Advanced Manufacturing Processes (AMPs)

Abrasive Jet Machining

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Chapter Description

- Aims
  - To provide and insight on Abrasive Jet Machining processes
  - To provide details on why we need AJM and its characteristics

- Expected Outcomes
  - Learner will be able to know about AJM
  - Learner will be able to identify role of AJM in todays sceneries

- Other related Information
  - Student must have some basic idea of conventional manufacturing and machining
  - Student must have some fundamentals on materials

ABRASIVE JET MACHINING (AJM)

- A mechanical process to remove materials through impingement action by fine abrasive particles.
- Particles move at high velocity in a jet of air or gas such as nitrogen or carbon dioxide.
  (if in water → abrasive water jet machining, AWJM).
- Abrasives exit the nozzle at high pressure and velocity (150 – 300 m/s).

- By controlling the quantity of abrasive flow (using valves) fine or rough machining can be realised.
- Compared with sand blasting, abrasives are much finer and process parameters and cutting action are more controlled.
- Nozzle is held and controlled by hand. Automated nozzle or workpiece motion control is also used. There are machines that can cut directly from a CAD drawing or DXF file.

MECHANICS OF AJM

When abrasives hit work surface at high speed, the impact causes brittle fracture and the chips will be carried away by high air/gas flow.

Process is more suited to hard brittle material.

Pandey and Shan (1980) proposed a method to estimate the MRR:

$$v = X N d^{3} v^{3/2} (\rho / 12 Hw)^{3/4}$$

where:

