WELCOME TO THE COURSE

ON

MICRO MACHINING PROCESSES

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Abrasive jet micromachining

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Introduction

- Abrasive Jet Micro Machining (AJMM) is a relatively new approach to the fabrication of micro structures.
- AJMM is a promising technique to three-dimensional machining of glass and silicon in order to realize economically viable micro-electro-mechanical systems (MEMS)
- It employs a mixture of a fluid (air or gas) with abrasive particles.
- In contrast to direct blasting, the surface is exposed completely to the erosive action of the particle beam.
- Hence, before processing, the substrate material has to be partially shielded by applying an erosion resistant mask.
- Only where the mask does not protect the workpiece, material removal will take place.

Introduction

- This method is used for making accurate shallow holes or grooves, and, with the use of masks, patterns on target material.
- The resulting erosion of the target material can be controlled using masks and by varying **parameters such as impact angle and particle flux density, velocity, and particle properties.**
- In contrast to conventional micro-fabrication methods, such as wet and dry etching, AJMM is capable of machining anisotropic patterns and suspended structures with high erosion rate and relatively low cost.
- Globally, it introduces the concept of precision machining techniques to conventional blasting through the **use of fine and hard abrasive particles, constant powder feeding devices and masking technology.**

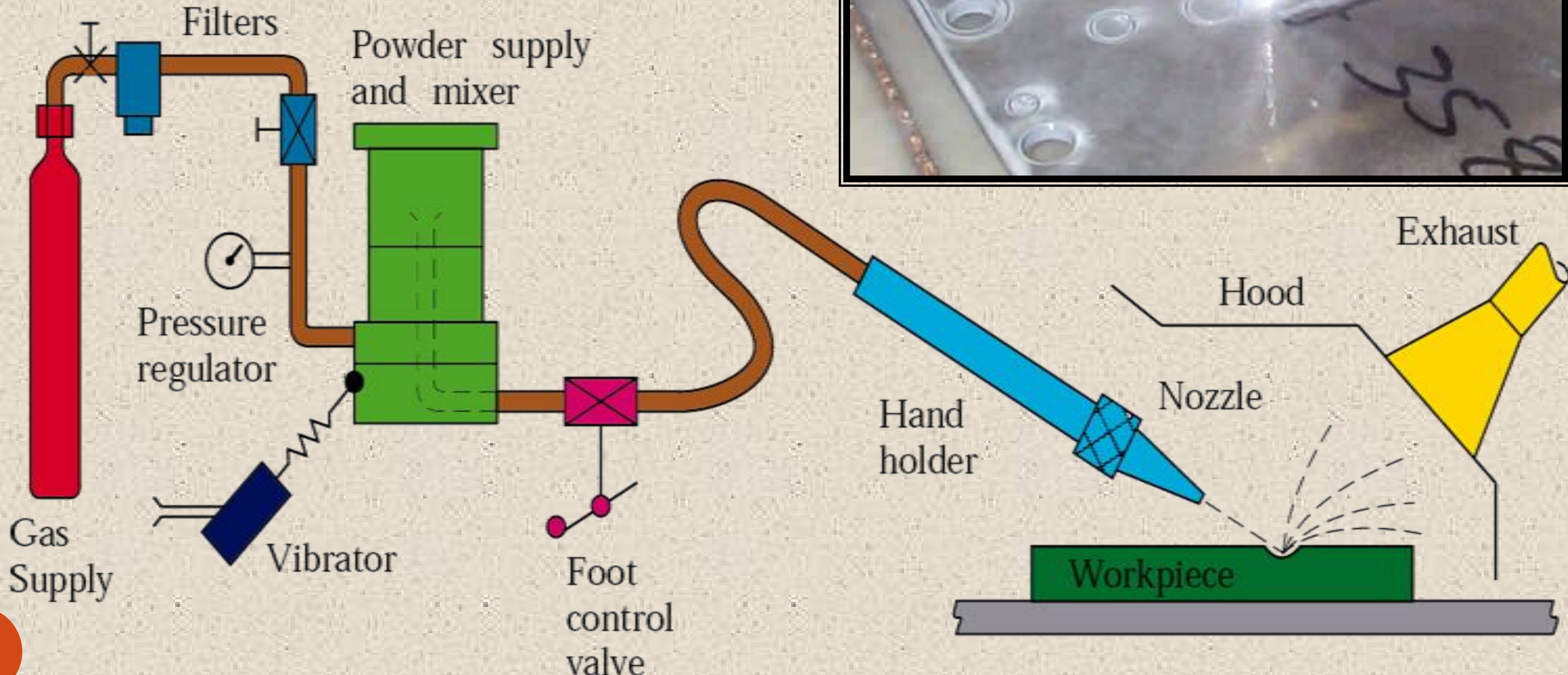
Introduction

- **Advantages of AJM**: (1) low capital and operating costs, (2) environmentally friendly process, (3) no major health hazards, and (4) ability to machine anisotropic and suspended structures on the same substrate.

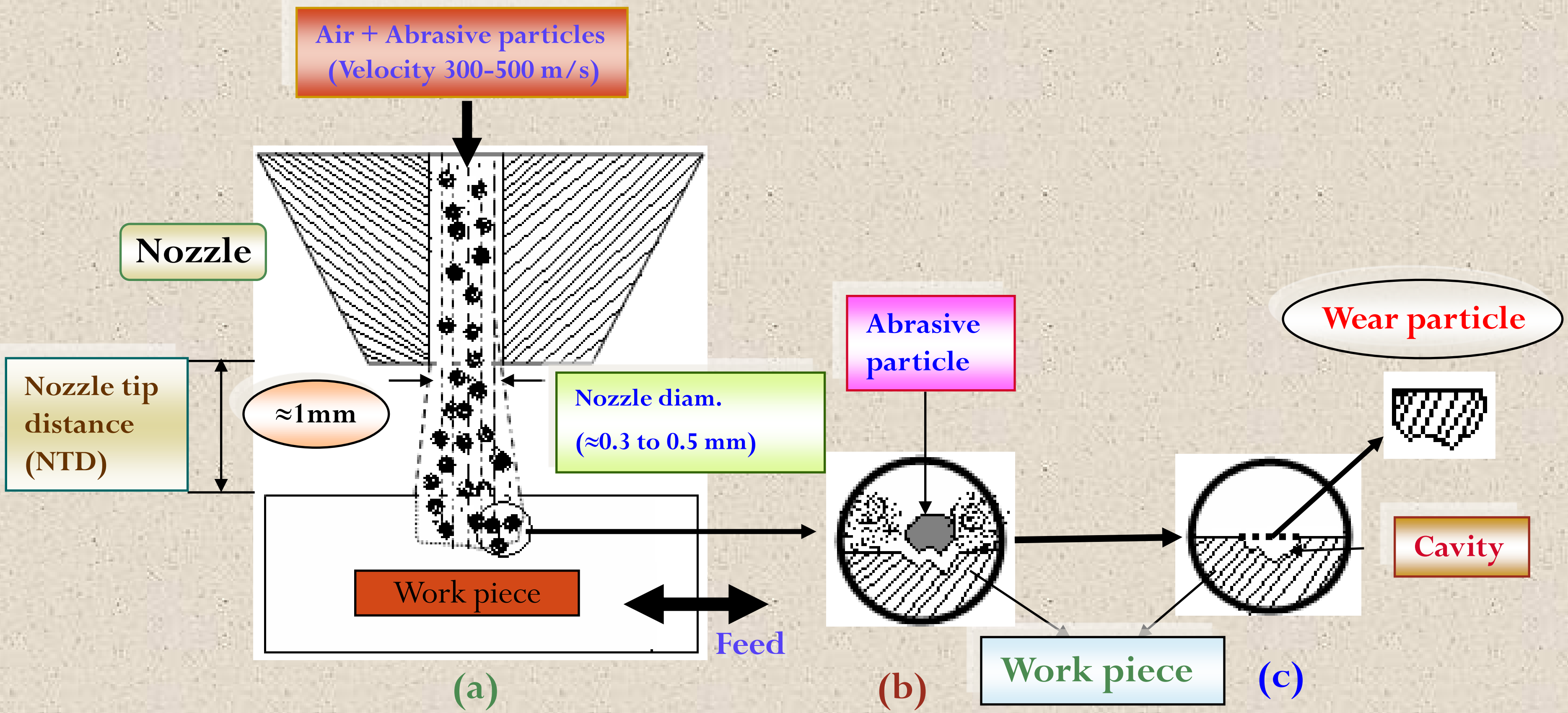
- **In addition, MULTIPLE DEPTH FEATURES can be machined on the same substrate, unlike chemical etching whereby the entire substrate is etched at a constant rate.**

- **Typical AJM applications include drilling, cutting and engraving of glass, ceramics and some hard materials. It can also be used to etch labels in plastics and metals, deburr, deflash and clean materials after conventional machining.**

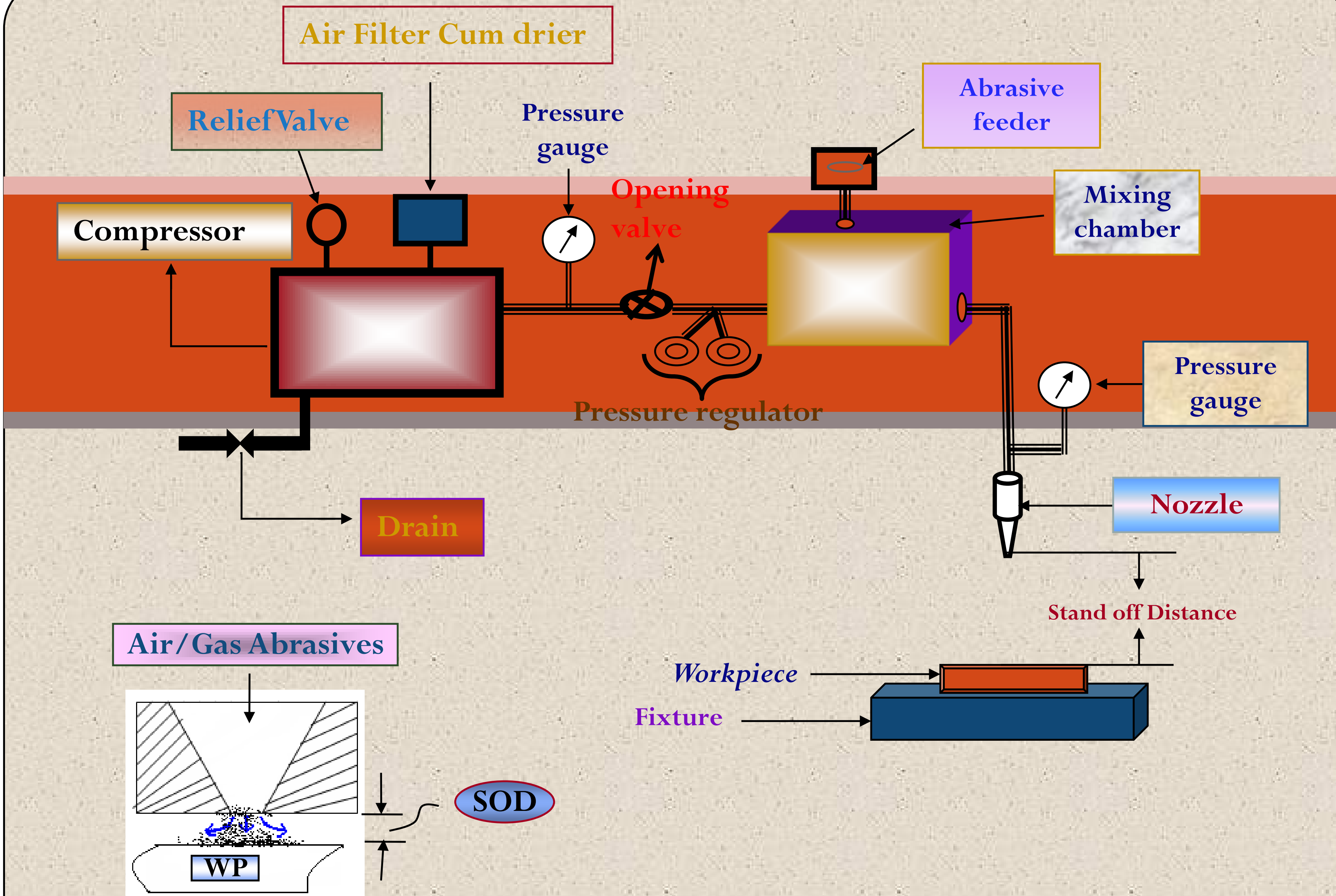
Schematic diagram of AJMM



Mechanism of Material Removal



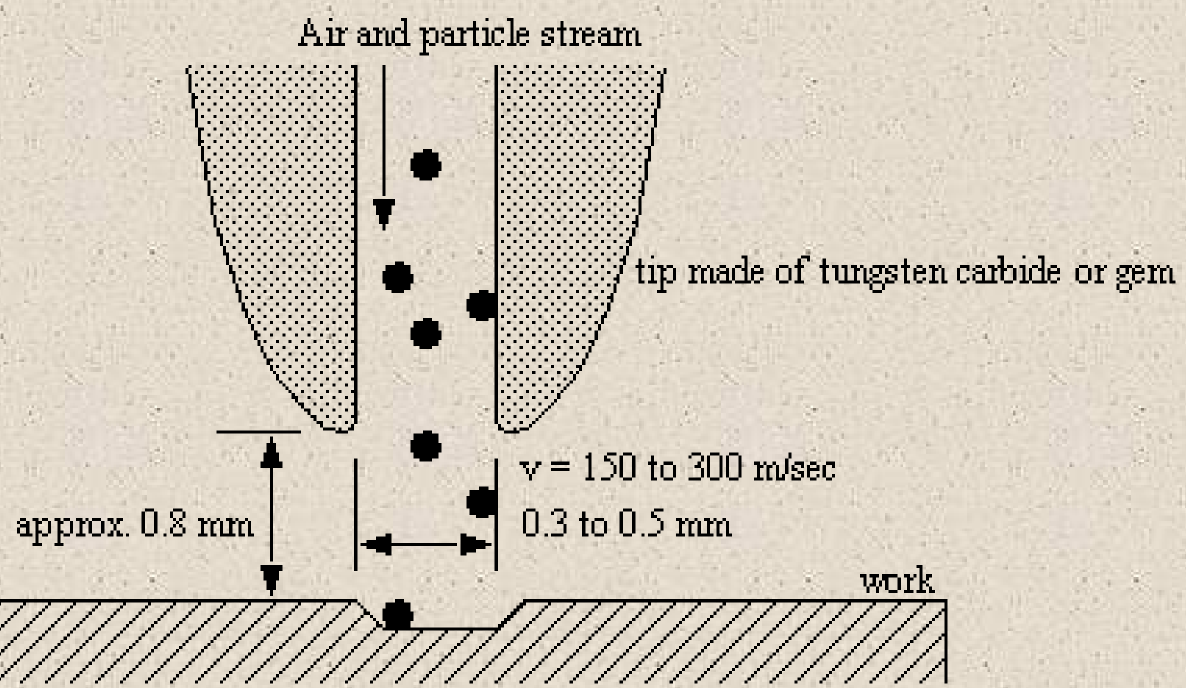
- Flaring of the Jet → Cavity dimension changes with a change in NTD.
- Abrasive particles repeatedly hit on the work surface.
- Brittle fracture separates out tiny particles (wear particles) to produce a cavity.
- Cavity width ≥ Nozzle inner diam. (Depends on NTD).
- Cavity Depth depends on work piece feed rate, abrasive particle mass (or density) and pressure (or velocity of the jet).



