Abrasive Jet Machining (AJM)

ME312: Manufacturing Technologies - II
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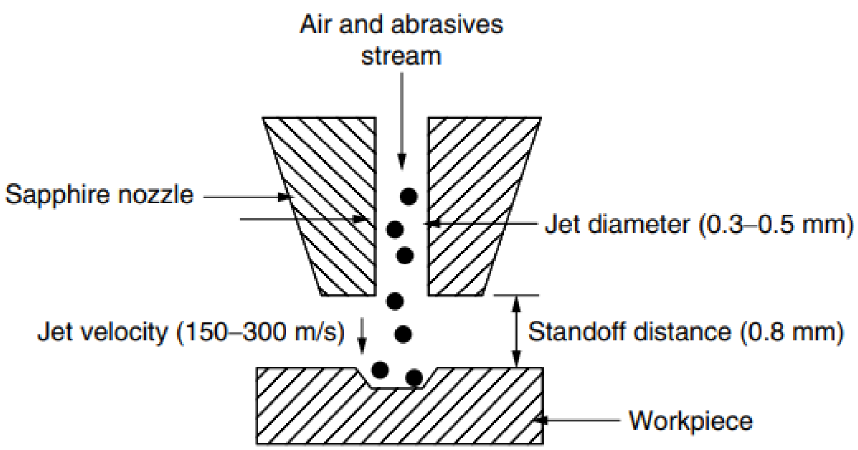
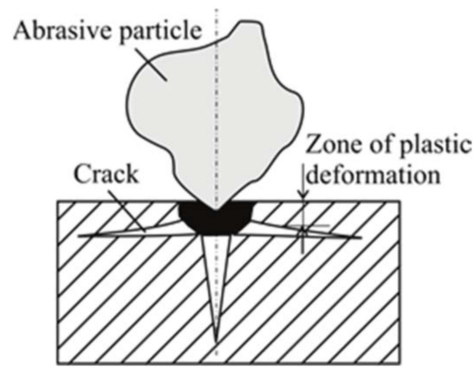
Abrasive Jet Machining

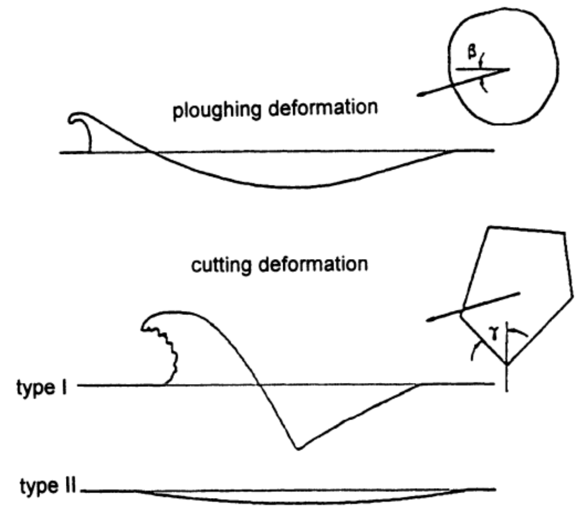
- WJM and AWJM use water jet and abrasive water jet for cutting operation
- In abrasive jet machining (AJM) high-pressure gas or air at a high velocity is used as carrier
- The material is removed by the mechanical abrasion action of the high-velocity abrasive particles
- Material removal occurs through a chipping action, which is especially effective on hard, brittle materials such as glass, Silicon, tungsten, and ceramics.
- Soft, resilient materials, such as rubber and some plastics, resist the chipping action and thus are not effectively processed by AJM

