Advanced Manufacturing Processes (AMPs)

Water Jet Machining

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Chapter Description

- Aims
  - To provide and insight on Water Jet Machining (WJM)
  - To provide details on why we need (WJM) and its characteristics
- Expected Outcomes
  - Learner will be able to know about WJM
  - Learner will be able to identify role of WJM in todays sceneries
- Other related Information
  - Student must have some basic idea of conventional manufacturing and machining
  - Student must have some fundamentals on materials
- References
- Lecture notes by Mr. Wahaizad (Lecturer, UMP, FTeK)

WATER JET MACHINING (WJM)

It is known that water can cut. However, efficiency and reliability is low.

In water jet machining, high velocity water jet is allowed to strike a given workpiece. During this process, its kinetic energy is converted to **pressure** energy. This induces a stress on the workpiece. When this induced stress is high enough, unwanted particles of the workpiece are automatically removed.

Material removal is by **erosive action** of water, through impact of high velocity water. Very high pressure, up to 400 MPa (50,000 psi) produces water jet velocity up to 900 m/s (mach 3).

Small nozzle orifice produces very narrow kerf (width of cut).

Water jet **velocity**: (Bernoulli's equation)

$v = \sqrt{(2p/\rho)}$

where:

p = pressure

ρ = fluid density

Volume **flow rate**:

$Q = C_D Av$

where:

C_D = orifice coefficient

A = orifice area

Power required:

$W = pQ/\eta$

where:

η = efficiency.

