Non-Traditional Machining

Introduction

- Machining is a broad term to describe removal of material from a workpiece.
- Machining categories:
  - Cutting involves single-point or multipoint cutting tools, each with a clearly defined geometry.
  - Abrasive processes, such as grinding.
  - Nontraditional machining, utilizing electrical, chemical, and optical sources of energy.

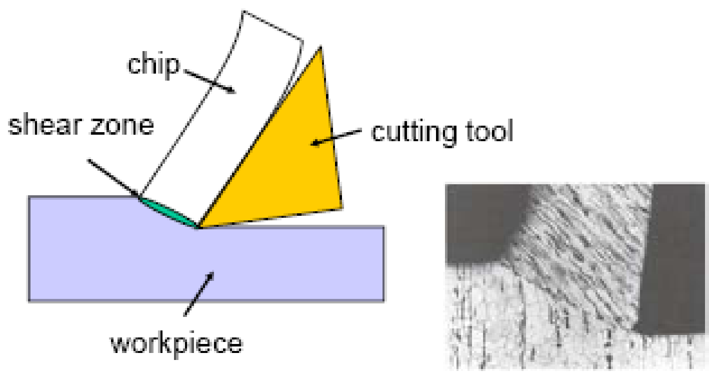
Nontraditional Machining

- Ultrasonic Machining (USM)
- Water-Jet Machining & Abrasive-Jet Machining
- Chemical Machining
- Electrochemical Machining (ECM)
- Electrical-Discharge Machining (EDM)
- High-Energy-Beam Machining
  - Laser-beam machining (LBM)
  - Electron-beam machining (EBM)

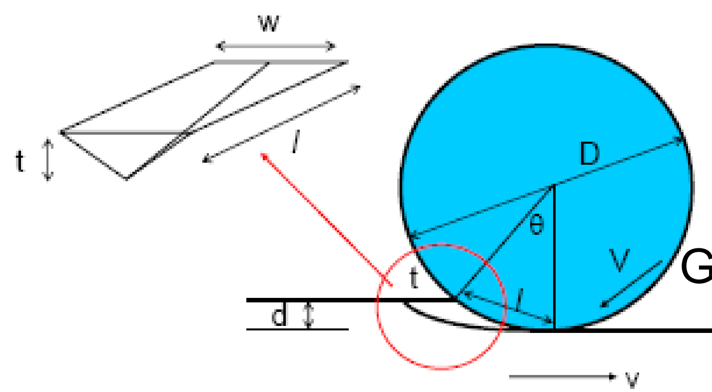
Traditional vs. Nontraditional

- Primary source of energy
  - Traditional: mechanical.
  - Nontraditional: electrical, chemical, optical
- Primary method of material removal
  - Traditional: shearing
  - Nontraditional: does not use shearing (e.g., abrasive water jet cutting uses erosion)

