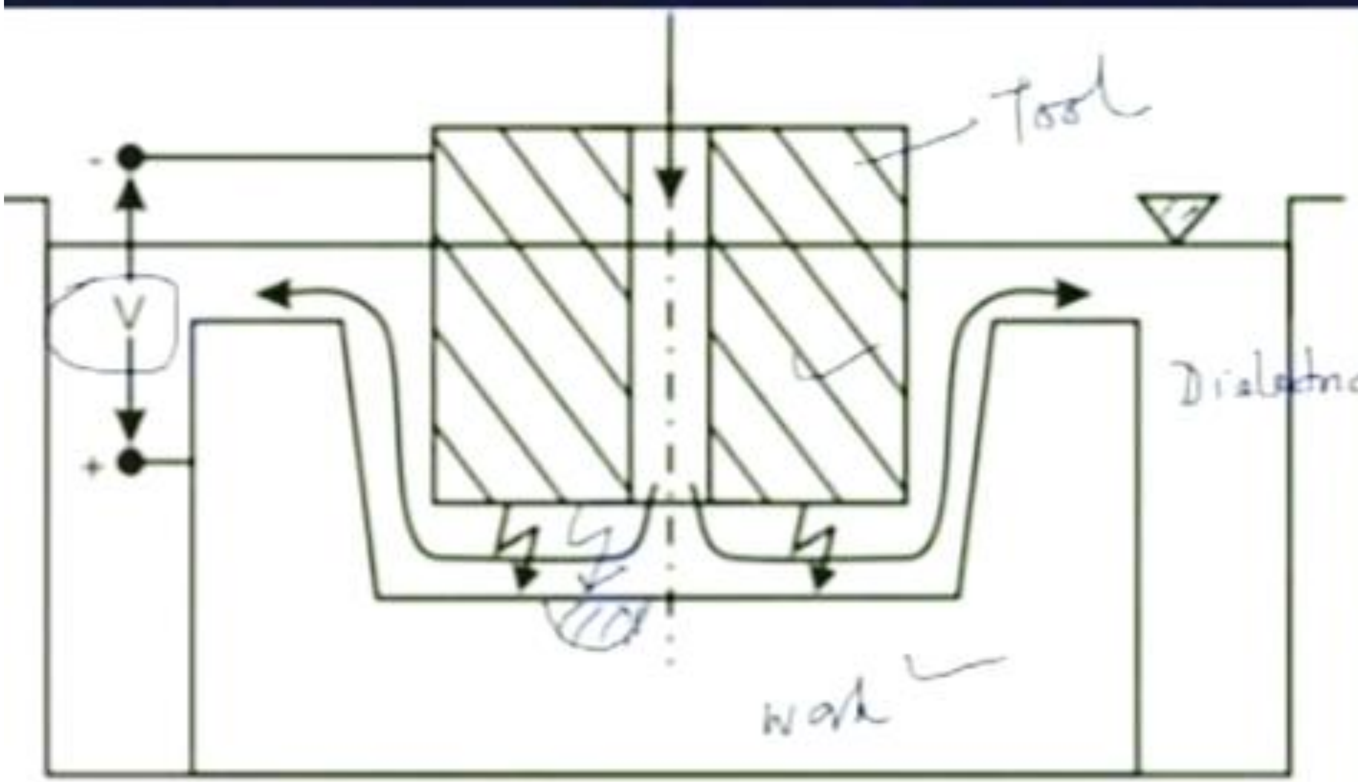
- Esotic Materials: innovative design and requirement, tighter tolerances and micromachining, economy
- Intricate shaped blind hole- e.g. square hole of 15mm x 15mm with a depth of 30mm
- Difficult to machine material- e.g same example as above in inconel, Ti-alloys or carbons
- Low Stress Grinding- Electrochemical Grinding is preferred as compared to conventional grinding
- Deep hole with small hole diameter- e.g. Φ 1.5 mm hole with d=20
- Machining of composites

Ultrasonic Machining (USM)