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EQUIPMENT

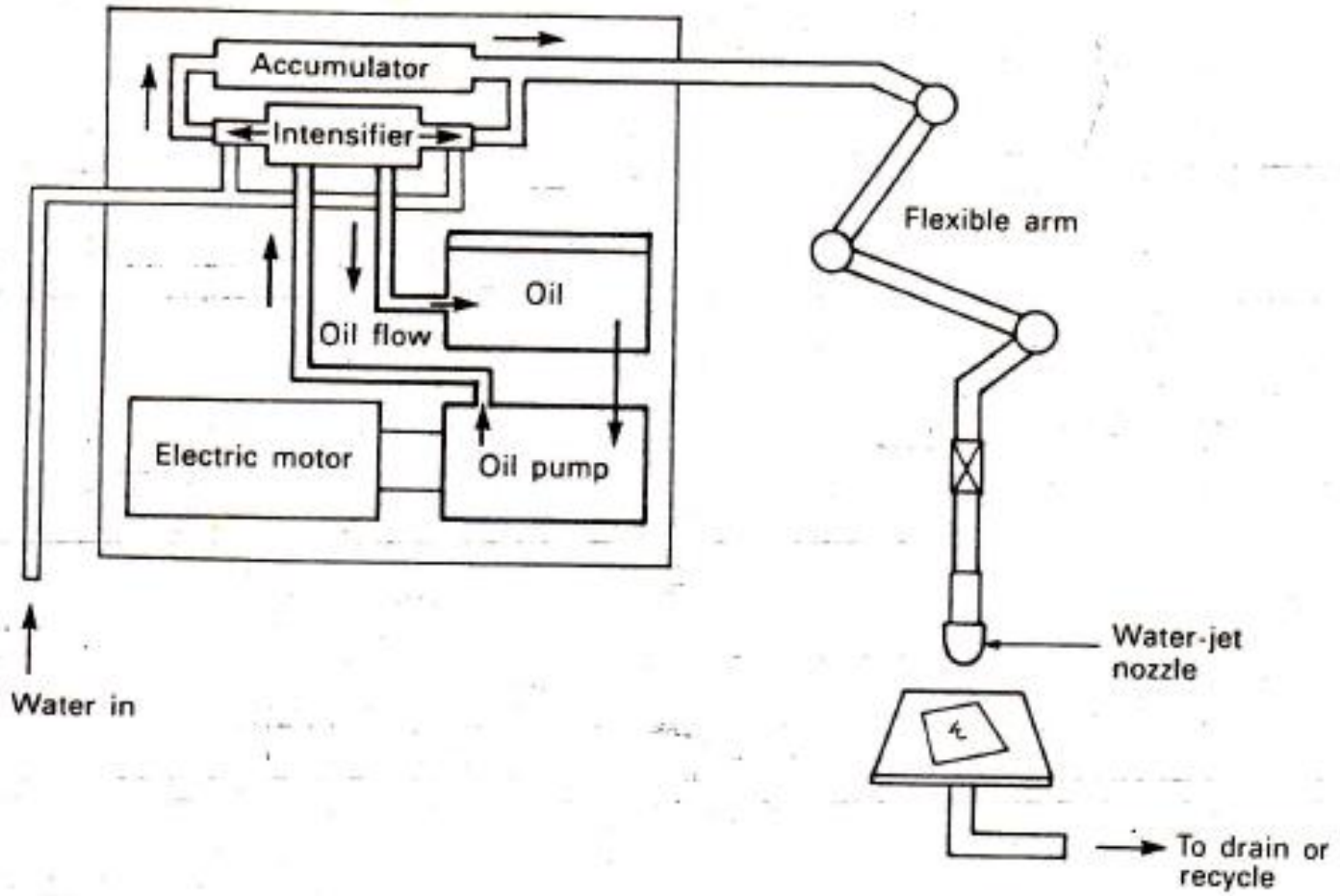


Figure: Water jet machining system

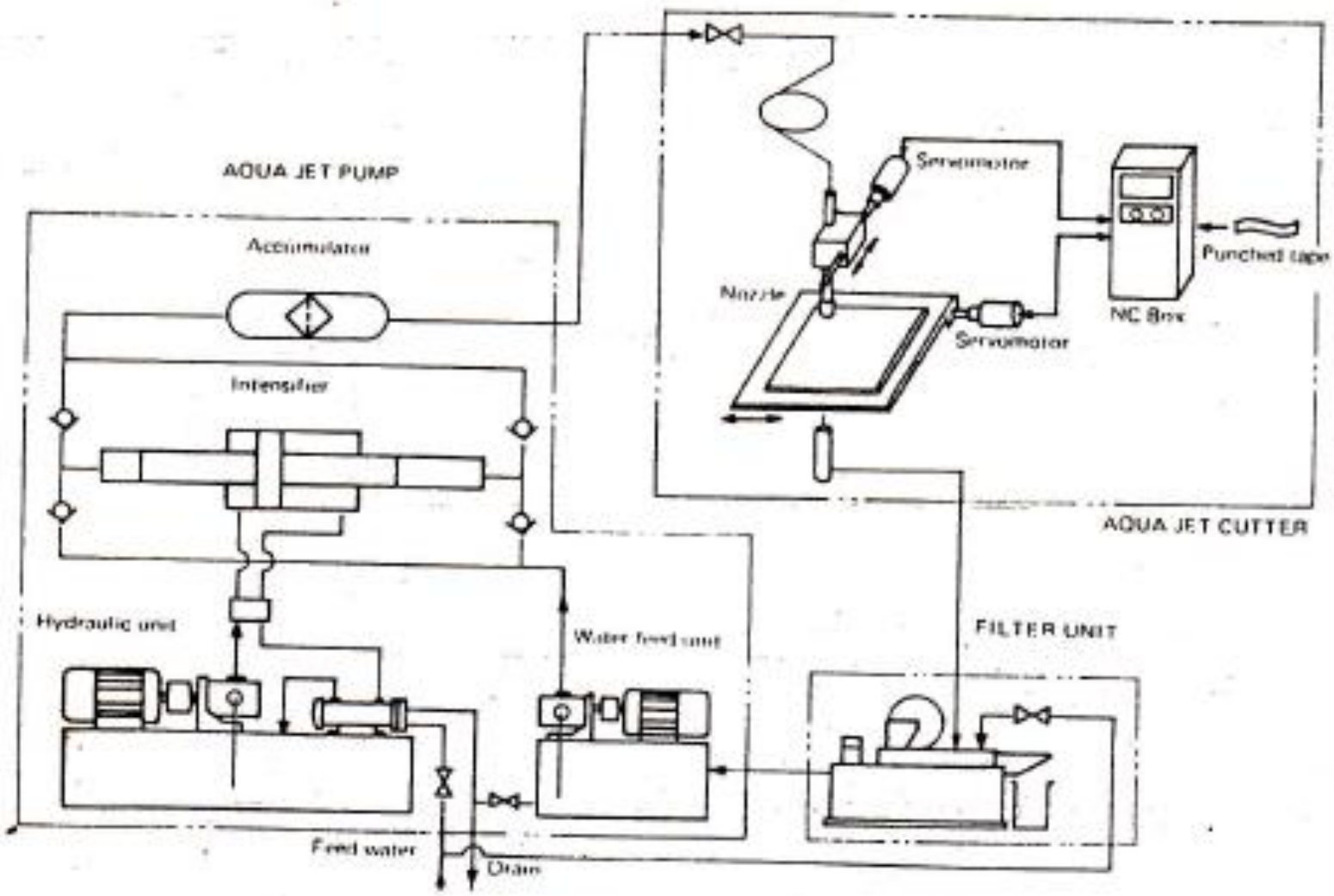


Figure: Water jet cutting system consisting of:
(1) water jet pump unit, (2) filter unit, and (3) cutting unit

EQUIPMENT

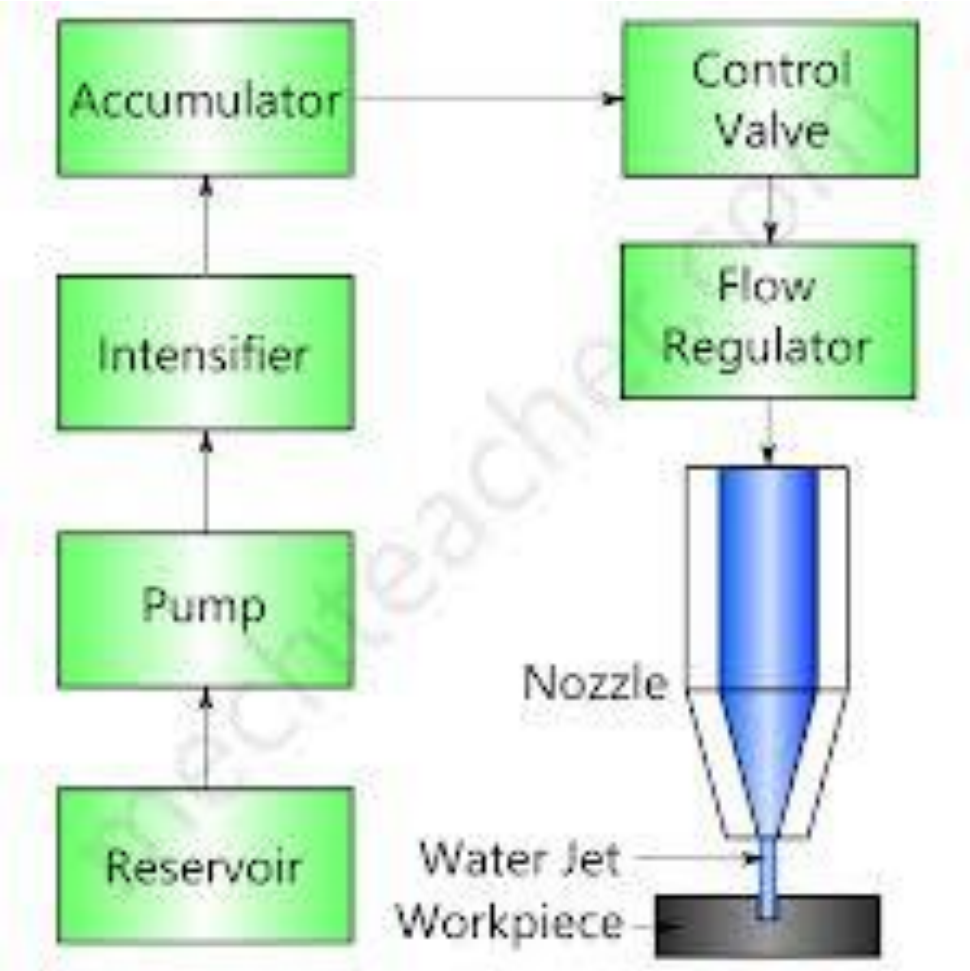
- WJM equipment consists of pump, cutting unit, and filtering unit.
- Hydraulic pump powered by electric motor (about 30 kW) provides pressure up to 117 bars to drive a reciprocating ram (intensifier). Pressure intensifier, in combination with accumulator is used to produce very high water pressure. Input water pressure of 4 bars is increased to output pressure of 3800 bars.