N = no of abrasive particles hitting per unit time

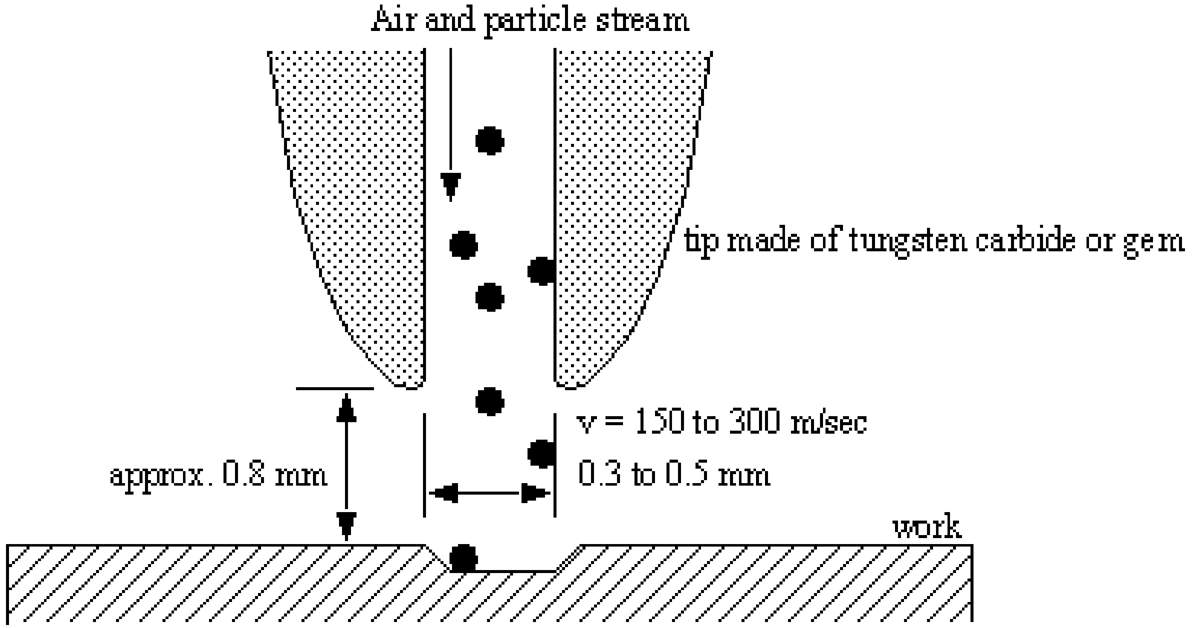
d = average particle diameter

v = particle speed

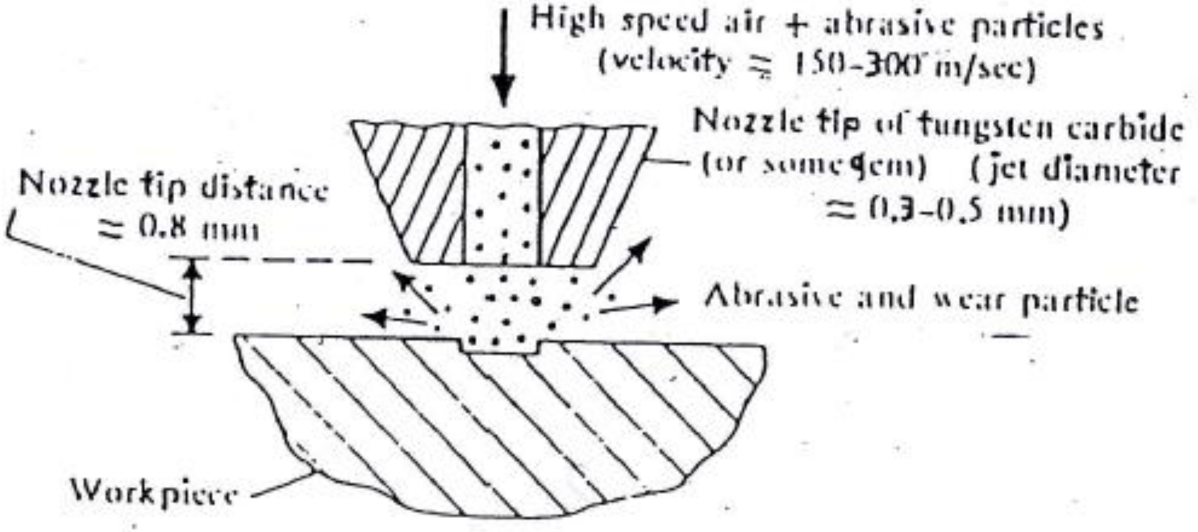
ρ = particle material density

Hw = work material hardness

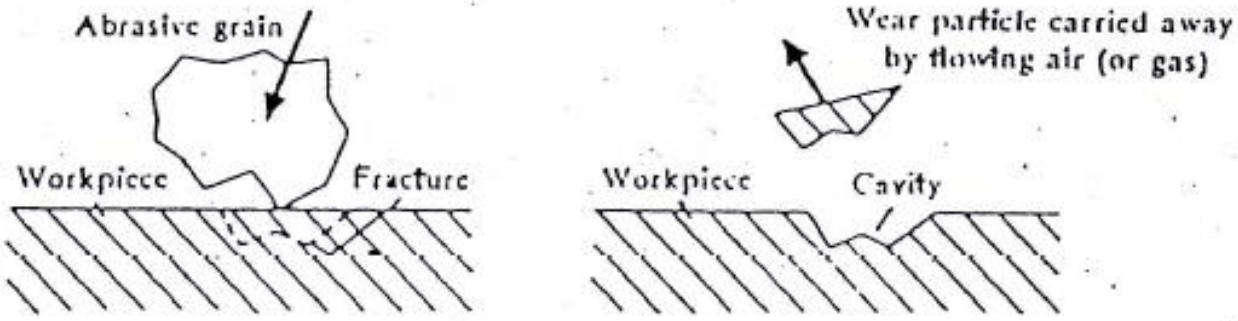
X = constant



Schematic of material removal in AJM



Abrasive jet machining.



(a) Fracture of work surface (b) Formation of cavity

Working Principle

- Dry air or gas is filtered and compressed by passing it through the filter and compressor.
- A pressure gauge and a flow regulator are used to control the pressure and regulate the flow rate of the compressed air.
- Compressed air is then passed into the mixing chamber. In the mixing chamber, abrasive powder is fed. A vibrator is used to control the feed of the abrasive powder. The abrasive powder and the compressed air are thoroughly mixed in the chamber. The pressure of this mixture is regulated and sent to nozzle.
- The nozzle increases the velocity of the mixture at the expense of its pressure. A fine abrasive jet is rendered by the nozzle. This jet is used to remove unwanted material from the workpiece.

EQUIPMENT

The AJM system consists of :

- ✓ air compressor
- ✓ mixing chamber/vibrator
- ✓ work chamber
- ✓ dust collector