Schematic diagram of AJM

Principle of AJMM

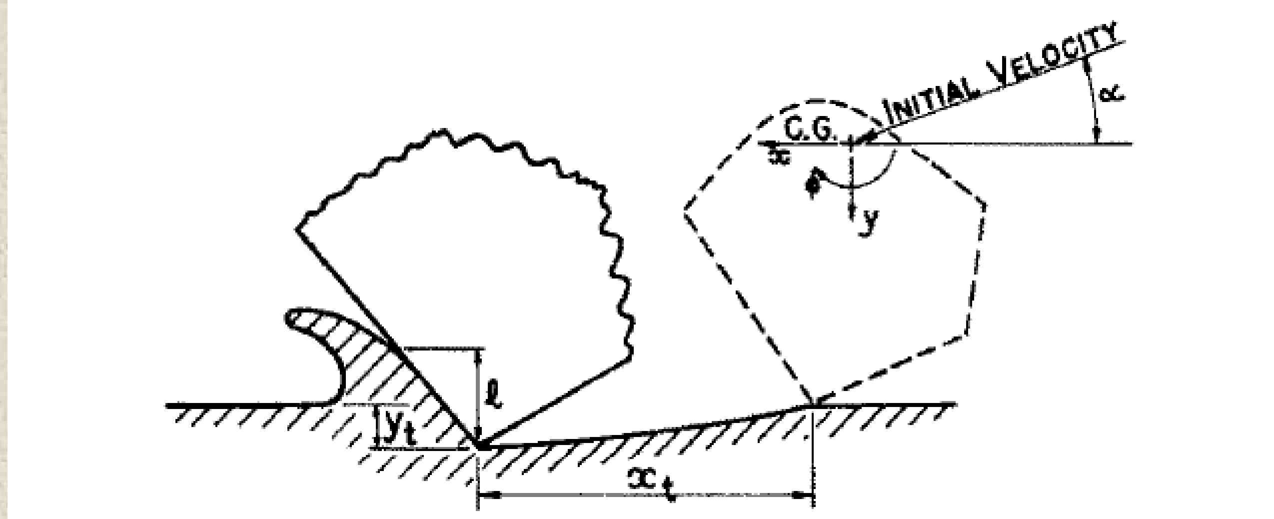
- Fine micro abrasive particles are accelerated in a gas stream (commonly air at a few times atmospheric pressure).
- The particles are directed towards the focus of machining (less than 1 mm from the tip).
- As the particles impact the surface, they fracture off the surface and create cavities.
- As the particle impacts the surface, it causes a small fracture, and the gas stream carries both the abrasive particles and the fractured (wear) particles away.



Mechanism of material Removal

- **For ductile material like Aluminium work hardening due to repeated deformation then cracking of surface layers.**

Cutting wear: (by FINNIE)



- **SIMILAR TO MATERIAL REMOVAL IN MILLING OR GRINDING.**
- **FOR DUCTILE MATERIAL, CUTTING WEAR IS ALSO IN EVIDENCE.**

Process Parameters of AJM

- **The abrasive:**

  composition, strength, size, mass flow rate.

- **The gas:**

  composition, pressure, temperature and velocity.

- **The nozzle:**

  Geometry, material, Stand-Off-Distance (SOD) or Nozzle-Tip-Distance (NTD), feed rate, inclination angle to the normal to the workpiece surface.

Abrasive particles

- **The choice of abrasive particles depends on the type of machining operation.**
- **The abrasives should have a sharp and irregular shap**e for better performance.
- **FINE ENOUGH TO REMAIN SUSPENDED IN THE CARRIER GAS.**
- **It should have excellent flow characteristics so that narrow and fine areas are reachable to them.**

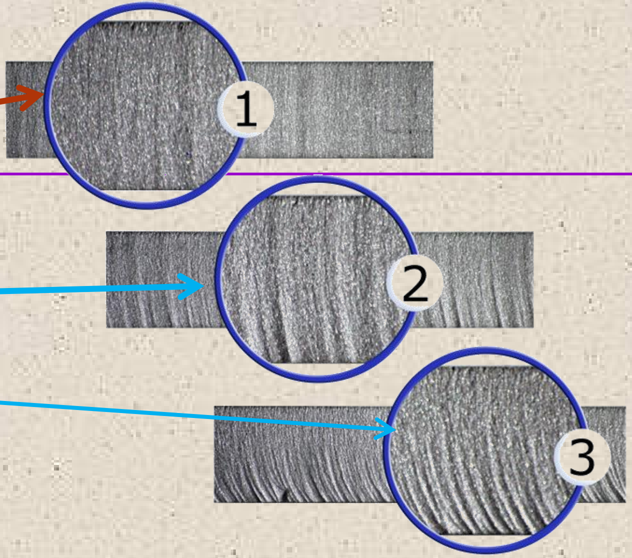
- **Al_2O_3 :For cleaning, cutting and deburring**
- **SiC :Similar applications as Al_2O_3 but for harder work** materials
- **Glass beads :Matte finish**
- **Sodium Bicarbonate : Cleaning, cutting and deburring of soft materials**

Carrier gas

- It should be non toxic, cheap, easily available.
- It MUST NOT FLARE EXCESSIVELY when discharged from the nozzle.
  - Commonly used gases are CO_2, nitrogen, and air.
  - Air is mostly preferred due to universal availability, practically at no cost, and its non-toxic nature.

Nozzle materials

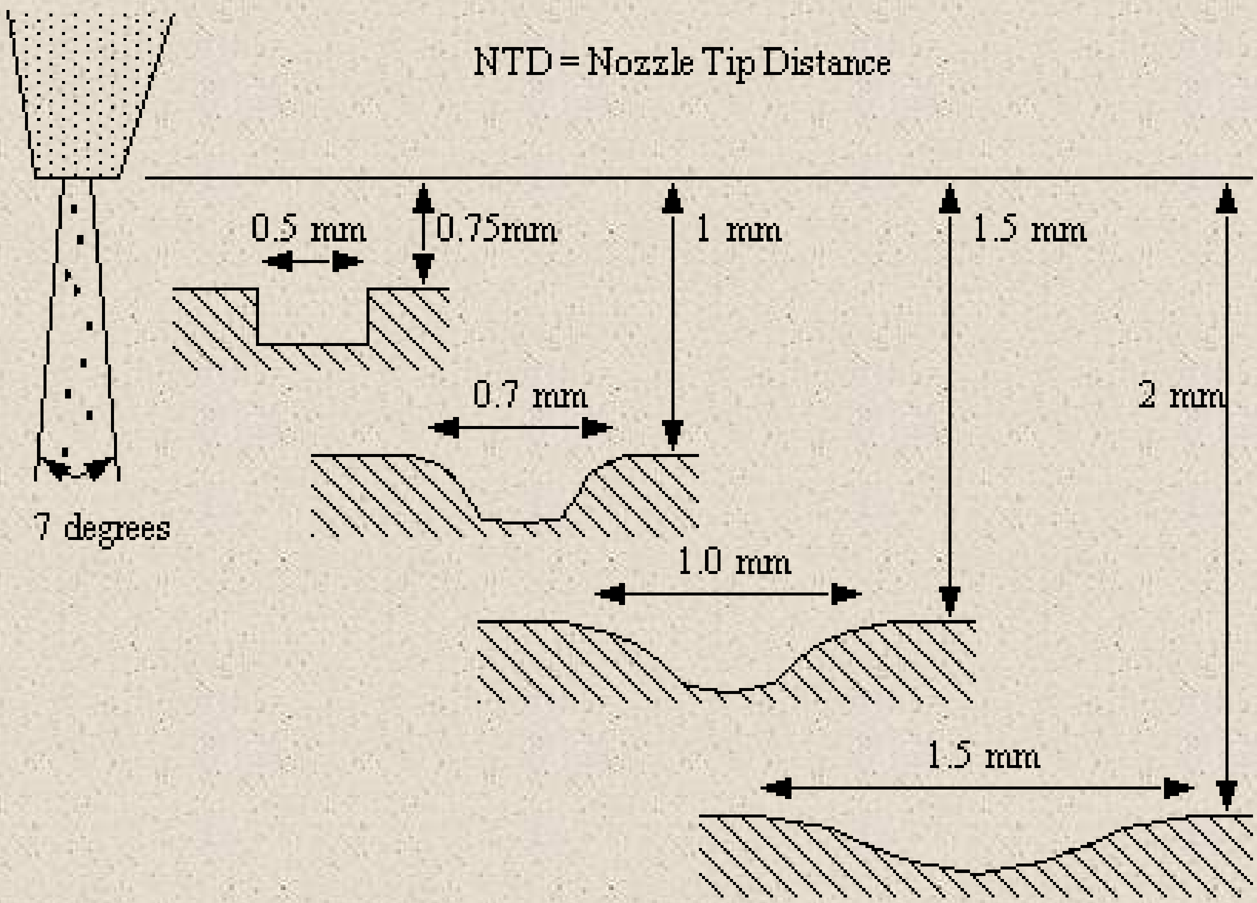
- The following requirements have to be fulfilled on nozzle design:
  - Pressure-less constant feeding system.
  - Supersonic air flow velocity in the nozzle.
  - Homogeneous dispersion of abrasive particles over the width of the nozzle.
  - Long life time of the nozzle (It has to withstand the erosive action of abrasive particles)
- Materials for nozzle: Tungsten Carbide (WC) and sapphire
- Effect of feed rate
  1. Low feed rate
  2. Medium feed rate
  3. High feed rate



WHICH FEEDRATE IS BETTER?

Effect of Stand-Off-Distance (SOD)

A decrease in SOD improves accuracy, decreases kerf width and reduces taper in the machined groove.



WHAT IS A KERF? WHICH SOD IS MORE ACCURATE:0.5 mm, 1 mm?

Abrasive flow rate

- **MRR increases only up to a certain value of abrasive flow rate beyond which it starts decreasing**
- **As abrasive flow rate increases, the number of abrasive particles cutting the material also increases thereby increasing MRR.**
- **After a certain value of abrasive flow rate, abrasive flow velocity decreases to the extent that it results in reduction in MRR.**

Mechanism of material removal (ductile fracture)

In the case of ductile materials, material is removed by plastic deformation and cutting wear, or plastic strain and deformation wear

- Ductile fracture
  - During impact, when the yield strength of the material is locally exceeded, plastic deformation takes place in the vicinity of the impact.
  - After multiple impacts, a plastically deformed surface layer may form near the eroded surface, and, therefore, the yield strength of the material increases due to **STRAIN HARDENING**.
  -
  - Upon further deformation, the **YIELD STRENGTH AT THE SURFACE OF THE MATERIAL WILL EVENTUALLY BECOME EQUAL TO ITS FRACTURE STRENGTH**, and no further plastic deformation will occur.
  - At this point, **the material surface becomes brittle and its fragments may be removed by subsequent impacts.**

Mechanism of material removal (brittle fracture)

During brittle erosion process, particle impact produces different types of cracks and chipping, with negligible plastic deformation.

- **Brittle fracture**

  In the case of brittle materials, it may take place due to

  - Indentation rupture
  - Elastic–plastic deformation
  - Critical plastic strain theory
  - Radial cracking and propagation or surface energy criterion

Mass loss of workpiece

- The mass loss of workpiece is proportional to the amount of abrasive

$$mass.loss = K\frac{\rho}{H}\frac{1}{2}mv^2$$

where, K (> 2) is a dimensionless factor, m and v amount and velocity of particles, and ρ and H are density and hardness of the eroded material, respectively.

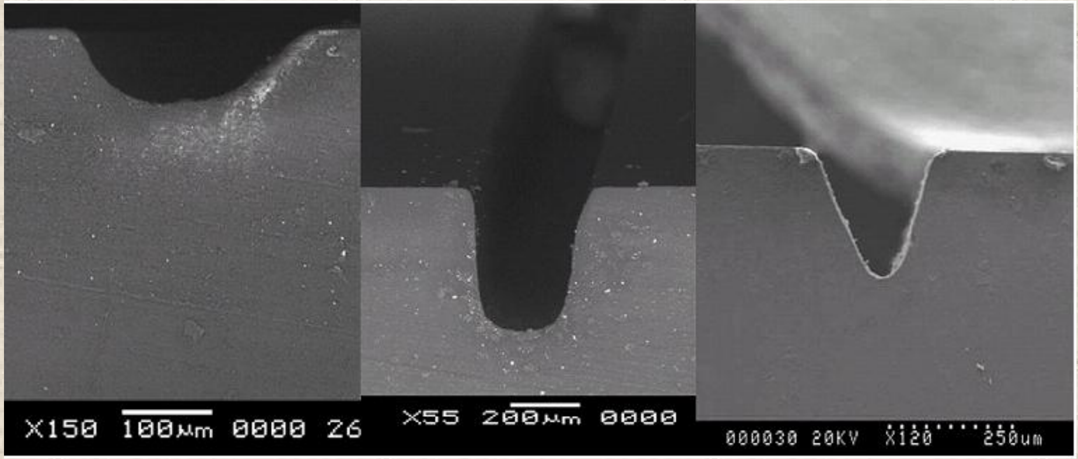
- The above relation is true for brittle erosion but not for softer materials (elastomers and some metals) due to time variant erosion behavior.
- Especially at normal impact angle, particles tend to embed in the material, resulting in an initial gain in weight of the specimen.
- After this incubation time steady-state erosion is established and mass loss from the eroded material is proportional to the amount of abrasive particles.
- The principal empirical relation between erosion rate E_{rate}, expressed as the quotient of mass loss and amount of abrasive, and particle velocity is given as a power function by

$$E_{rate} \approx v^k$$

velocity coefficient k commonly reported for metals between 2.3 and 3, for glasses between 2 and 4 and for elastomers between 1.8 and 3.2

Machining of PMMA and glass

- AJMM can machine much steeper sidewalls and flatter bottom section in PMMA than those in glass.
- For PMMA, there is only a small probability of a particle rebounding from the steep sidewall and hitting the opposite side.
- In addition, it is likely that particles lose more energy at first strike in PMMA than in glass, causing less damage during the second strike.

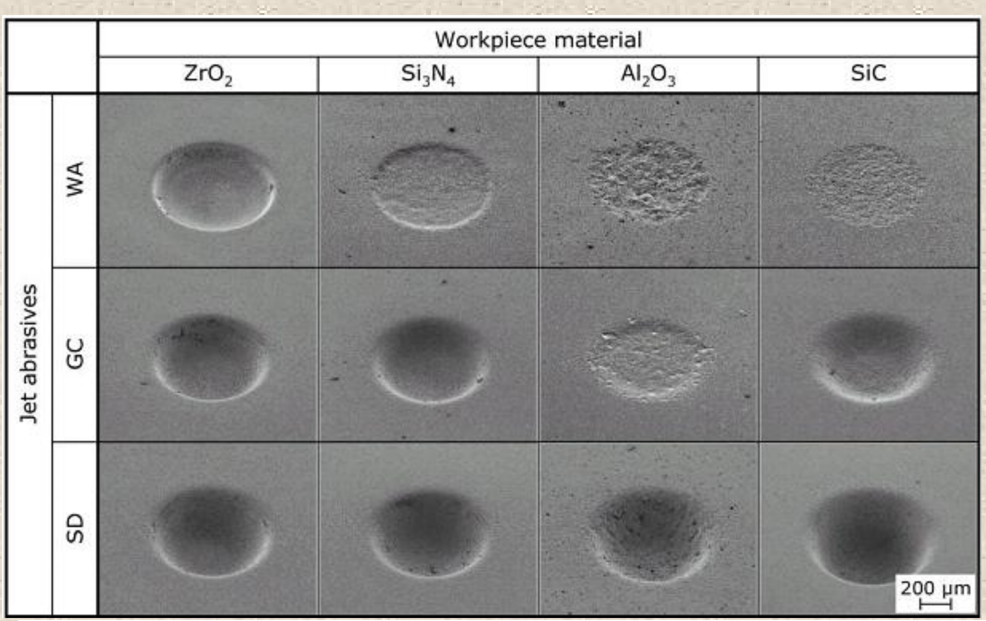


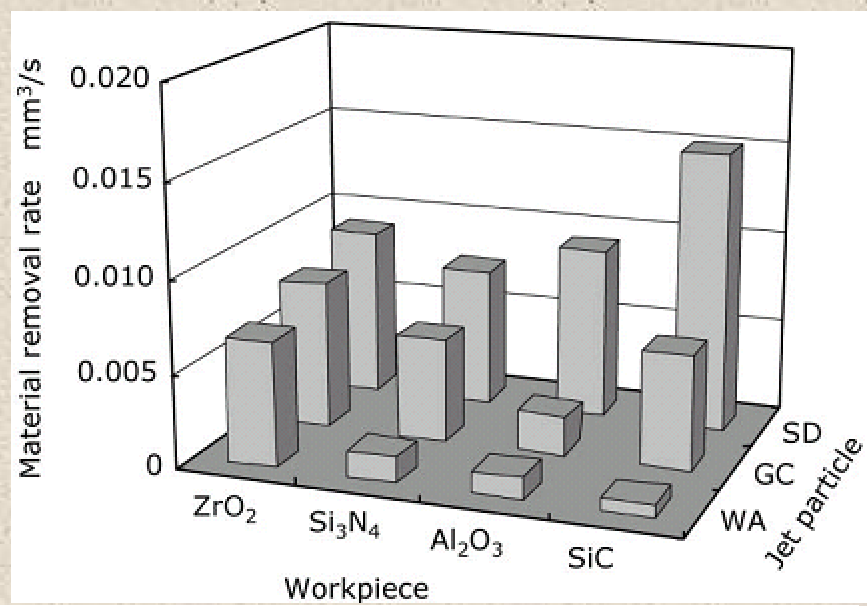
Cross-sectional profiles of typical masked PMMA channels: (a) 1 pass, (b) 11 passes of the nozzle, (c) cross-section of a 250m channel machined in Borofloat glass after 11 passes.