Water jet machining



2D cutting process



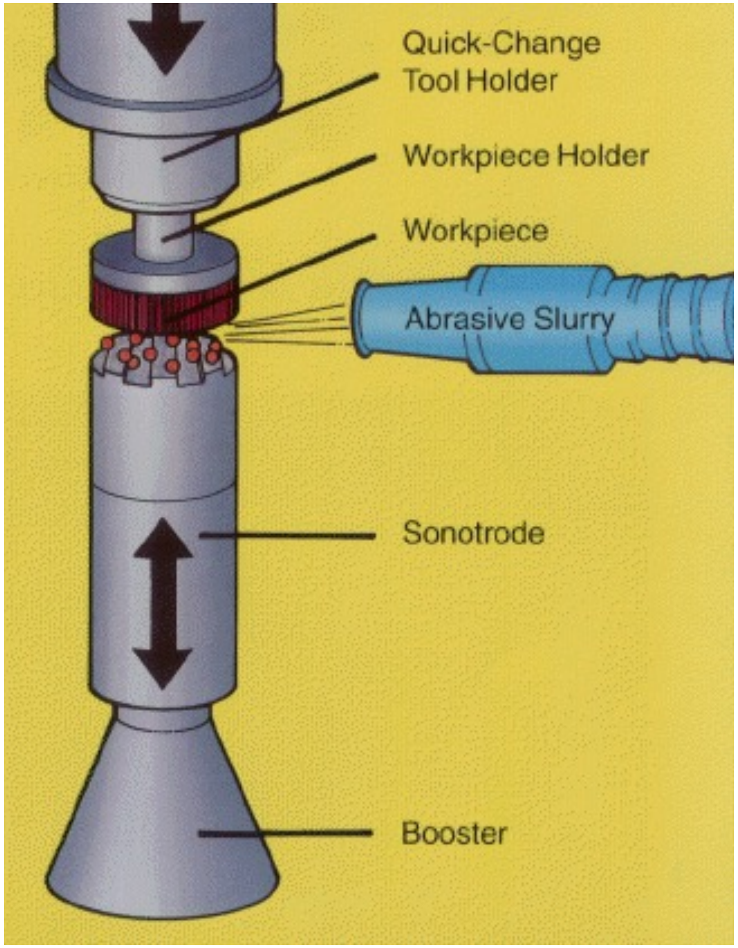
Grinding

Why Nontraditional Machining?

- Situations where traditional machining processes are unsatisfactory or uneconomical:
  - Workpiece material is too hard, strong, or tough.
  - Workpiece is too flexible to resist cutting forces or too difficult to clamp.
  - Part shape is very complex with internal or external profiles or small holes.
  - Requirements for surface finish and tolerances are very high.
  - Temperature rise or residual stresses are undesirable or unacceptable.

Ultrasonic Machining (USM)

- Process description
  - The tool, which is negative of the workpiece, is vibrated at low amplitude (0.013 to 0.08 mm) and high frequency (about 20 kHz) in an abrasive grit slurry at the workpiece surface.
  - The slurry also carries away the debris from the cutting area.
  - The tool is gradually moved down maintaining a constant gap of approximately 0.1 mm between the tool and workpiece surface.



USM (Cont.)

- Cracks are generated due to the high stresses produced by particles striking a surface.
- The time of contact between the particle and the surface is given by:

$$t_0 \approx \frac{5r}{c_0}\left(\frac{c_0}{v}\right)^{1/5} \qquad (10-100\,\mu s)$$

r: radius of a spherical particle

c_0: workpiece elastic wave velocity $= \sqrt{E/\rho}$

v: velocity of particle striking surface

Force of a particle on surface:

$$F = d(mv)/dt$$

Average force of a particle striking the surface:

$$F_{ave} = 2mv/t_0$$

USM (Cont.)

- *Example*: Explain what change, if any, takes place in the magnitude of the impact force of a particle in ultrasonic machining as the temperature of the workpiece is increased.

Solution:

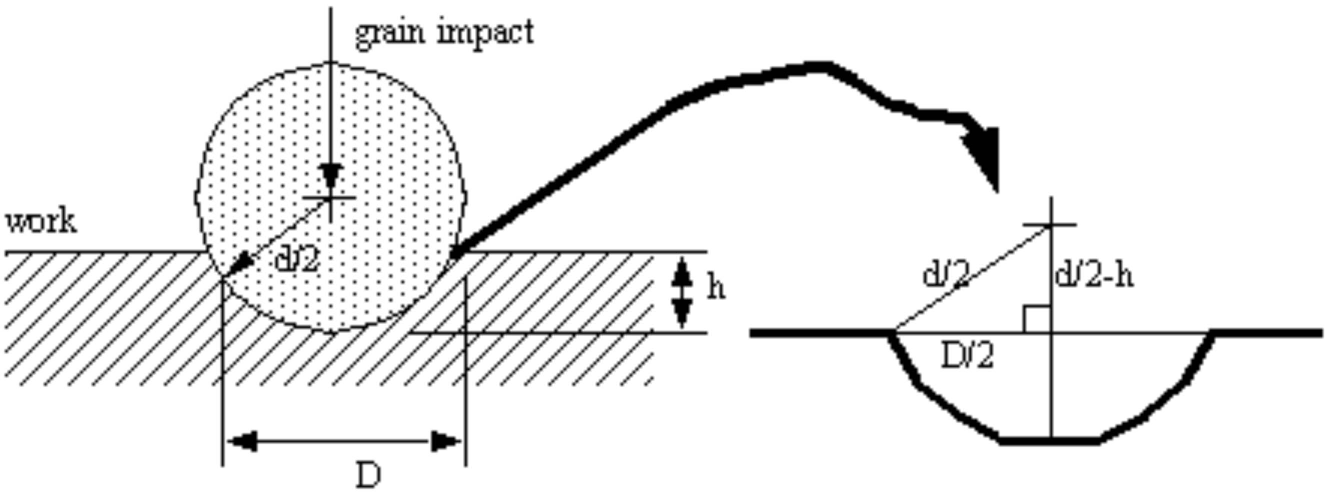
Here, *m* and *v* are constant.

$$t_0 = \frac{5r}{c_0}\left(\frac{c_0}{v}\right)^{1/5} \Rightarrow t_0 \propto \frac{1}{c_0^{4/5}} \propto \frac{1}{E^{2/5}}$$

When temperature increases, *E* decreases and t_0 increases. Hence, *F decreases.*

USM (Cont.)