Alternatively, multiple piston pumps are used.

- Jet nozzle can be manipulated manually.

- Jet nozzle can be easily automated since nozzle is not in contact with work material.

Elements in WJM system



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Construction of WJM

The apparatus of water jet machining consists of the following components:

- **Reservoir:** used to store water to be used in machining operation.
- **Pump:** pumps water from reservoir.
- **Intensifier:** is connected to the pump. It pressurizes the water acquired from the pump to a desired level.
- **Accumulator:** used to temporarily store pressurized water. It is connected to the flow regulator through a control valve.
- **Control Valve:** controls direction and pressure of pressurized water that is to be supplied to the nozzle.
- **Flow regulator:** used to regulate flow of water.
- **Nozzle:** renders the pressurized water as a water jet at high velocity.

Working of Water Jet Machining (WJM)

- Water from **reservoir** is pumped to intensifier using hydraulic pump.
- The **intensifier** increases water pressure (typically 200 to 400 Mpa).
- Pressurized water is then sent to accumulator. **Accumulator** temporarily stores pressurized water.
- Pressurized water then enters **nozzle** by passing through control valve and flow regulator.
- **Control valve** controls direction of water and limits the pressure of water under permissible limits.
- **Flow regulator** regulates and controls flow rate of water.
- Pressurized water finally enters the nozzle. Here, it expands with tremendous increase in its kinetic energy. High velocity water jet is produced by the nozzle.
- When this water jet strikes the workpiece, stresses are induced. These stresses are used to remove material from the workpiece.
- Water used in WJM may or may not be used with stabilizers. **Stabilizers** are substances that improve the quality of water jet by preventing its fragmentation.

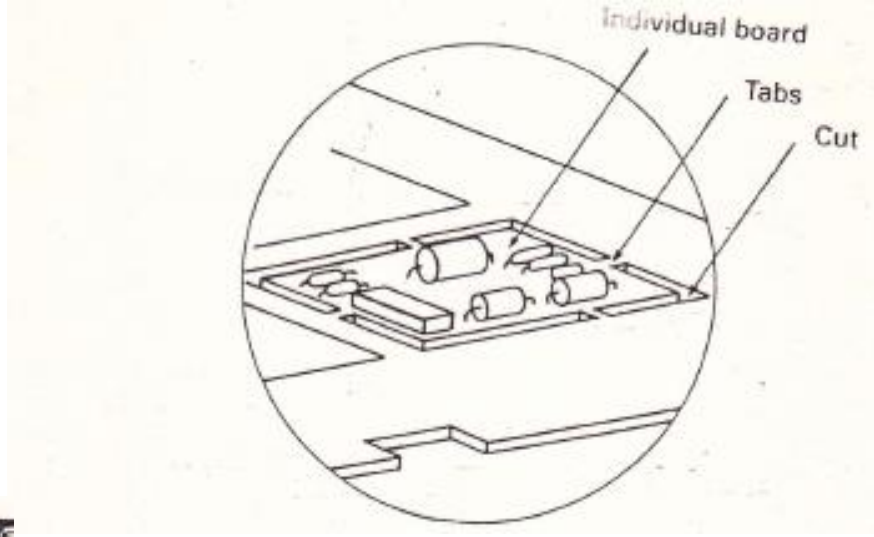
EQUIPMENT

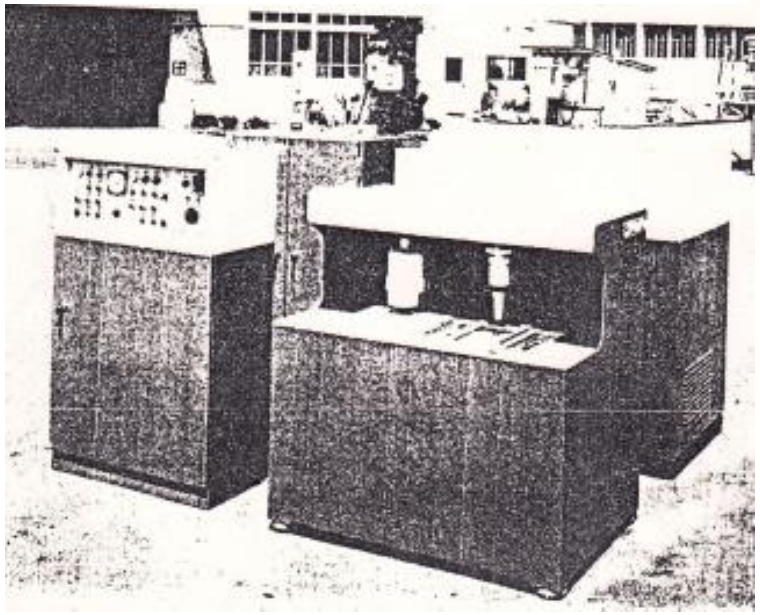
Available systems:

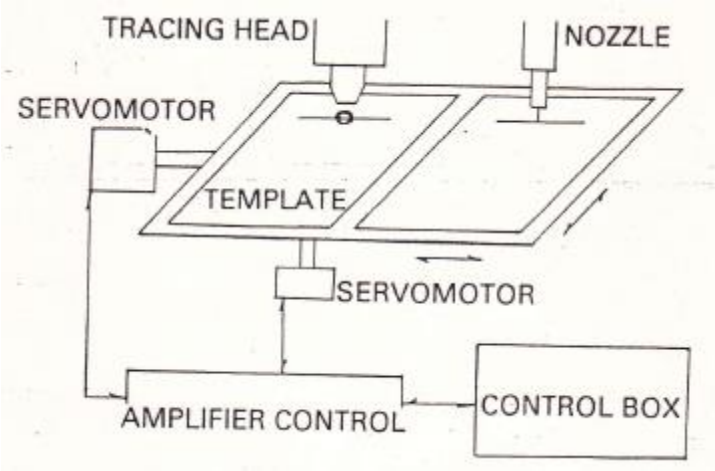
- Optical tracing system – optical scanner traces line drawing which produces electronic signals to control x and y axes.
- Nozzle attached to robot wrist.
- Nozzle held over NC coordinate table. 3D controlled can be achieved to produce non-uniform surface. NC is suitable for mass production of any shape continuously, accurately and repetitively.

Advanced systems are used in aircraft, automobile, paper and pulp, and wood industry.

Optical tracing system







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Robot operated

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[Spectraglass, Oldham, UK]

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Multiple heads WJM

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Nozzle

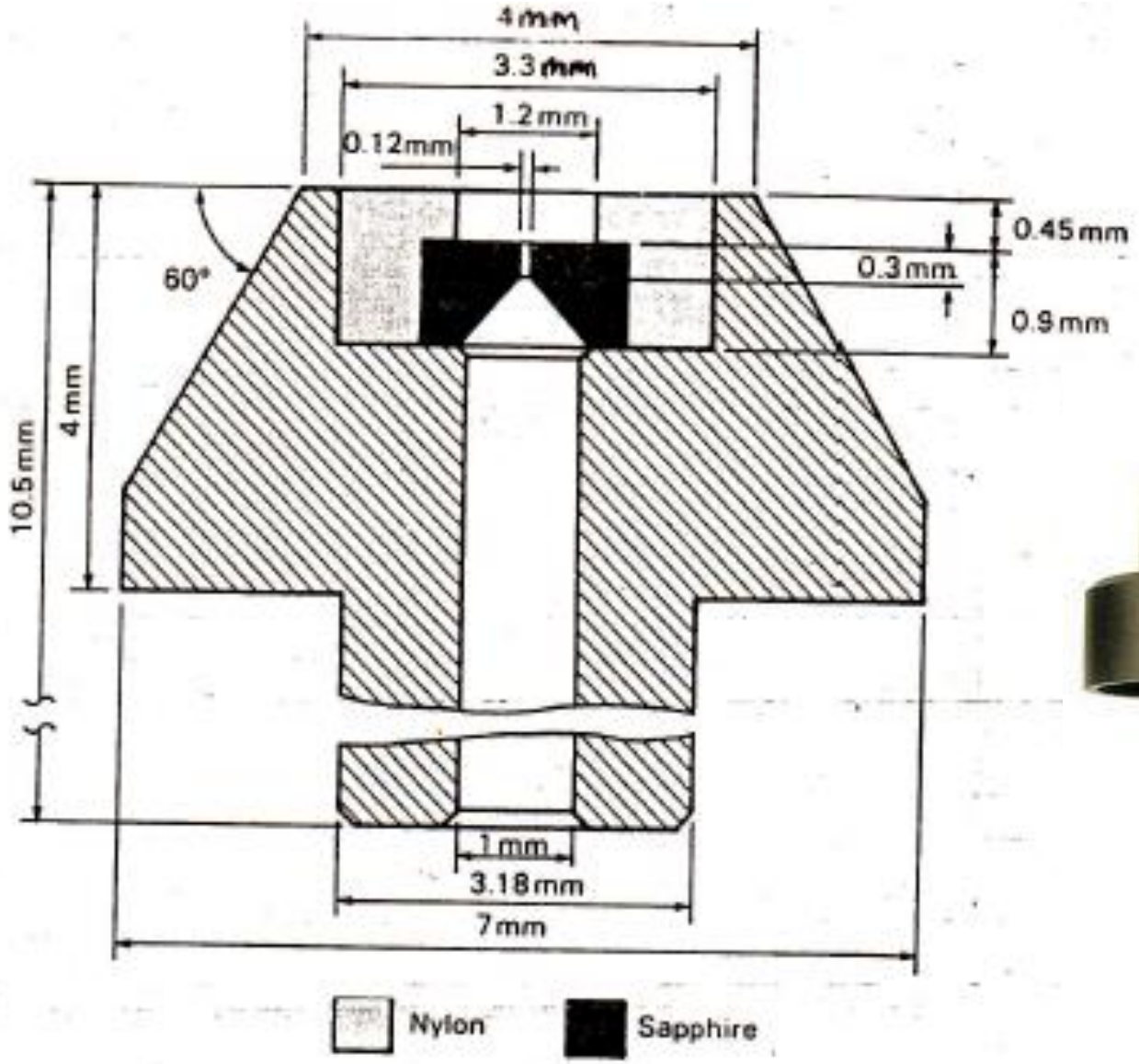
Nozzle consists of **insert** from diamond, sapphire or ruby, stainless steel **body** and nylon **holder**. Orifice diameter: 0.1 to 0.4 mm (0.05 to 1 mm [*Kalpakjian*]).