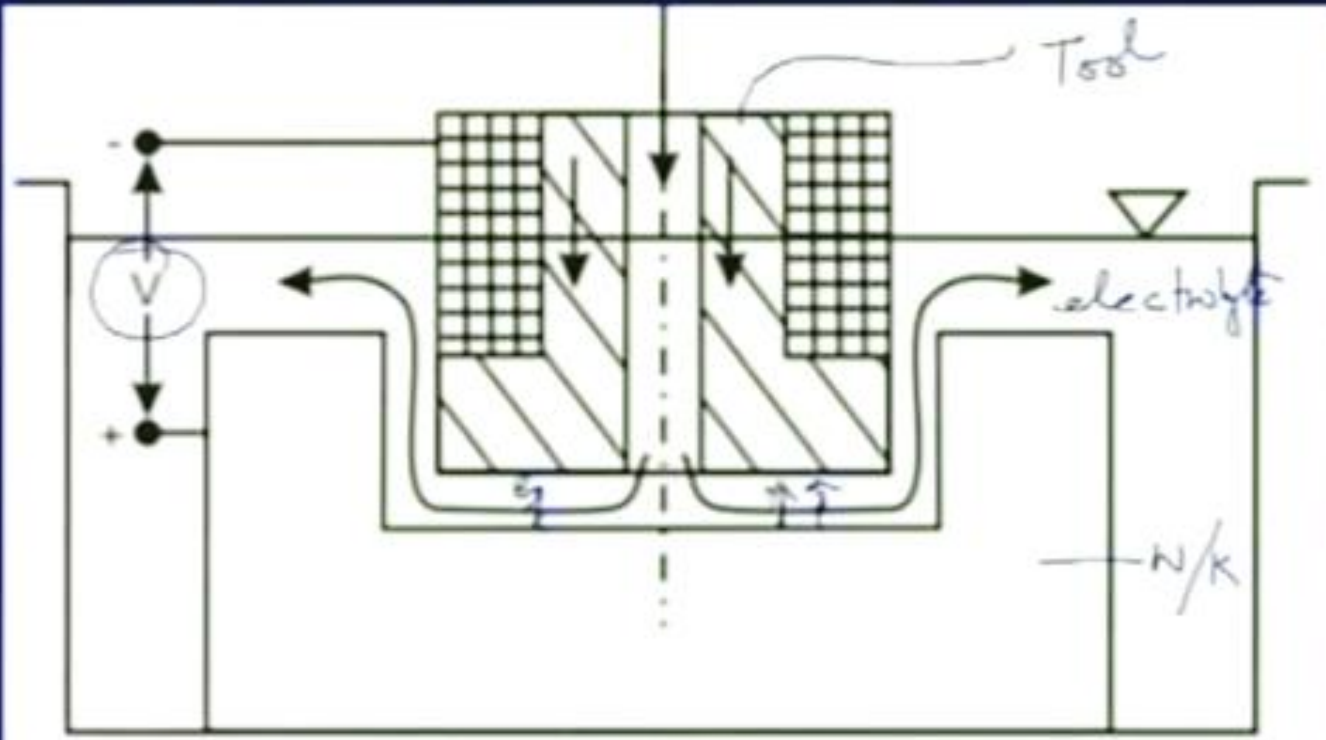
USM

Electro Discharge Machining (EDM)