Assuming hemispherical brittle fracture



$$V = \frac{2\pi}{3}\left(\frac{D}{2}\right)^3$$

$$D \approx 2\sqrt{dh}$$

$$V = \frac{2\pi}{3}(dh)^{3/2}$$

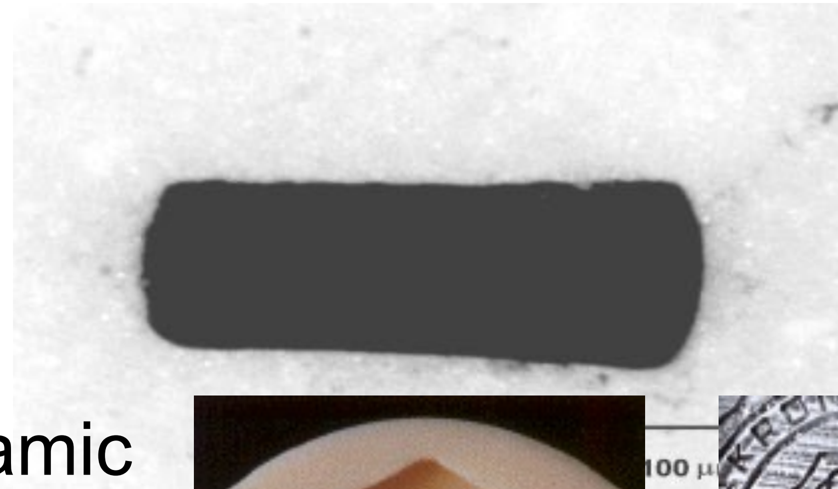
MRR = $\eta V Z f$

where V = volume removed by a single grain
f = frequency of operation
Z = number of particles impacting per cycle
η = efficiency

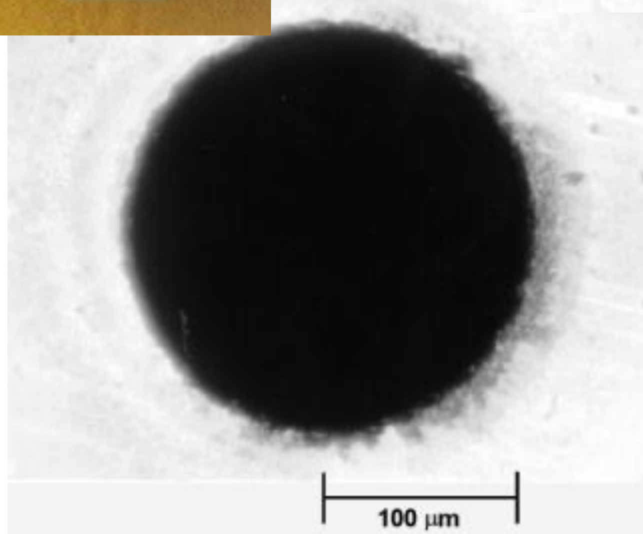
USM (Cont.)

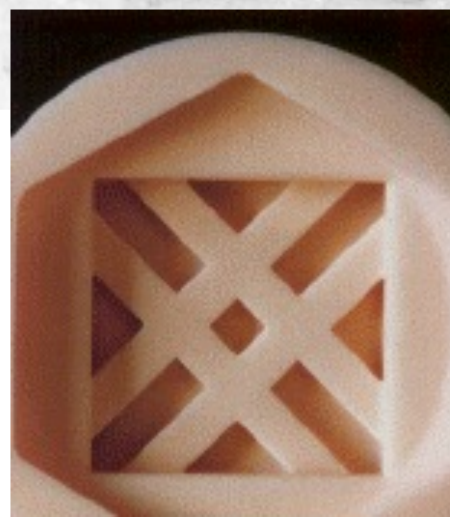
- Applications
  - USM is best suited for hard, brittle materials, such as ceramics, carbides, glass, precious stones, and hardened steels. (Why?)
- Capability
  - With fine abrasives, tolerance of 0.0125 mm or better can be held. R_a varies between 0.2 – 1.6 μm.
- Pros & Cons:
  - *Pros*: precise machining of brittle materials; makes tiny holes (0.3 mm); does not produce electric, thermal, chemical damage because it removes material mechanically.
  - *Cons*: low material removal rate (typically 0.8 cm^3/min); tool wears rapidly; machining area and depth are limited.