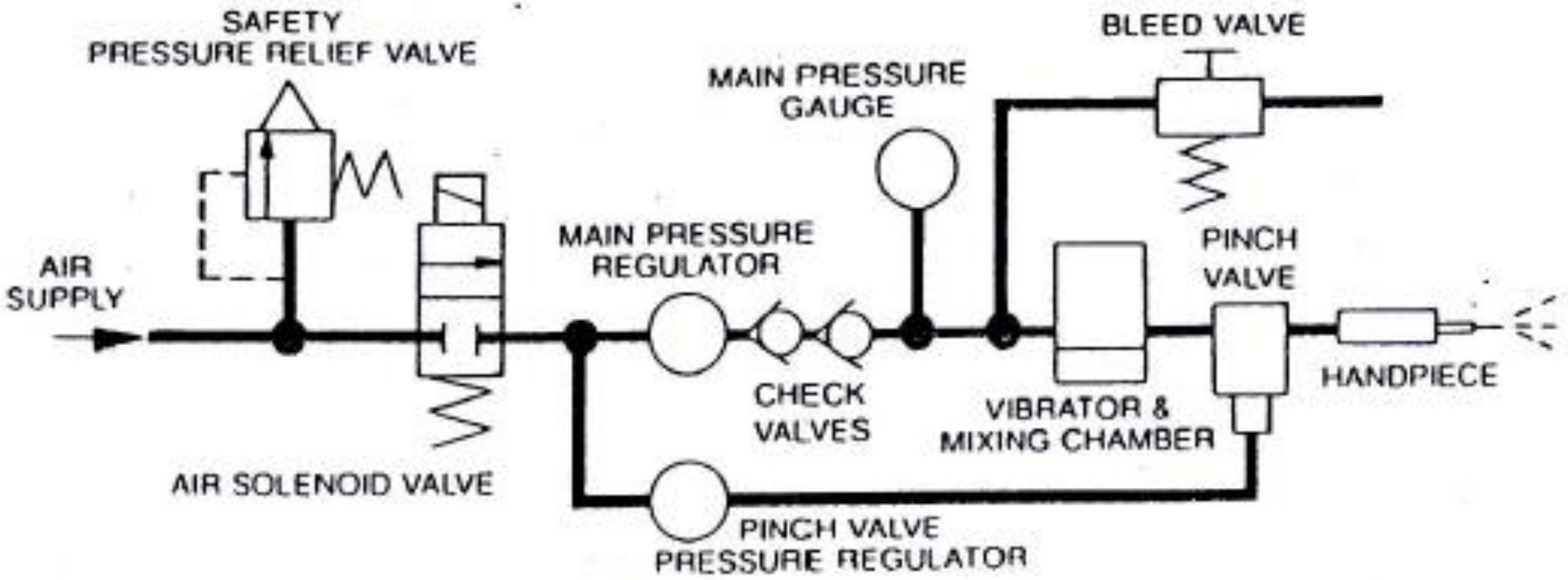
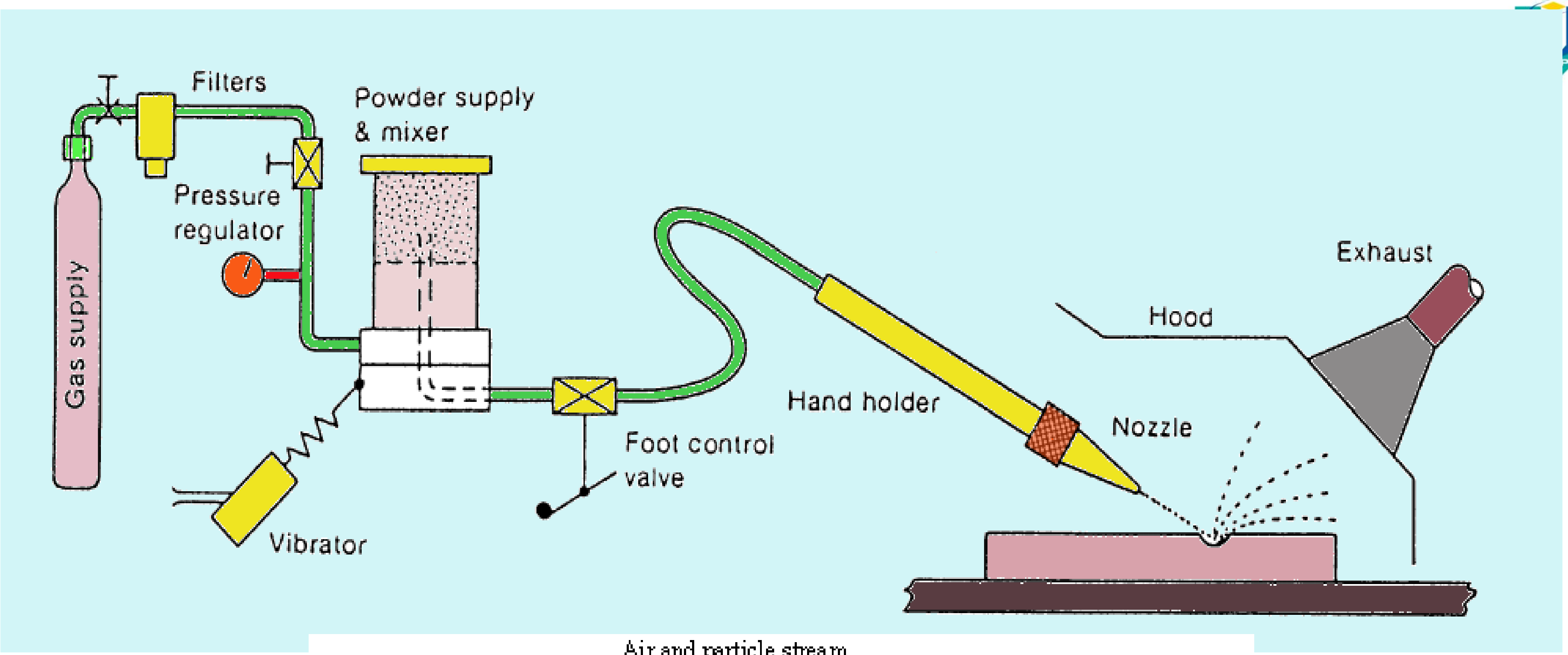
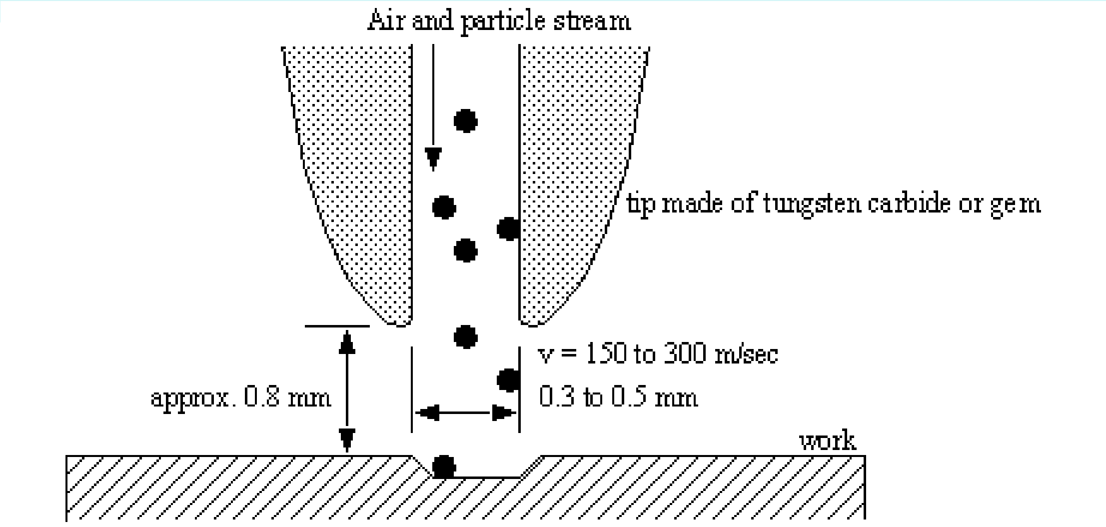


Figure 2-32. Schematic of *Airbrasive* unit. (*Courtesy, S.S. White Company*)


Filters
Powder supply
& mixer
Pressure
regulator
Gas supply
Exhaust
Hood
Hand holder
Nozzle
Foot control
valve
Vibrator


Air and particle stream
tip made of tungsten carbide or gem
v = 150 to 300 m/sec
0.3 to 0.5 mm
approx. 0.8 mm
work