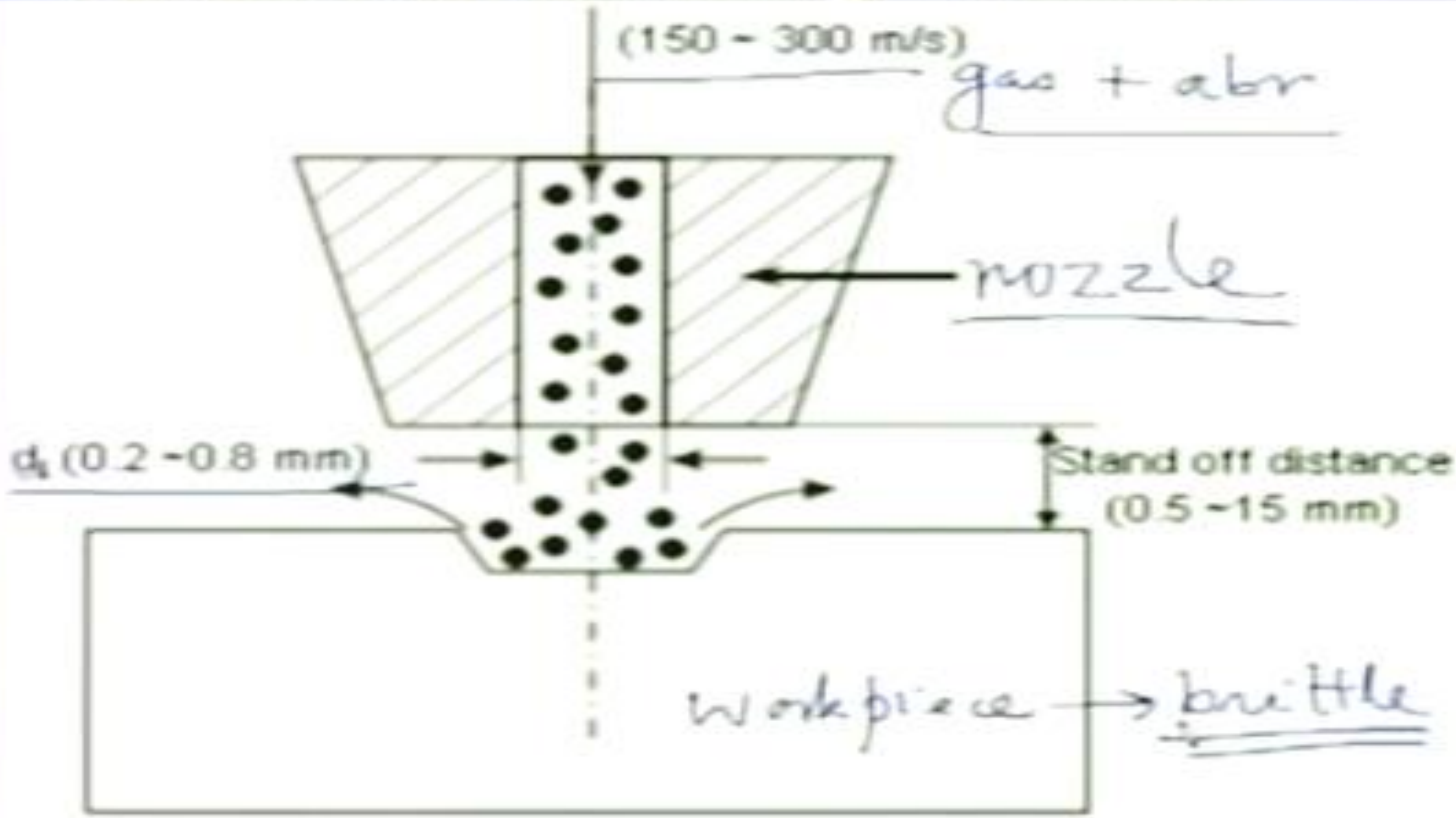
EDM

Electro Chemical Machining (ECM)