Getu et al. (2007) Abrasive jet micromachining of polymethylmethacrylate, Wear 263, 1008–1015.

Effect of different abrasives and wp. materials

- Appearance of the dimples during AJM for 10 s. for various machining sets of abrasives and ceramic materials.
- properties of the dimples do not differ in terms of the removed volume, but also the roughness of the struck face for different combination of abrasive particles and workpiece material.





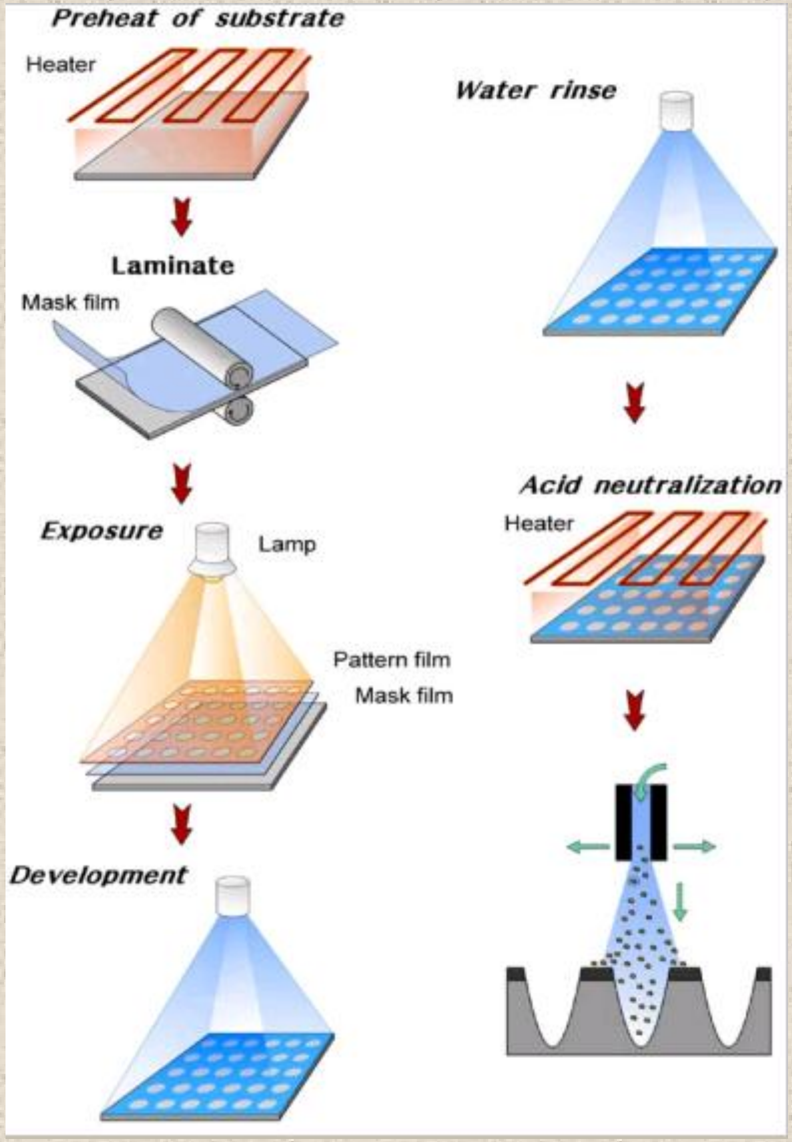
WA – Aluminum oxide, GC – Silicon carbide, SD – Synthetic diamond

da et al. (2002) Effect of workpiece properties on machinability in abrasive jet machining of ceramic materials, Prec. Engg. J. of Int. Soc. for Prec. Engg. and Nanotec., 26, 193–198.

Micro pattern fabrication for AJMM

- In AJMM, the substrate has to be shielded by a wear resistant mask that is patterned with the desired contour.
- The mask determines the accuracy of the dimensions in the plane of desired structure.
- During blasting, the workpiece is exposed to an abrasive air jet (pressure: 0.2 -0.8 MPa and abrasive particles: avg. dia.: 10 - 100 µm.
- The scan strategy and the particle beam profile of the nozzle are of great importance.
- All process steps are summarized in Figure.

Park et al. (2004) Micro-grooving of glass using micro-abrasive jet machining, Journal of Materials Processing Technology 146 (2004) 234–240.



Micro-pattern making process for the AJMM

Masking technology

- The quality of the mask influences the performance of AJMM.
- The main qualification for a good mask material is a low erosion rate.
- It also requires the capability of an accurate and easy pattern transfer, and the ability to retain their resistance in discontinuous layers.
- Three groups of mask materials can be applied to AJMM:
    - ductile materials such as metals,
    - elastic materials such as elastomers and
    - photo-resists as used in IC-industry.
- Each type needs a sufficient erosion resistance related to the substrate especially at normal blast angles.
- Furthermore, the achievable imaging accuracy determines the usability of a mask and minimum achievable features size.

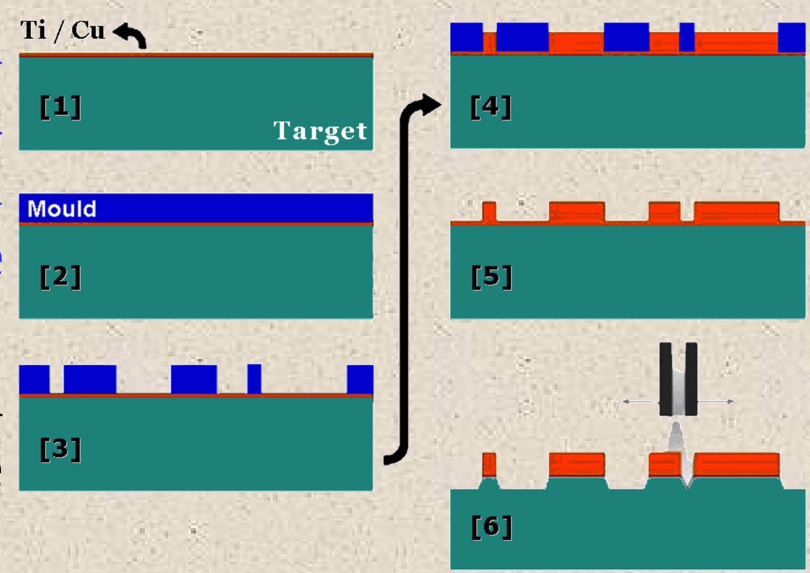
Metal mask

- Ductile materials, like metals, have a low erosion rate, especially at perpendicular impact. This makes them suitable to be used as a mask material.
- it can be used by means of a thin plate (e.g. stainless-steel).
- Micro pattern can be created by micro drilling, micro milling or laser machining in this type.
- To apply this mask plate for AJMM, it can be magnetically clamped directly to the target or by introducing an intermediate protection/adhesion layer.
- A relatively thick metal layer lasts for a long time, so a mask can be used on several targets.
- The disadvantages of this mask type are the limitations in feature size (approximately 50 μm) and pattern constraints (circular patterns cannot be used because the inside should be supported).

Metal mask

- In order to combine the low erosion rate of a metal, and the high resolution of a lithographic process, a metal mask can be applied on the target by electroplating.
- Copper is used by this method, while Zinc mask can be made by electro-forming.
- (1), the whole target is covered by titanium (15 nm)/copper (400 nm) seed layer by sputtering

- In order to combine the low erosion rate of a metal, and the high resolution of a lithographic process, a metal mask can be applied on the target by electroplating.
- It works as an intermediate adhesion layer, between the target and the copper.



Steps of applying copper mask

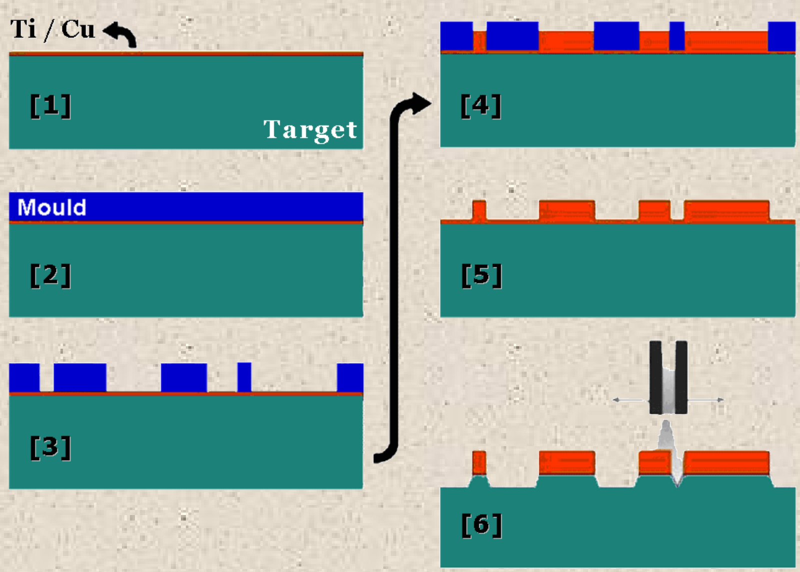
Metal mask

- (2), a thick polymer foil that is commonly used with electroplating is applied as a mould in which the copper is grown.

- (3), Micro pattern is lithographically defined.
- (4), Now the target is plated with copper.

- (5), After which the polymer is removed with a 10% KOH solution at room temperature.
- (6), The thin seed layer beneath the resist mould is generally not removed separately, but is easily
- etched away during the blasting

- After blasting, the remaining copper can be removed with a strong acid, such as HNO_3.



Steps of applying copper mask

Elastomer mask

- The erosion mechanism of rubber-like materials differs essentially from that of brittle materials or ductile materials.
- No lateral cracks are formed in elastomers as found in brittle materials.
- Neither do any evidence of cutting or ploughing wear as found in metals.
- Since the erosion mechanism of this class of materials is based on fatigue, they display a good erosion resistance.
- The photosensitive materials can be patterned accurately using lithography. Photosensitive-Elastomer can be a good option.
- However, in contrast to ductile or brittle materials, elastomers behavior is dependent on temperature, rate of deformation and particle velocity.
- Thus elastomers can show ductile, elastic and brittle behavior and experiments have to be carried out under relevant practical conditions.
- These types of mask usually provide in the form of ready-made foil with self-adhesive properties.

Photo-resist mask

- **Photoresists are photosensitive materials.**
- **There are two types of photoresists: positive and negative.**
- **For positive resists, the resist is exposed with UV light wherever the underlying material is to be removed.**
- **In these resists, exposure to the UV light changes the chemical structure of the resist so that it becomes more soluble in the developer.**
- **The exposed resist is then washed away by the developer solution, leaving windows of the bare underlying material.**
- **In other words, "whatever shows, goes." The mask, therefore, contains an exact copy of the pattern which is to remain on the wafer.**
- **Negative resists behave in just the opposite manner.**
- **Epoxy-based SU-8 is one of the good negative resists. It is able to provide features with high aspect ratios (>10) with UV-lithography.**

Comparison of masks

Metal masks:

- Stainless steel masks are very suitable for high particle velocities and fast machining operations.
- Structures with high aspect ratios are achievable due to the low erosion rate of steel.
- Attention has been paid to the adhesive layer, which should not only stick the two materials together but also avoid under etching.
- The limiting factors for all metal masks are the feature width and the structuring procedure where no free-standing contours are possible.
- Metal masks should be applied preferably for medium and large sizes.

Elastomer mask:

- Elastomer foils are easy to pattern and allow a high complexity of the design but the procedure is somewhat time consuming.
- They are not suitable for high air pressures due to their elastic deformation behavior.

Comparison of masks

- The adhesion is significantly weaker for complex patterns and higher particle velocities that may cause release of the foils from the substrate.
- Their applicability is limited to single workpieces and features sizes down to 75 µm.

Photo-resist mask:

- A good compromise in terms of feature size and imaging accuracy gives the epoxy based photo-resist SU8.
- A drawback is the expensive equipment to prepare the mask and its low selectivity.

- Since the maximum thickness of a SU8 layer is about 300 µm, no high aspect ratio is achievable and its application is limited to shallow cavities.

Abrasive powder feeding

- One of the major difficulties with the AJMM process is the handling of very fine abrasive particles.
- Powder flowability and compatibility are greatly influenced by particle size, size distribution, moisture content, and surface texture.
- Inter-particle adhesion is further enhanced by moisture that adsorbs readily onto these hygroscopic (having a tendency to absorb moisture) surfaces.
- Consequently, the relative humidity of stored air can have a major influence on the adhesive forces at the interface of particles.
- Furthermore, it is well known that the movement of powder leads quickly to stratification and the creation of gradient of particle size and/or shape.
- Such problems result in alteration of the powder mass flow rate during the course of AJMM experiments.

WHAT IS A HYDOPHOBIC SURFACE?

HAVING NO AFFINITY FOR WATER

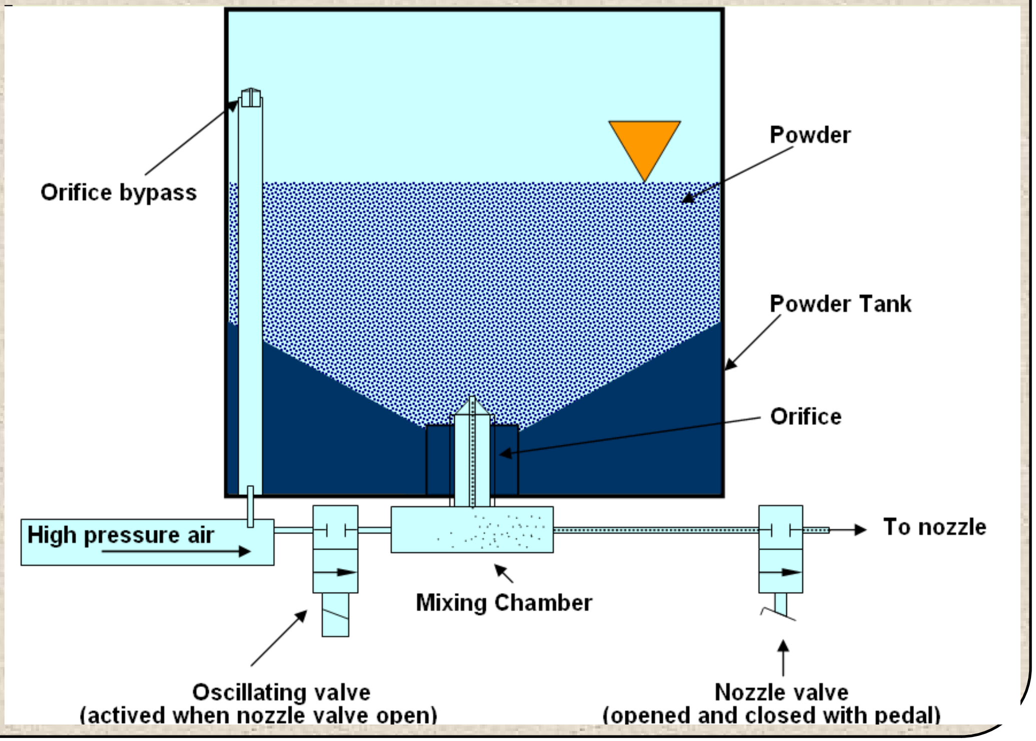
Powder feeding control

- Powder feed control of two micro-blasting systems is considered into two types.
  - Pressurized powder feed system
  - Fluidized bed powder spray system

- Other approaches to the control of powder mass flow rate include vibratory and screw or auger feeding in which the powder is fed to the conveying air through an auger (similar to the tool used for boring earth).
- Introducing a vibrator to a screw system improved the steadiness of the powder feed
- But the improvement diminished with fine, more cohesive materials such as zeolite and cement powders due to phenomena such as powder bridging, compaction, and agglomeration.

