Abrasive Water Jet Machining (AWJM)

ME312: Manufacturing Technologies - II
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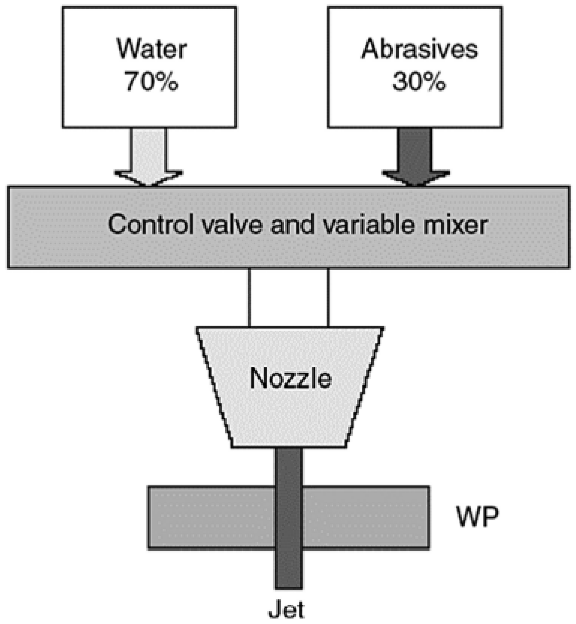
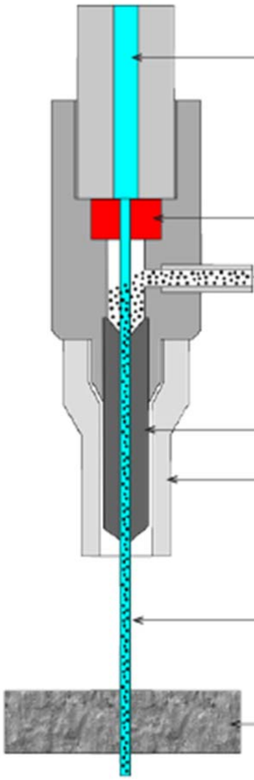
Abrasive Water Jet Machining

- Water jet machines use pure water
- WJM is suitable for cutting plastics, foods, rubber insulation, automotive carpeting and headliners, and most textiles.
- Mixing of abrasives with water jet enhances the material removal rate
- AWJM cuts around 10 times faster than the conventional machining methods of composite materials.
- Cut variety of materials (thick or thin) without any thermal damages



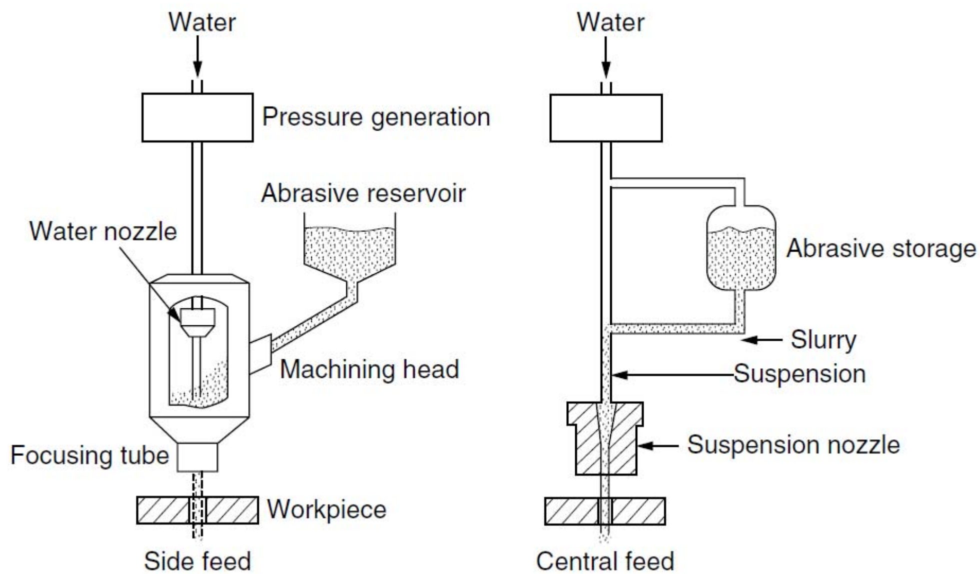
The machining system

- Water delivery
- Abrasive hopper and feeder
- Intensifier
- Filters
- Mixing chamber
- Cutting nozzles
- Catcher