USM Parts

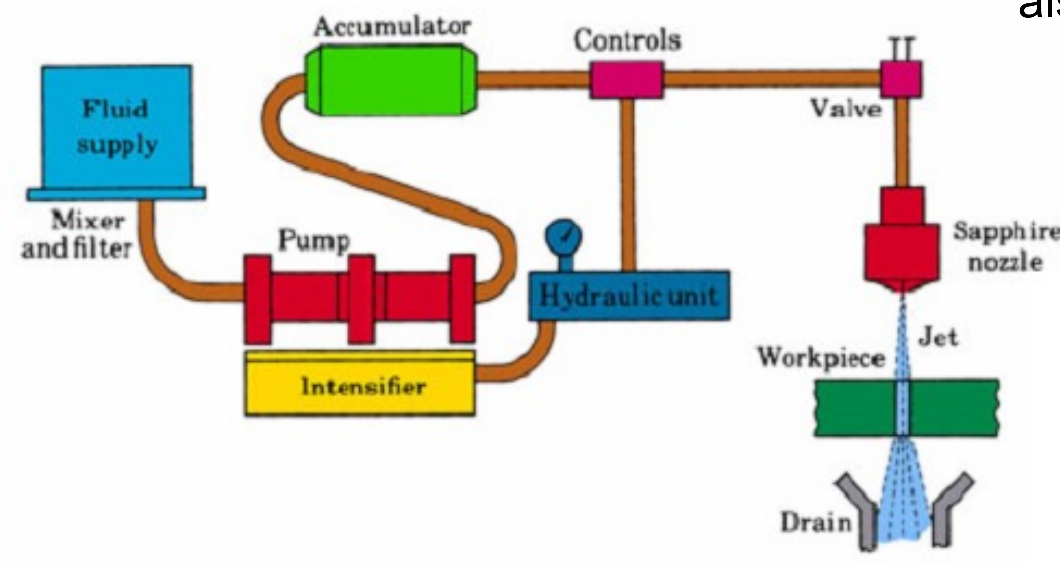


Ceramic

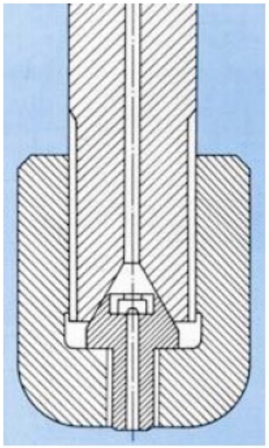




Water-Jet Machining (WJM)



also called hydrodynamic machining



nozzle

WJM is a form of micro erosion. It works by forcing a large volume of water through a small orifice in the nozzle.

The extreme pressure of the accelerated water particles contacts a small area of the workpiece and acts like a saw and cuts a narrow groove in the material.

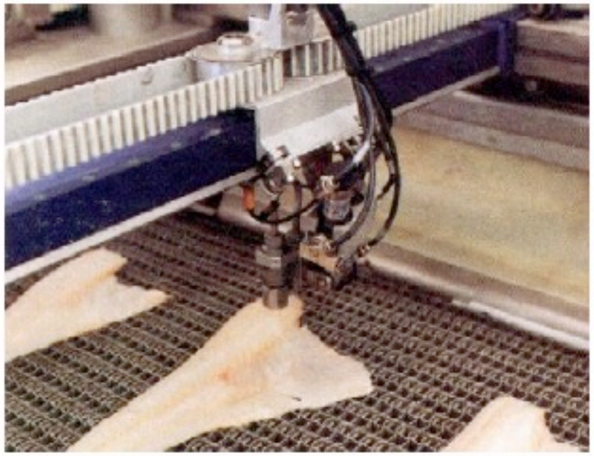
http://www.flowcorp.com/waterjet-resources.cfm?id=360

WJM (Cont.)