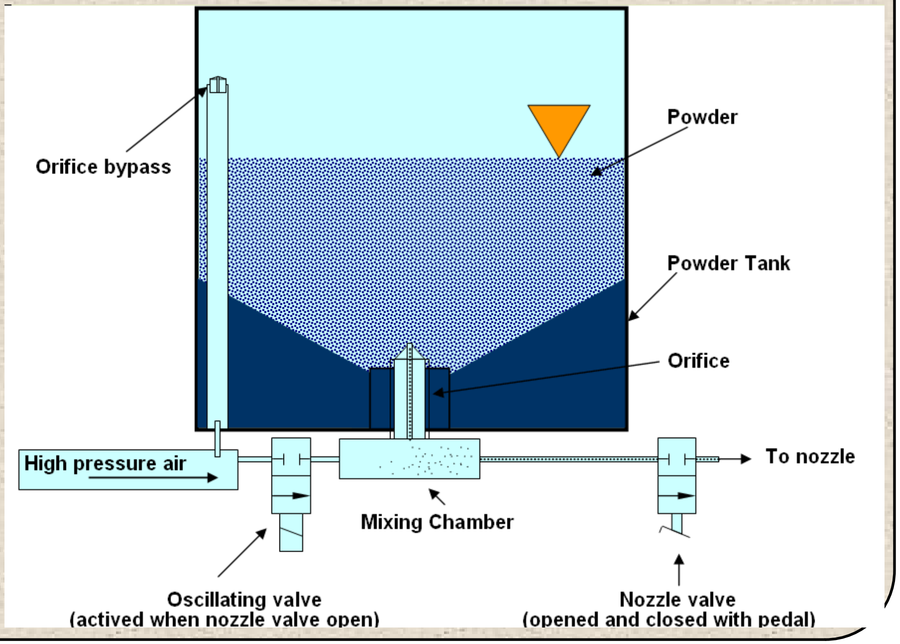
Pressurized powder feed system

- The powder is fed to the air stream from a pressurized reservoir through an orifice and mixing chamber.
- The system utilizes an oscillating valve that splits the operation cycle into two halves.
- The operation cycle is activated by a switch only after the entire system, including reservoir, has initially been pressurized by closing the nozzle end and opening the oscillating valve to the main air supply.
- During the first half of the operation cycle, the oscillating valve is open, allowing air to flow from the pressure regulator to the mixing chamber while some enters the powder reservoir and the rest flows out through the opened nozzle.



Pressurized powder feed system

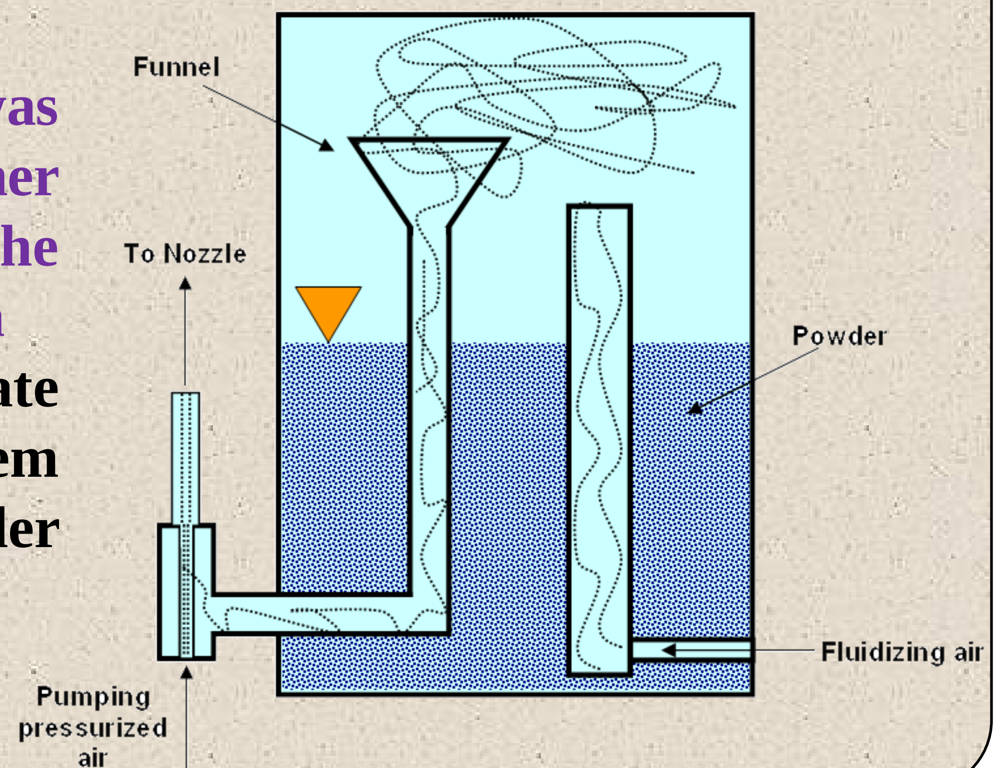
- It is during this first half-cycle that any powder that has entered the mixing chamber is forced out of the nozzle.
- In the second half of the cycle, the oscillating valve is closed, stopping air flow through the system.
- At this point, the reservoir is still pressurized, but the mixing chamber is at atmospheric pressure due to the open nozzle.
- This creates a pressure differential that forces the powder down through the orifice at the bottom of the reservoir and into the mixing chamber.
- The oscillating valve then opens again and the cycle is repeated.
- Limited control of the powder mass flow rate is possible by regulating the air flow rate through the reservoir, by changing the orifice by pass, and the size of the reservoir orifice.



Fluidized bed powder spray system

- In this system, upward high-speed air flow from the bottom of the reservoir through the powder bed created a cloud of suspended particles.
- Some of which settled into a collection funnel at the top of the reservoir that is connected to the air stream leading to the nozzle.
- The mass flow rate could be regulated to some extent by changing the diameter of the funnel.

- Fluidized bed powder spray was operated at significantly higher powder mass flow rate than the pressurized powder feed system
- The powder mass flow rate obtained by fluidized system decreased rapidly as the powder in the reservoir was consumed

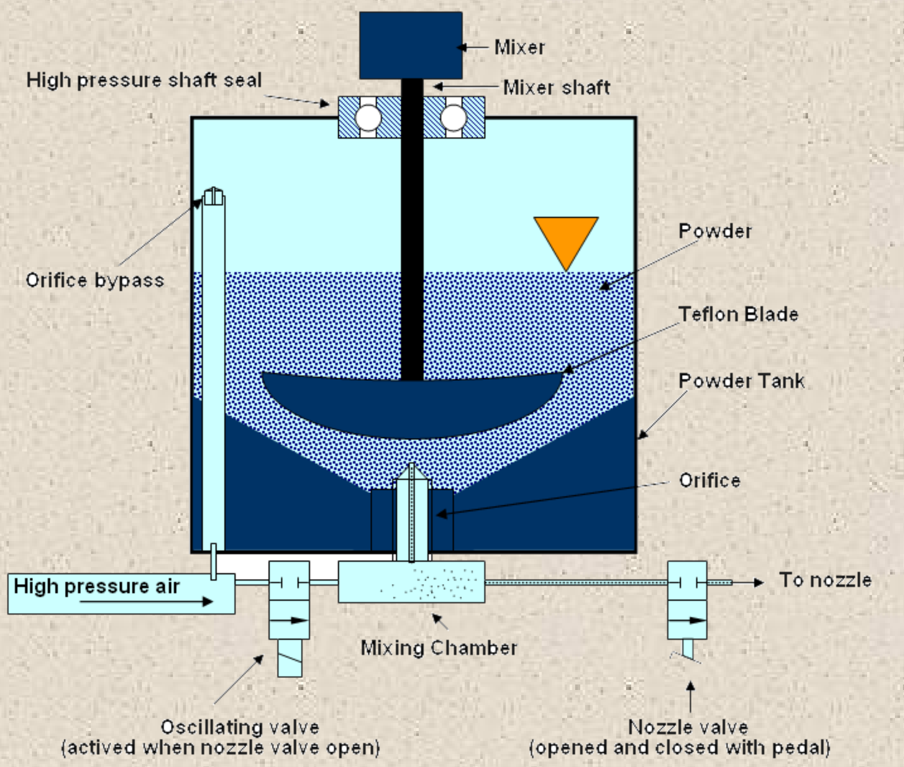


Factors affecting constant powder feeding

Powder compaction

- **This phenomenon usually happens in pressurized powder feed system. The powder is firmly compacted during the course of AJMM process. And by such way, cavities often form in the vicinity of the orifice, likely causing variations in the powder mass flow rate as the cavity walls collapse randomly, injecting bursts of powder into the nozzle.**

- **In order to reduce powder compaction in the reservoir of pressurized powder feed system, the system can be modified by mounting a variable speed rotary electric mixer above the reservoir with the shaft passing through a pressure-seal bearing that had been mounted into the reservoir cap.**



Factors affecting constant powder feeding

Effect of reservoir powder level

- The powder flow rates in fluidized system were an order of magnitude higher than in pressurized system.
- It is found to have good repeatability when the powder level in the reservoir was maintained at a constant level.

Powder stratification

- Powders stratify as they flow and it depends on particle size.
- Mixing time did not appear to affect the degree of particle stratification significantly.
- Therefore, the powder size distribution changes while blasting, as the smaller particles are ejected first, leaving the larger ones to remain in the reservoir.
- However, in most practical applications, a relatively small amount of powder is used during a single machining operation, and therefore a negligible change in the powder size distribution occurs.
- Nevertheless, to ensure repeatable results, the powder reservoir should be emptied and refilled with fresh powder often.

Factors affecting constant powder feeding

Powder humidity

- Mechanical properties of powder are influenced by humidity.
- Increasing humidity decreases the fracture toughness, which can have a large effect on the resulting solid particle erosion rates.
- Humidity can also greatly influence the powder flowability and the repeatability of particle mass flow rates, since it has a direct effect on inter-particle adhesion.
- To minimize these effects, sacks of desiccant were placed inside the sealed powder storage bottles, and both a desiccant-based and a refrigeration air dryer were used to dry the compressed air.
- Achieving a moisture free powder reservoir however, is difficult because of its frequent exposure to atmospheric moisture when it was opened to be refilled.
- This effect was minimized by ensuring that powders were left in the reservoir for the minimum amount of time.
- The use of the mixing device also presumably helped in breaking the particle–particle bonds caused by moisture.

EFFECT OF MASK MATERIAL ON EROSION RATES (16)

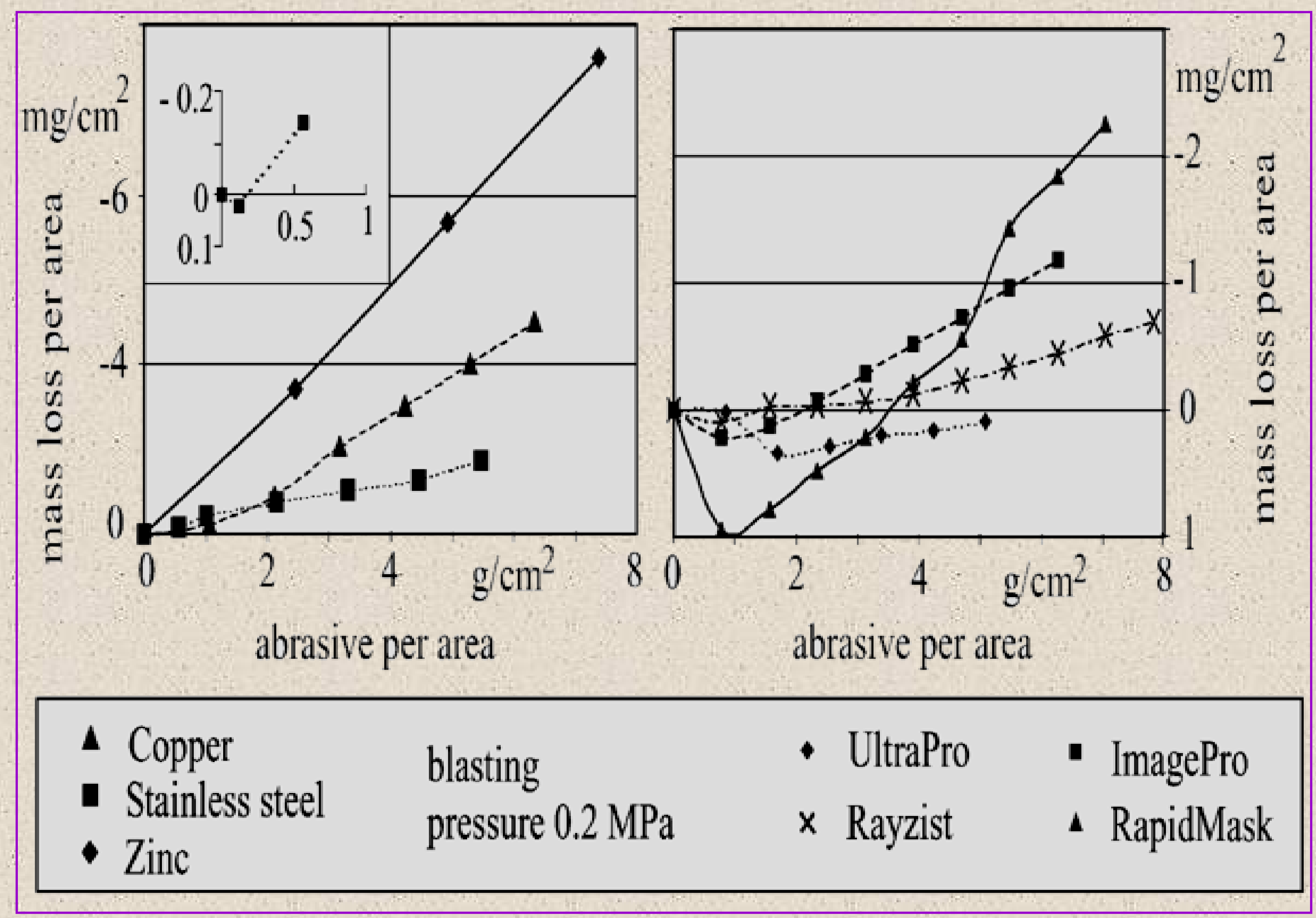
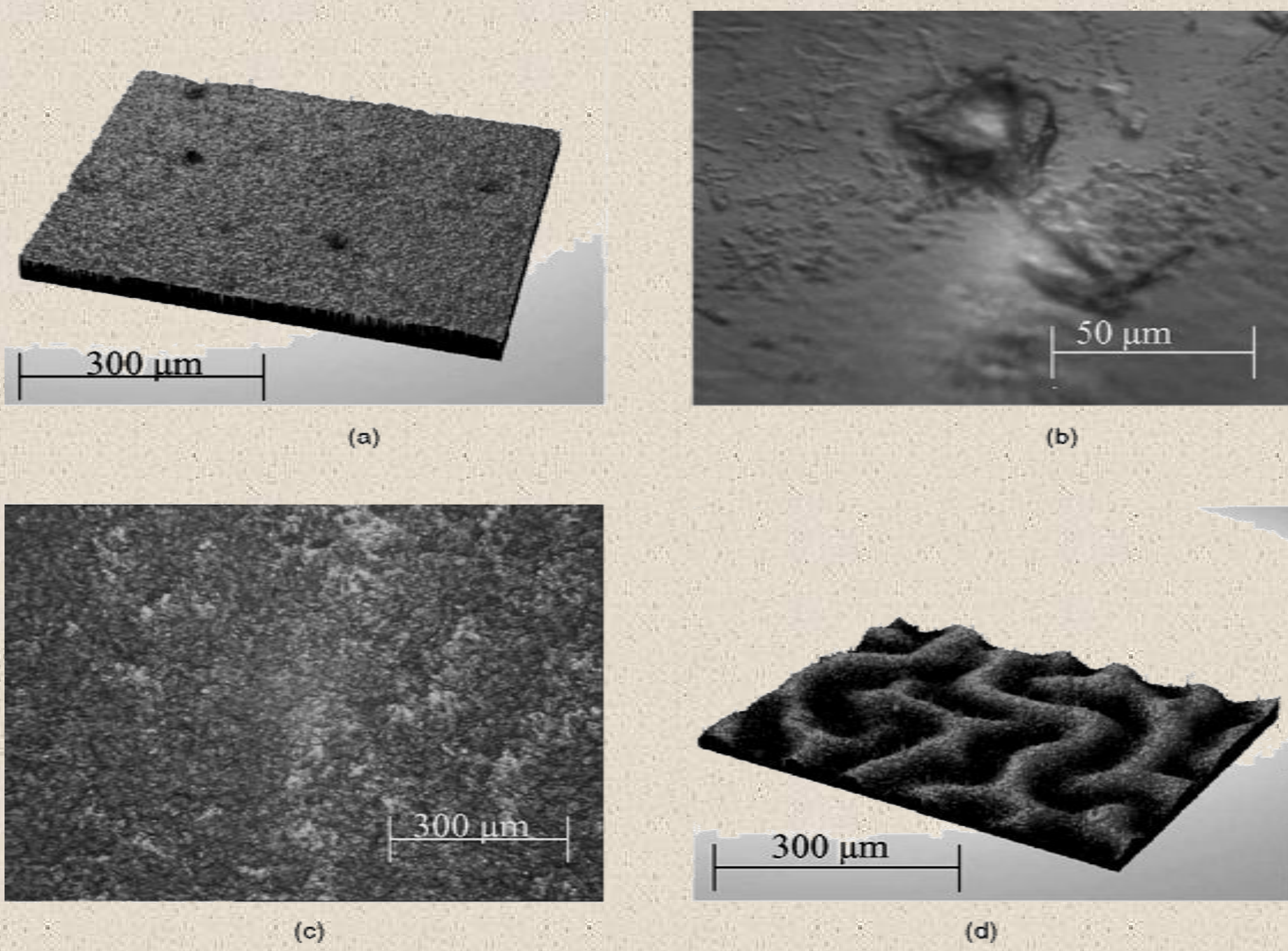
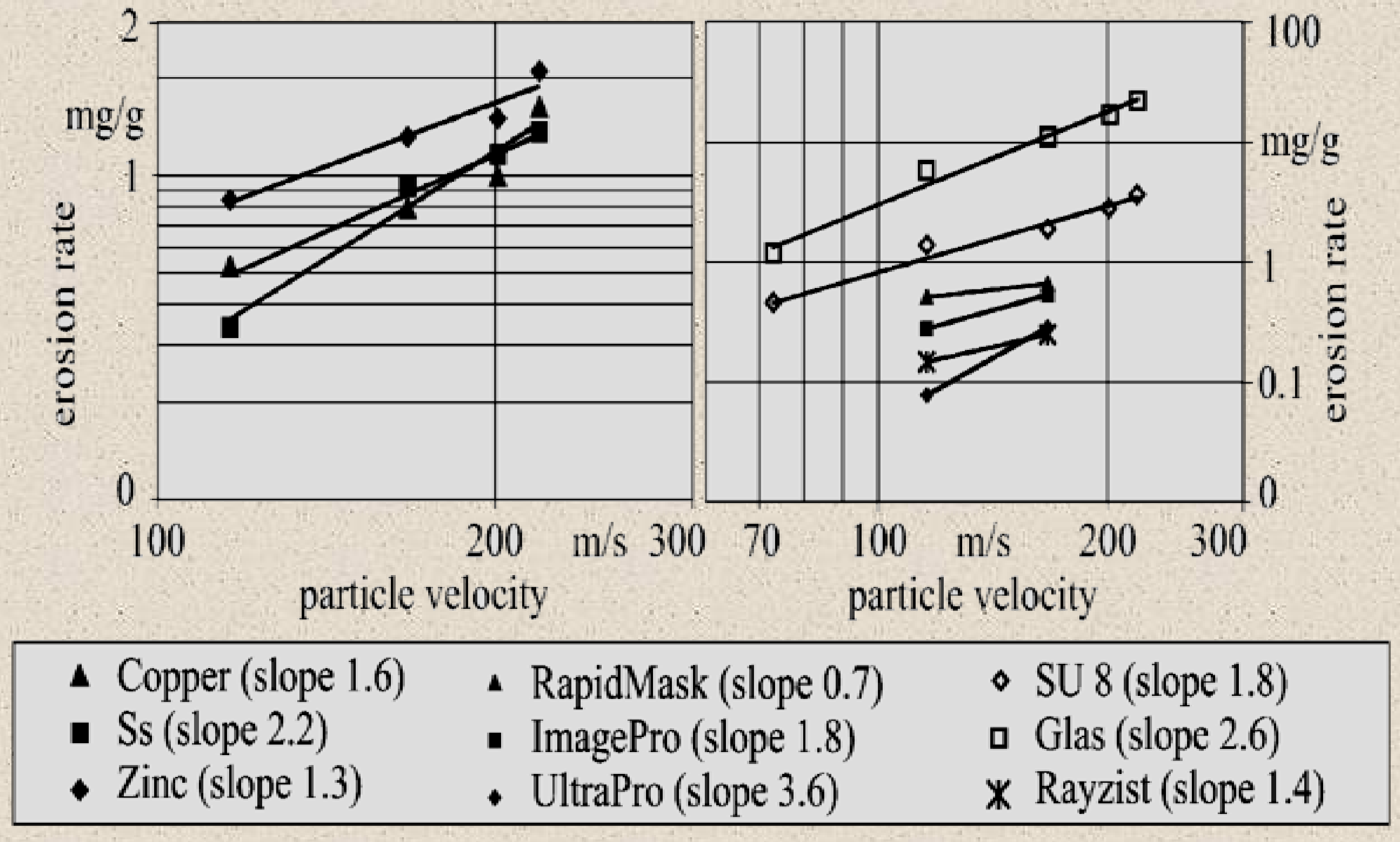


