Abrasive Jet Machining

Synopsis

- Introduction
- Principle
- Equipment
- Material removal rate
- Process parameters
- Advantages
- Limitations
- Applications

Introduction - 1

- Type of Energy: Mechanical
- Mechanism of material removal: Erosion
- Transfer media: High velocity particles
- Energy source: Pneumatic / Hydraulic pressure
- Abrasive jet machining (AJM) removes material through the action of a focused stream of abrasive-laden gas
- AJM can be used to cut hard, brittle materials (germanium, silicon, mica, glass and ceramics) in a large variety of cutting, deburring, etching, polishing and cleaning operations

Introduction - 2

- Not so effective on soft materials like aluminum, rubber etc.,
- Process is inherently free from chatter and vibration problems because the tool is not in contact with the workpiece
- The large quantity and small mass of the abrasives result in uniform loading of the part. This enables AJM to produce fine, intricate detail in extremely brittle objects – e.g of AJM processed eggshell
- Cutting action is cool, because the carrier gas also serves as a coolant and so workpiece experience no thermal damage

AJM processed egg shell

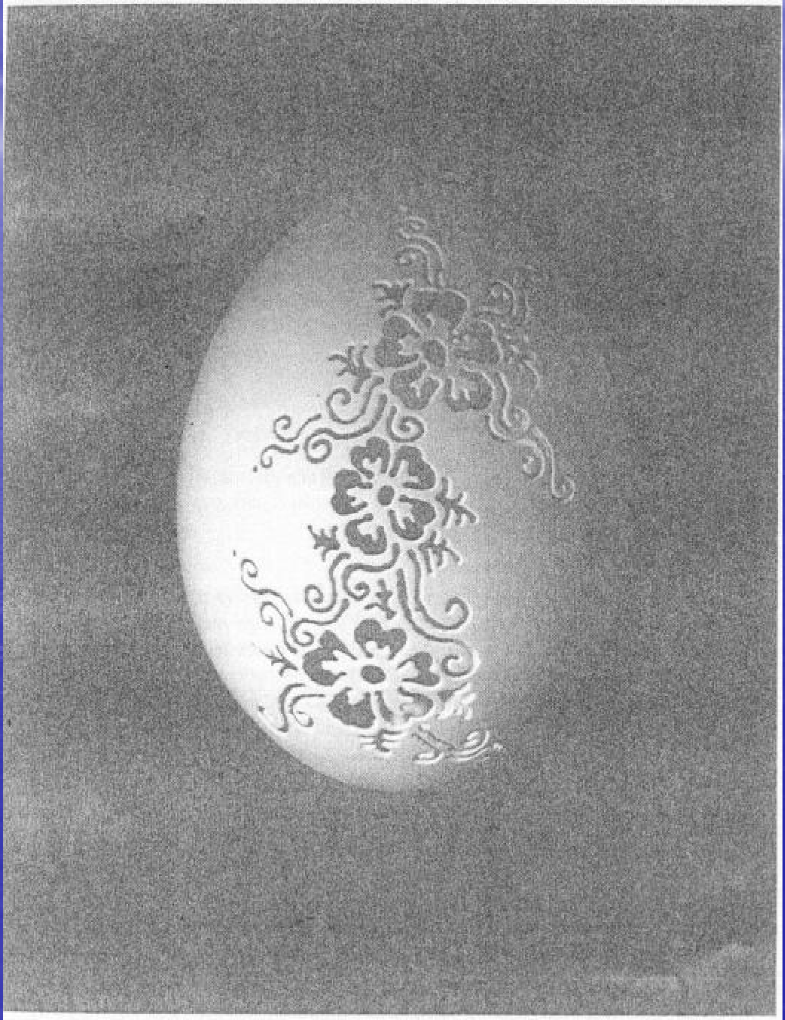


Figure 2.1 An AJM-machined egg shell showing the ability of the process to machine intricate shapes into brittle workpieces (Source: S. S. White Industrial Products, Pennwalt Corporation, Piscataway, NJ).

