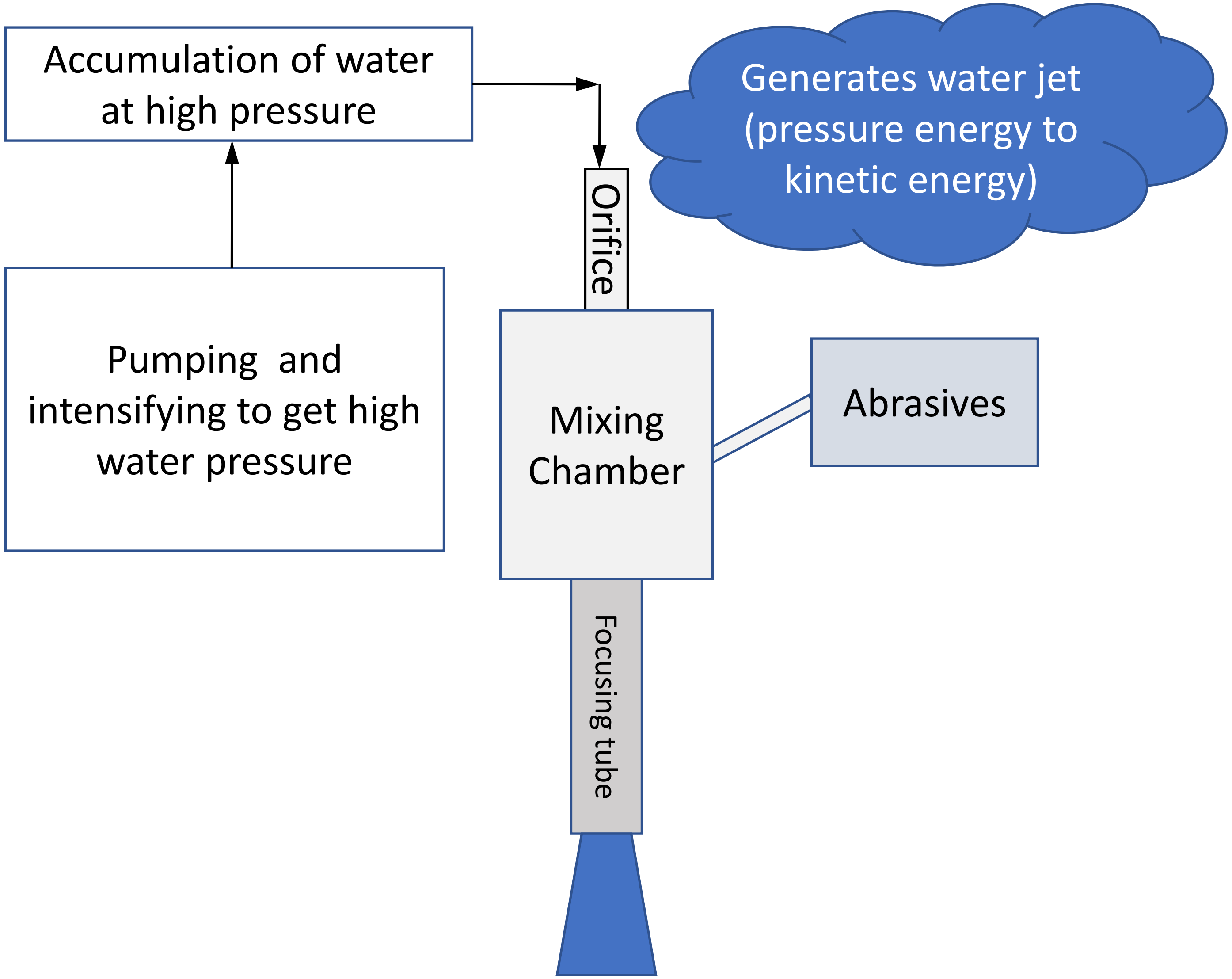
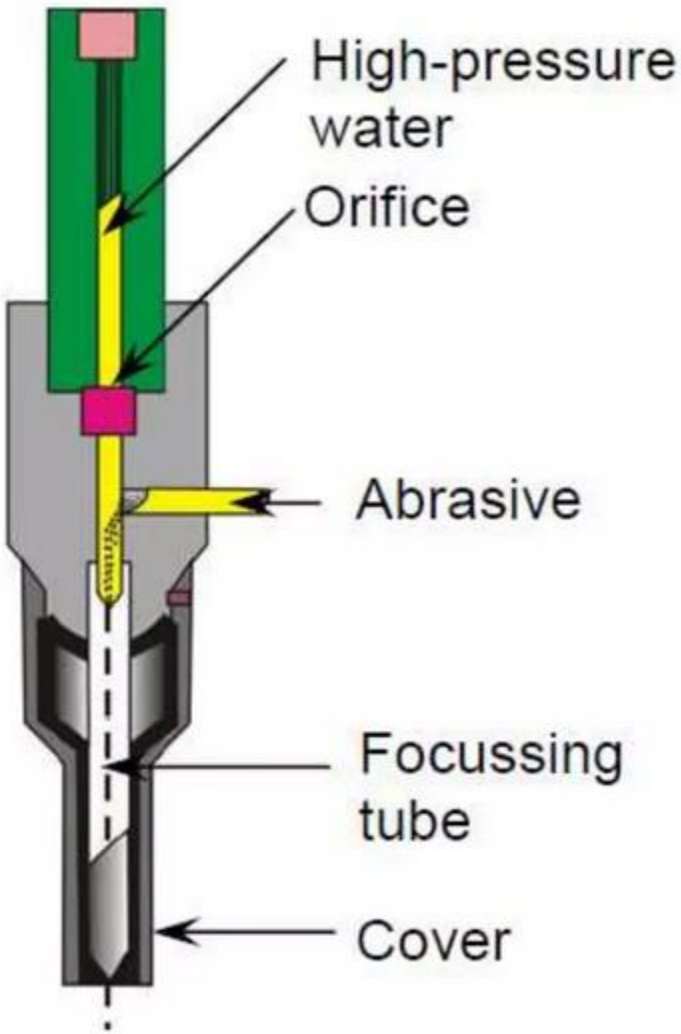
Water Jet Machining (AJM) and Abrasive Water Jet Machining (AWJM)