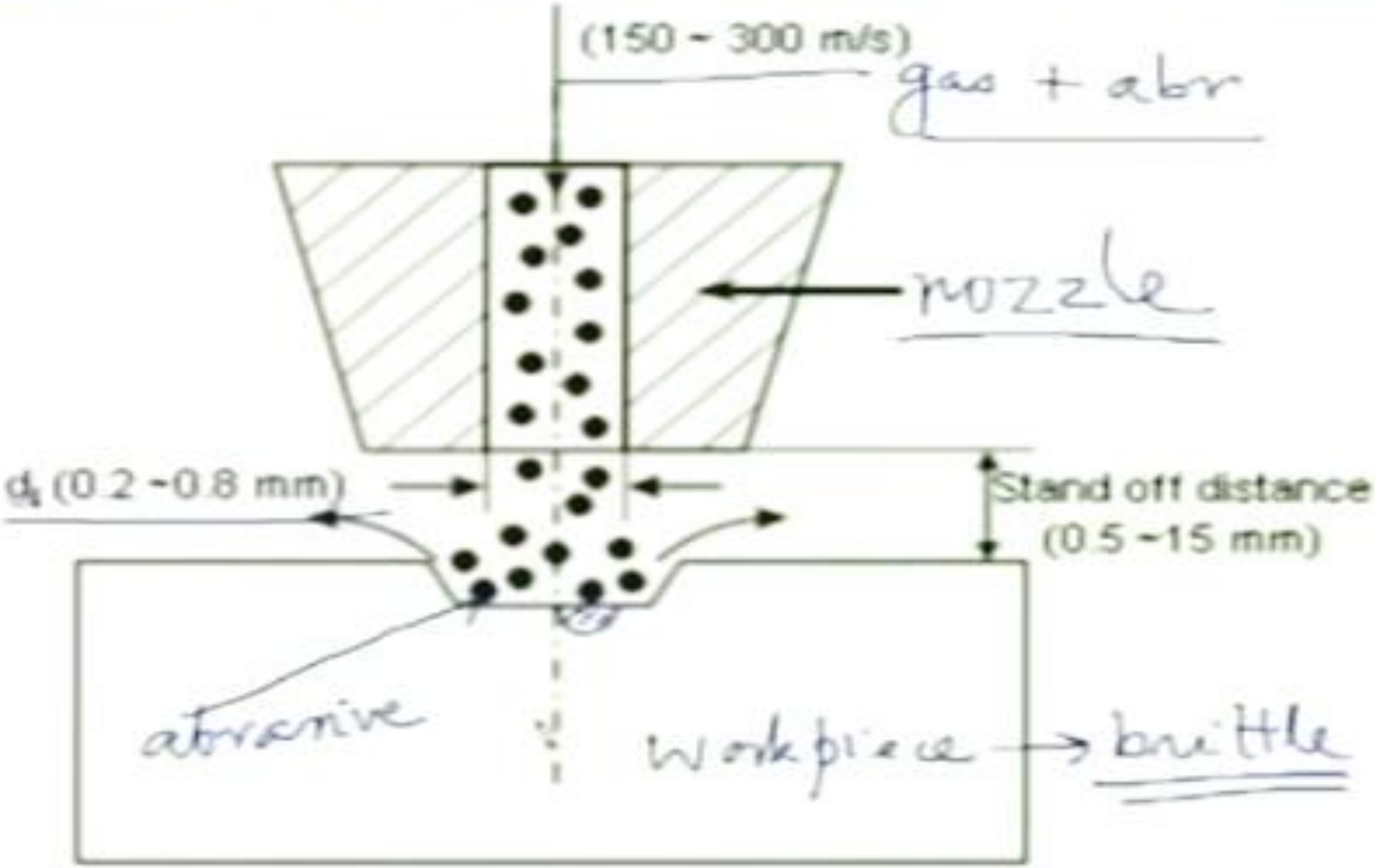
ECM

Abrasive Jet Machining – Process



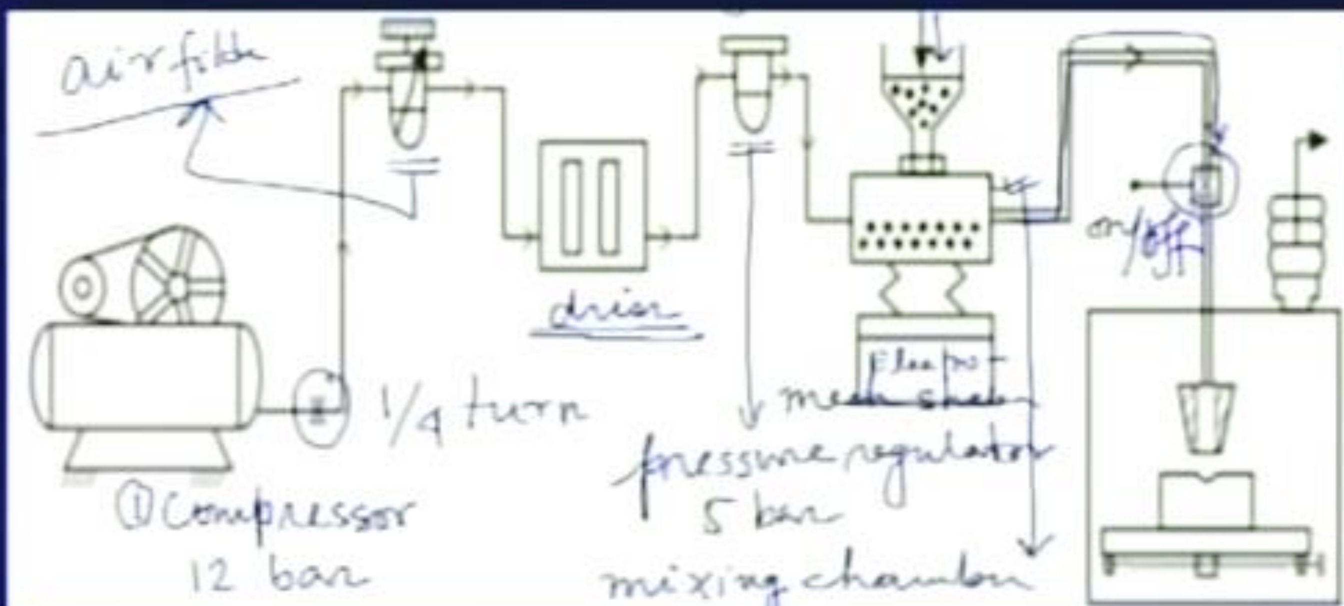
AJM

Abrasive Jet Machining – Process

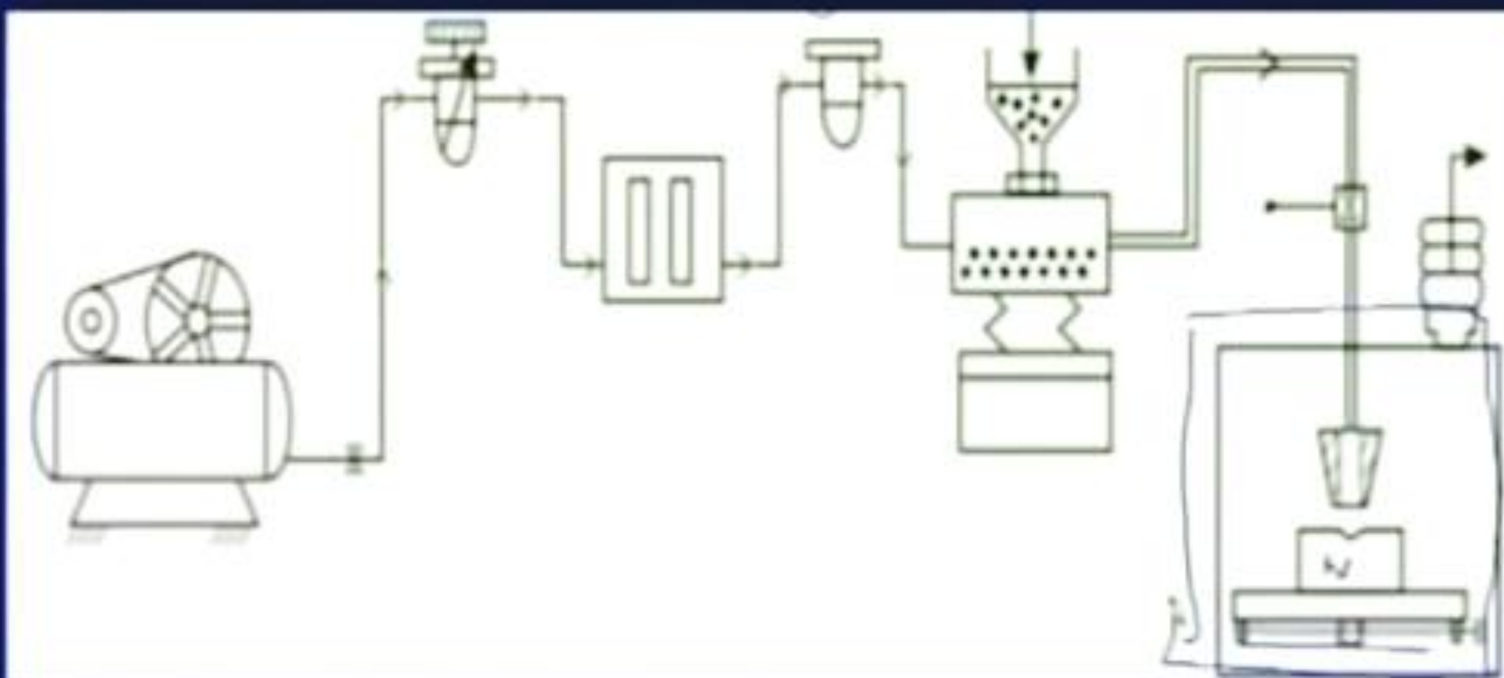


AJM

AJM – Equipment



AJM – Equipment



PROCESS VARIABLES

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