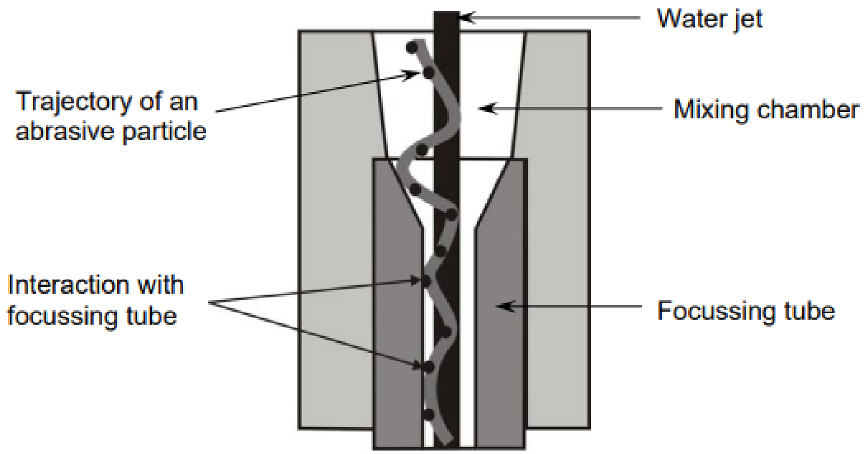
Abrasive Delivery

- After the pure water jet is created, abrasives are added using either the injection or suspension methods
- Entrained type– three phase – abrasive, water and air
- Suspended type – two phase – abrasive and water
- Abrasive particles like sand (SiO2), glass beads are used



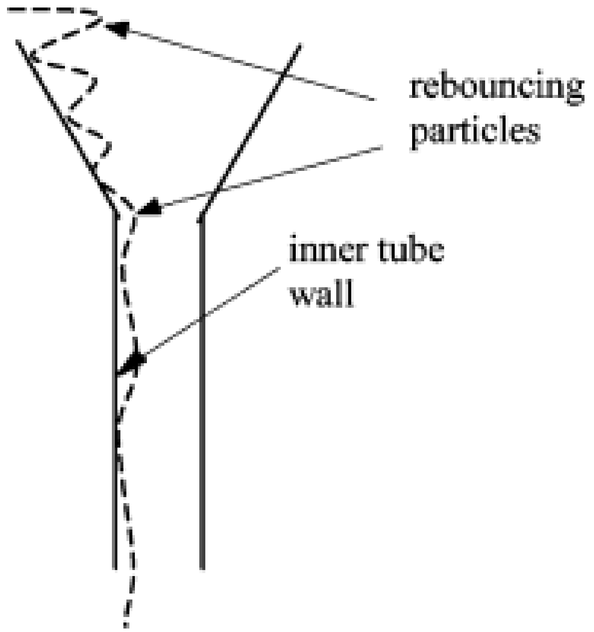
Mixing

- Gradual entrainment of abrasive particles within the water jet and finally the abrasive water jet comes out of the focusing tube or the nozzle
- The abrasive particles are gradually accelerated due to transfer of momentum from the water phase to abrasive phase
- Both phases, water and abrasive, are assumed to be at same velocity.