Material Removal Mechanism

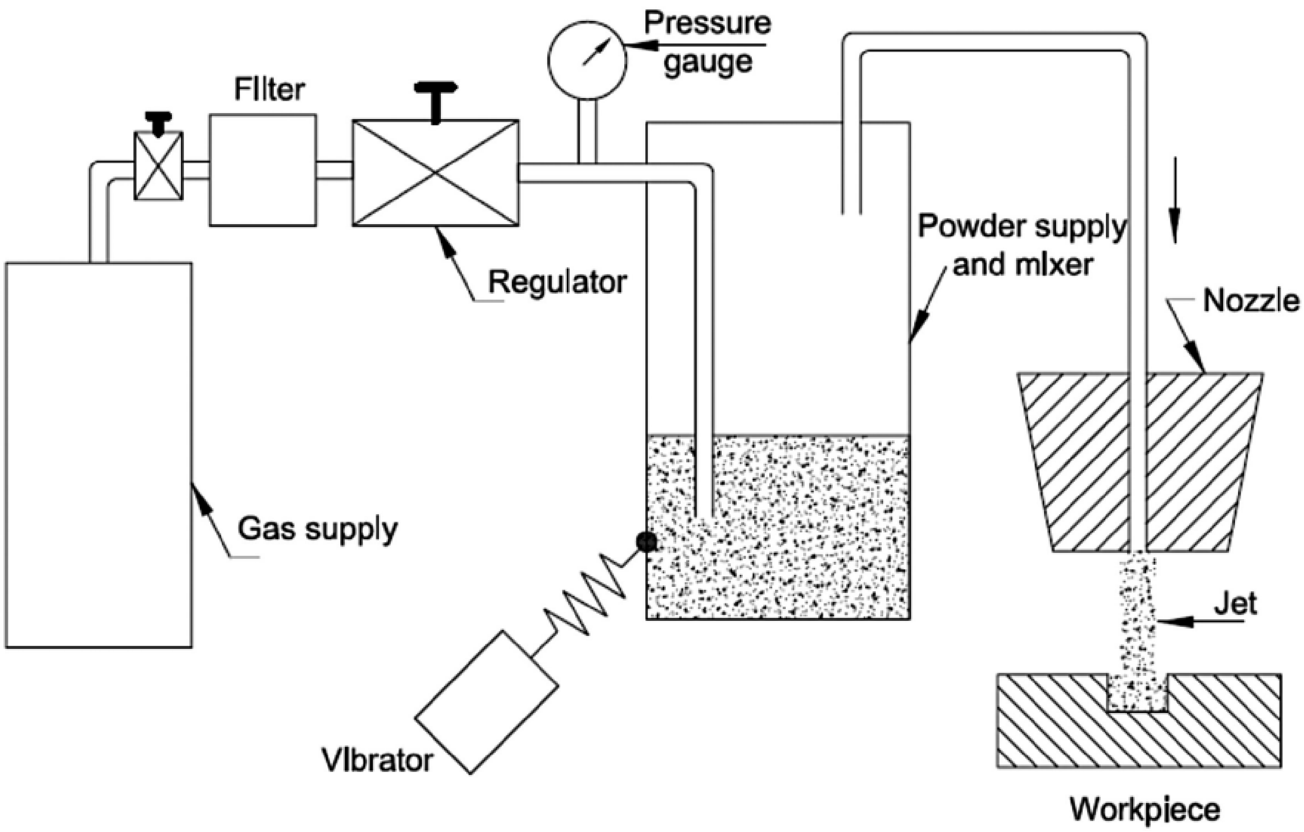
- When the sharp-edged abrasive particles hit a brittle and fragile material at high speed, tiny brittle fractures are created from which small particles dislodge
- The lodged-out particles are carried away by the air or gas.







Machining system



Machining system

- Gas (Nitrogen, CO_2, or air) is supplied under a pressure of 2 to 8 kg/cm^2
- After filtration and regulation, the gas is passed through a mixing chamber that contains abrasive particles and vibrates at low frequency
- Al_2O_3 or SiC abrasives, of grain size ranging from 10 to 80 µm, are used
- The nozzles are generally made of sintered carbides (WC) or synthetic sapphire of diameters 0.2 to 2 mm
- To limit the jet flaring, nozzles may have rectangular orifice
- The abrasives attain a high speed ranging from 150 to 350 m/min
- The abrasive powder feed rate is controlled by the amplitude of vibrations in the mixing chamber