PROCESS VARIABLES

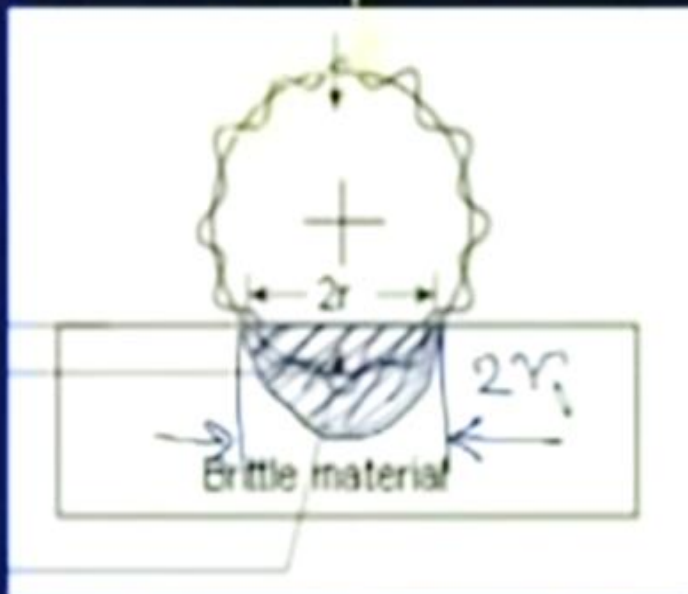
- Abrasive Jet
  - Velocity - 100 – 300m/s
  - Burning ratio – mass flow ratio of abrasive to gas
  - Stand-off distance – 0.5 - 5 mm
  - Impingement Angle - 60° - 90°
- Nozzle
  - Material- WC/ Sapphire
  - Diameter – (internal) 0.2- 0.8 mm
  - Life - 10 -300 hours