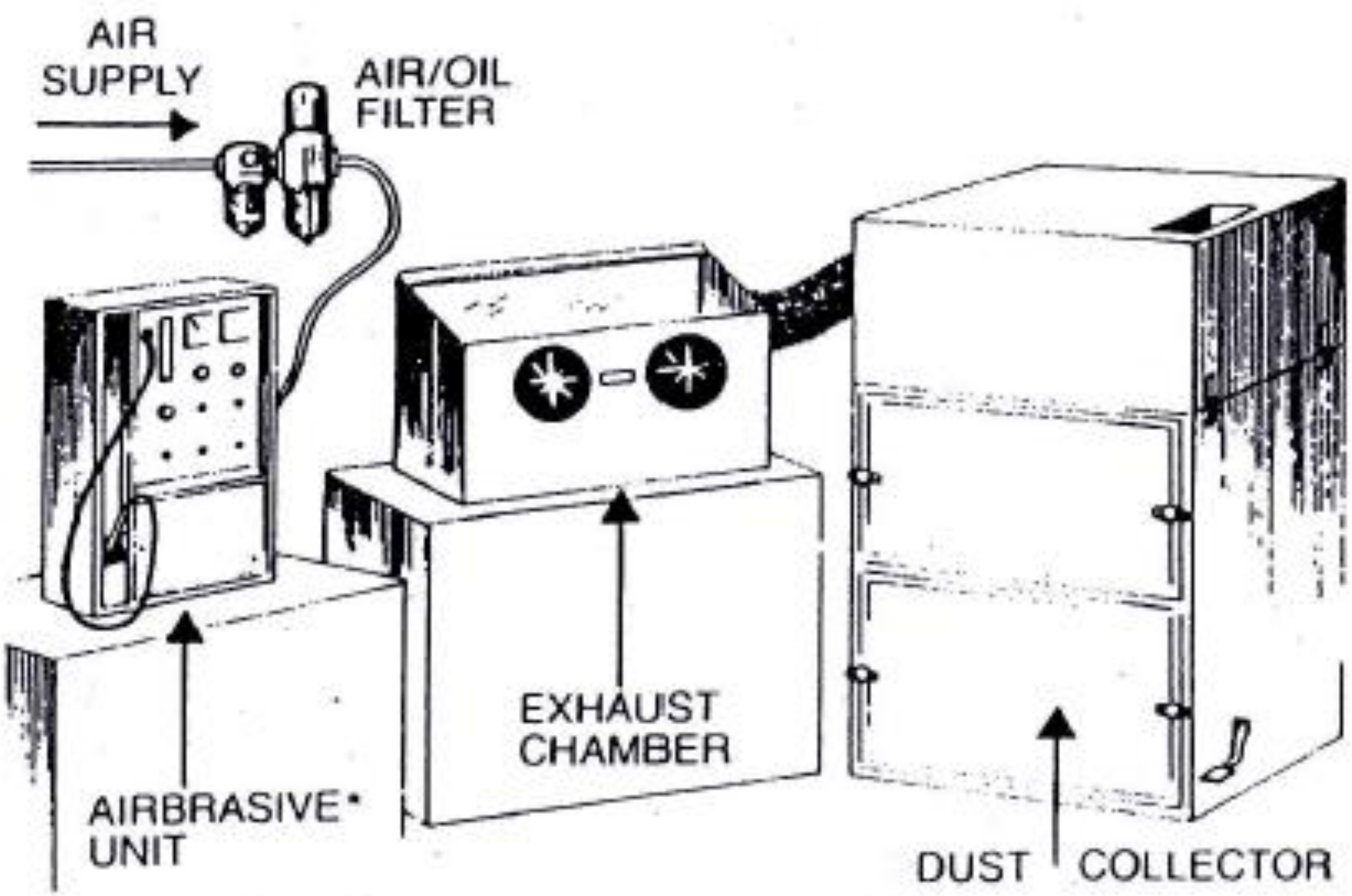


Figure 2-30. Airbrasive unit. *(Courtesy, S.S. White Company)*

Elements of AJM equipment

Abrasive jet: It is a mixture of a gas (or air) and abrasive particles. Gas used is carbon-di-oxide or nitrogen or compressed air. The selection of abrasive particles depends on the hardness and material removal rate (MRR) of the workpiece. Most commonly, aluminium oxide or silicon carbide particles are used.

Mixing chamber: It is used to mix the gas and abrasive particles.

Filter: It filters the gas before entering the compressor and mixing chamber.

Compressor: It pressurizes the gas.

Hopper: Hopper is used for feeding the abrasive powder.

Pressure gauges and flow regulators: They are used to control the pressure and regulate the flow rate of abrasive jet.

Vibrator: It is provided below the mixing chamber. It controls the abrasive powder feed rate in the mixing chamber.

Nozzle: It forces the abrasive jet over the workpiece. Nozzle is made of hard and resistant material like tungsten carbide.

Operations that can be performed using AJM

The following are some of the operations that can be performed using Abrasive Jet Machining:

- Drilling
- Boring
- Surface finishing
- Cutting
- Cleaning
- Deburring
- Etching
- Trimming
- Milling

MACHINING RATE

Because of very small stream of abrasive particles, MRR is low. AJM is a finishing process, not intended for bulk material removal.

Cutting is controlled by gas pressure, position of nozzle, type of abrasive, abrasive flow rate, and time.

Typical MRR around 0.014 mm^3 /s. For glass, a rate of 0.272 mm^3/s (16.3 mm^3/min) can be achieved. Actual rate depends on abrasive size, speed, material cut and mixing ratio.

SURFACE FINISH

The finer the abrasive particles, the finer the surface finish.

For grit size 10 – 50 μm (0.01 – 0.05 mm), a finish up to 0.5 μm (RMS) can be achieved.

TOLERANCE

- Tolerance is very good – a precision process. Tolerances of ± 0.05 mm are possible. Dimensional tolerance to within ± 0.013 mm (± 0.0005 in) is achievable (Omax Corp).
- Hole accuracy: ± 50 μm (0.05 mm). Holes made in metals tend to be tapered.
- Practical minimum width of cut is 0.125 mm.
- Flow of free abrasives tends to round off corners, so designs for AJM should avoid sharp corners. A minimum radius of 0.1 mm is practical

PROCESS PARAMETERS

Process performance is evaluated based on:

- ✓ Material removal rate
- ✓ Tolerance and geometry of cut
- ✓ Surface finish
- ✓ Nozzle wear rate

Parameters that influence the above quantities:

1. **ABRASIVE** (composition, strength, size, flow rate)
2. **PROPELLANT** (composition, pressure, velocity)
3. **NOZZLE** (geometry, material, nozzle distance, striking angle)

1. ABRASIVE (composition, strength, size, flow rate)

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Two main types:

- aluminium oxide (Al_2O_3) – preferred
- silicon carbide (SiC)

Softer particles are used for cleaning, etching and polishing:

- dolomite [calsium magnesium carbonate]
- natrium bicarbonate).