Machining system

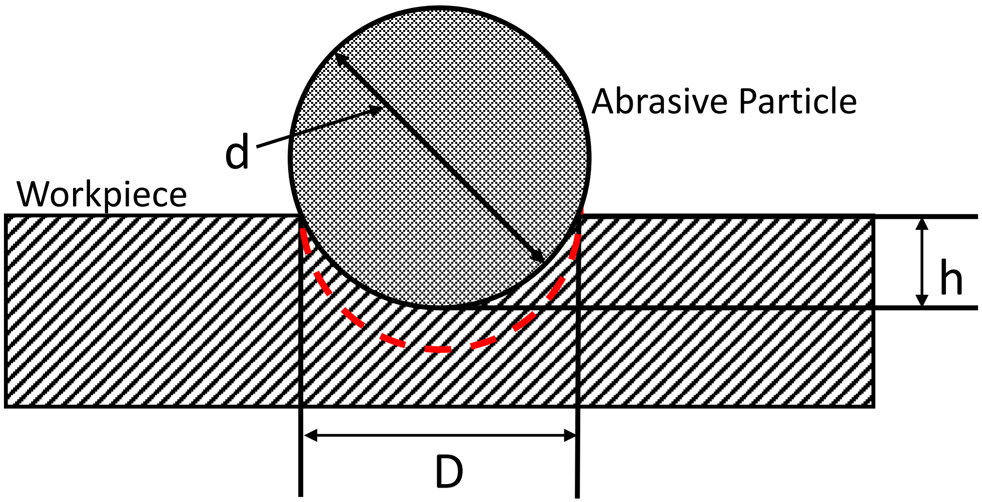
- As the particles impact the surface of workpiece, it causes a small fracture and wear, which is carried away by the gas along with the abrasive particles
- The abrasive particles once used, cannot be re-used as its shape changes partially
- The workpiece material is also clogged with the abrasive particles during impingement and subsequent flushing by the carrier gas
- Oxygen should never be used because it causes a violent chemical reaction with workpiece chips or abrasives
- Dust removal equipment is incorporated to protect the environment

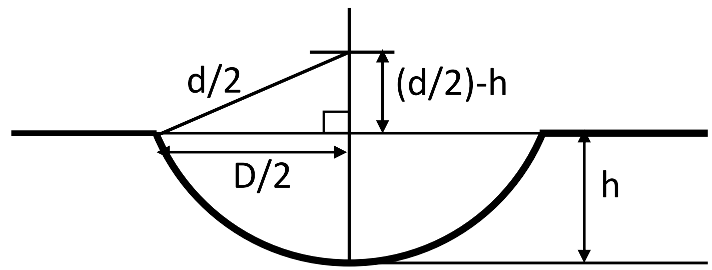
Material Removal Rate

Assumptions:

- Abrasives are rigid and spherical in shape having diameter d (grit diameter)
- Kinetic energy of particle is used to cut the material
- For brittle materials, volume of material removal is considered to be hemispherical in shape having diameter D
- For ductile materials, volume of material removal is assumed to be equal to the indentation volume due to abrasive particle impact.

Volume of Material Removed/Particle





$$\left(\frac{d}{2}\right)^2 = \left(\frac{d}{2} - h\right)^2 + \left(\frac{D}{2}\right)^2 \longrightarrow D \approx 2\sqrt{dh}$$

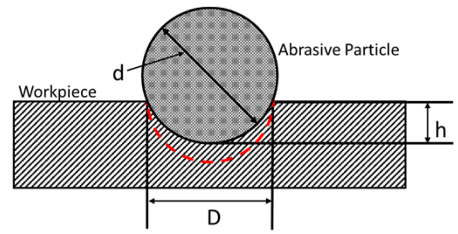
Energy Balance

- The Kinetic Energy

$$KE = \frac{1}{2}\,\mathrm{m}\,(V)^2$$

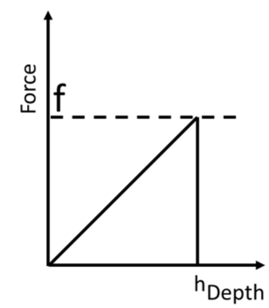
m= mass of abrasive particle

V= velocity of abrasive particle



- An abrasive particle penetrates to the depth equal to 'h' into the workpiece. Then the work done by a particle is given by

$$W_p = \frac{1}{2}\,fh$$



Energy Balance

- Force in terms of mean stress of workpiece (σ_w)

$$f = \sigma_w A_w = \sigma_w \pi h d$$

- Energy balance

$$\frac{1}{2}\left(\frac{4\pi}{3}\left(\frac{d}{2}\right)^3 \rho_p\right)(V)^2 = \frac{1}{2}\sigma_w \pi h^2 d$$

$$h = \sqrt{\frac{\rho_p}{6\sigma_w}}\, dV$$

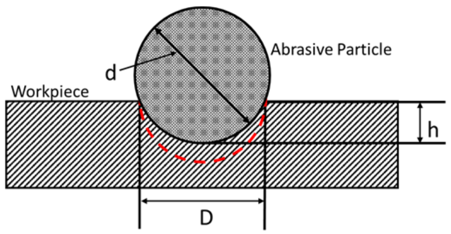
$\sigma_w \approx H$

H= hardness of workpiece material

Material Removal Rate (Brittle Materials)