Mixing

- The focusing tube is generally made of tungsten carbide
- Tungsten carbide is used for its abrasive resistance
- Abrasive particles during mixing try to enter the jet, but they are reflected away due to interplay of buoyancy and drag force
- They go on interacting with the jet and the inner walls of the mixing tube, until they are accelerated using the momentum of the water jet



Mathematical model for Mixing

- During mixing process as has been discussed both momentum and energy are not conserved due to losses that occur during mixing
- But initially it would be assumed that no losses take place in momentum, i.e., momentum of the jet before and after mixing is conserved

$$\sum(\dot{m}v)_{before} = \sum(\dot{m}v)_{after}$$

$$\left(\dot{m}_{air}v_{air} + \dot{m}_{water}v_{wj} + \dot{m}_{ab}v_{ab}\right)_{before}$$
$$= \left(\dot{m}_{air}v_{air} + \dot{m}_{water}\, v_{wj} + \dot{m}_{ab}v_{ab}\right)_{after}$$

Models proposed by Hashish, 1989

Mathematical model for Mixing

- The momentum of air before and after mixing will be neglected due to very low density

$$(v_{ab})_{after} = (v_{wj})_{after} = v_{awj}$$

$$\dot{m}_{water} v_{wj} = (\dot{m}_{water} + \dot{m}_{ab}) v_{awj}$$

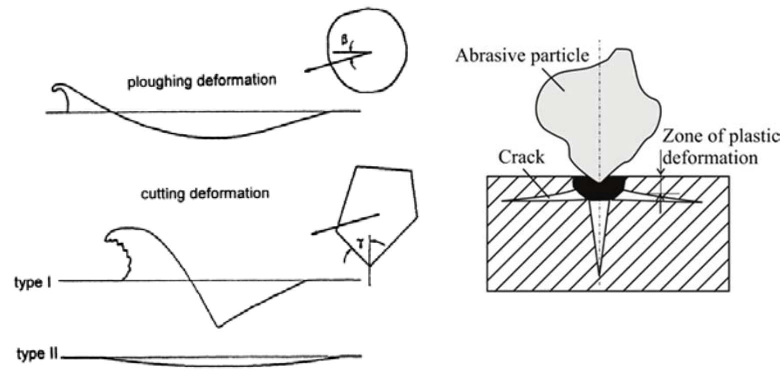
$$v_{awj} = \frac{\dot{m}_{water}}{\dot{m}_{water}+\dot{m}_{ab}} v_{wj} \rightarrow \quad v_{awj} = \frac{1}{1+R} v_{wj}$$ (R=loading factor = $\frac{\dot{m}_{ab}}{\dot{m}_{water}}$)

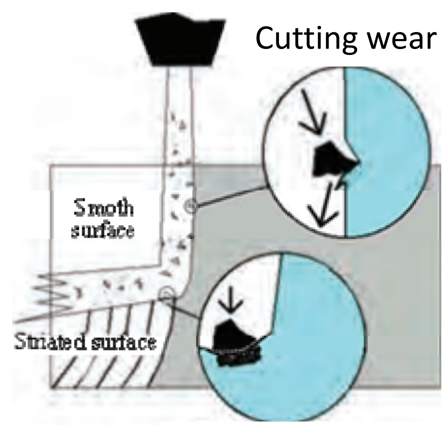
Considering momentum loss in mixing process

$$v_{awj} = \eta \frac{1}{1+R} v_{wj}$$ (η = momentum loss factor)

Cutting Mechanism

- Impact of solid particles is the main mechanism in the process of removing material by abrasive water jet
- For ductile material, micro-cutting and separating by material plastic deformation are the removal mechanism
- For brittle materials, mechanism of separation of materials, consisting of the phenomenon of brittle fracture and plastic deformation
- With increasing depth, the removal mechanism is changing from cutting to the separating material by plastic deformation





Material Removal Rate

- The power of the abrasive phase of the abrasive water jet can be estimated as,

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

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

$$V_{wj} = \sqrt{\frac{2p_w}{\rho_w}}$$ and $$\dot{Q}_w = c_d \frac{\pi}{4} d_0^2 \sqrt{\frac{2p_w}{\rho_w}}$$

$$P_{ab} = \rho_w c_d \frac{\pi}{8} d_0^2 R \left(\frac{1}{1+R}\right)^2 \left(\sqrt{\frac{2p_w}{\rho_w}}\right)^3$$