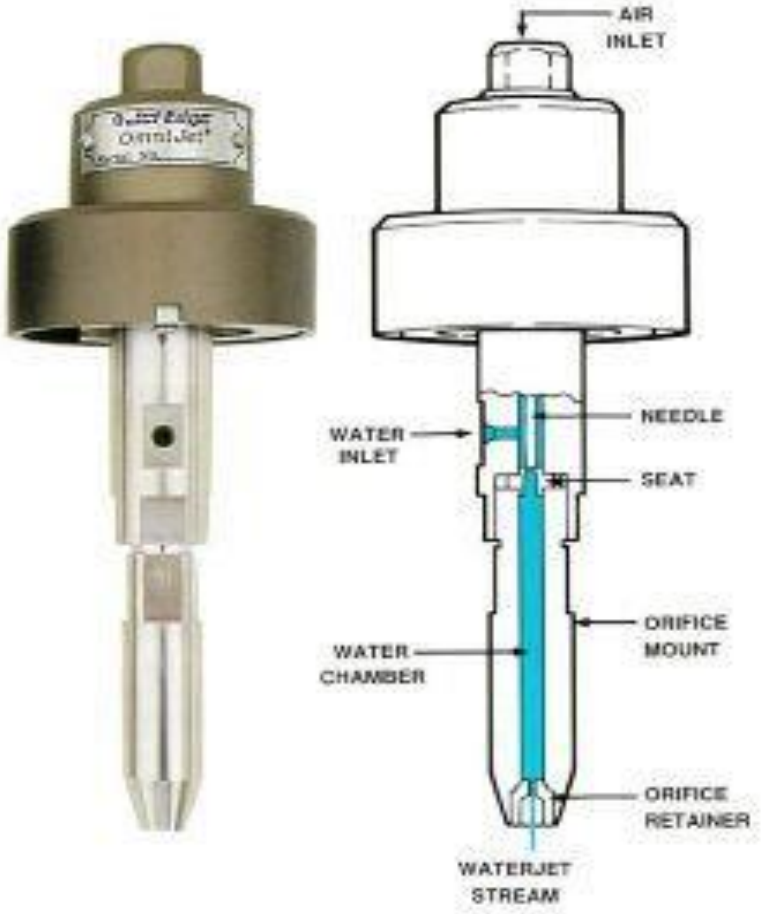
Constant **nozzle tip distance** can be controlled to produce uniform cut.

Fluid

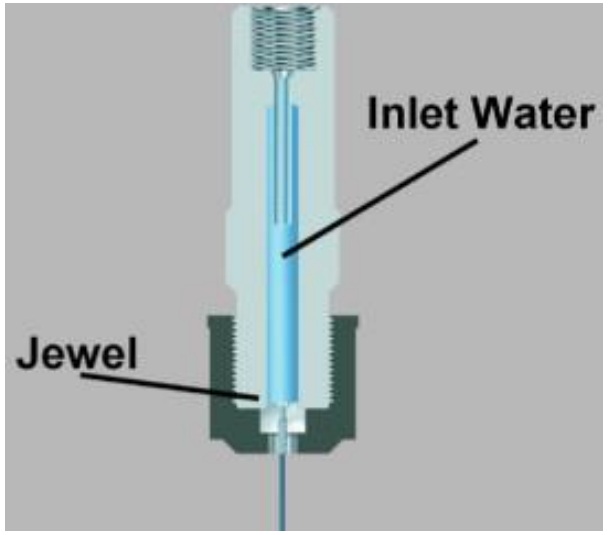
Fluid used: water or polymer solution (water and additives) such as glycerin and polyethylene oxide. Polymer solution produces more coherent jet and sharper corners.

Apart from providing erosive action, fluid carries chips. Liquid needs to be filtered.

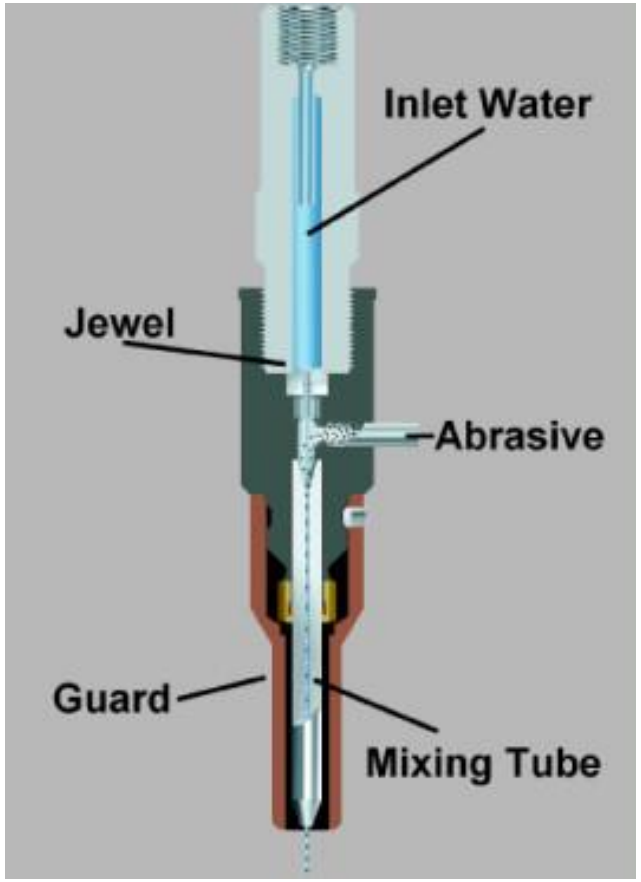




Typical jet cutting nozzle (body: stainless steel, holder: nylon, insert: diamond, ruby or sapphire) *[Engemann]*