Working principle

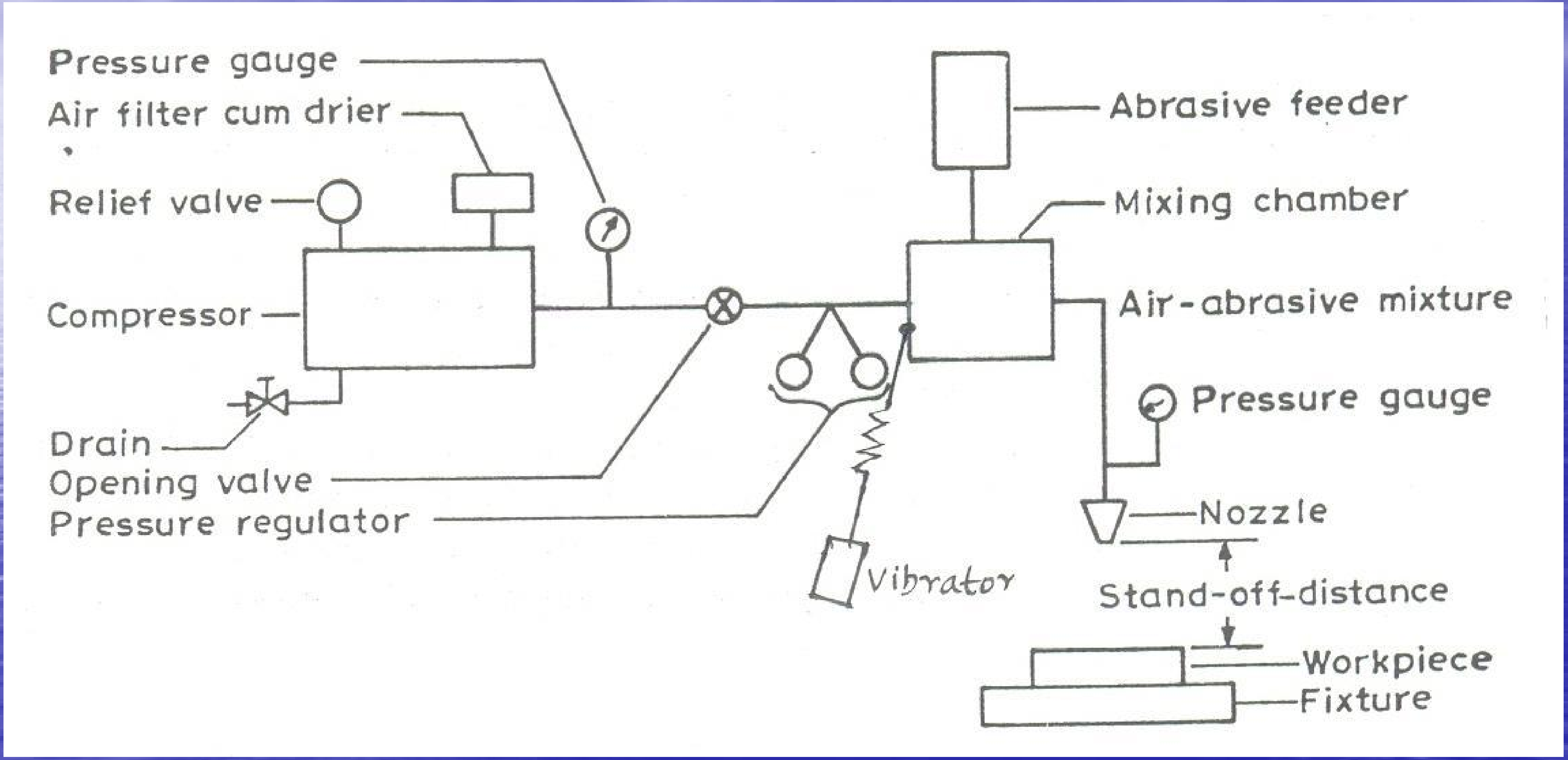
- Material is removed from the workpiece by the impingement of fine abrasive particles entrained in a high-velocity gas stream
- A jet of inert gas consisting of very fine abrasive particles strikes the workpiece at high velocity (usually between 200-400 m/sec) resulting in material removal through chipping / erosive action

Equipment

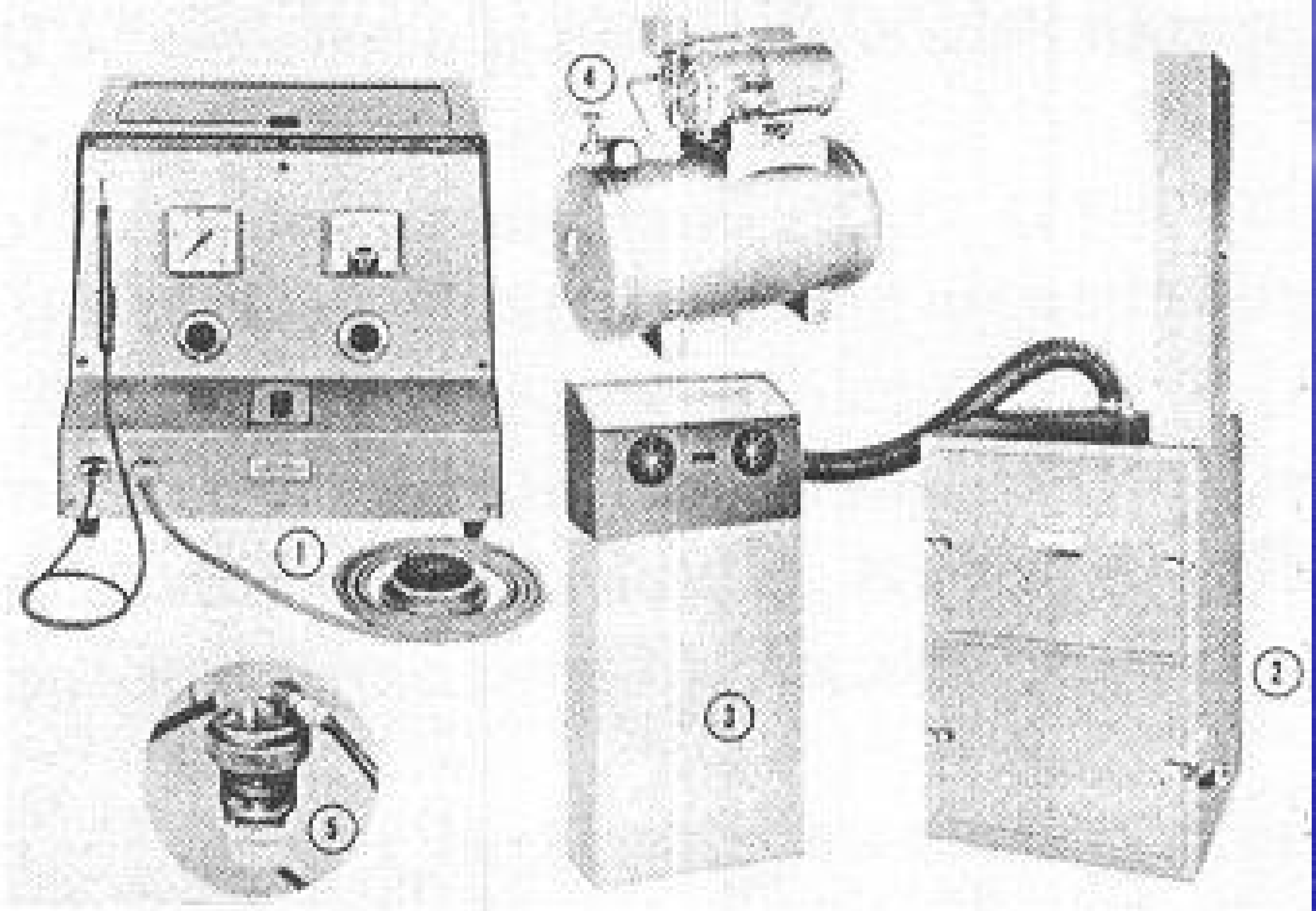
- One of the least expensive nontraditional processes to incorporate is AJM
- A typical AJM system can be purchased for under $5000
- AJM system consists of four major subsystems:

1. Gas propulsion system
2. Metering system
3. Delivery system
4. Abrasive collection system

Schematic of AJM setup



AJM equipment



1. AIRBRASIVE UNIT
2. DUST COLLECTOR
3. EXHAUST CHAMBER
4. AIR COMPRESSOR
5. AIR FILTER

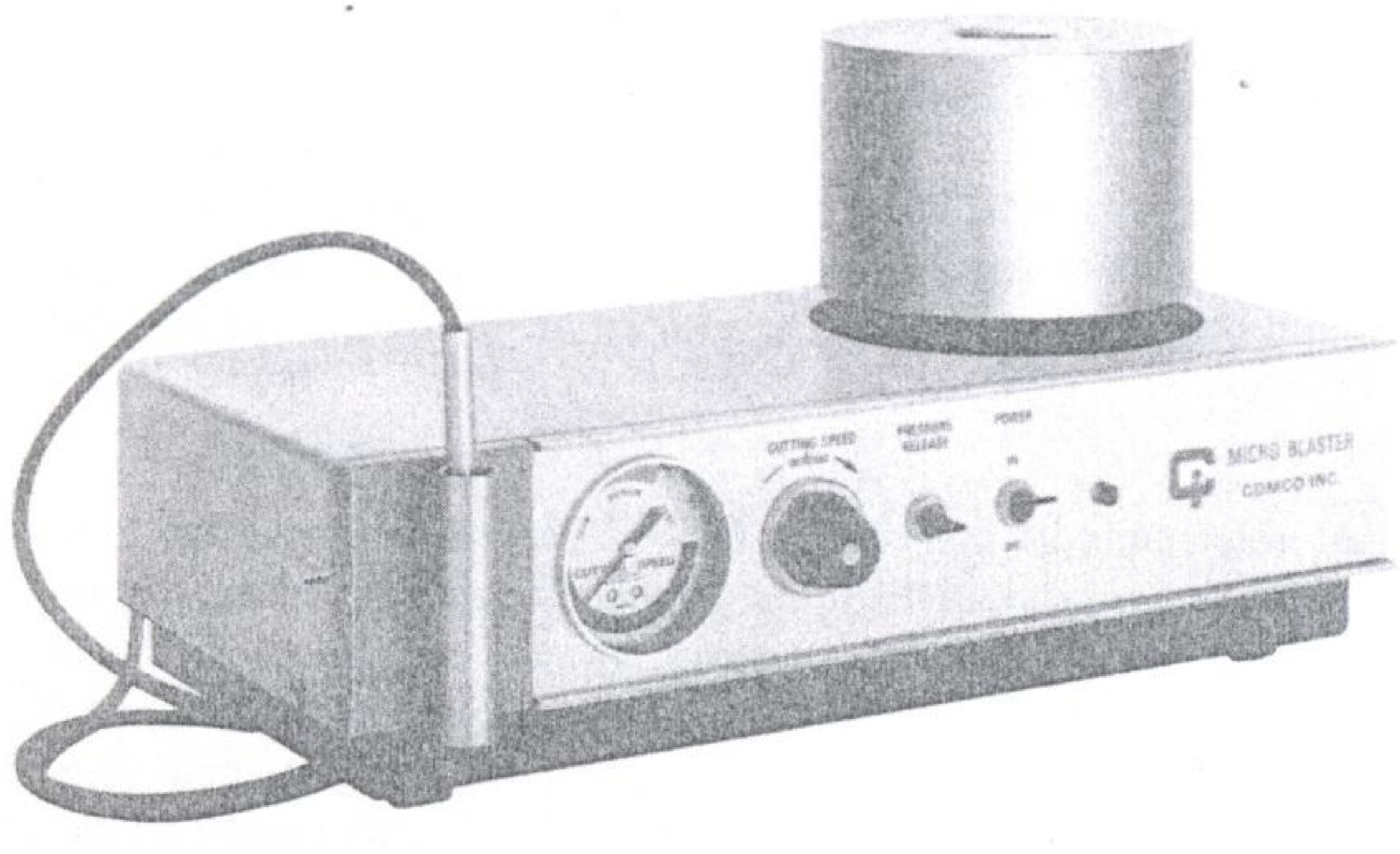


Figure 2.3 An AJM system showing main unit, powder hopper, and hand-piece (Source: Comco, Inc. Burbank, Calif).