Figure.5 Change in mass during blasting (16)

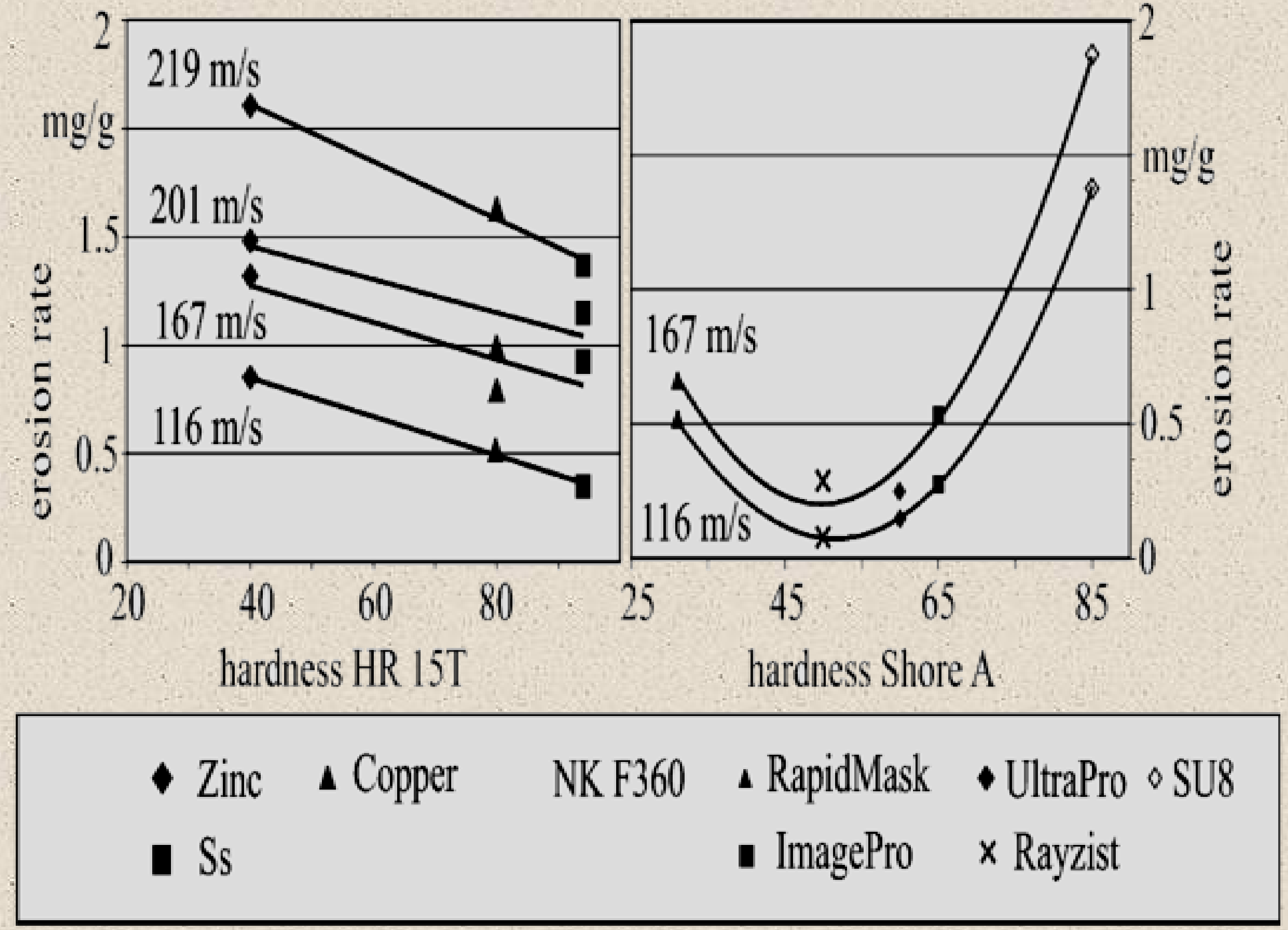
SURFACE OBSERVATIONS AFTER BLASTING: (A) IMAGE PRO; (B) SINGLE IMPACT IN RAYZIST; (C) SU8; (D) RIPPLES ON THE SURFACE OF ULTRAPRO (16)



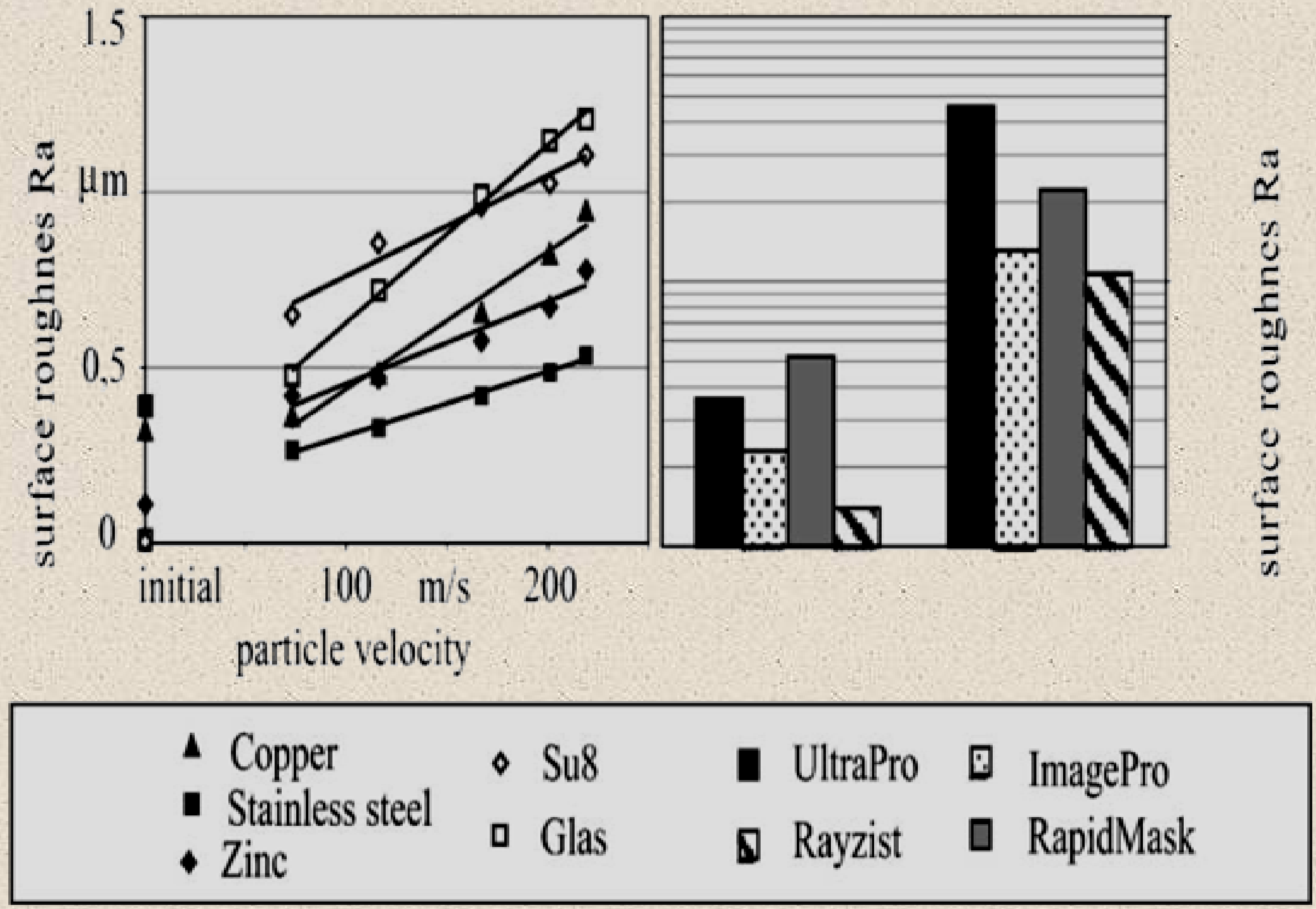
VELOCITY COEFFICIENTS OF EROSION RATE (16)

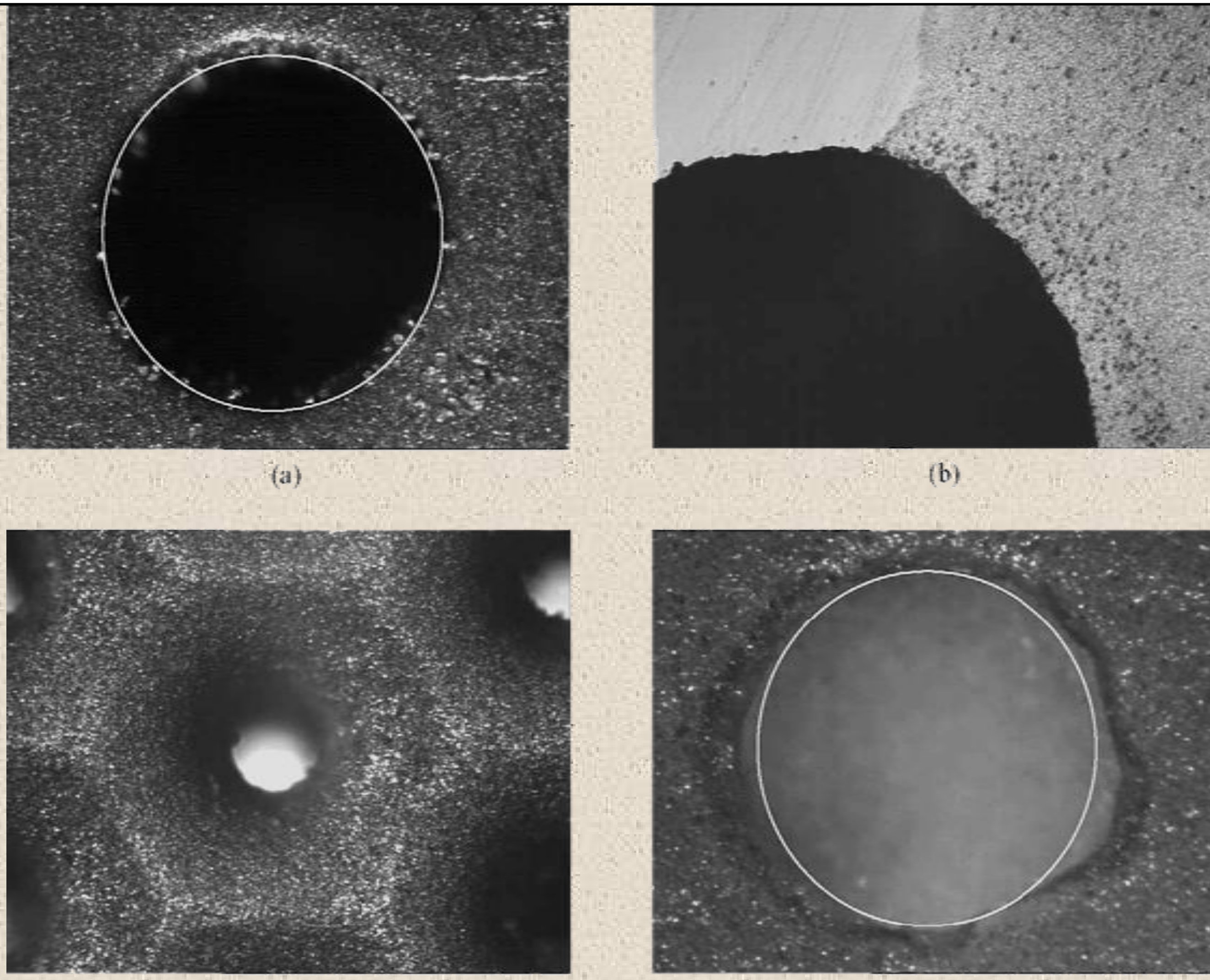


EROSION RATE DEPENDENT ON MATERIAL HARDNESS FOR SEVERAL PARTICLE VELOCITIES (16)