- MRR will be equal to MRR due to one impact multiplied by number of impacts per second
- Number of impact per second will be ratio of mass flow rate of abrasives and mass of one abrasive

$$N = \frac{\dot{m}_{ab}}{\left(\frac{\pi d^3 \rho_p}{6}\right)}$$

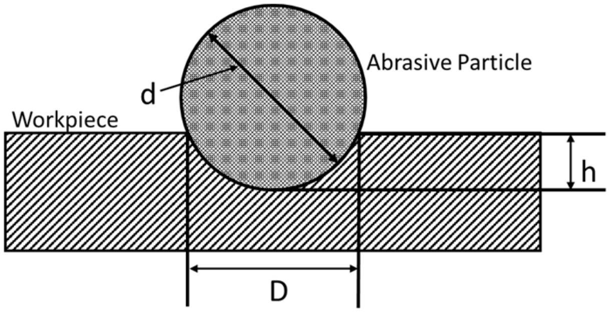


- Material Removal Rate:

$$MRR = \frac{\pi D^3}{12} \frac{\dot{m}_{ab}}{\left(\frac{\pi d^3 \rho_p}{6}\right)} = \frac{\pi \left(2\sqrt{dh}\right)^3}{12} \frac{\dot{m}_{ab}}{\left(\frac{\pi d^3 \rho_p}{6}\right)} = \frac{4\dot{m}_{ab} V^{3/2}}{\rho_p{}^{1/4} (6\sigma_w)^{3/4}}$$

Material Removal Rate (Ductile Materials)

- Volume removal per particle = $\frac{\pi h^2 (3(\frac{d}{2}) - h)}{3} = \frac{\pi h^2 d}{2}$



$$MRR = \frac{\pi h^2 d}{2} \frac{\dot{m}_{ab}}{\left(\frac{\pi d^3 \rho_p}{6}\right)} = \frac{\pi d \left(\sqrt{\frac{\rho_p}{6\sigma_w}} dV\right)^2}{2} \frac{\dot{m}_{ab}}{\left(\frac{\pi d^3 \rho_p}{6}\right)}$$