Waterjet nozzle.
Note: jewel = orifice



Abrasive waterjet nozzle

Waterjet nozzle (left);
Abrasive waterjet nozzle (right)

PARAMETERS

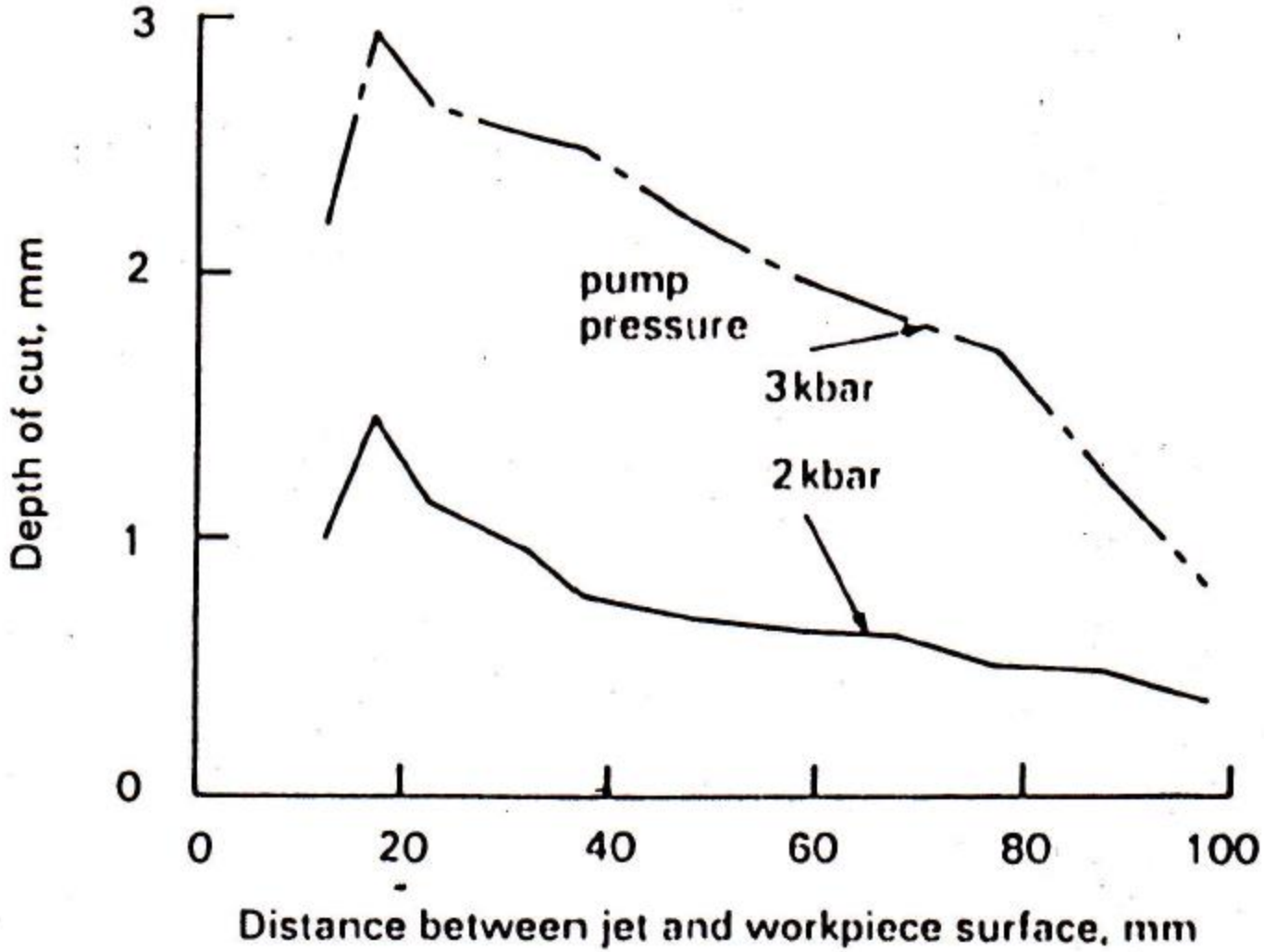
Performance is affected by **orifice diameter**, water **pressure**, cutting **feedrate**, nozzle **distance**.