Water Jet and Abrasive water jet machining

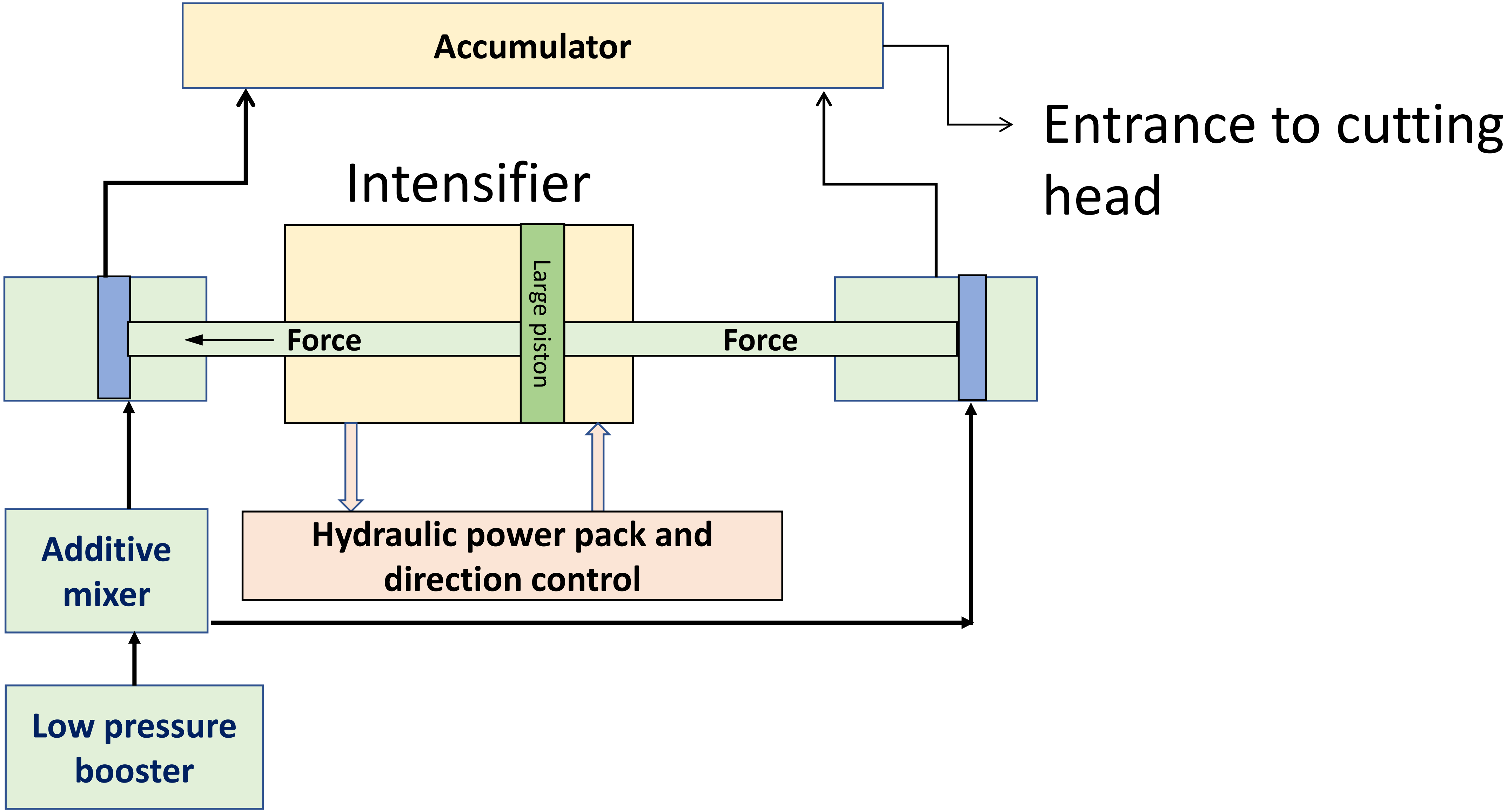
- **Water Jet Machining :** Pure water (commercially pure) or with stabilizers
- **Abrasive water jet machining** : Abrasives added to the water.
- Can machine almost all materials. No thermal effects.
- Employing water (and abrasives) for cutting metals, rocks and stones.
- Water is first taken up to a pressure of ~ 4000 bar and is made to exit from a nozzle at speeds near 1000 m/s, containing abrasive grits inside it and is made to impinge on work material.

Abrasive water jet machining





High pressure build up



AWJM : General parameters

- **Pressure** : 2500 – 4000 bar
- **Abrasive flow rate** : 0.1 kg/min - 1 kg/min
- **Abrasives** : Garnet or Olivine
- **Standoff distance** : 1 - 2 mm
- **Groove depth** : 1 mm - 250 mm
- **Grooving / cutting speed** : 100 mm/min – 5 mm/min
- **Focusing tube** : Premium Composite carbide, 0.8 – 2.4 mm
- **Mixing chamber** : Premium composite carbide like WC
- **Orifice**: Sapphire, ruby or diamond, 0.1 – 0.4 mm
- **Diamond** –Life of 800 – 2000 hrs while others give ~ 40 – 100 h
- **Traverse speed** : 100 mm/min to 5 m/min
- **Depth of Cut** : 1 mm to 250 mm

WJM : Applications

- Plastics, Cardboard, Paper, Insulation, Rubber
- Paper
- Paint removal
- Cleaning
- Soft materials
- Textile : Carpets, Some varieties of clothes
- Leather
- Food industry

AWJM : Applications

- Glass, Ceramics, Composites, Semiconductors
- Polymers, Metal matrix composites, Ceramic Matrix Composites
- Ti and Ti-alloys, Ni and Ni-alloy, Brass, Aluminum, Steel, Inconel
- Stone, Granite, Rocks.
- Concrete
- Glass fiber metal laminates
- Cutting, Turning, drilling.
- Peening

Advantages

- Cut virtually any material. (pre hardened steel, mild steel, copper, brass, aluminum; brittle materials like glass, ceramic, quartz, stone)
- Cut thin stuff, or thick stuff.
- Make all sorts of shapes with only one tool.
- No heat generated.
- Leaves smooth finish, thus reducing secondary operations.
- Clean cutting process without gasses or oils.
- Very safe.
- Stacks of thin parts can be cut all at once.