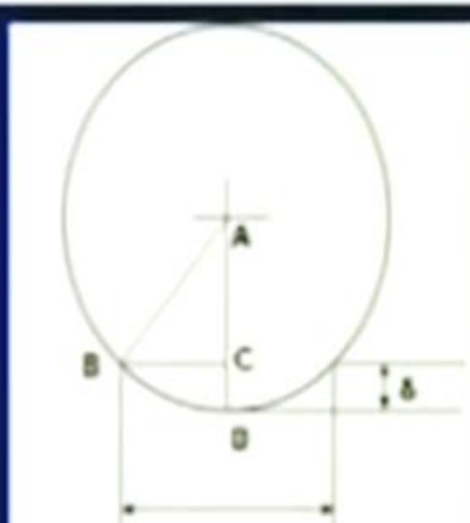
MODELING OF MATERIAL REMOVAL IN AJM

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

Single impact material removal

Modelling of MRR in AJM





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

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

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

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

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

Modelling of MRR in AJM

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

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

$$W = \frac{1}{2}F\delta$$

$F =$ indentation area x hardness

$$F = \pi r^2 H$$

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

Modelling of MRR in AJM

$W = K.E.$

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

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

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

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

MATERIAL REMOVAL RATE

Modelling of MRR in AJM

$$MRR_B = \Gamma_B N$$

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

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

Modelling of MRR in AJM

$$MRR_B = \left(\frac{4m_a}{\rho_g}\right)\left(\frac{\delta}{d_g}\right)^{3/2} \quad as \quad \delta = d_g v\left(\frac{\rho_g}{6H}\right)^{1/2}$$

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

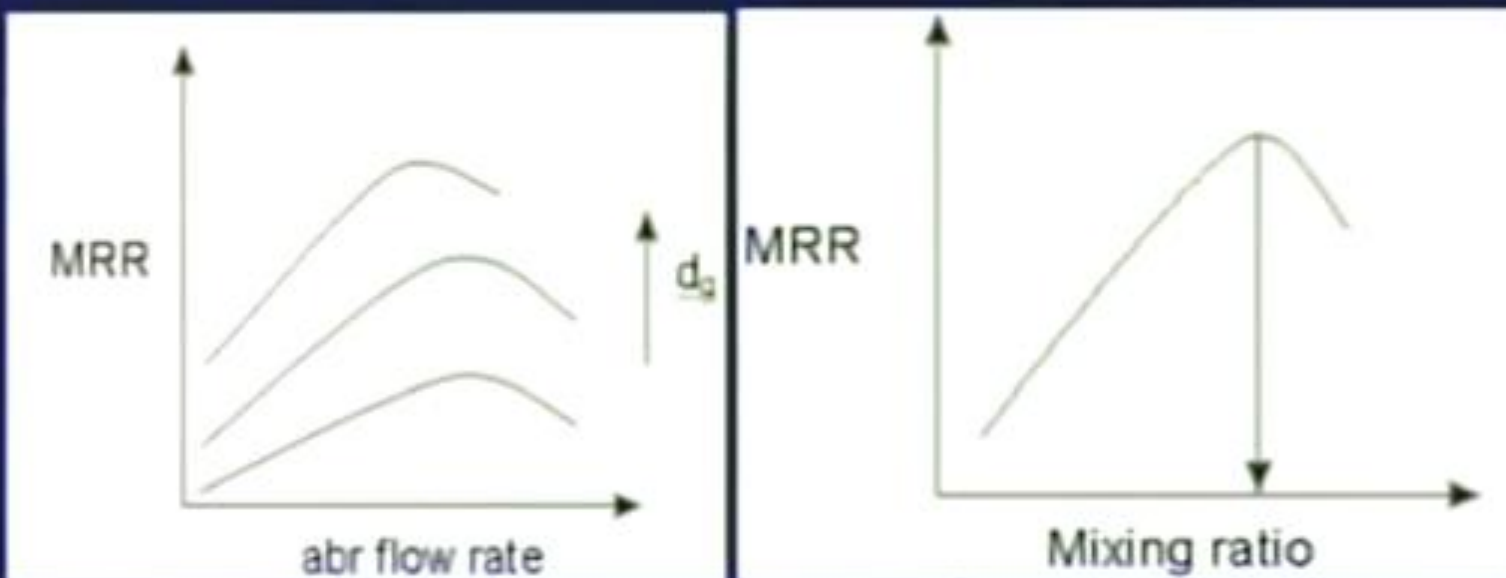
$$MRR_B = \frac{4m_a v^{3/2}}{6^{3/4}\rho_g{}^{1/4}H^{3/4}} \approx \frac{m_a v^{3/2}}{\rho_g{}^{1/4}H^{3/4}}$$

Volume of material removed in a single impact

- MMR = Amount of material removed in a single impact x number of impacts.