SURFACE QUALITY DEPENDENT ON PARTICLE VELOCITY (16

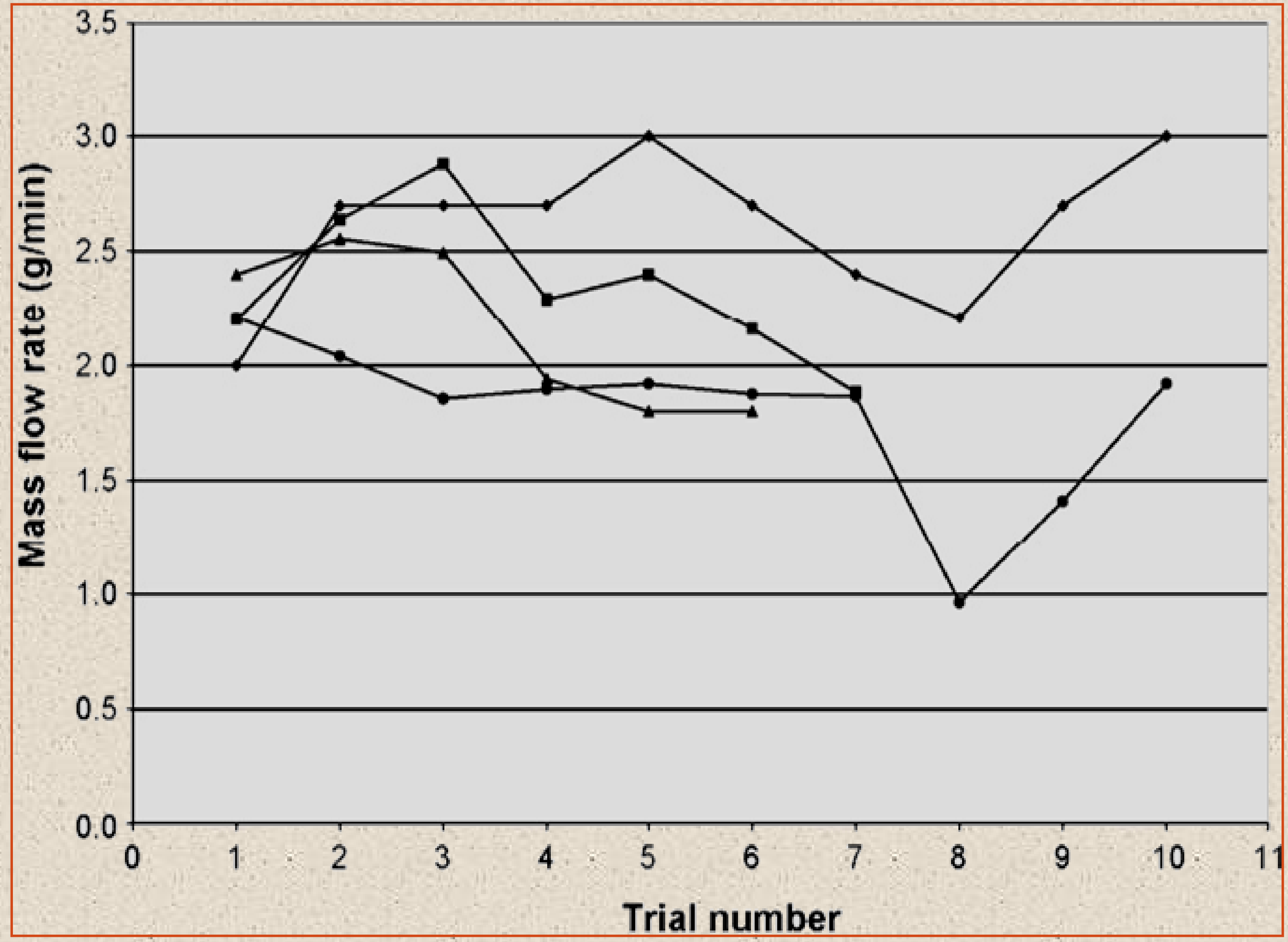




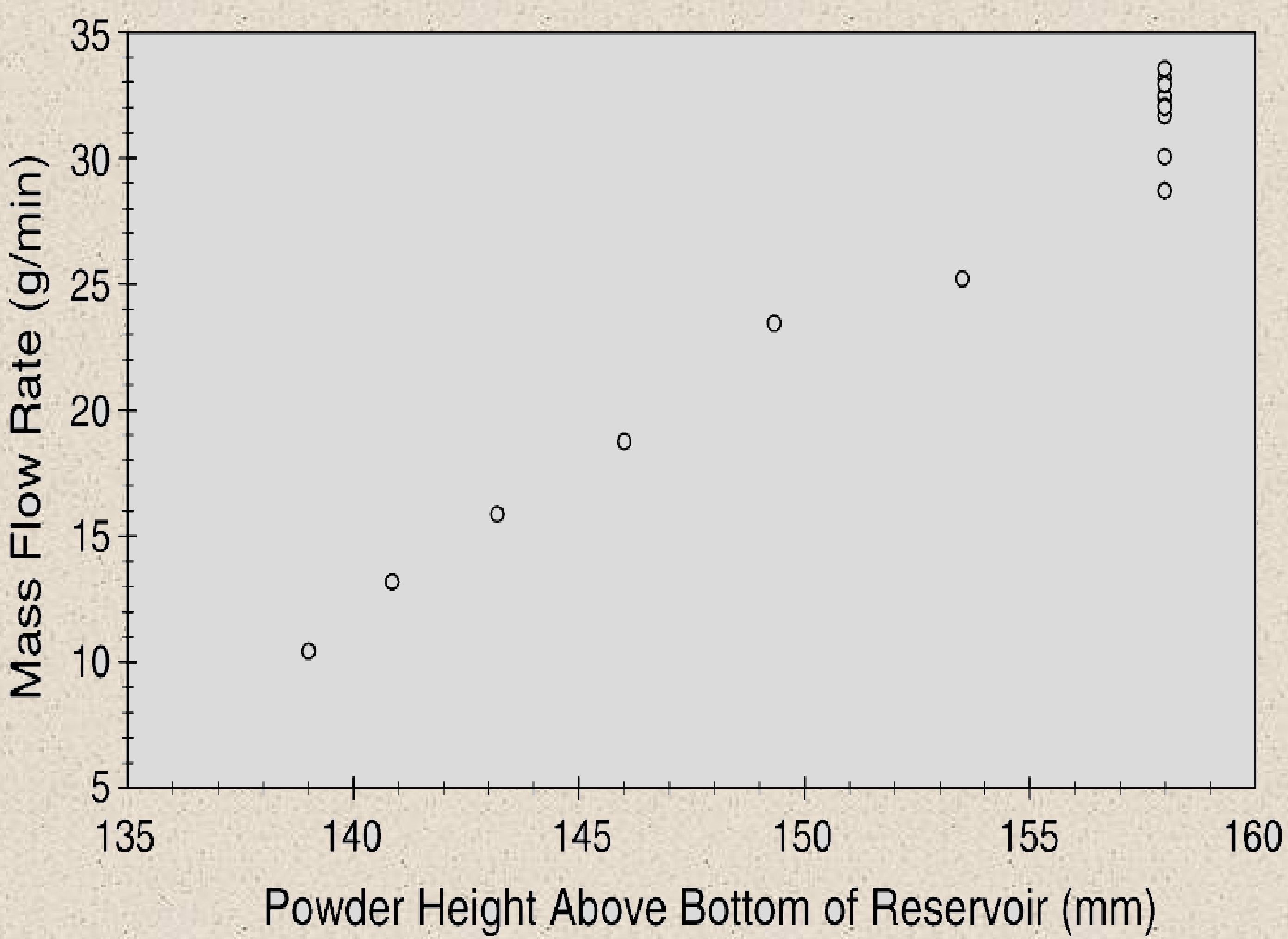
(a) (b)

(c) (d)

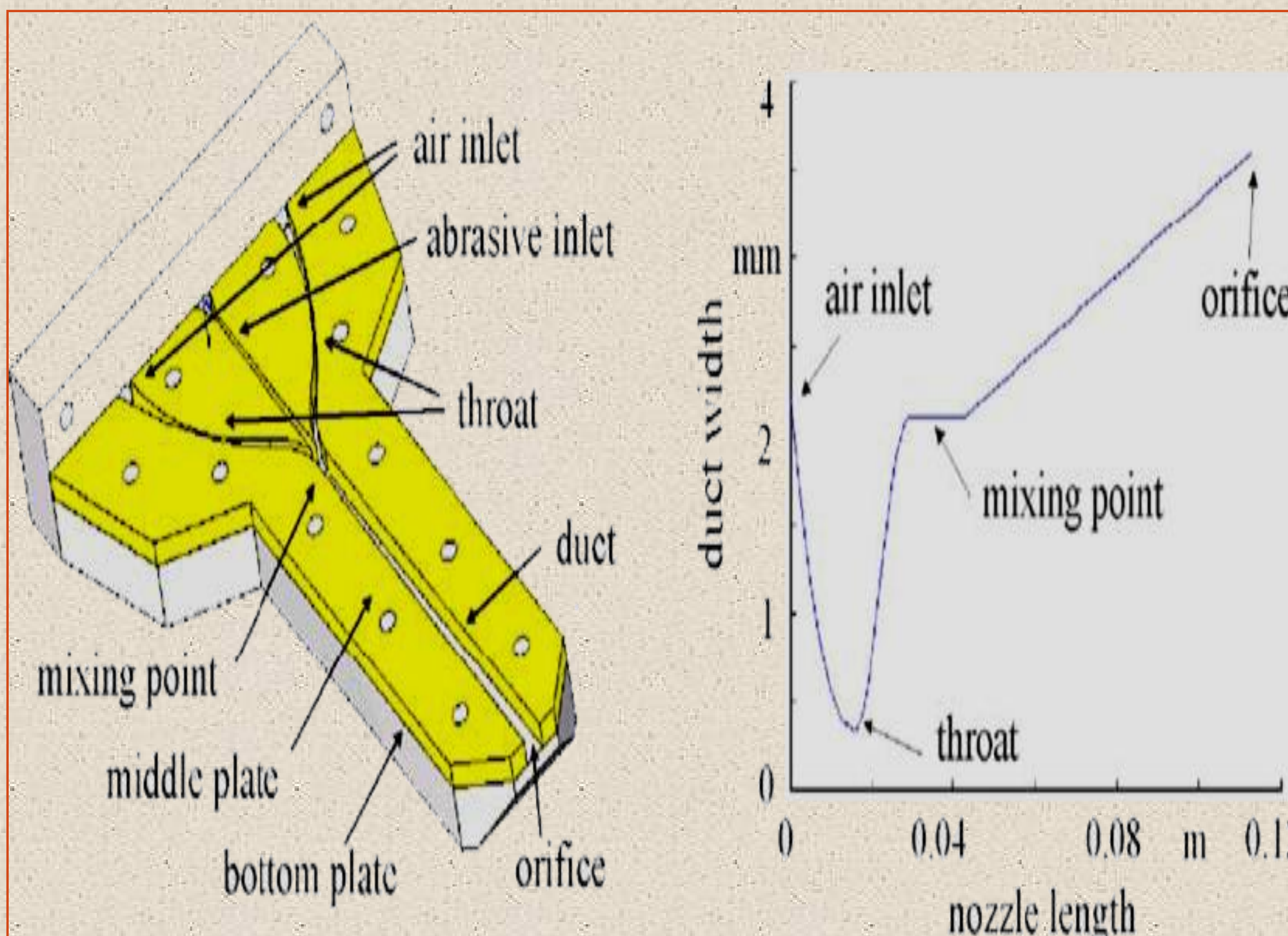
Imaging accuracy: (a) and (b) 1mm hole in steel and resulting under etching in glass after blasting with 0.8MPa; (c) electro-grown 0.3mm structure in zinc after blasting with 0.8MPa; (d) widening of Image Pro after blasting with 0.4MPa (16)



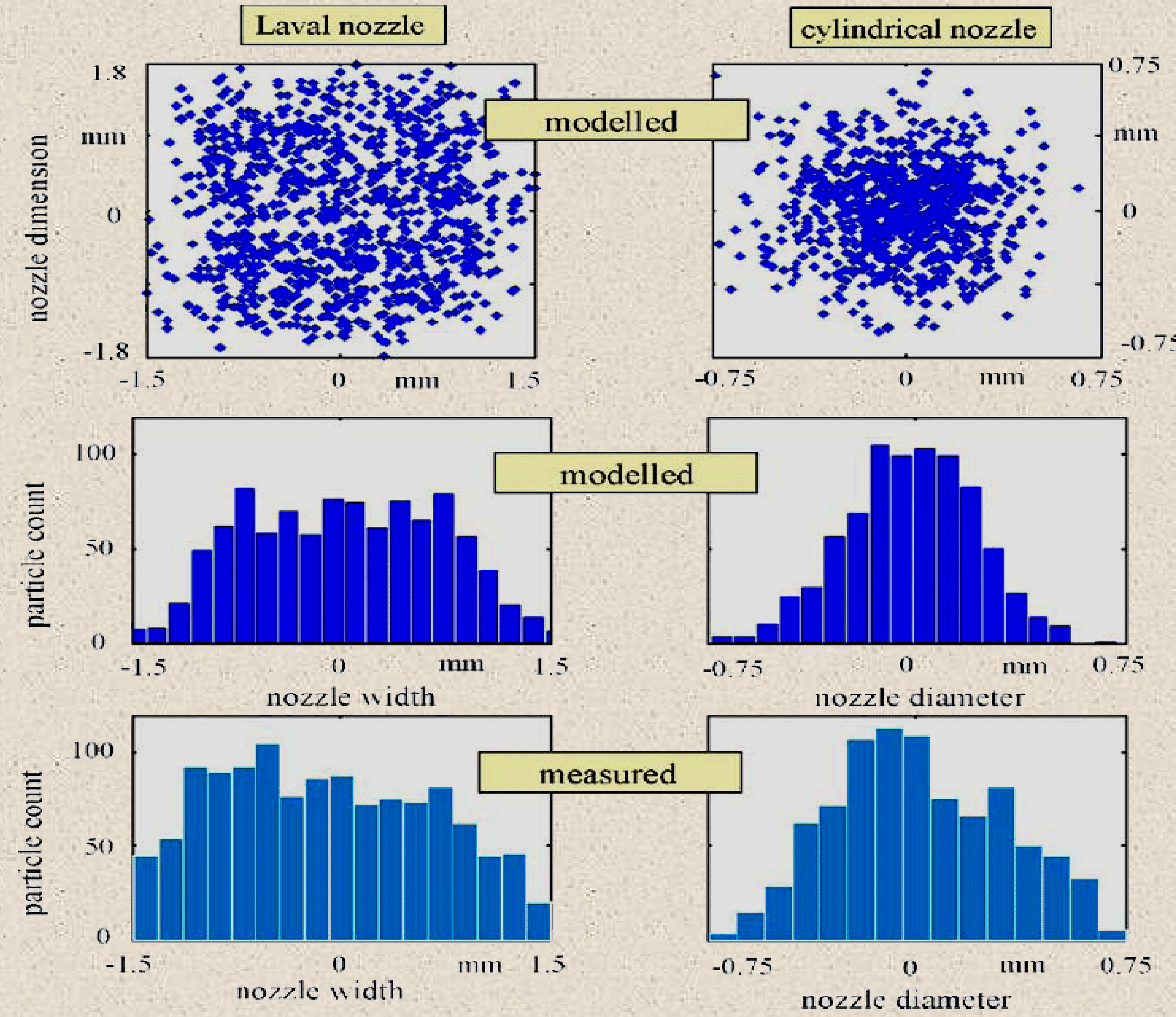
Repeatability of powder mass flow rate in pressurized system. Consecutive trials using sampling times of: (◆) 2 s, (■) 5 s, (▲) 10s, (●) 120 s. (21)