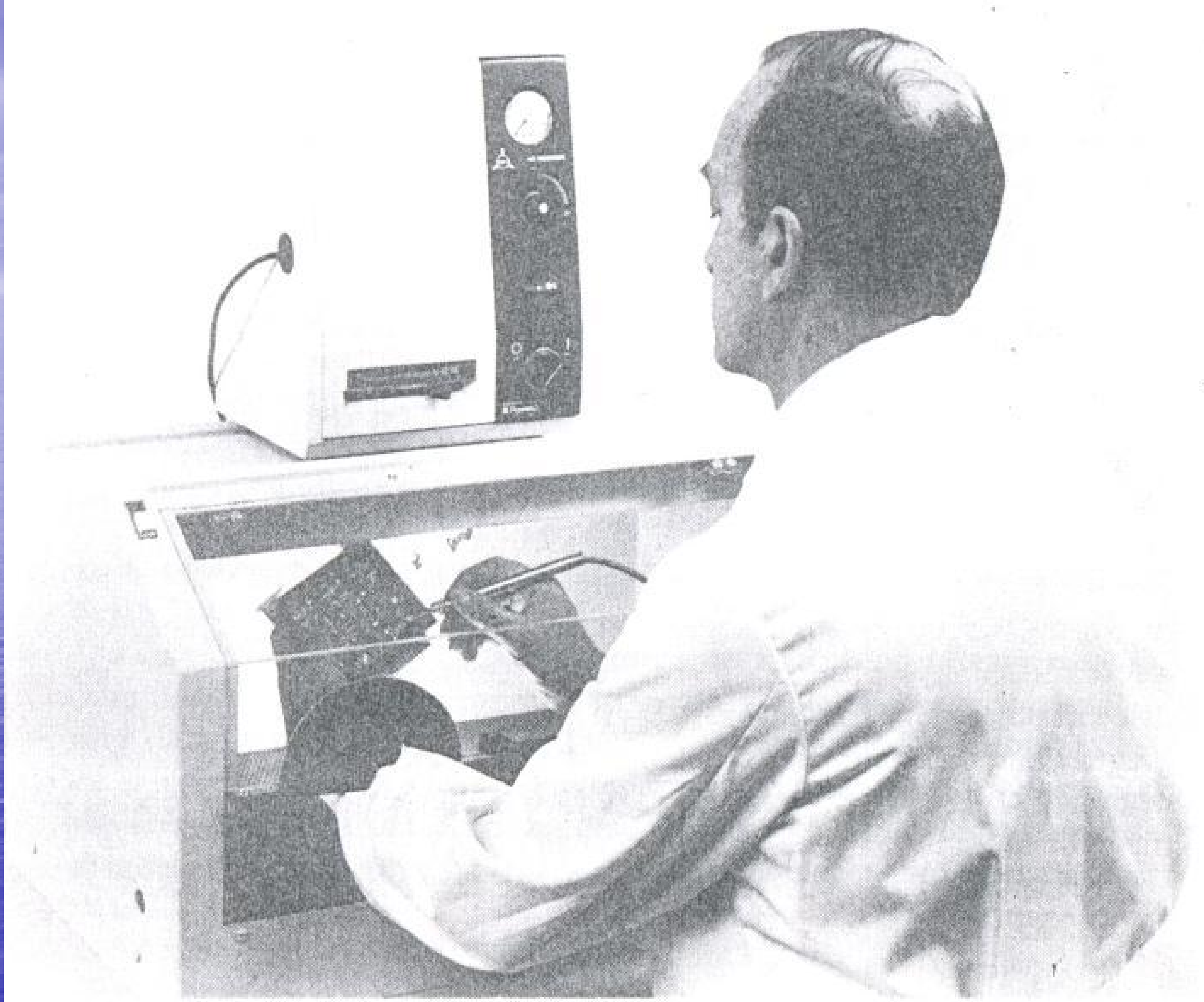


Figure 2.4 An AJM system being used inside a dust-collecting work chamber (Source: S. S. White Industrial Products, Pennwalt Corporation, Piscataway, NJ).

Equipment - Gas propulsion system

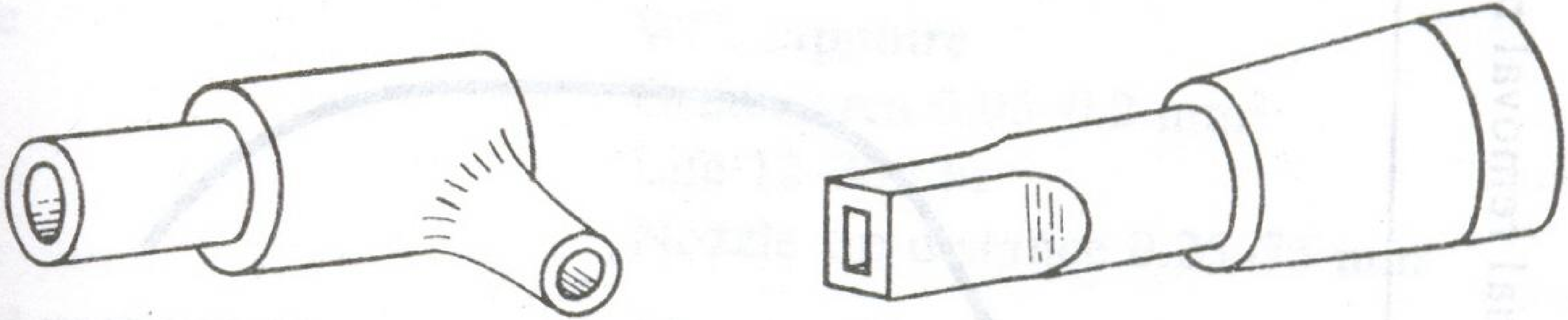
- Provides the steady supply of clean, dry gas used to propel the abrasive particles
- Depending upon the demands of the installation, either an air compressor or bottled gas may be used
- If an air compressor is used, proper line filters must be installed to avoid water or oil contamination of the abrasive powders
- Bottled gas systems are advantages since they guarantee clean and dry gas (consumption rates are only 9.5 lit/hr)
- The least expensive and thus the most common gas to use, are nitrogen and carbon dioxide. Oxygen should never be used as it presents a fire hazard