$$\mathrm{MRR} = \frac{\dot{m}_{ab} V^2}{2\sigma_w}$$

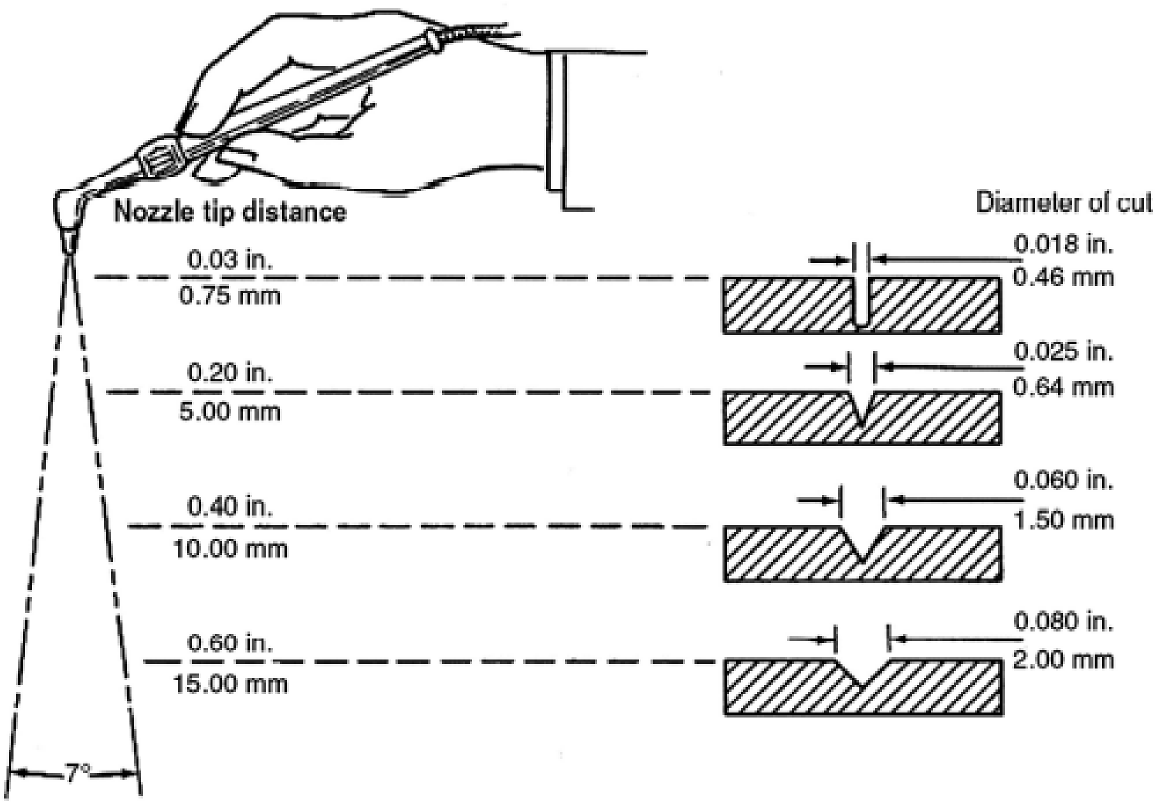
Numerical Example

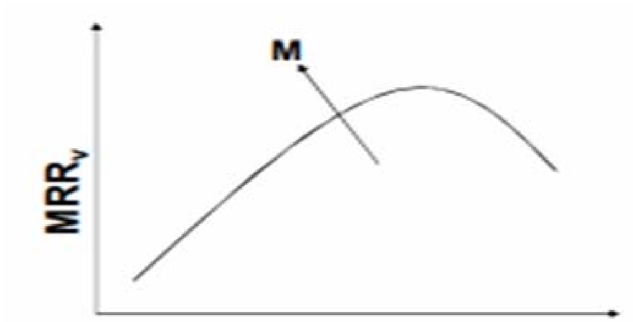
- Estimate the MRR in AJM of a material with flow strength of 3 GPA. The abrasive flow rate is 2.5 gm/min, velocity is 205m/s, density of abrasive is 3 gm/cc. dia of abrasive is 100 micron

(a) Consider brittle material MRR=80 mm^3/min

(b) Consider ductile material MRR=17.5 mm^3/min

Effect of Stand-Off Distance

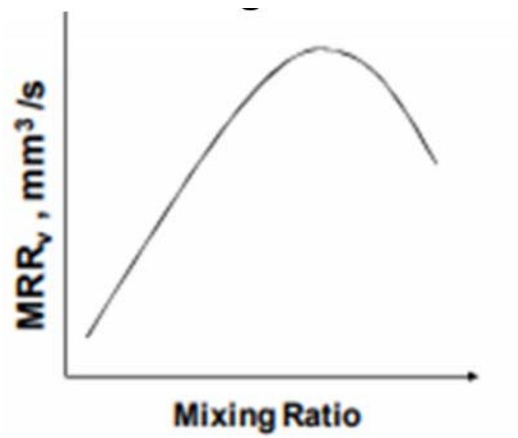


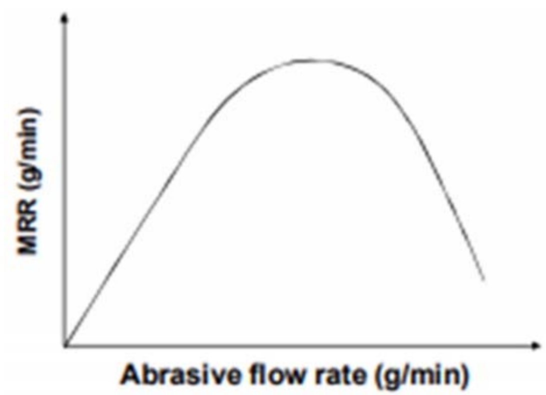


Effect of Mixing Ratio

$$Mixing\ ratio = \frac{Volume\ flow\ rate\ of\ abrasive\ particles}{Volume\ flow\ rate\ of\ carrier\ gas}$$

$$Mass\ ratio = \frac{Mass\ flow\ rate\ of\ abrasive\ particles}{Mass\ flow\ rate\ of\ carrier\ gas\ and\ abrasive} = \frac{\dot{m}_{ab}}{\dot{m}_{ab} + \dot{m}_{gas}}$$