- Number of impacts is mass flow rate of abrasives divided by the mass of a single grit

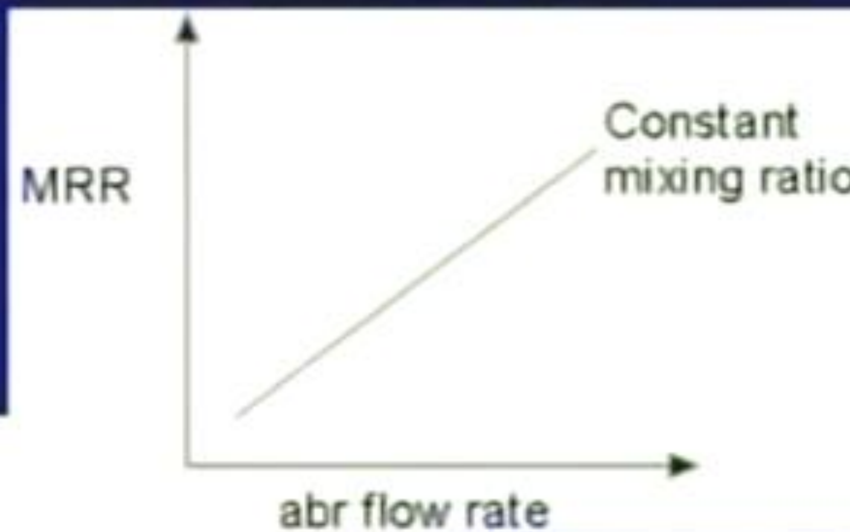
Effect of Process Parameters on MRR

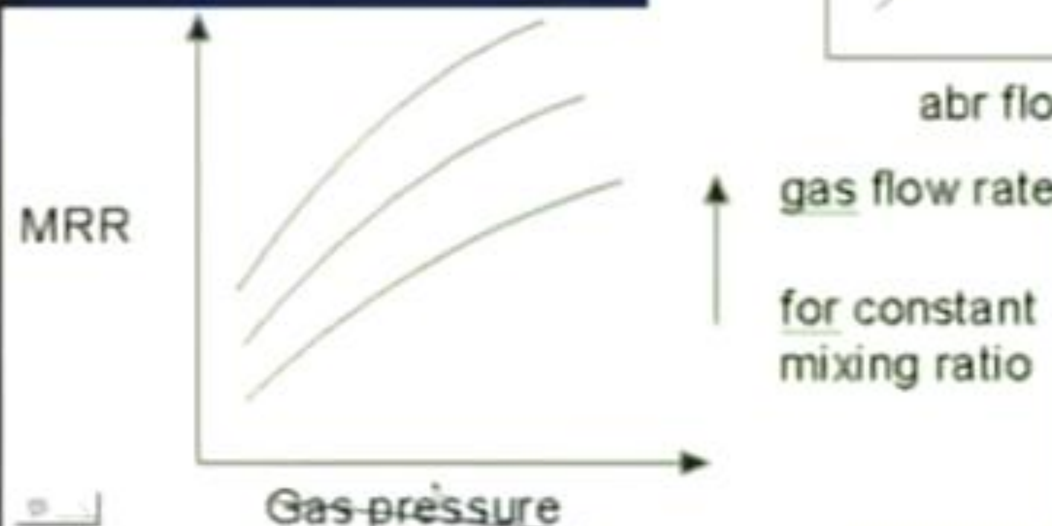


$$MRR_B \approx \frac{\dot{m}_a v^{3/2}}{\rho_g^{1/4} H^{3/4}}$$

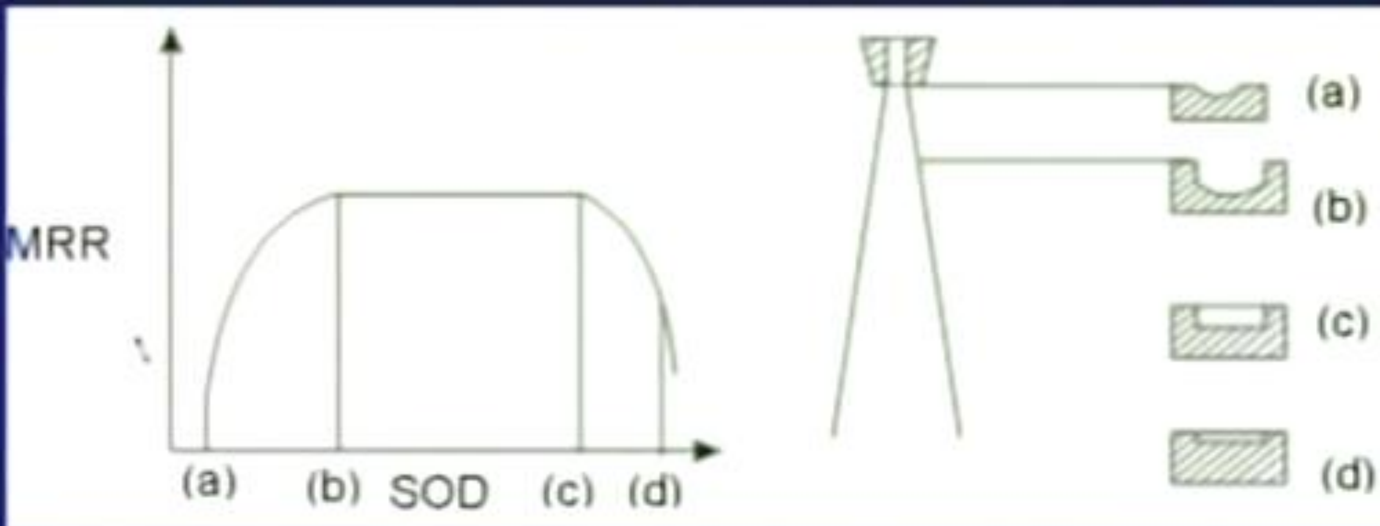
Effect of Process Parameters on MRR

$$MRR_B \approx \frac{\dot{m}_a V^{3/2}}{\rho_g^{1/4} H^{3/4}}$$





Effect of Process Parameters on MRR



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

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

LIMITATIONS

- MRR is rather low (around – 15 mm^3/min for machining glass)
- Abrasive particles tend to get embedded specially if the work material is ductile
- Tapering occurs due to flaring of the jet
- Environmental load is rather high

QUIZ

1. AJM nozzles are made of
   - Low carbon steel
   - HSS
   - WC
   - Stainless steel
2. Material removal in AJM of glass is around
   - 0.1 mm^3/min
   - 15 mm^3/min
   - 15 mm^3/s
   - 1500 mm^3/min

QUIZ

3. Material removal takes place in AJM due to
   - Electrochemical action
   - Mechanical impact
   - Fatigue failure of the material
   - Sparking on impact
4. As the stand off distance increases beyond 5 mm, the depth of penetration in AJM