Equipment - Metering system

- Metering system must inject a uniform, adjustable flow of abrasive particles into the gas stream
- Accomplished by a powder hopper that feeds into a vibrating chamber, which in turn causes the powder to be metered uniformly into the jet stream
- The powder flow rate is directly adjustable by varying the amplitude of the vibration

Equipment – Delivery system (Nozzle)

- The stream of fine grained abrasive mixed with air or some other carrier gas at high pressure is directed by means of a suitably designed nozzle on to the work surface
- Nozzles are typically made of either tungsten carbide or sapphire (three to eight times more expensive than carbide but last an average ten times more)
- Nozzles available with either round or rectangular holes
- Life of nozzle partly defined by application – cutting requires that nozzles be changed more often than when etching or cleaning
- As nozzles wear, the jet stream tends to diffuse faster resulting in material damage outside the intended line of cut – rectangular nozzles create less over spray compared with round ones



(a) Right angle head (b) Straight head

Equipment – Abrasive collection system

- A dust collection system is incorporated into AJM systems, when found necessary, to maintain operator's exposure to dusts within permissible limits
- A vacuum dust collector is some times used to draw the dust particles from the exhaust chamber to keep the operator's viewing clear
- Special considerations must be given to the dust collection system if toxic materials such as beryllium are being abraded

Process parameters

- Major parameters that influence the rate of metal removal and accuracy of machining are:

1. Carrier gas
2. Type of abrasive
3. Size of abrasive grain
4. Velocity of the abrasive jet
5. Mean number of abrasive particles per unit volume of the carrier gas
6. Work material
7. Stand off distance (SOD)
8. Nozzle design
9. Shape of cut

Carrier gas

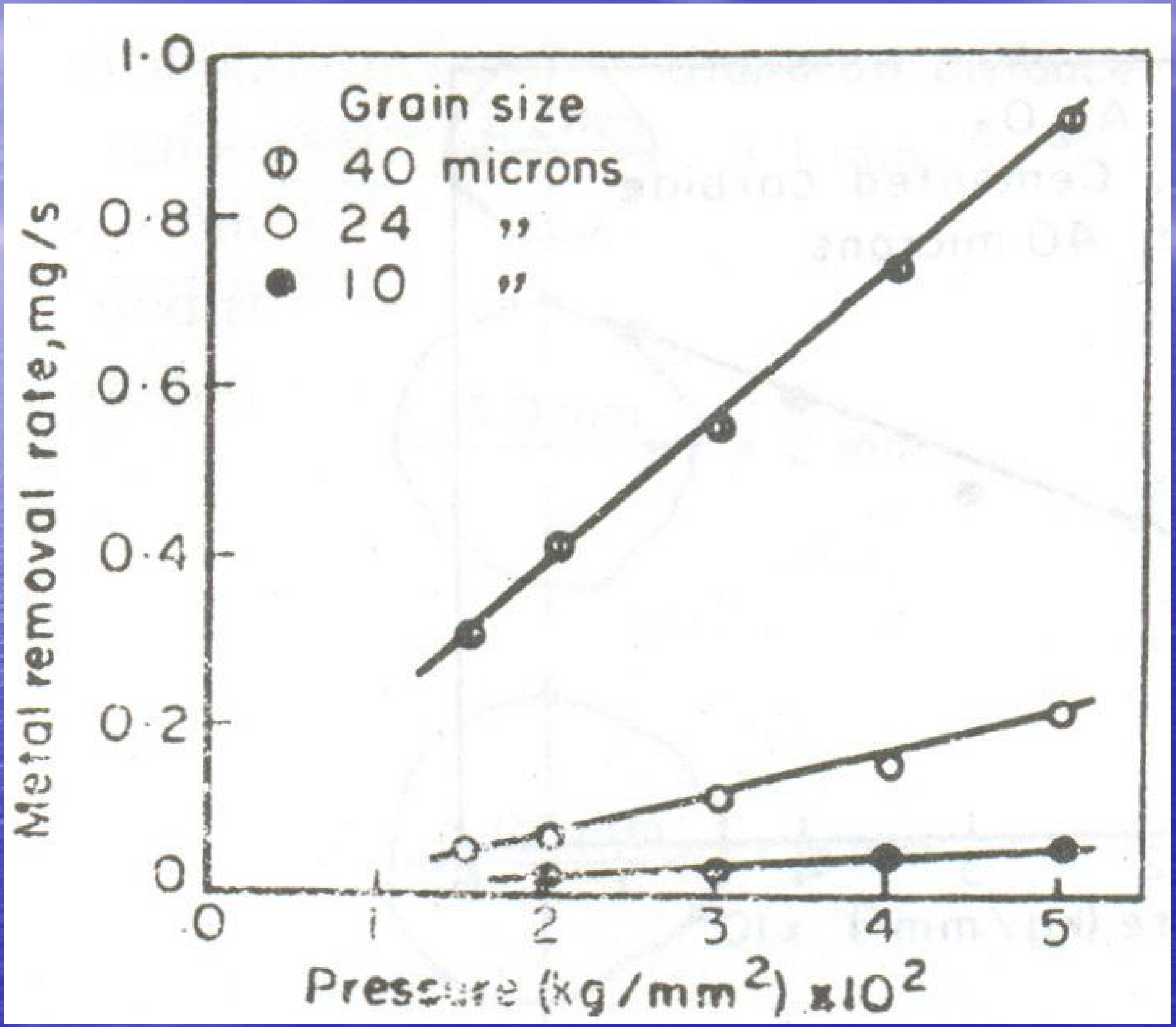
- Must not flare excessively when discharged
- Should be nontoxic, cheap, easily available and capable of being dried and cleaned without difficulty
- E.g. Air, carbon-di-oxide or nitrogen. Air is most widely used