Conversion of pressure energy to kinetic energy

- Pressure head of the water so developed is ultimately converted to velocity head
- This is done by passing the water through an orifice – which is typically 0.2 to 0.4 mm in diameter
- The velocity of the water jet developed at exit of the orifice :

$$V^2 = \frac{2P}{\rho}$$

Volume flow rate of water or Discharge volume (Q_w) = Area of Cross-section of orifice x Velocity

$$Q_w = c_d \frac{\pi}{4} d^2 \times V = c_d \times \frac{\pi}{4} d^2 \times \sqrt{\frac{2P}{\rho}}$$

c_d is the discharge coefficient

Material Removal Rate (MRR)

Total power carried by the water jet (P_{wj})= Pressure of the water (P_w) x Volume flow rate (Q_w)

$$P_{wj} = P_w \times Q_w = P_w \times \frac{\pi}{4} d^2 \times V = P_w^{\frac{3}{2}} \times c_d \times \frac{\pi}{4} d^2 \times \sqrt{\frac{2}{\rho}}$$

$$MRR \propto P_{wj}$$

$$MRR = \left(\frac{1}{S_{job}}\right) \times c_d \times \frac{\pi}{4} d^2 \times \sqrt{\frac{2 {P_w}^3}{\rho_w}}$$

Mixing in AWJM

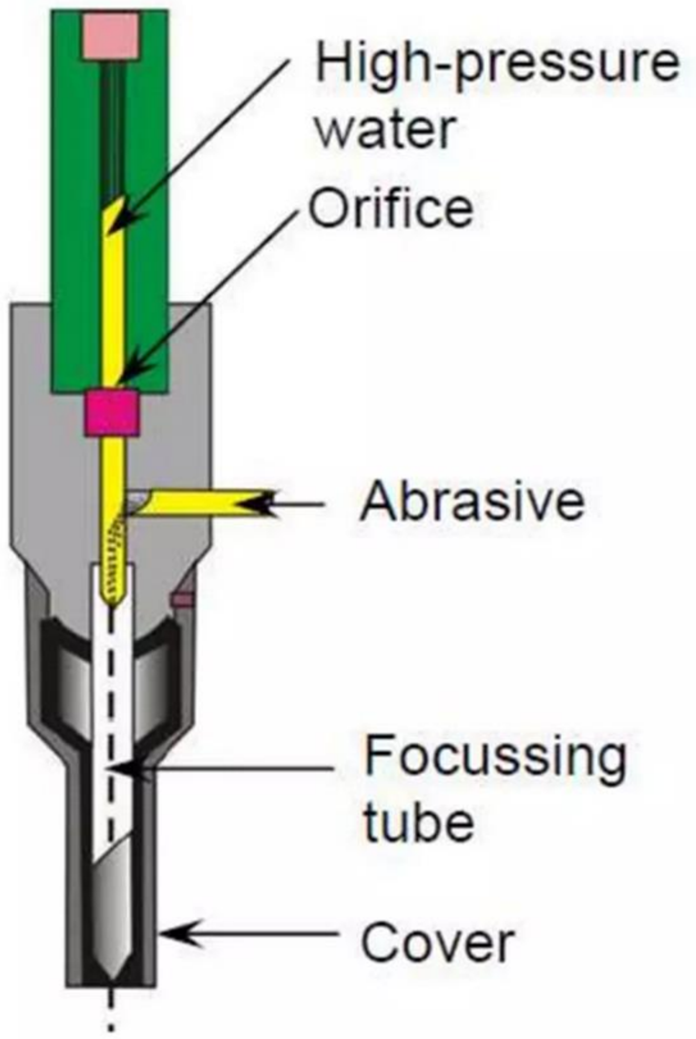
- Due to mixing, the abrasive particles take up energy from the water jet stream and for conservation of momentum

$$\dot{m}_w v_{wj} + \dot{m}_{ab} v_{ab} = \dot{m}_{ab} v_{awj} + \dot{m}_{wj} v_{awj}$$