Material Removal Rate

$$P_{ab} = \frac{\pi}{4} c_d\, d_0^2 R \left(\frac{1}{1+R}\right)^2 {p_w}^{3/2} \left(\sqrt{\frac{2}{\rho_w}}\right)$$

Assumption: the material removal rate is proportional to the power of abrasive phase of AWJ

The water phase does not contribute to material removal in AWJM

$$MRR \propto P_{ab}$$

$$MRR = \left(\frac{1}{u}\right) \frac{\pi}{4} c_d\, d_0^2 R \left(\frac{1}{1+R}\right)^2 {p_w}^{3/2} \left(\sqrt{\frac{2}{\rho_w}}\right)$$

u is the specific energy requirement and would be a property of the work material.

Penetration Height

$$MRR = h\, w v_c$$

h = depth of penetration

w = width or diameter of the water jet

v_c = traverse speed of the AWJ or cutting speed

$$h = \left(\frac{1}{u}\right)\frac{\pi}{4} c_d\, d_0^2 R \left(\frac{1}{1+R}\right)^2 \frac{{p_w}^{3/2}}{w v_c}\left(\sqrt{\frac{2}{\rho_w}}\right)$$

Numerical Example

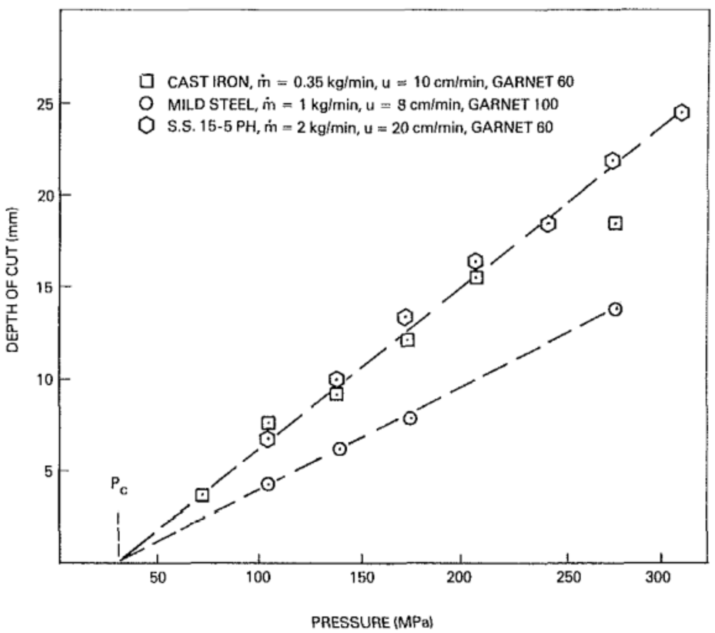
(a) Assuming no losses, determine water jet velocity, when the water pressure is 3000 bar, being issued from an orifice of diameter 0.1 mm

(b) Determine the mass flow rate of water for the given problem assuming all related coefficients to be 1.

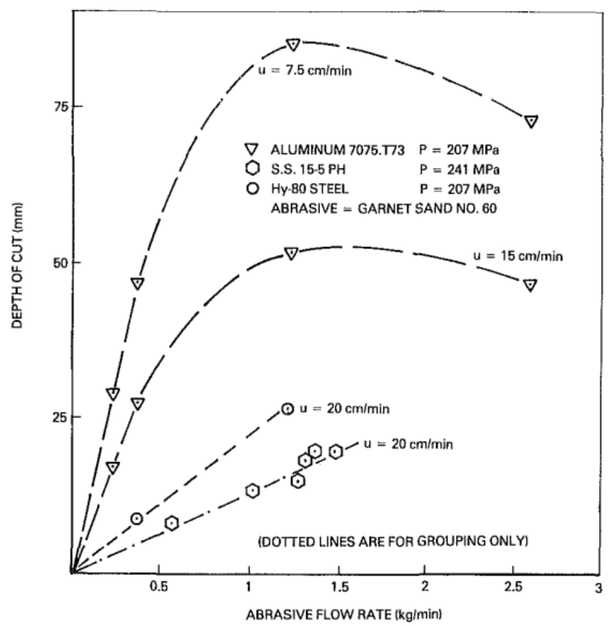
(c) If the mass flow rate of abrasive is 0.8 kg/min, determine the abrasive water jet velocity assuming no loss during mixing process