Type of abrasive

- Choice of abrasive depends on the type of machining operation, for e.g roughing, finishing etc., work material and cost
- Should have a sharp and irregular shape and be fine enough to remain suspended in the carrier gas
- Should have excellent flow characteristics
- E.g Al_2O_3 and SiC; Sodium bicarbonate, dolomite, glass beads etc., are used for cleaning, etching, deburring and polishing
- Re-use of abrasives is not recommended because not only does its cutting ability decrease, but contamination also clogs the orifice of the nozzle

Grain size

- Finer grains are less irregular in shape and hence posses lesser cutting ability; they also tend to stick together and choke the nozzle
- Most favorable grain sizes range from 10 to 50
- Coarse grains are recommended for cutting, whereas finer grains are useful in polishing, deburring, etc.



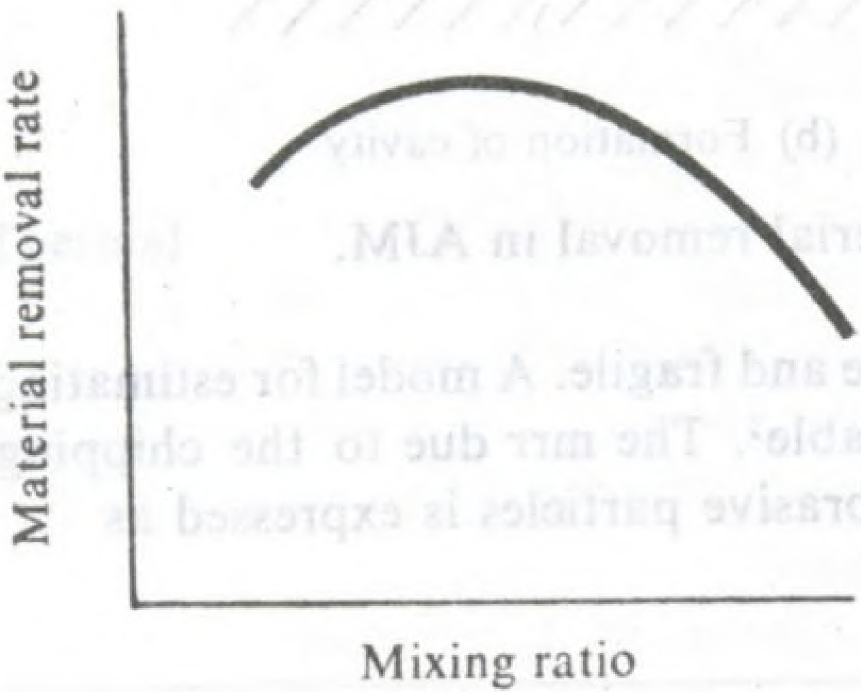
Grain size
40 microns
24 "
10 "
Metal removal rate, mg/s
1·0
0·8
0·6
0·4
0·2
0
0
1
2
3
4
5
Pressure (kg/mm²) x10²