   - Increases
   - Decreases
   - Does not change
   - Initially increases and then remains steadily

Solved Problem – 1

Estimate the material removal rate in AJM of a brittle material with flow strength of 4 GPa. The abrasive flow rate is 2 gm/min, velocity is 200 m/s and density of the abrasive is 3 gm/cc.

$$MRR_B \approx \frac{m_a v^{3/2}}{\rho_g^{1/4} H^{3/4}} = \frac{\frac{2x10^{-3}}{60} x (200)^{3/2}}{(3000)^{1/4} x \left(4x10^9\right)^{3/4}}$$

$$MRR_B = 8x10^{-10} m^3/s = 8x10^{-1} x60 \quad mm^3/s$$

$$\cong 48 \quad mm^3/\min$$

Solved Problem – 2

Material removal rate in AJM is 0.5 mm³/s. Calculate material removal per impact if mass flow rate of abrasive is 3 gm/min, density is 3 gm/cc and grit size is 60 μm as well as indentation radius.

$$\text{Mass of grit} = \frac{\pi}{6} d_g^{\,3} . \rho_g$$

$$\therefore \text{No. of impact / time} = \frac{m_a}{\frac{\pi}{6} d_g^{\,3} \rho_g} = \frac{6x \frac{3x10^{-3}}{60}}{\pi x \left(50x10^{-6}\right)^3 x3000}$$

N = 254648

Solved Problem – 2 (contd)

$$\Gamma_B = \frac{MRR}{N} = \frac{0.5mm^3/s}{2546648/s} = 1.96x10^{-6}\,mm^3 = 1960\mu m^3$$

$$\text{Indentation volume} = \frac{2}{3}\pi r^3 = 1960 \quad \mu m^3$$

Indentation radius, $r \approx 9.78 \approx 10\mu m$