(d) Determine depth of penetration, if a steel plate is AWJ machined at a traverse speed of 100 mm/min with an insert diameter of 1 mm. The specific energy of steel is 13.4 J/mm^3 .

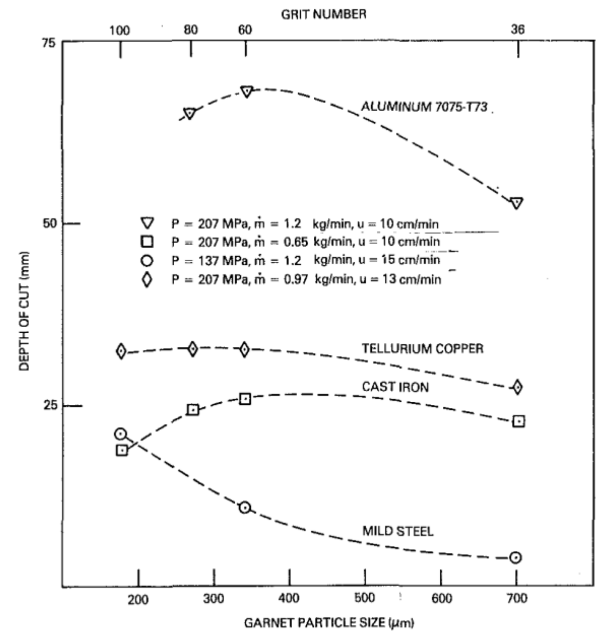
Effect of Parameters on Depth of Cut



Effect of water pressure

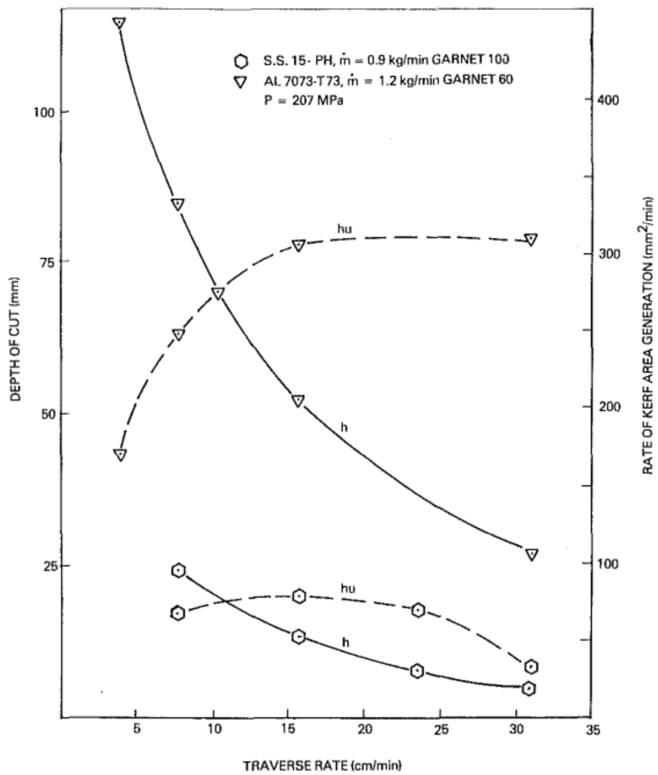


Effect of abrasive flow rate

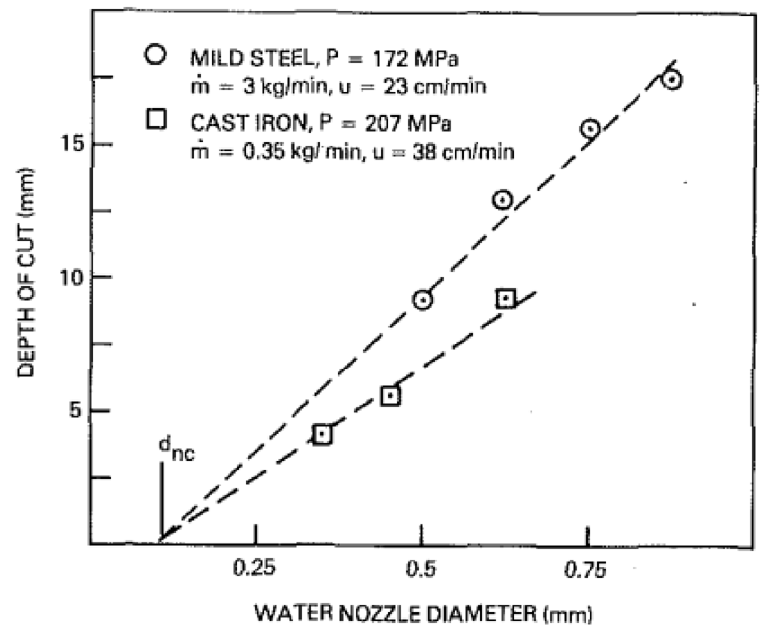


Effect of garnet particle size

Effect of Parameters on Depth of Cut

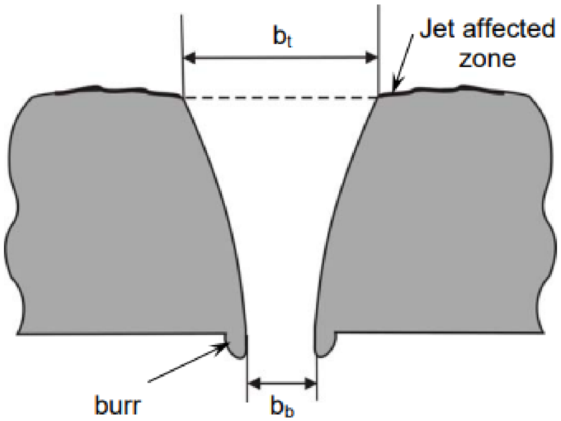