Jet Velocity

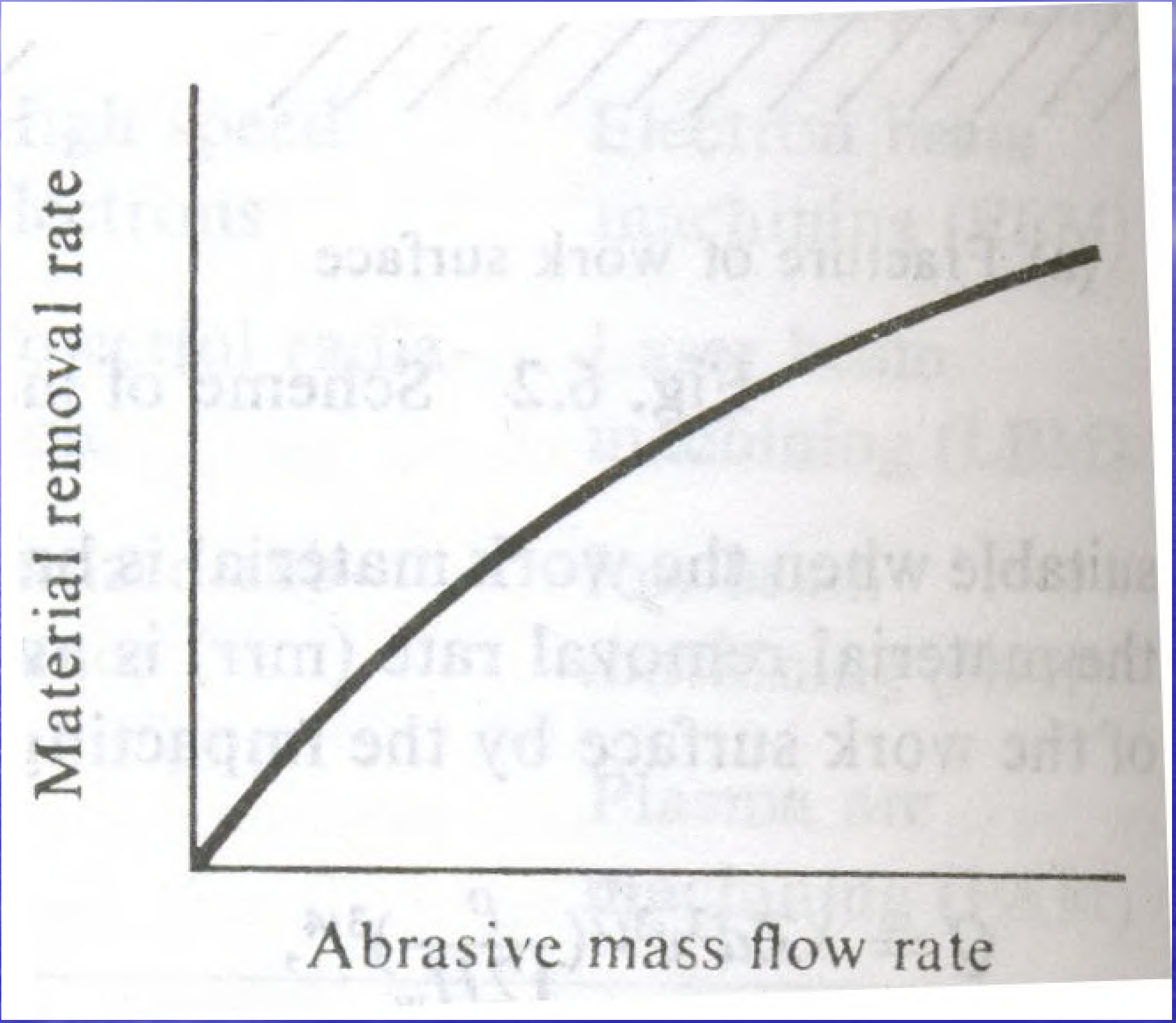
- K.E of the abrasive jet is utilized for metal removal by erosion
- Function of the nozzle pressure, nozzle design, abrasive grain size and the mean number of abrasives per unit volume of the carrier gas

Mean number of abrasive grains per unit volume of the carrier gas

- An idea about the mean number of abrasive grains per unit volume of the carrier gas can be obtained from the mixing ratio, M
- Mixing ratio: defined as the ratio of the volume flow rate of the abrasive per unit time to the volume flow rate of the carrier gas per unit time
- Large value of M should result in higher rates of MRR but a large abrasive flow rate has been found to adversely influence jet velocity and may sometimes clog the nozzle



(a) Variation with mixing ratio


Material removal rate
Abrasive mass flow rate

Work material

- Recommended for processing of brittle materials, such as glass, ceramics, refractories etc.,
- Practically ductile materials are unmachinable by AJM
- Rate of material removal has been found to depend upon the Mohr's hardness of the material to be machined

Stand off Distance (SOD) or Nozzle tip distance (NTD)

- Distance between the face of the nozzle and the working surface of the work
- Considerably affects the MRR and accuracy (shape and size of the cavity produced)
- When NTD increases, the velocity of the abrasive particles impinging on the work surface increases due to their acceleration after they leave the nozzle. This in turn, increases the MRR
- Large SOD results in the flaring up of the jet (velocity reduces due to the drag of the atmosphere) which leads to decrease in MRR and poor accuracy