Abrasives need to be graded according to **size** and kept in dry place in order to avoid crumpling together. If particles are **too fine**, they tend to stick together when stored. **Vibration** of grit/powder container is desirable to ensure uniform flow.

Available size: 10 – 50 µm. Best size for cutting: 10 – 20 µm.

Abrasive (cont….)

Particle shape is not important, but for more effective removal, particles should have sharp edges.

Reuse of particles is not encouraged because:

- chips will clog the fine nozzle orifice
- cutting efficiency will drop.

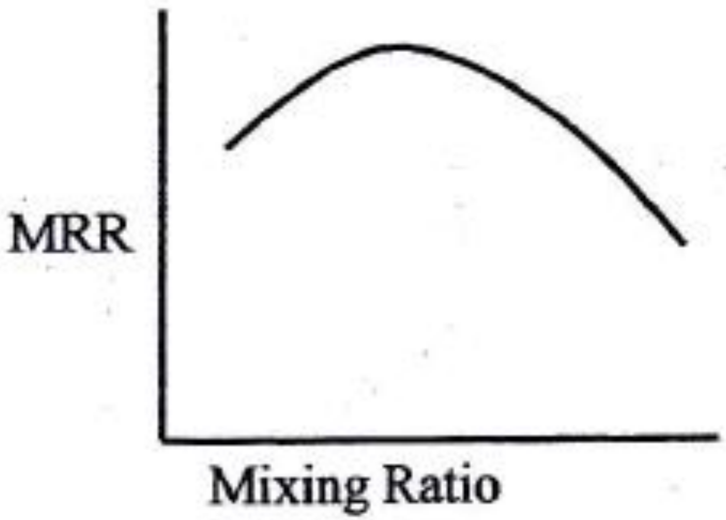
Abrasive mass flow rate depends on mixing ratio and propellant flow rate.

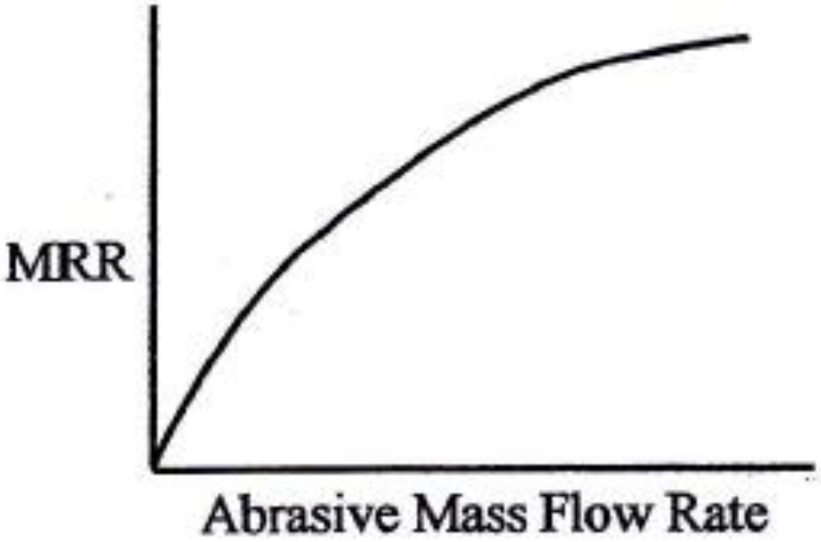
When the ratio of abrasives in jet mixture increases, MRR increases initially, reaching a maximum and then decreases.