Effect of traverse rate

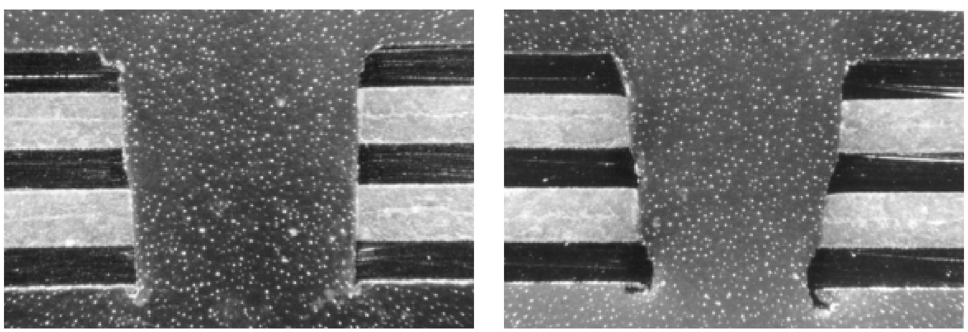


Effect of waterjet nozzle diameter

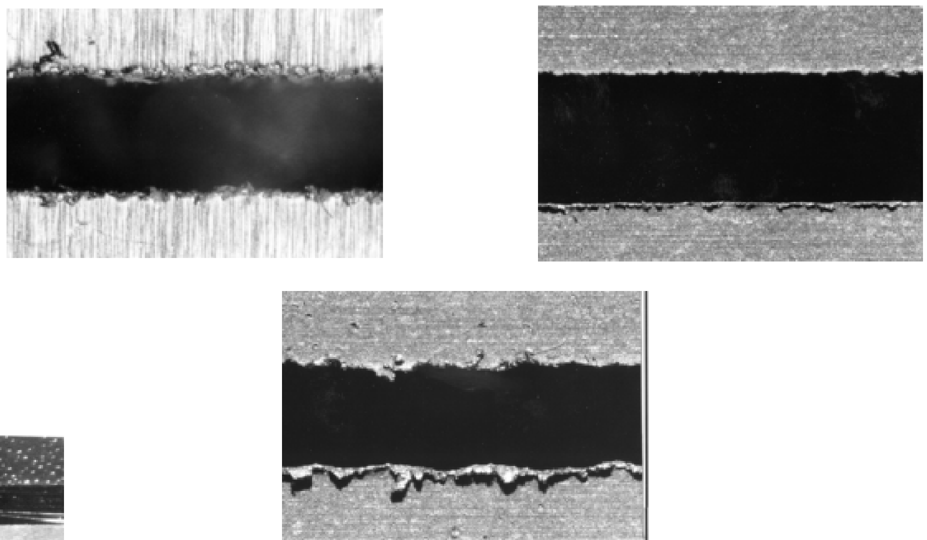
Cut /Kerf Quality



Schematic of AWJM kerf

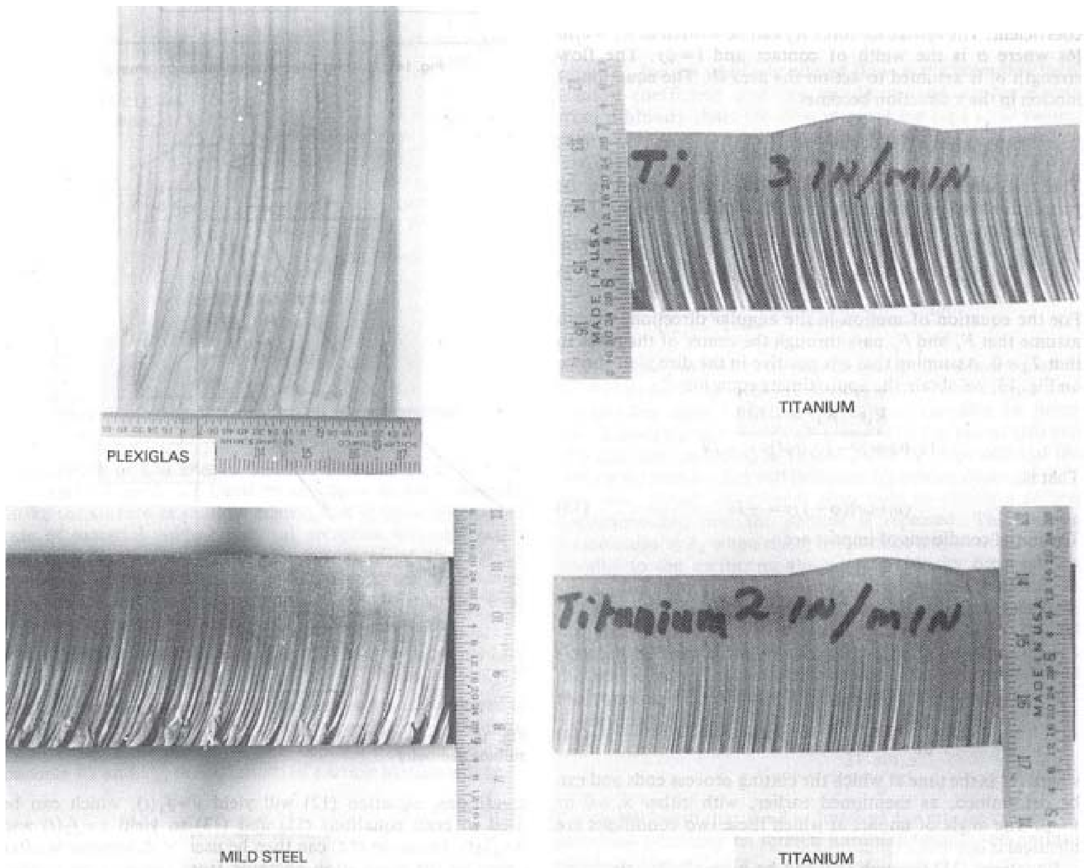


Cross section of Cut



Back Side of Cut

Surface Quality

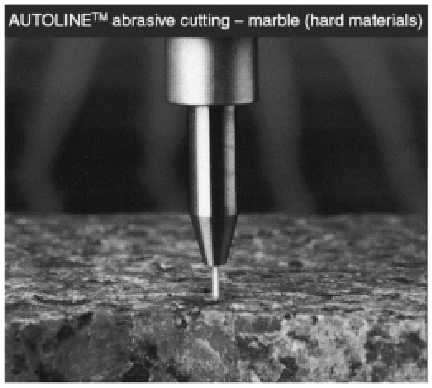


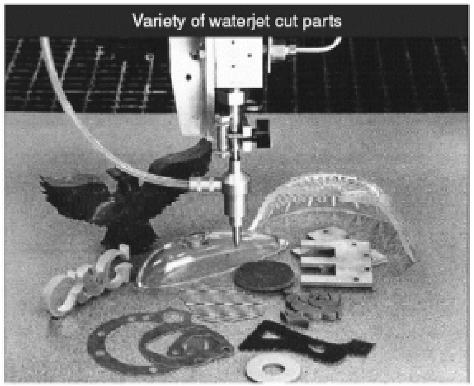
Process Parameters

- Orifice – Sapphires – 0.1 to 0.3 mm
- Focusing Tube – WC – 0.8 to 2.4 mm
- Pressure – 2500 to 4000 bar