- Pros: no need for predrilled holes, no heat, no workpiece deflection (hence suitable for flexible materials), minimal burr, environmentally friendly.
- Cons: limited to material with naturally occurring small cracks or softer material.
- Applications:
  - Mostly used to cut lower strength materials such as wood, plastics, rubber, paper, leather, composite, etc.
  - Food preparation
  - Good for materials that cannot withstand high temperatures of other methods for stress distortion or metallurgical reasons.

WJM Examples

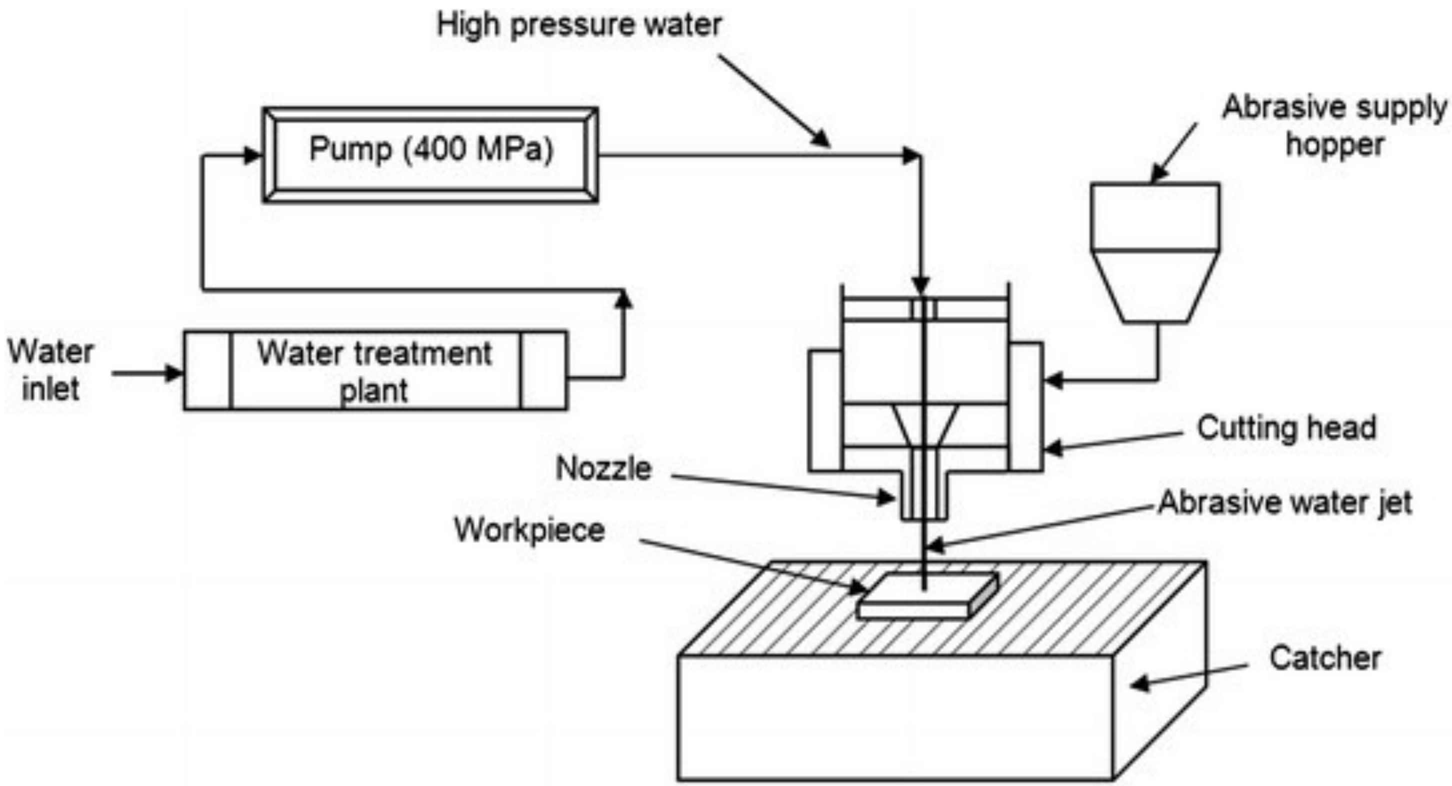
cake



fish

PWB (printed wire board)