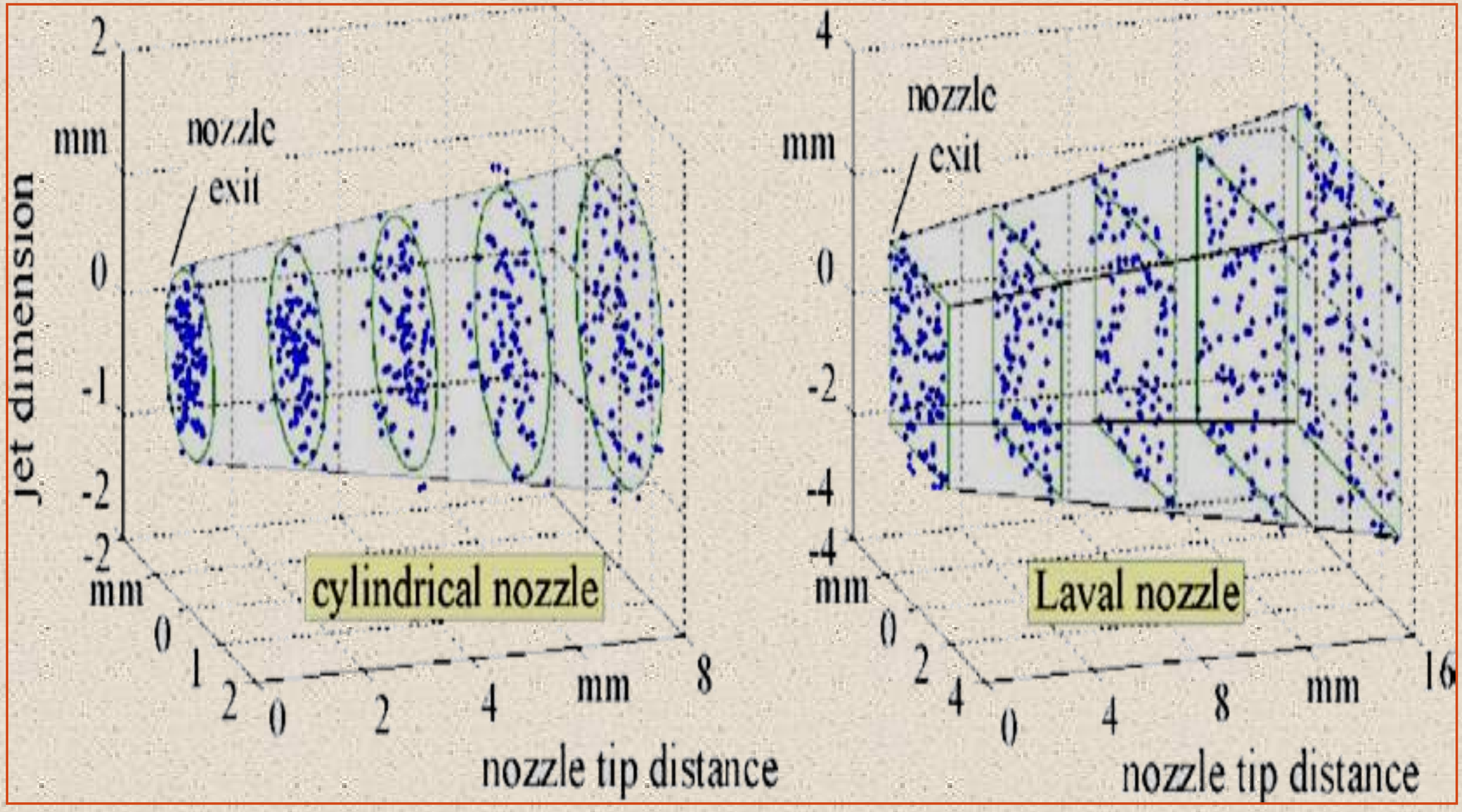
Mass flow rate as a function of powder level in fluidized system (21)



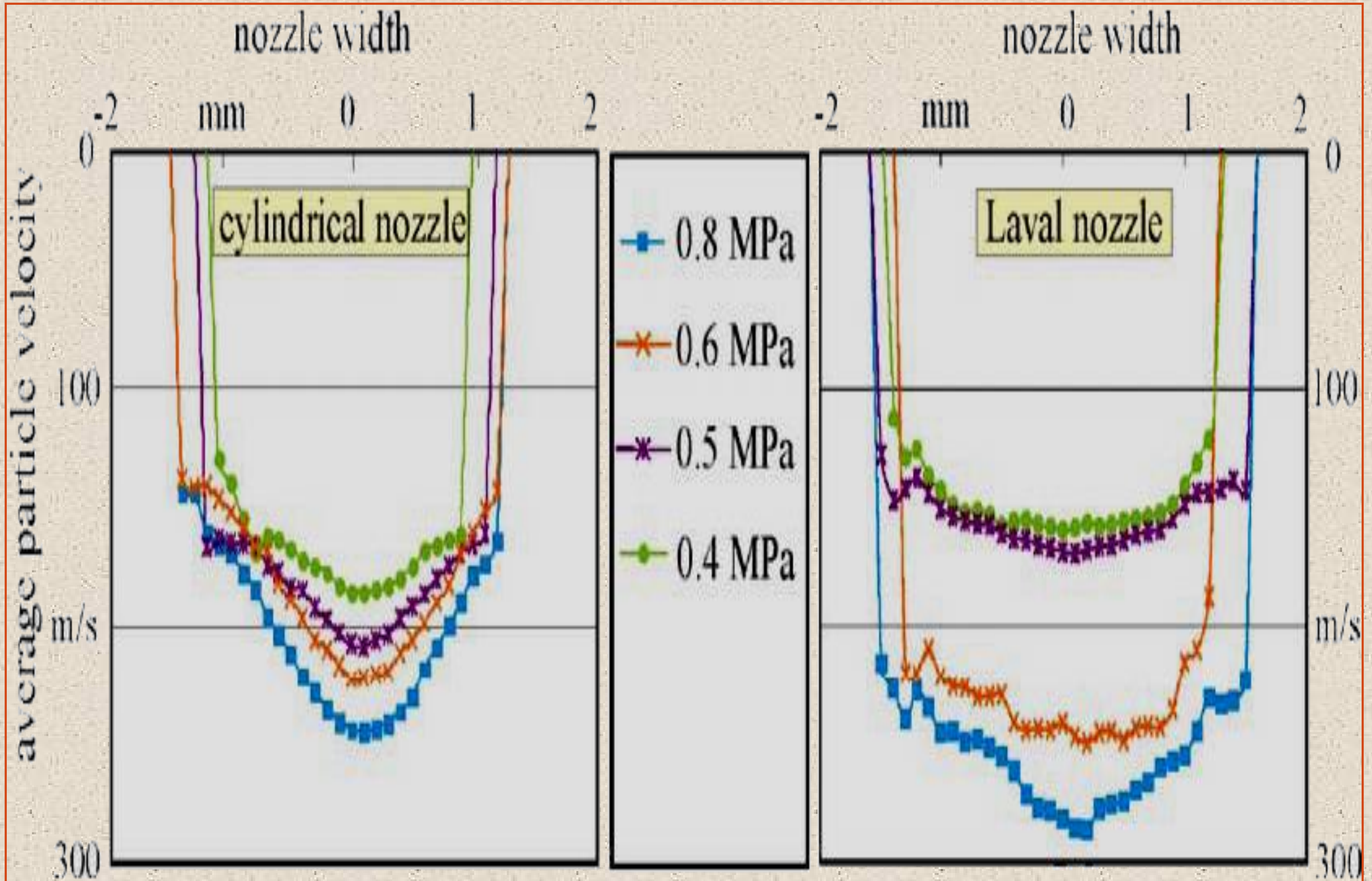
Laval nozzle design. The top plate is removed (32)



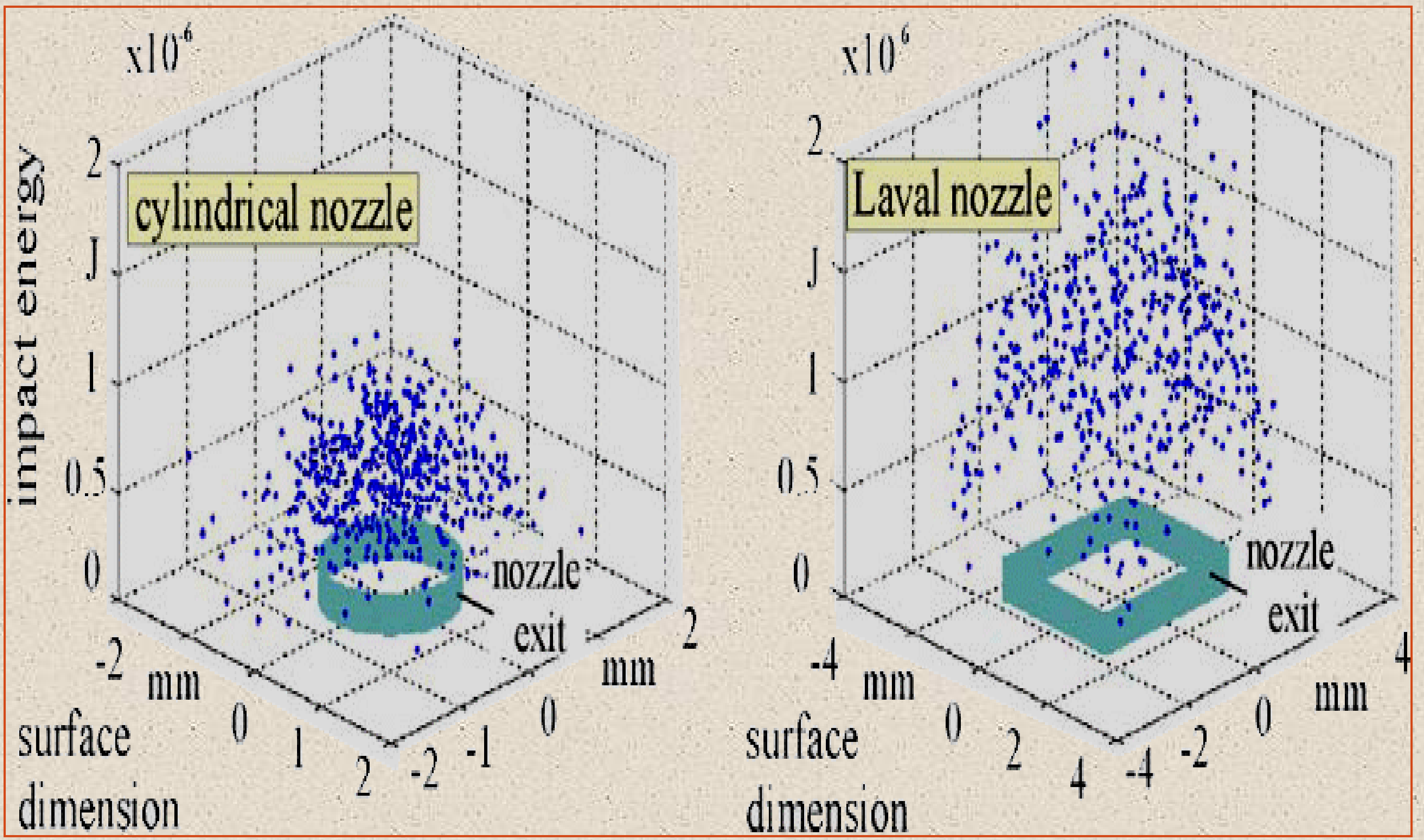
Modeled and measured particle density distribution at the exit of both nozzles (32).



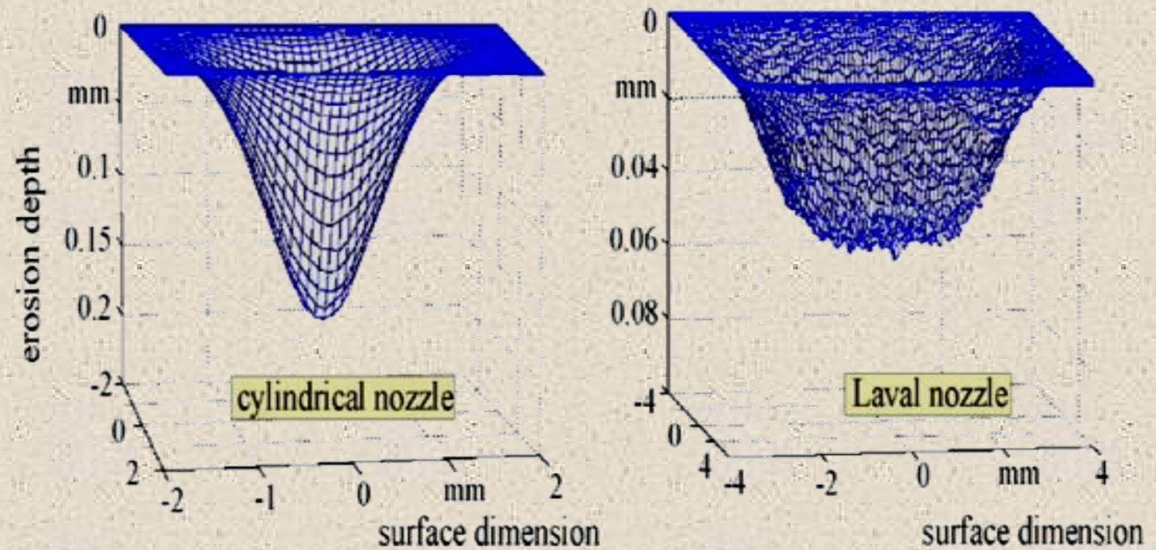
Modeled particle dispersion and jet expansion after leaving the nozzle



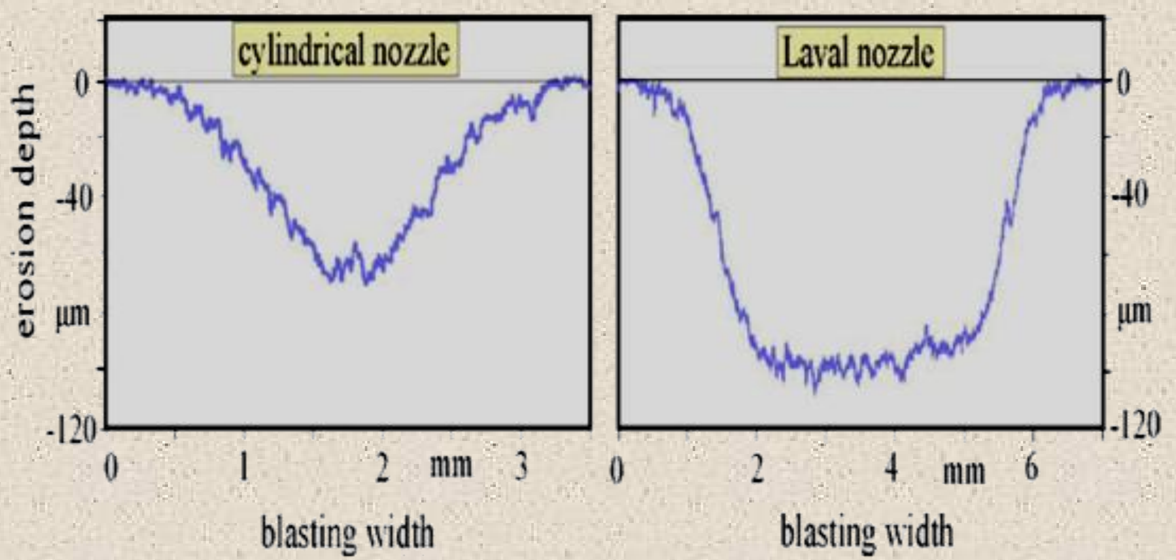
Measured axial velocity profiles of both nozzles (32).



Energy intensity distribution of 500 particles for 0.8MPa (32).



Blasting profiles with a stand still nozzle (32).