Process parameters and Capabilities

- Abrasives – Al_2O_3 ,SiC, Glass beads – 10 to 50 microns – 2-20 gm/min
- Carrier Gas – Air, CO_2, N_2 – 500 to 700 m/s – 2 to 10 bar
- Abrasive Jet – Velocity - 100 to 300 m/s – Stand off distance 0.5 to 15mm – Impingement angle – 60 to 90 deg
- Nozzle – Material – WC/Sapphire – Diameter – 0.2 to 0.8 mm
- Material removal rate – 0.015 cm3 /min
- Narrow slots – 0.12 to 0.25mm
- Surface finish -0.25 micron to 1.25 micron
- Sharp radius up to 0.2mm is possible
- Steel up to 1.5mm ,Glass up to 6.3mm is possible to cut

Advantages

- Best suited for machining brittle and heat-sensitive materials like glass, quartz
- Used for machining superalloys and refractory materials
- Not reactive with any workpiece material
- No tool changes are required
- Intricate parts of sharp corners can be machined
- The machined materials do not experience hardening
- No initial hole is required for starting the operation
- Material utilization is high
- Characterized by low capital investment and low power consumption

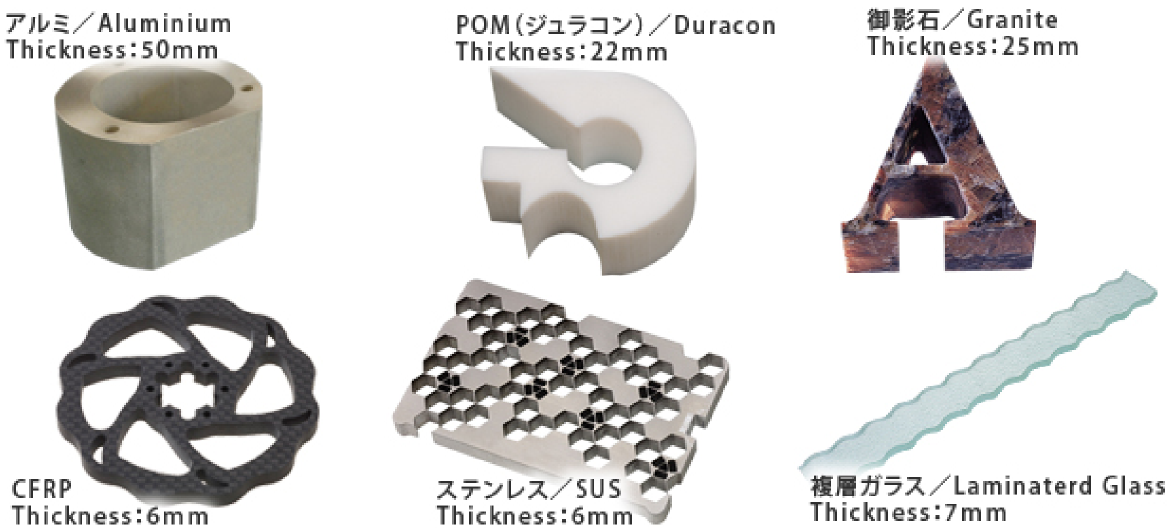
Disadvantages/ Limitations

- The removal rate is slow
- Stray cutting can't be avoided (low accuracy of ± 0.1 mm)
- The tapering effect may occur especially when drilling in metals
- The abrasive may get impeded in the work surface
- Suitable dust-collecting systems should be provided
- Soft materials can't be machined by the process
- Silica dust may be a health hazard
- Ordinary shop air should be filtered to remove moisture and oil

Applications

- Drilling holes, cutting slots, cleaning hard surfaces, deburring, polishing, and radiusing
- Machining intricate shapes or holes in sensitive, brittle, thin, or difficult-to-machine materials
- Insulation stripping and wire cleaning without affecting the conductor
- Micro-deburring of hypodermic needles
- Frosting glass and trimming of circuit boards
- Removal of films and delicate cleaning of irregular surfaces because the abrasive stream is able to follow contours

Applications



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