Assumption : Momentum before and after mixing of abrasives is conserved

$$v_{ab} \text{ is very less compared to } Vwj$$

$$v_{awj} = \left(\frac{\dot{m}_w}{\dot{m}_w + \dot{m}_{ab}}\right) v_{wj}$$



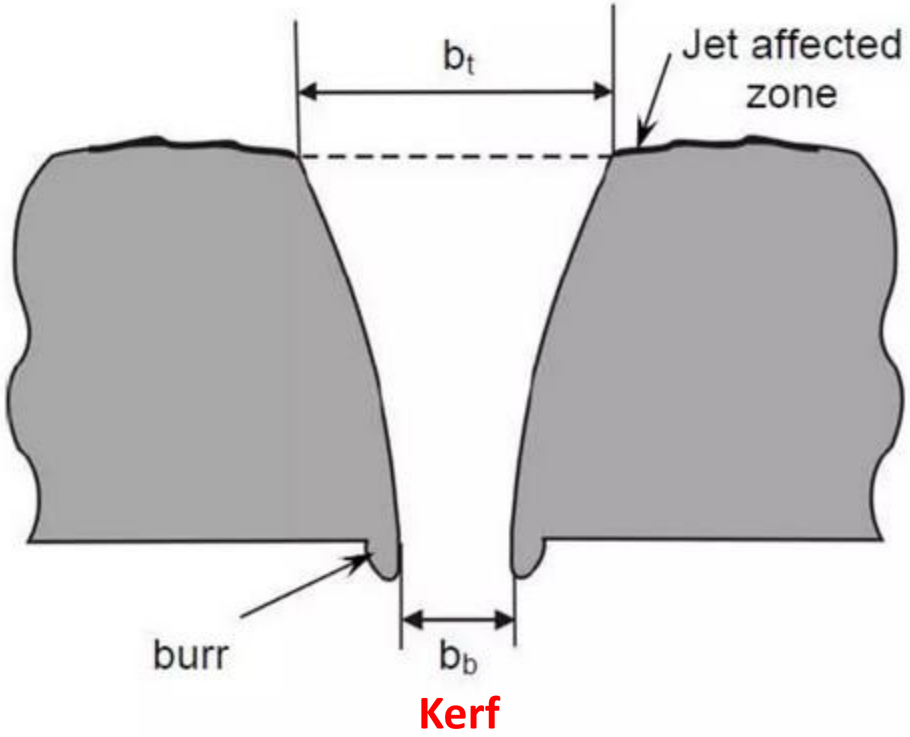
R = loading factor $R = \dfrac{\dot{m}_{abr}}{\dot{m}_{w}}$

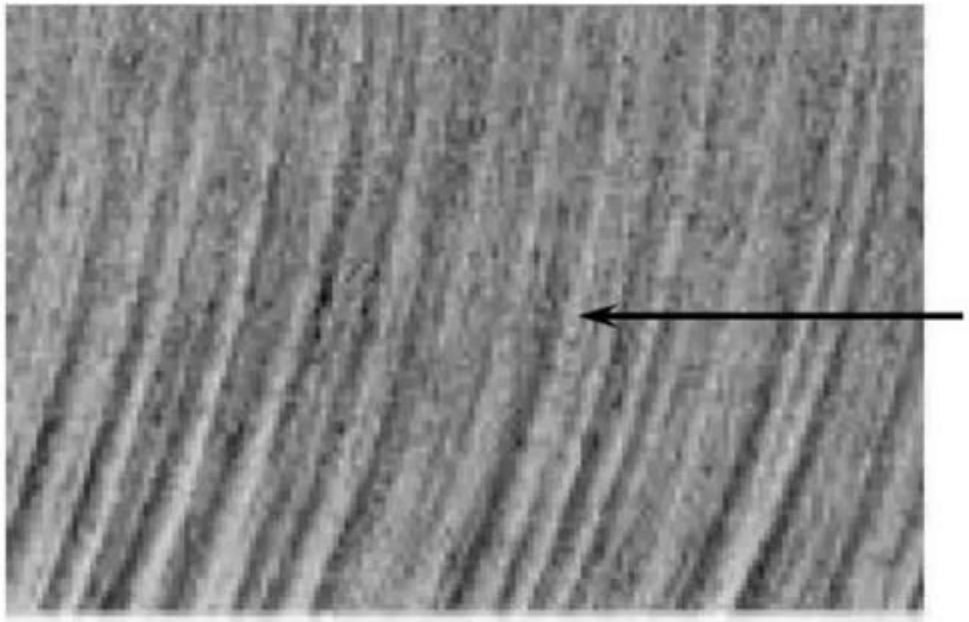
$$v_{awj} = \left(\frac{1}{1+R}\right) v_{wj}$$