- Abrasive – garnet and SIO_2
- Abrasive flow – 0.1 to 1.0 Kg/min
- Stand off distance – 1 to 5 mm
- Machine Impact Angle – 60^0 to 90^0
- Traverse Speed – 0.1 m/min to 5 m/min
- Depth of Cut – 1 mm to 250 mm

Advantages

- Same as Water jet machining process
- Capability to machine soft and hard materials at very high speeds
- In most of the cases, no secondary finishing required
- No cutter-induced distortion
- The burr produced is minimal.

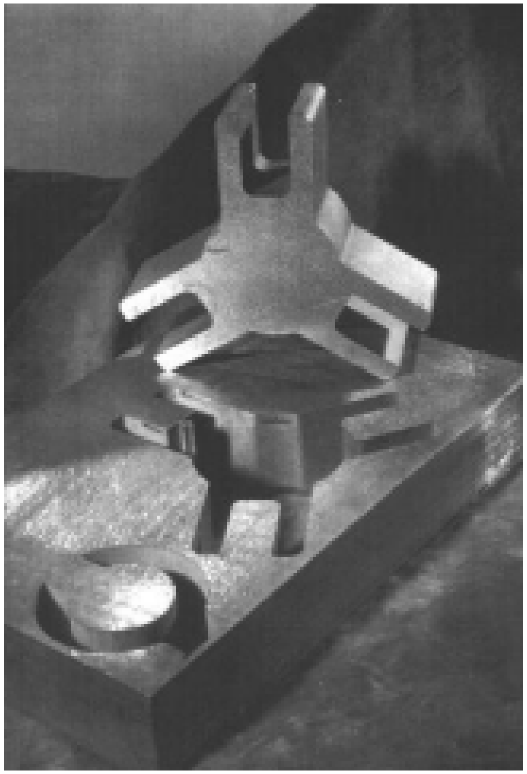




Disadvantages

- Due to the existence of the abrasives in the jet, there is an excessive wear in the machine and its elements.
- The process is not environmentally safe as compared to WJM.
- Surface finish degrades at higher cut speeds which are frequently used for rough cutting
- The major disadvantages of abrasive water jet cutting are high capital cost and high noise levels during operation

Applications



Stainless steel plate (50 mm thick)
(Omax Corporation, USA)

Different engineering components
(Omax Corporation, USA)