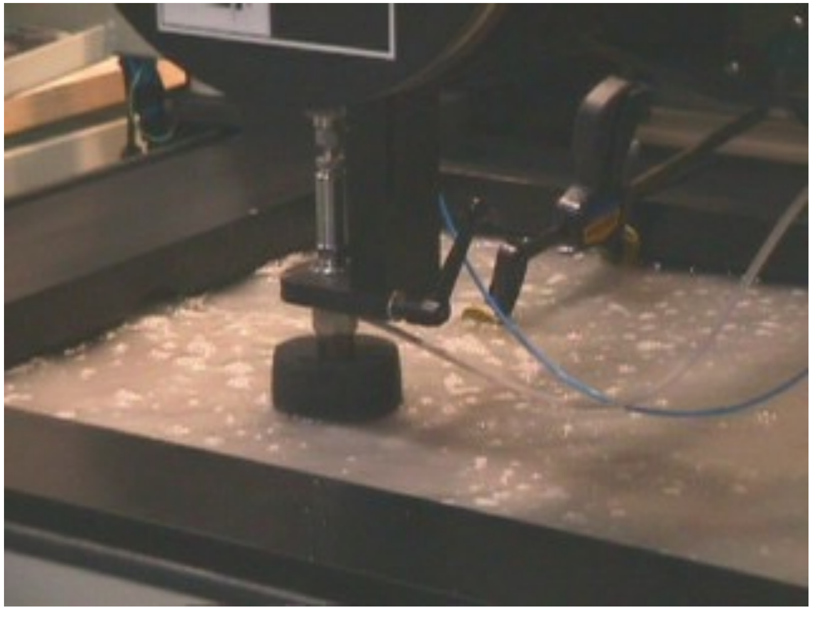
AWJM


High pressure water
Pump (400 MPa)
Abrasive supply hopper
Water inlet
Water treatment plant
Cutting head
Nozzle
Abrasive water jet
Workpiece
Catcher

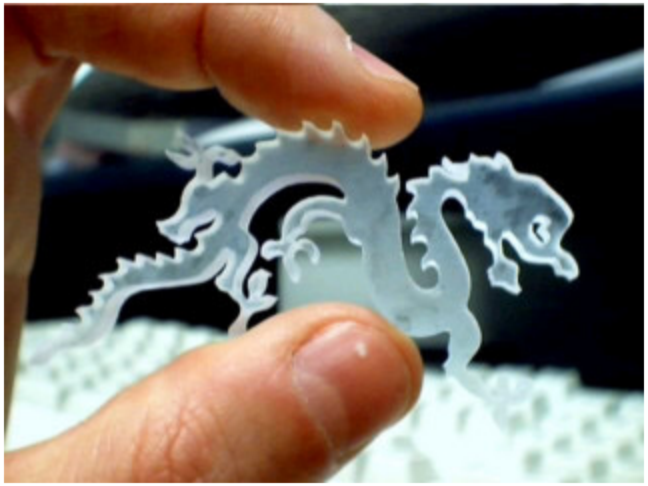
Abrasive Water-Jet Machining (AWJM)

The water jet contains abrasive particles such as silicon carbide, thus increasing MRR.

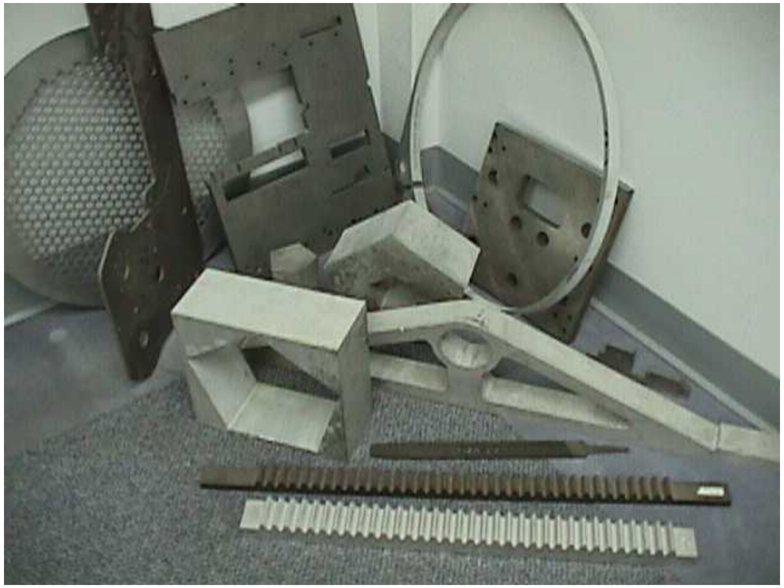
Metallic materials can be cut. Particularly suitable for heat-sensitive materials.