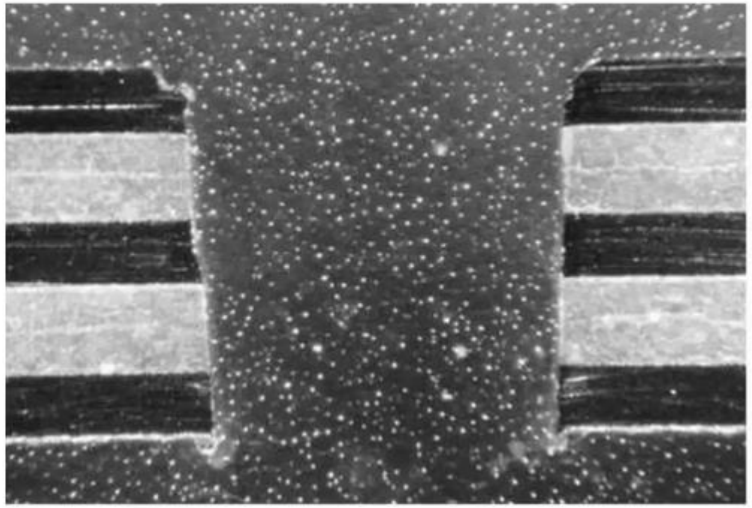
- η = momentum loss factor

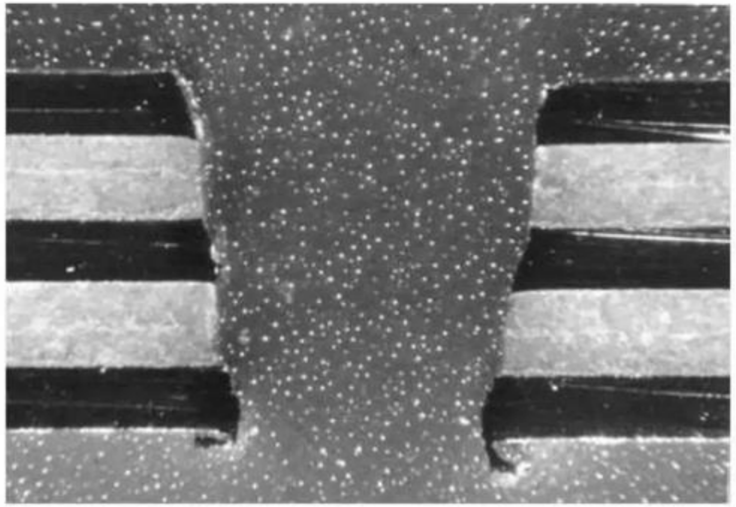
$$v_{awj} = \eta \left(\frac{1}{1+R}\right) v_{wj}$$

Material Removal in AWJM









Material Removal Mechanisms in AWJM

- Ploughing and micro-cutting at low angles of impact.
- Plastic deformation at higher angles of impact.
- Crack propagation in brittle materials.

Power of the abrasive phase of the jet

$$P_{awj} = P_{abr} = \frac{1}{2} \times \dot{m}_{abr} \times {v_{awj}}^2$$

- Power of abrasive water jet is equal to abrasive.
- Water does not contribute to cutting.

$$R = \frac{\dot{m}_{abr}}{\dot{m}_w}$$

$$P_{abr} = \frac{1}{2} \times R \times \dot{m}_w \times \left(\eta \left(\frac{1}{1+R} \right) v_{wj} \right)^2$$

$$P_{abr} = \frac{1}{2} \times R \times \rho_w \times c_d \times \frac{\pi}{4} d^2 \times \sqrt{\frac{2P}{\rho}} \times \left(\eta \left(\frac{1}{1+R} \right) v_{wj} \right)^2$$