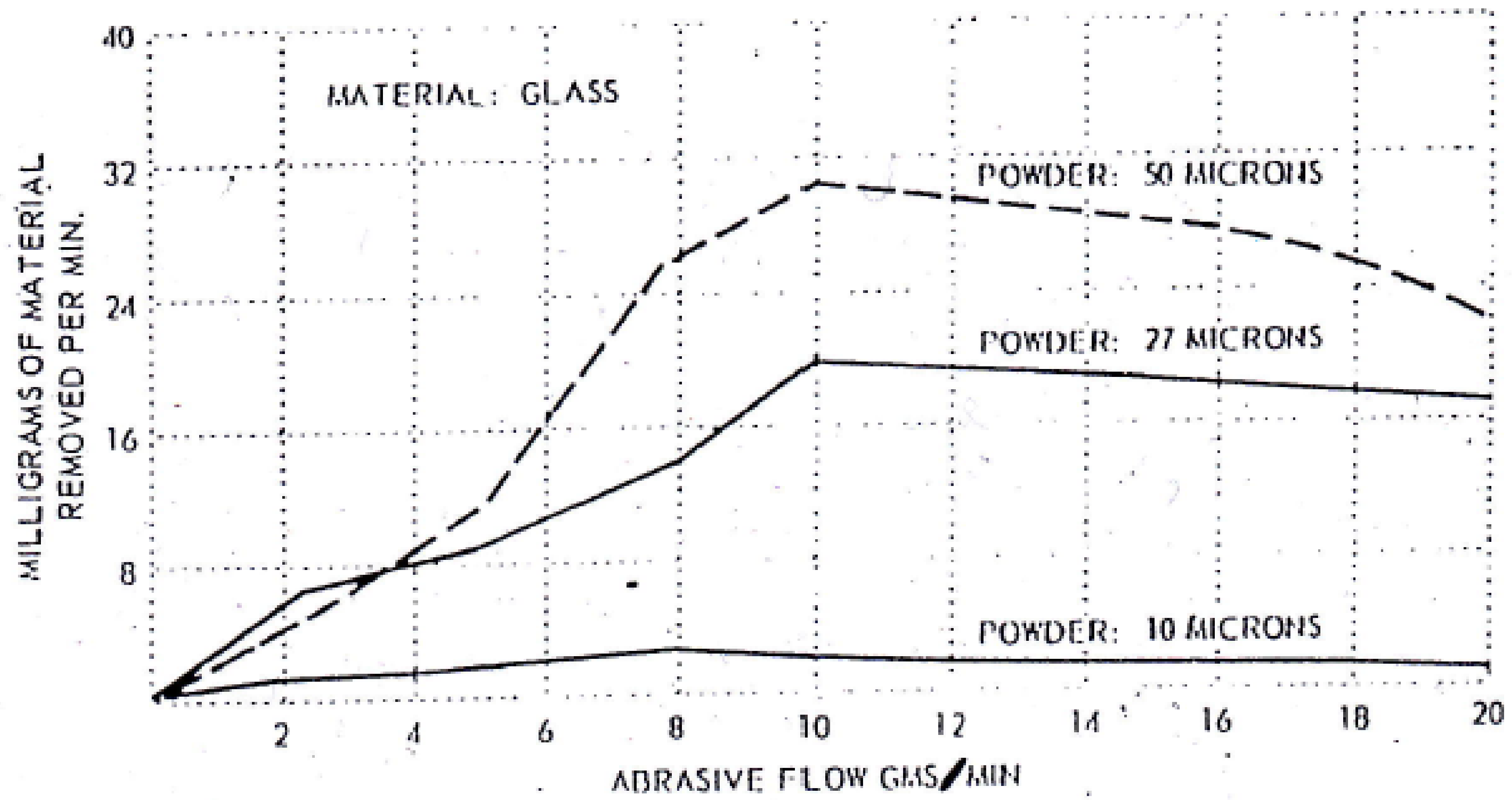
Reason: abrasives collide with each other, hence speed of particles impinging the work material decreases.

Abrasive (cont…)

If mass flow rate increases, MRR also increases.
For optimum operation, particles weight ≈ 1/3 weight of air flowing at any time through the nozzle.



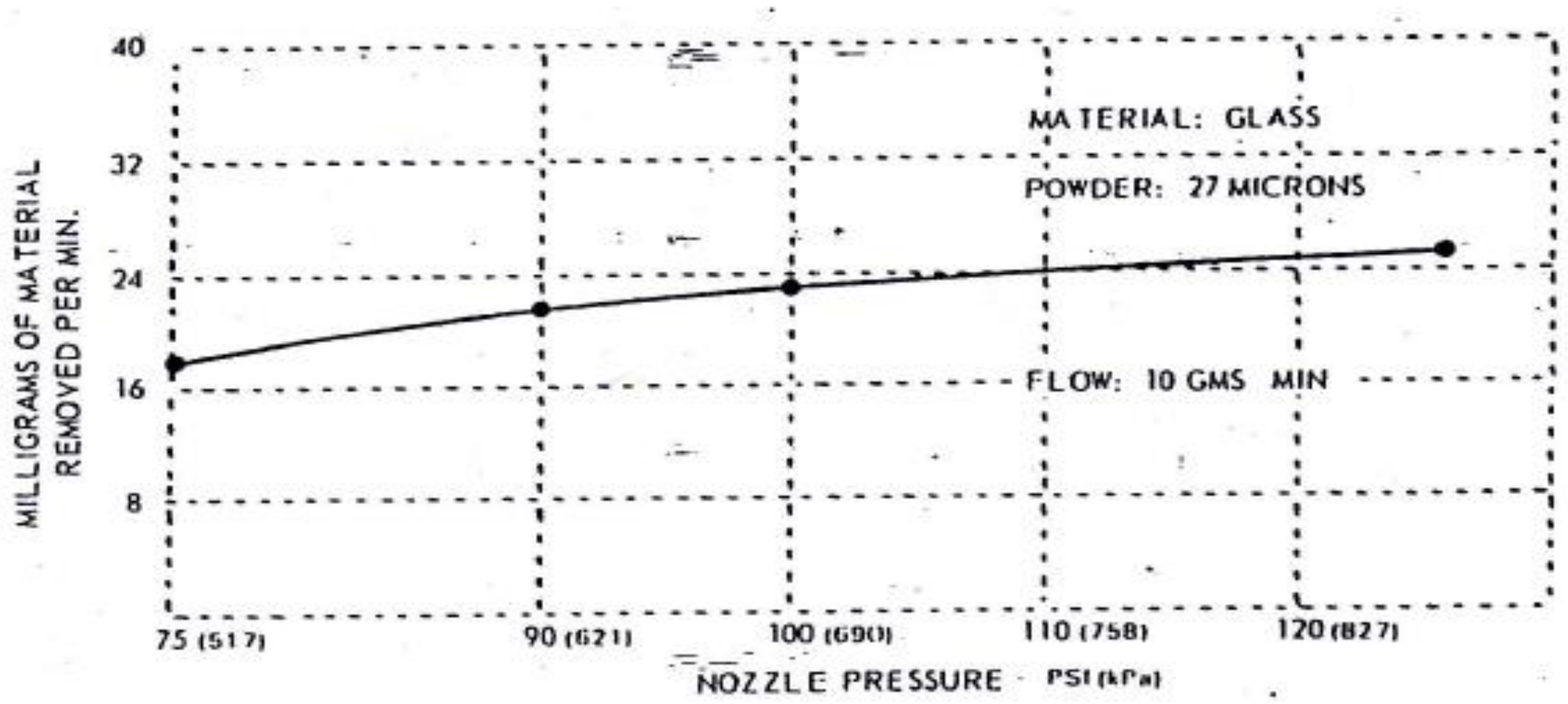




How type of abrasive powder affects cutting speed in glass. (*Courtesy, S.S. White*

2. **PROPELLANT** (composition, pressure, velocity)

- Normally an AJM unit employs 2 – 10 atm pressure (0.2 – 1 N/mm^2).
- Gas composition influences speed-pressure relationship and indirectly influences MRR.
- High speed will increase MRR, even if abrasive mass flow rate remains the same.