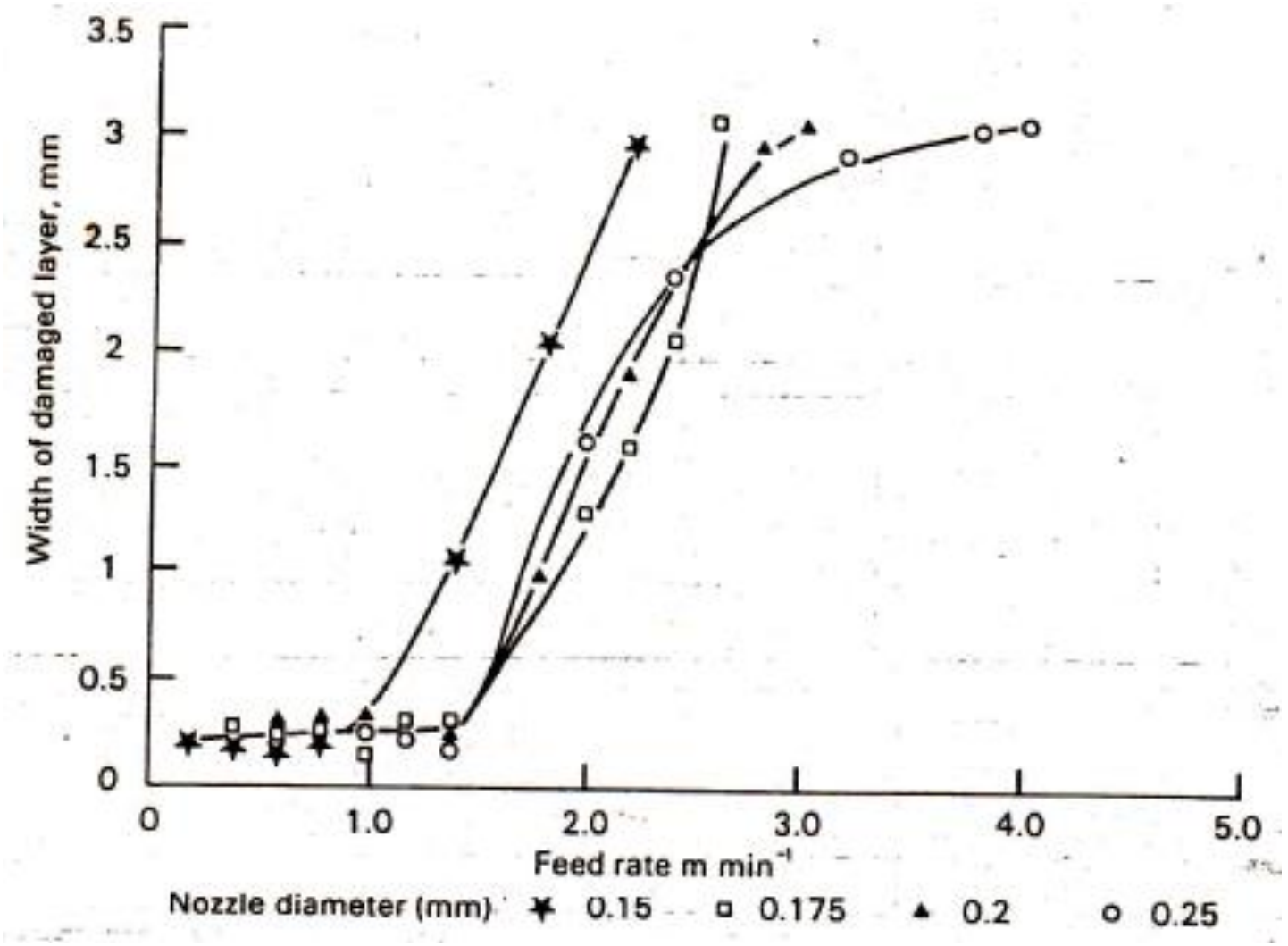
When nozzle tip distance increases, the thickness of work that can be cut decreases.

Good cutting quality is normally produced by:

- **high pressure**,
- **small orifice diameter**,
- **low feedrate**,
- **small nozzle distance**.

Tests are required to determine best parameter combination.


Depth of cut, mm
3
2
1
0
pump
pressure
3 kbar
2 kbar
0
20
40
60
80
100
Distance between jet and workpiece surface, mm



Effect of feed rate on width of damaged layer *[Koenig et al]*

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Sample cutting conditions for WJM

Materials	Thickness (mm)	Nozzle Dia (mm)	Pressure ksi (MPa)	Feed Rate (mm/s)	Remarks
Leather	2.2	0.2	294	330	Density 0.09g/cm^3
Vinyl Leather	0.7	0.2	245	500	Density 0.10g/cm^3
Synthetic Rubber	1.5	0.2	196	830	
Vinyl Chloride	3	0.2	294	8	
Polyethylen	3.6	0.2	196	100	
Polyester	2	0.2	431	2500	
FRP	0.5	0.2	294	33	
Kevlar	3	0.2	294	50	
Graphite	2.3	0.2	294	80	
Urethane	2.5	0.2	294	170	
Sythrene Foam	14	0.2	147	83	
Glass Wool	25	0.2	98	167	
Felt	9	0.2	196	5	
Ceiling Board	9	0.2	196	2330	Density 0.04g/cm^3
Gypsum Board	10	0.2	196	100	Density 0.06g/cm^3
Asbestos Board	6	0.2	98	17	Soft Type
Cement Asbestos	18	0.2	392	17	
Rock Wool	100	0.2	294	830	Density 80kg/m^3
Corrugated Board	7	0.2	255	3300	Double Wall, 900g/m^2
Paper Board	1	0.2	245	8330	Tri Wall, 800g/m^2
Pulp Sheet	2	0.2	196	2000	Density 0.05g/cm^3
Press Board	0.5	0.2	294	2500	
Plywood	6	0.2	294	17	Density 0.05g/cm^3
Sponge Cake	60	0.2	294	167	
Butter	50	0.2	294	8	Discolored
Ice	230	0.3	294	17	

ADVANTAGES

- no tool wear (nozzle life: 200 hours; damage is due to flow, and mineral deposit)
- a cool process, does not burn or thermally affect the cut surfaces.
- easy maneuverability of workpieces. Unlike saws which cut mainly in straight lines, water jet can cut curves, tapered or beveled holes, and complex shapes
- tolerances of the order of ±0.13 mm can be obtained.
- relatively fast
- no chips or abrasives embedded in work material
- clean surface
- requires little attention
- eco-friendly

Disadvantages

1. Not a powerful process. Limited to soft materials. While it is possible to cut tool steel and other hard materials, cutting rates will drop dramatically and the time to cut the part may be very long and thus not economical.
2. Very thick materials cannot be easily machined.
3. Jet has limited transverse stability. Effects:
    - can result in grooves on surface
    - jet deflection can cause fibres in composites to be jumped over.

   Thus, slow feed rate must be used to avoid the above problems.