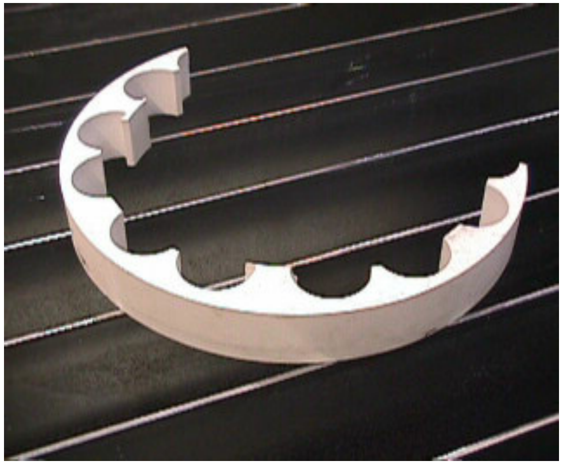
AWJM Parts



Bullet Proof Glass Part



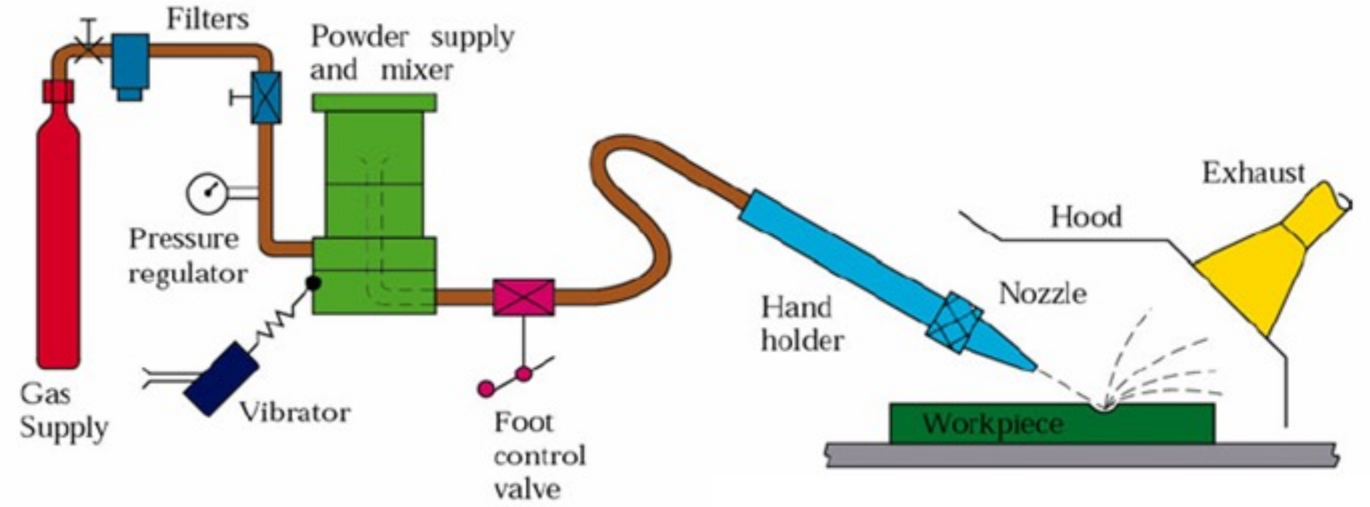
Steel rack (75 mm thick)



Ceramic Part

Source: http://www.waterjets.org/

Abrasive-Jet Machining (AJM)



A high-velocity jet of dry air, nitrogen, or carbon dioxide containing abrasive particles is aimed at the workpiece surface under controlled conditions.

The gas supply pressure is on the order of 850 kPa (125 psi) and the jet velocity can be as high as 300 m/s and is controlled by a valve.

AJM Process Capability

- Material removal
  - Typical cutting speeds vary between 25 -125 mm/min
- Dimensional Tolerances
  - Typical range $\pm$2 - $\pm$5 μm
- Surface Finish
  - Typical R_a values vary from 0.3 - 2.3 μm

AJM Applications & Limitations

- Applications
  - Can cut traditionally hard to cut materials, e.g., composites, ceramics, glass
  - Good for materials that cannot stand high temperatures
- Limitations
  - Expensive process
  - Flaring can become large
  - Not suitable for mass production because of high maintenance requirements