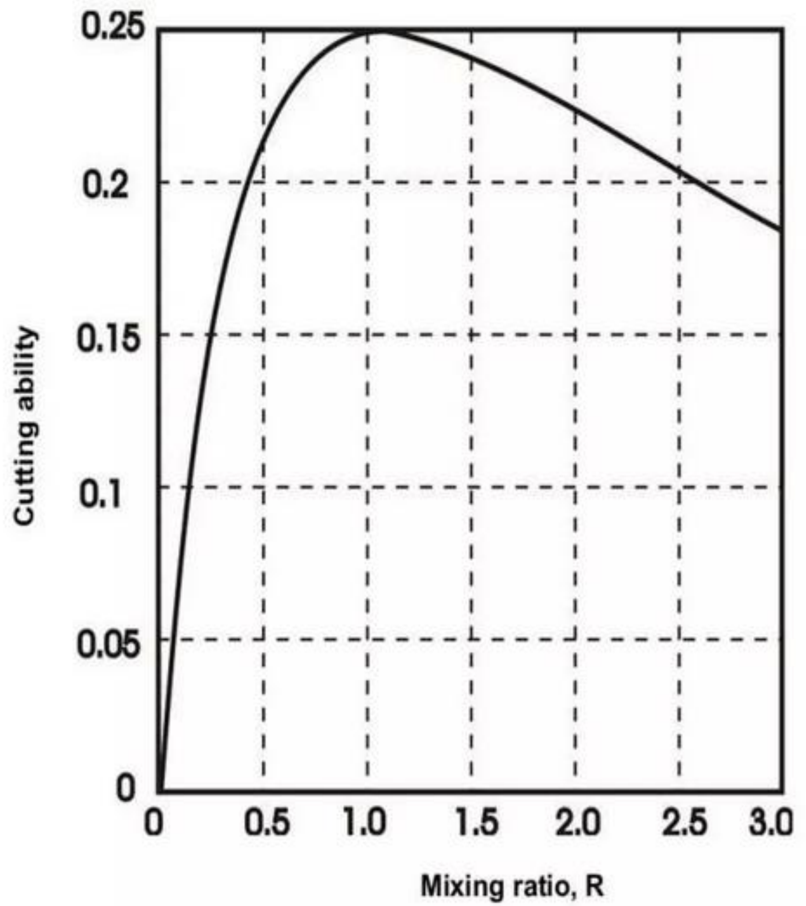
$$v_{awj} = \eta \left(\frac{1}{1+R} \right) v_{wj}$$

$$P_{abr} = c_d \times \frac{\pi}{8} \times d^2 \rho_w \times R \times \left(\frac{\eta}{1+R} \right)^2 \left(\frac{2p_w}{\rho_w} \right)^{3/2}$$

Depth of penetration depends on

- Water Pressure
- Orifice diameter
- Exit nozzle diameter
- Traverse speed
- Grit sharpness
- Efficient mixing chamber an orifice
- Mixing ratio

$$d_g = \xi \times c_d \times \frac{\pi}{4} d_0{}^2 \times R \left(\frac{\eta}{1+R}\right)^2 \times \frac{p_w^{3/2}}{w_g \times V_g \times S_{job}} \sqrt{\frac{2}{\rho_w}}$$



$$d_g = \xi \times c_d \times \frac{\pi}{4} {d_0}^2 \times R\left(\frac{\eta}{1+R}\right)^2 \times \frac{p_w^{3/2}}{w_g \times V_g \times S_{job}} \sqrt{\frac{2}{\rho_w}}$$

- *d_g = groove depth*
- *w_g = groove width; Assume that the groove width w_g does not change with change in grooving speed.*
- *ξ = constant (depends on grit sharpness*
- *c_d = discharge coefficient = 1*
- *d_0 = orifice diameter*
- *ρ_w = density of water*
- *p_w = pressure of water*
- *S_{job} = Specific energy requirement for cutting the job material*
- *V_g = grooving speed*

Limitations

- Limited number of materials can be cut economically. Cutting rate is greatly reduced for materials like tool steels.
- Cutting very thick parts with dimensional accuracy.
- Taper in very thick materials
- AWJM is sometimes a very expensive process.
- Not suitable for mass production because of high maintenance requirements.

Thank you