3. NOZZLE (geometry, material, nozzle distance, striking angle)

- Nozzle is always in contact with the particles which flow at high speed. So, nozzle material should be of sufficient hardness in order to avoid excessive wear.

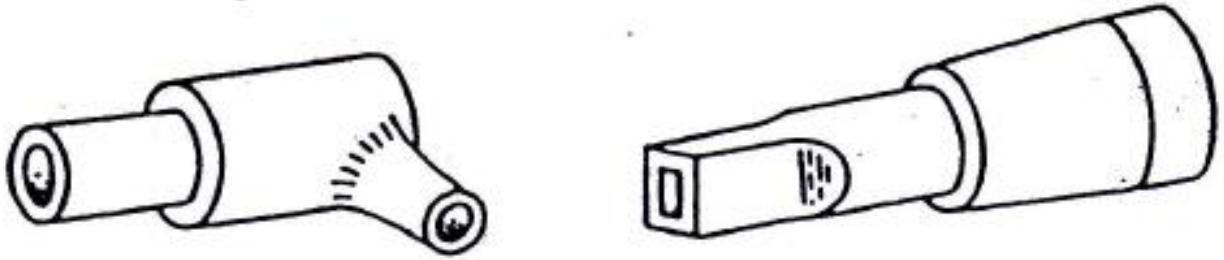
- Materials that can be used:
  - Tungsten carbide (WC) – life: 12 –30 hours
  - Synthetic sapphire – life: 300 hours

- Orifice size depends on particle size and particle flow quantity.

- For normal operation, orifice area is 0.05 – 0.2 mm^2 (diameter 0.07 – 0.46 mm).

- The use of orifice diameter exceeding 1 mm is also reported.

Orifice **geometry**: circular and square.



(a) Right angle head (b) Straight head

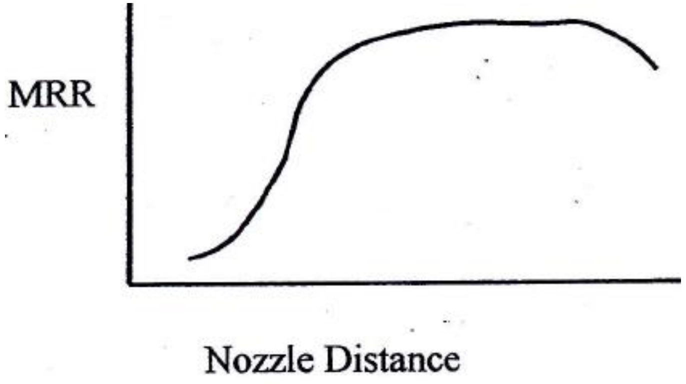
Fig. 6.4 Types of nozzle heads.

Distance of nozzle tip distance influences:

- MRR
- shape and size of cut

If distance increases, abrasive speed increases due to particle acceleration as it leaves the nozzle. So, MRR increases

After that the speed decreases due to air resistance.