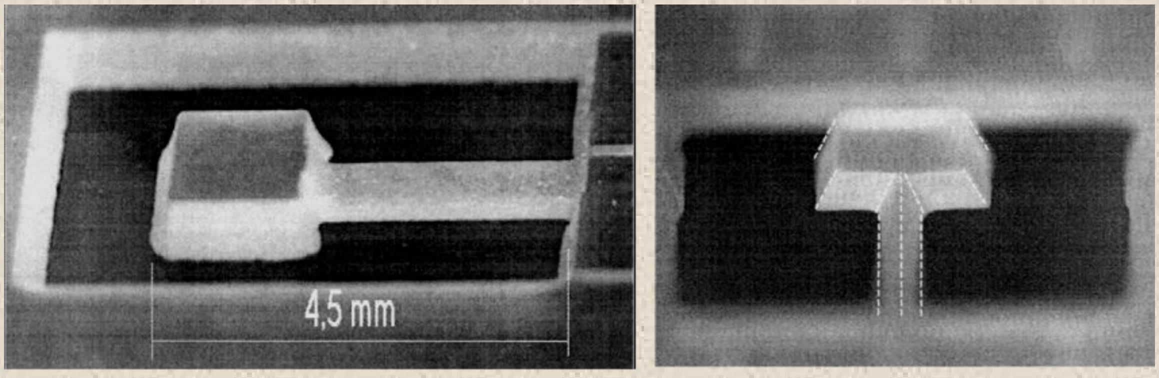
Measured cross-section of both blasting profiles (32).

Applications

- Shallow depth cut on ceramic materials
- Trenches for micro-medical applications
- Mesas to reduce the surface area of chuck and other semiconductor components
- Reference cavities for pressure sensors
- Thru-holes for air and chemical flow
- Cavities for mechanical locations
- Removing flash and parting lines from injection molded parts
- Deburring and polishing plastic, nylon and teflon components
- Cleaning metallic mould cavities which otherwise may be inaccessible
- Cutting of thin sectioned fragile components made of glass, ceramics, etc.
- Removing glue and paint from paintings and lather objects
- Frosting interior surfaces of glass tubes
- Etching / marking on glass cylinder

Applications - Micro Accelerometer Beam

- **Cantilever beam in Pyrex glass wafers for inertial sensor applications can be fabricated by AJMM.**
- **Fig. (a) made by a two-step erosion process: the first step consists of etching through the complete wafer (sensing mass and thick supporting beam)**
- **Using a second mask, it has locally thinned the cantilever beam for tuning the resonance frequency of this device.**
- **Such results could be obtained in one single step using the mask size depending upon erosion rate of the AJMM process.**
- **Another way to change the geometry of the mass supporting beams (resonance frequency), is to apply an oblique erosion process.**
- ***Fig. (b) shows the narrowed supporting beam by two oblique exposures at 45º.***

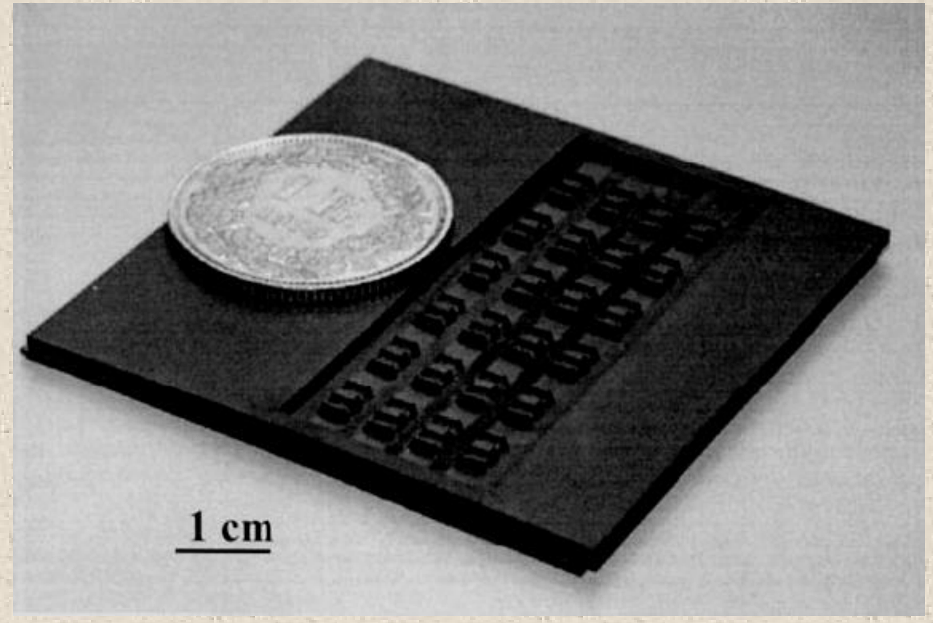


(a) (b)

(a) Picture of an accelerometer beam realized in two steps by powder blasting from the two substrate sides. (b) Glass cantilever beam realized by a two-step angular powder blasting process from one wafer side.

Applications - Matrix of micro E-cores

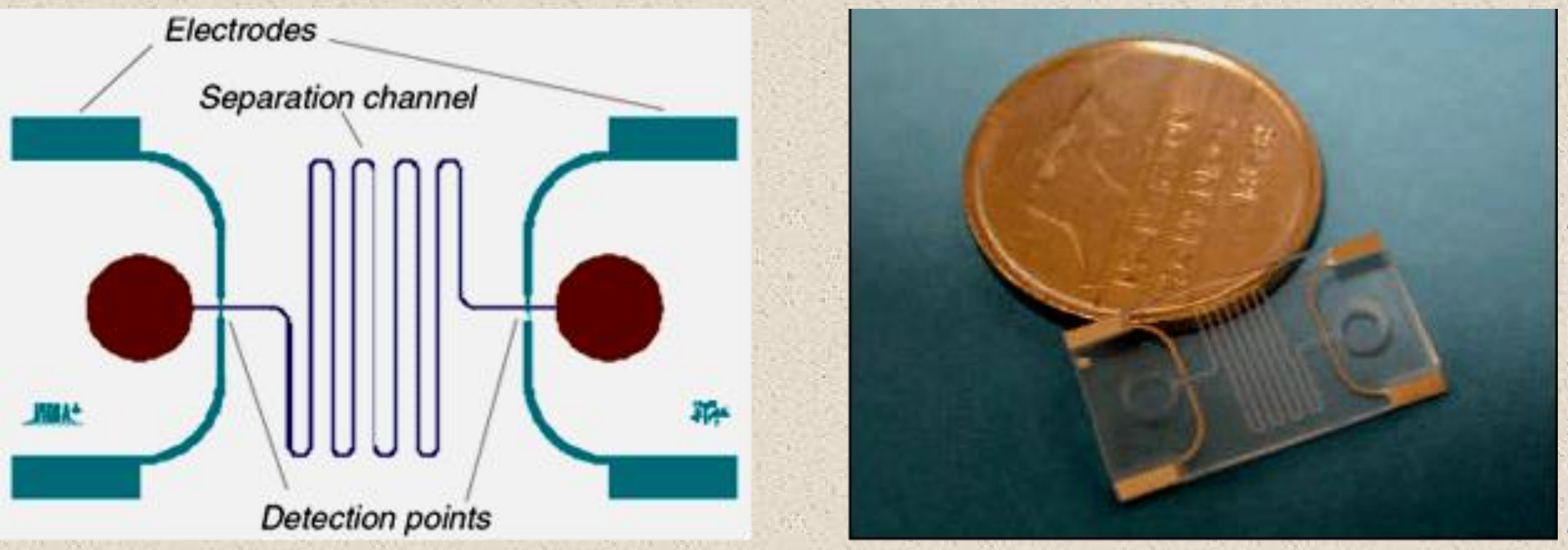
- **Another possible application of the powder blasting technology is the microstructuring of ferrite substrates.**
- **Fig. shows a matrix of 4-mm-wide E-cores, structured in a 1-mm-thick ferrite substrate for magnetic device applications like micro-transformers**
- **In this case, powder blasting proved to be not only the most appropriate, but also a very fast and cheap way to get such structures.**



Miniaturized *E*-cores microstructure by AJMM in a 1-mm-thick ferrite substrate for magnetic device applications

Applications - Capillary Electrophoresis (CE) chips

- The device consists of a glass chip which contains a single separation channel as well as an integrated conductivity detection cell.
- In contrast to most micro-fluidic glass devices, the channels are not wet etched in HF but machined by AJMM which allows the creation of microstructures below 100 µm, and additionally makes parallel holes machining at very low costs outside the clean room environment.

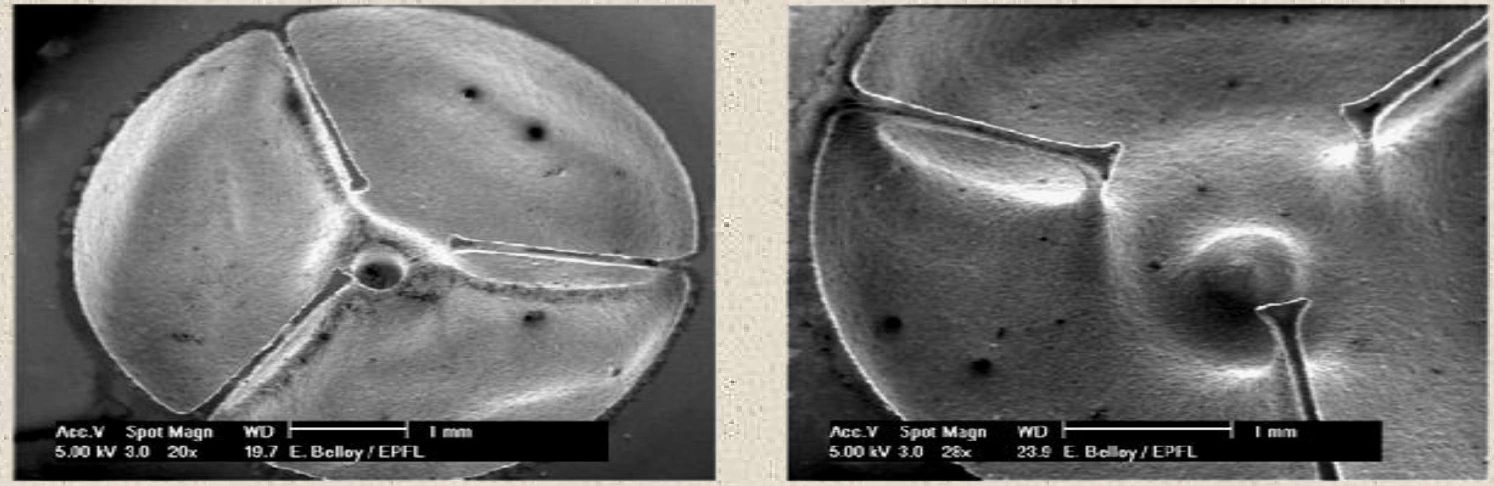


(a) (b)

(a) Mask layout of the CE chip. Two different electrode designs are incorporated. (b) The finished CE chip. Chip size 9 × 17 mm2 separation channel dimensions: length 6 cm, width 85 µm wide, depth 22 µm

Applications - 3D suspended microstructure

- Complex three-dimensional and monolithic suspended microstructure in glass was realized using normal and oblique AJMM.
- By controlling the under etching induced by oblique AJMM blasting, millimeter high microstructures in glass can be fabricated with an aspect ratio of 5:10, as well as free-standing monolithic 100-µm-wide structures, suspended over many millimeters.
- It also observed that the flexo-polymer resist mask as a good alternative to the metallic contact mask for structures realized at normal incidence.



(a) (b)

(a) **SEM of a structure containing three suspended glass cantilever beams realized in two steps: a normal jet (90°) followed by an oblique jet (50°). (b) Closer look of the structure**

Applications - 3D Passive Glass Micro mixer

- A passive micro mixer with 3-dimensional feature fabricated by AJMM process by employing photopolymer as a mask on a glass slide target (Fig. (a), (b), ©)
- The mask using SU8, a photosensitive polymer is applied as a micro-pattern for AJMM process.
- The fabrication process involved three glass target slides and conducted multi masking processes with four different mask patterns.
- The fabricated proposed micro mixer had an overall length of 13 mm and a width of 2.5 mm.
- The micro channels had a semicircular shape, with an average width of 350 µm and an average depth of 150 µm.
- Three glass layers were successfully bonded in a single step using a direct bonding method.

(a) (b) (c)

3D spring-like micro-mixer (a) comparison with one cent coin; (b) side view, (c) cross-section view

Advantages

- Minimal tooling cost
- Quick turn around for prototyping and development work
- Feature sizes down to 100 µm and featured depths to just a few microns are possible
- Feature location and dimensional tolerances down to +/-25 microns are possible
- Multiple features can be machined in one operation
- Very high pattern densities are possible
- Features can be of any 2D shape: square, round, designed shapes, and connected channels
- Masks are made directly out of CAD files reducing the risk of pattern error
- The process generates no heat and does not change the material properties of the work-piece
- Process works well with metalized parts

Limitations

- **Unlike vertical side walls produced by ultrasonic machining, abrasive blasting machined features have tapered sidewalls ranging from 18 to 26°, depending on several factors**
- **Maximum aspect ratio is 3:1 (Thickness:Diameter)**
- **Applications are restricted to brittle materials because of low MRR in case of ductile materials**
- **Some time additional cleaning operation is required to machine parts to remove abrasives from the surface**
- **Machining accuracy is poor**
- **Nozzle wear rate is high**
- **The process tends to pollute the environment**

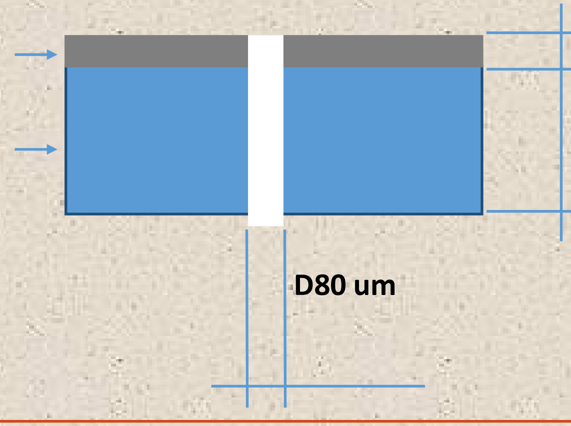
Problem-1

- Q1. **A glass specimen is covered by metal mask with thickness 100 μm and a hole pattern of 80 μm diameter. Specimen is a soda lime glass slide with size of 250x250x1.2 mm^3. The air pressure of 2 MPa gives a jet stream velocity of 150 m /s. The AJMM system used alumina as abrasive and set the feed rate at 0.02 g/s. How long would it take to get a through micro hole?**
- **Solution:**
- **(From Eq. (1))
  Principle: "**Mass loss of the erodent** is proportional to the **amount of abrasive**"
- → true for most brittle erosion
- Where:
  K = dimensionless factor
- m = amount of particles (kg)
- v = velocity of particles (m/s)
- ρ = density of the eroded material (kg/m^3)
- H = hardness of the eroded material (kg/mm^2)

Solution:

- (**From the problem and standard)**
- Soda lime glass = brittle material
- Erodent = alumina = abrasive particles
- Abrasive feed rate = 0.02 g/s = 2 x 10^{-5} kg/s
- gravity = 9.8 m/s^2
- (Density) ρ-alumina = 3.95 gr/cm^3 = 3950 kg/m^3
- (Density) ρ-soda lime glass = 2.5 gr/cm^3 = 2500 kg/m^3
- Hardness-soda lime glass = 585 kg/mm^2 = 586 x 10^6 kg/m^2
- v-abrasive = 150 m/s
- dia.-hole = 80um
- height-specimen = 1.2 mm = 1200 μm
- K-metal = 2.3 ~ 3
- 100 μm
- D80 um
- 1200 μm
- Soda lime glass
- Metal mask
-

  Volume-hole = $\pi r^2 h$ = (3.14)x(40 μm)^{2}x (1200 μm) = 6.03x10^6 μm^3= 6.03x 10^{-12} m^3
- m-abrasive = volume-hole x ρ-alumina = (6.03 x 10^{-12} m^3) x (3950 kg/m^3) = 23.73x 10^{-9} kg



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Weight.loss = K x $(\rho/H)_{\text{soda lime glass}}$ x (½) x $(m \times v^2)_{\text{abrasive}}$
= 3 x (2500) kg/m^3 x (1/586 . 10^6)m^2/kg x (½) x (23.73. 10^{-9}) kg x (150)^2 m^2/s^2
= 3.36 x 10^{-9} kg.m/s^2

Weight.loss = m x g → m = weight.loss / g = (3.36 . 10^{-9}) kg.m/s^2 x (1/9.8) s^2/m = 0.34 x 10^{-9} kg

Feed rate = m / t → t = m / federate = 0.234 . 10^{-9} kg x (1 / 2.10^{-5}) s/kg = 0.258 x 10^{-4} s


THANK
YOU