1. Taper. The deceleration of the head may reduce this.
5. High initial investment cost.

APPLICATIONS

- Soft and friable materials are easiest to cut.
- Brittle materials are not suitable because they crack or break under the action of the water jet.
- WJC is the process of choice for cutting sheets of paper, cloth, kevlar, glass epoxy, fibre-reinforced plastics.
- Also suitable for foods, leather, rubber, insulation, cardboard, automotive carpeting.
- Titanium and boron can be cut.

Examples of machining

Machining of fibre reinforced plastics (cutting feedrate is limited by quality of cut – smooth above and rougher below. High pressure [3500 bars] required to increase quality and speed)

Vinyl and foam coverings for some automobile dashboards (using multiple-axis, robot guided WJM)

Cutting of rocks

Water jet deburring

Cutting of PCB (typical speed 8 m/min, accuracy $\pm$ 0.13 mm)

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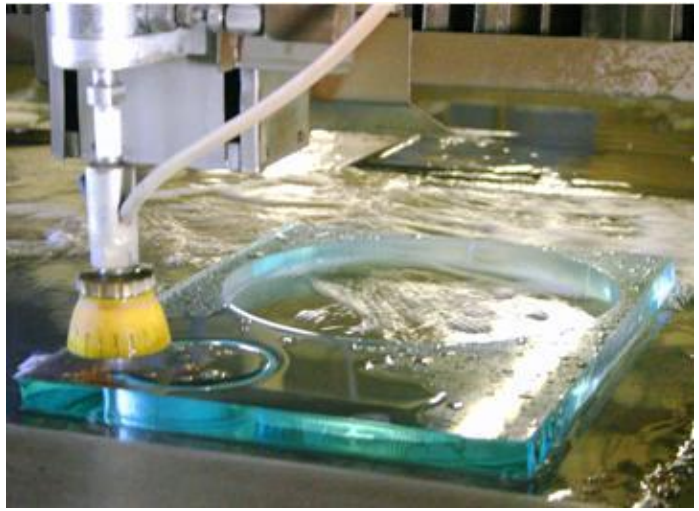
Material	Thickness (mm)	Feed rate ($m\ min^{-1}$)
GFRP Laminate	2.2	1.8 to 6.0
	3.0	1.4 to 5.0
	5.0	0.4 to 3.0
AFRP (Weave)	1.0	10.0
	2.0	2.4 to 4.0

Limiting feed rate for WJM. Data: water pressure – 3500 bar, nozzle diameter – 0.18 mm, standoff distance – 2 mm
[Koenig et al]



Low expansion optical glass. Typical speed: 13 mm/s for t = 25 mm

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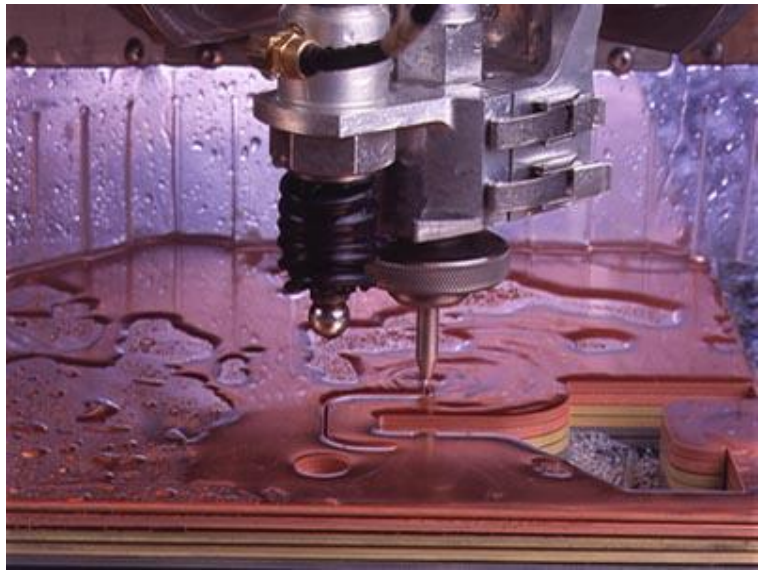
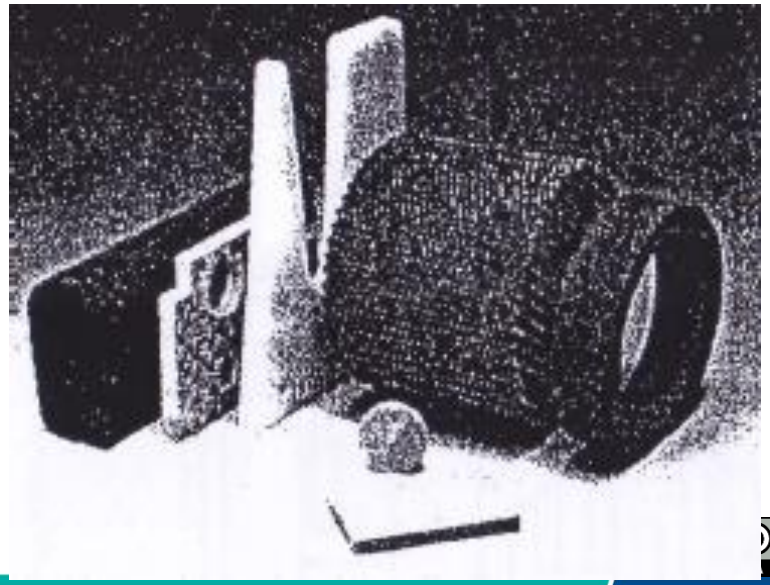


[Hayes & Stolz, Texas]

Jigsaw parts from wood

Parts from rubberised cork, felt, urethane and silicone



COMPETITIVE PROCESSES

EDM is more productive and competitive, but limited to electrically conductive work materials.

LBM and EBM are more powerful but require more complex and expensive equipment.

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