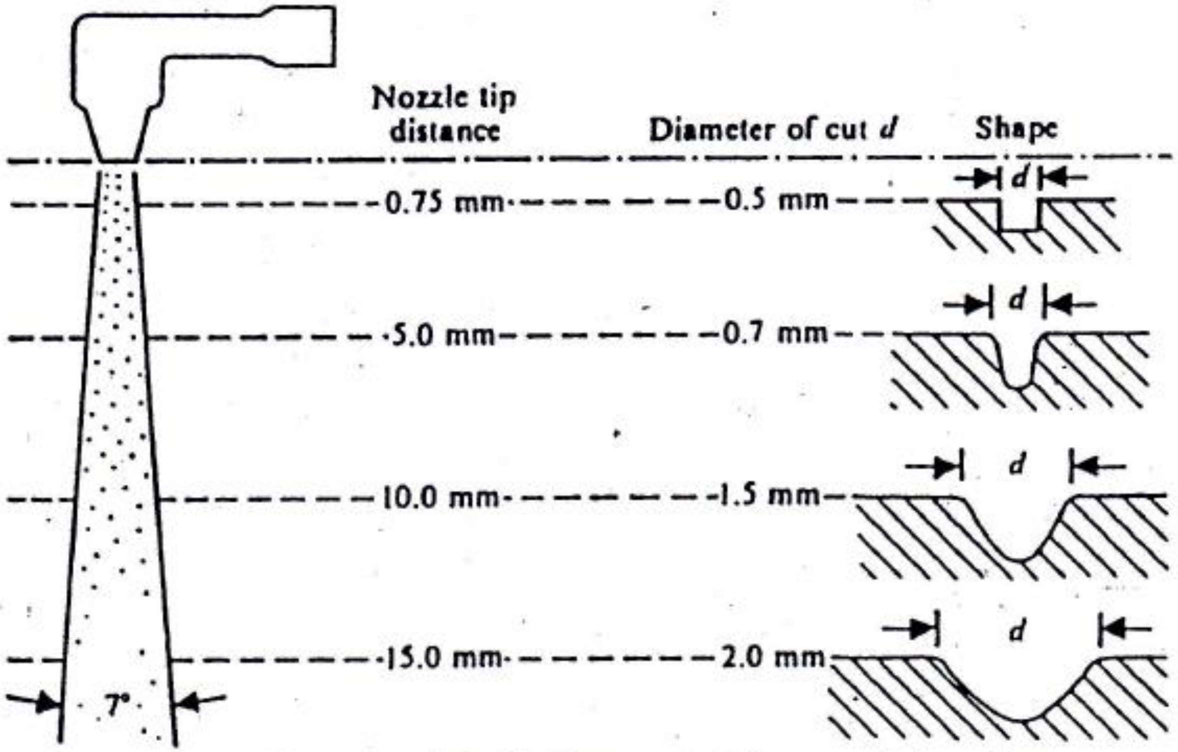
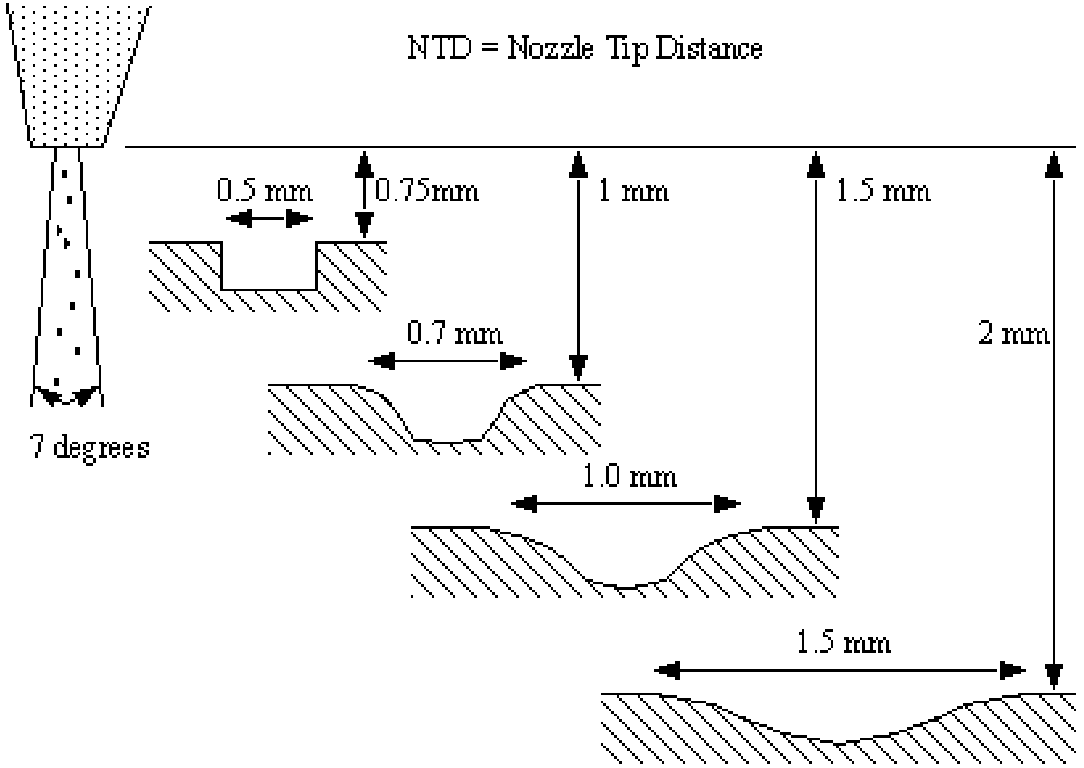


Fig. 6.5 Effect of nozzle tip distance on shape and size of cut.



Advantages of Abrasive Jet Machining

- ✓ Surface of the workpiece is cleaned automatically.
- ✓ Smooth surface finish can be obtained.
- ✓ Equipment cost is low.
- ✓ Hard materials and materials of high strength can be easily machined.
- ✓ Process is particularly suited to short runs and one-off production.
- ✓ Clamping is minimal because tool forces are low.
- ✓ Process is free from chatter since tool is not in contact with workpiece.
- ✓ Virtually no heat is generated in the workpiece because propellant media also acts as coolant.

Disadvantages of Abrasive Jet Machining:

- ✓ Metal removal rate is low
- ✓ In certain circumstances, abrasive particles might settle over the workpiece.
- ✓ Nozzle life is low. Nozzle should be maintained periodically.
- ✓ Abrasive Jet Machining cannot be used to machine soft materials.
- ✓ Because of airborne particulates, some health hazard is involved. Some type of dust collecting system is required.

APPLICATIONS

- To machine **hard and brittle** materials (more of a surface finishing than cutting). **Intricate** shapes can be cut in heat-sensitive or thin material. It also cuts **reflective** and both **conductive** and **non-conductive** materials.

- **Examples** of material: germanium, silicon, mica, glass, ceramics, composites. Even diamonds have been cut, using diamond dust as the abrasive.

- Not suitable for **soft** materials because abrasives tend to become embedded.

Examples of applications:

a) Cutting small holes, slots, or intricate patterns in very hard or brittle metallic or nonmetallic materials

b) Deburring or removing small flash from parts

c) Trimming and bevelling. Useful in the electronic industry. Examples: trimming of thin-film and thick-film resistors in hybrid circuit.

d) Removing oxides and other surface films

e) Cleaning/polishing of components with irregular surfaces

f) Frosting glass

g) ‘Etching’ patterns

What can AJM do that conventional equipment cannot?

- Drill a 0.2 mm hole, without burrs, in the side of a hypodermic needle.
- Trim a 0.075 mm bevel from the edge of a gallium arsenide wafer.
- Mill a 0.125 mm suspended beam into a fragile quartz crystal wafer without micro-fractures.
- Dice gallium arsenide, silicon or ceramic substrates without chipping or fracturing the margins.
- Micro-deburring of critical edges and internal/external diameters without affecting edge integrity.
- Clean and expose grit and dress CBN and diamond grinding wheels during production cycles.
- Reduce grinding wheel breakage by maintaining a constantly aggressive wheel face.
- Precisely prepare dental molds for crowns.
- 'Etch' a 0.025 mm groove in glass, ceramic or metal.
- Remove oxidation from a priceless masterpiece without disturbing the surface of the painting

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