ally called the *nozzle tip*

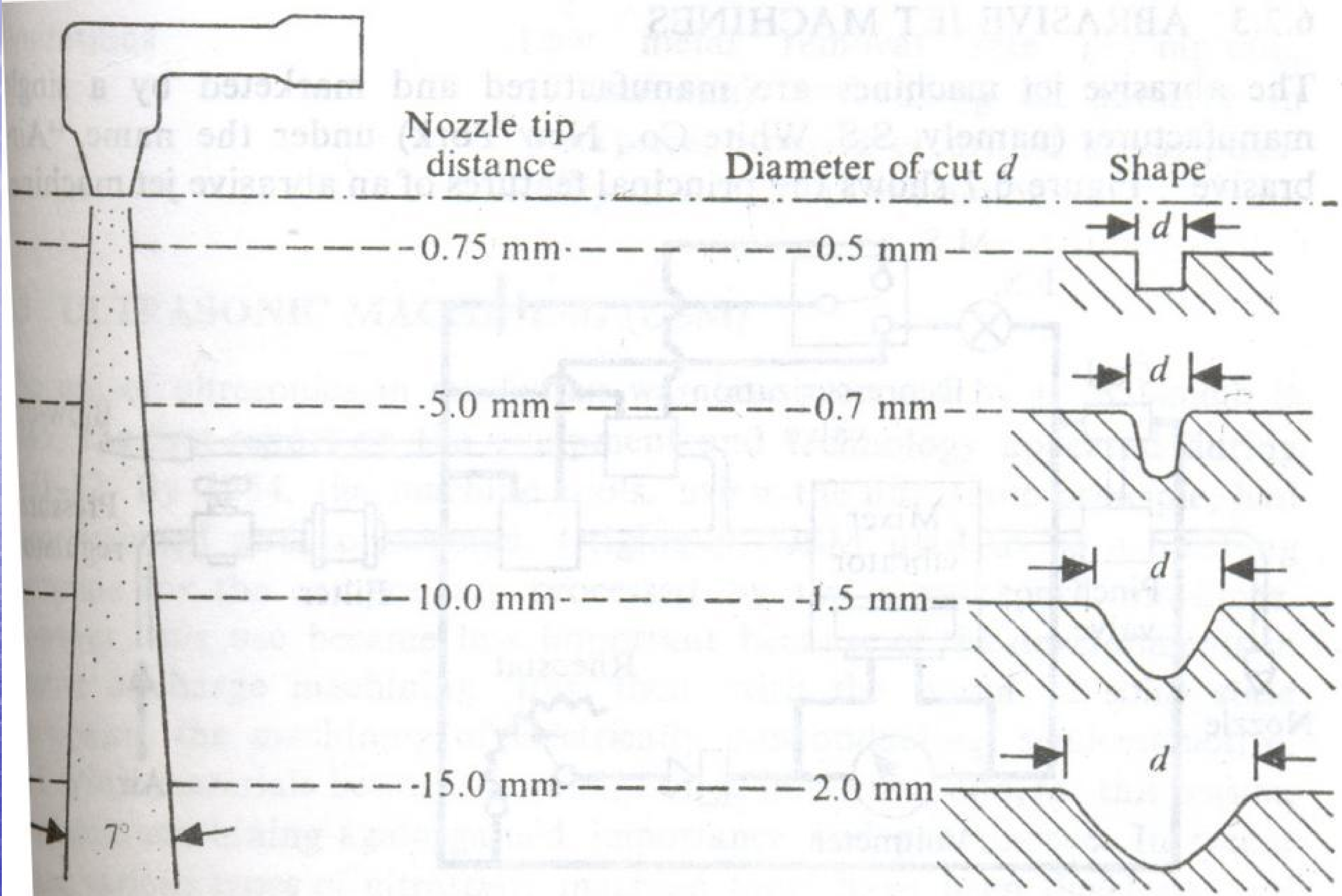


Fig. 6.5 Effect of nozzle tip distance on shape and size of cut.

... Figure 6.6 shows how the NTD affects the mrr.

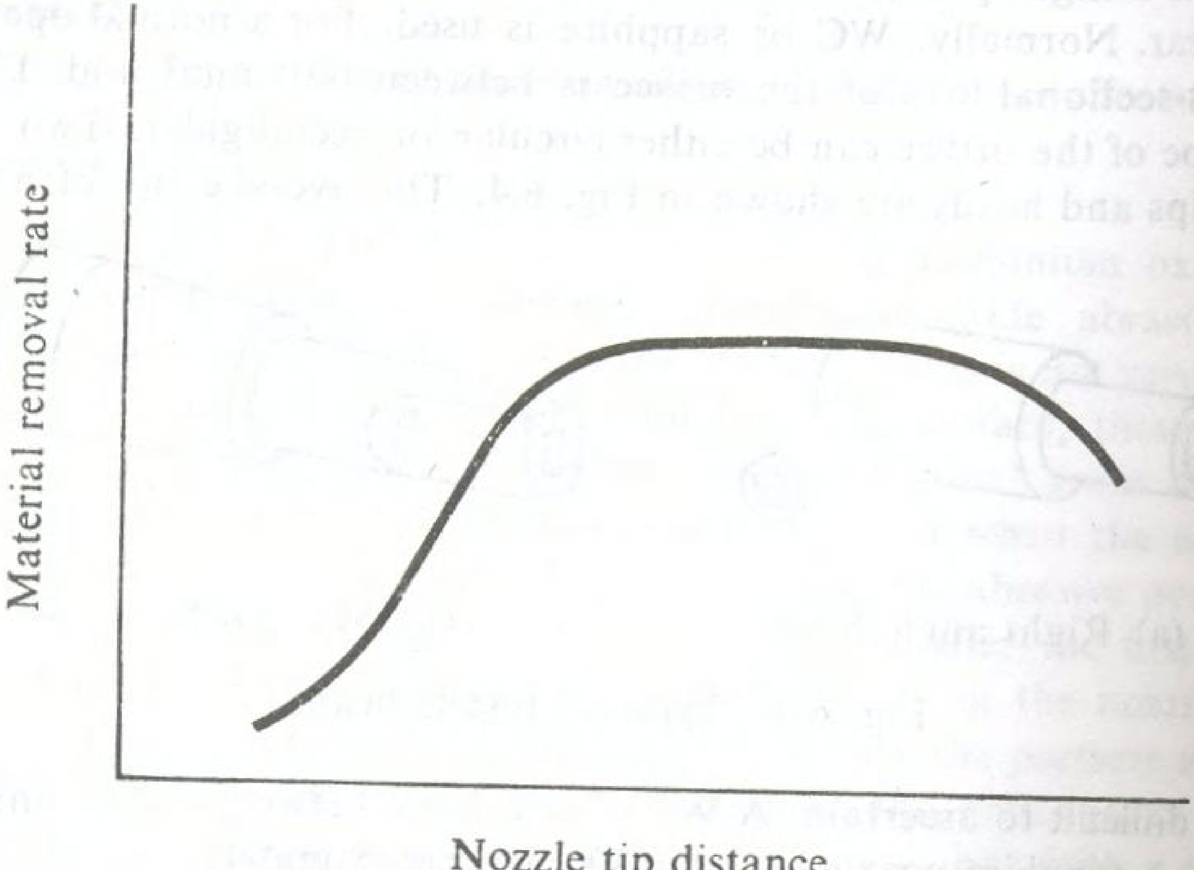


Fig. 6.6 Effect of nozzle tip distance on material removal rate.

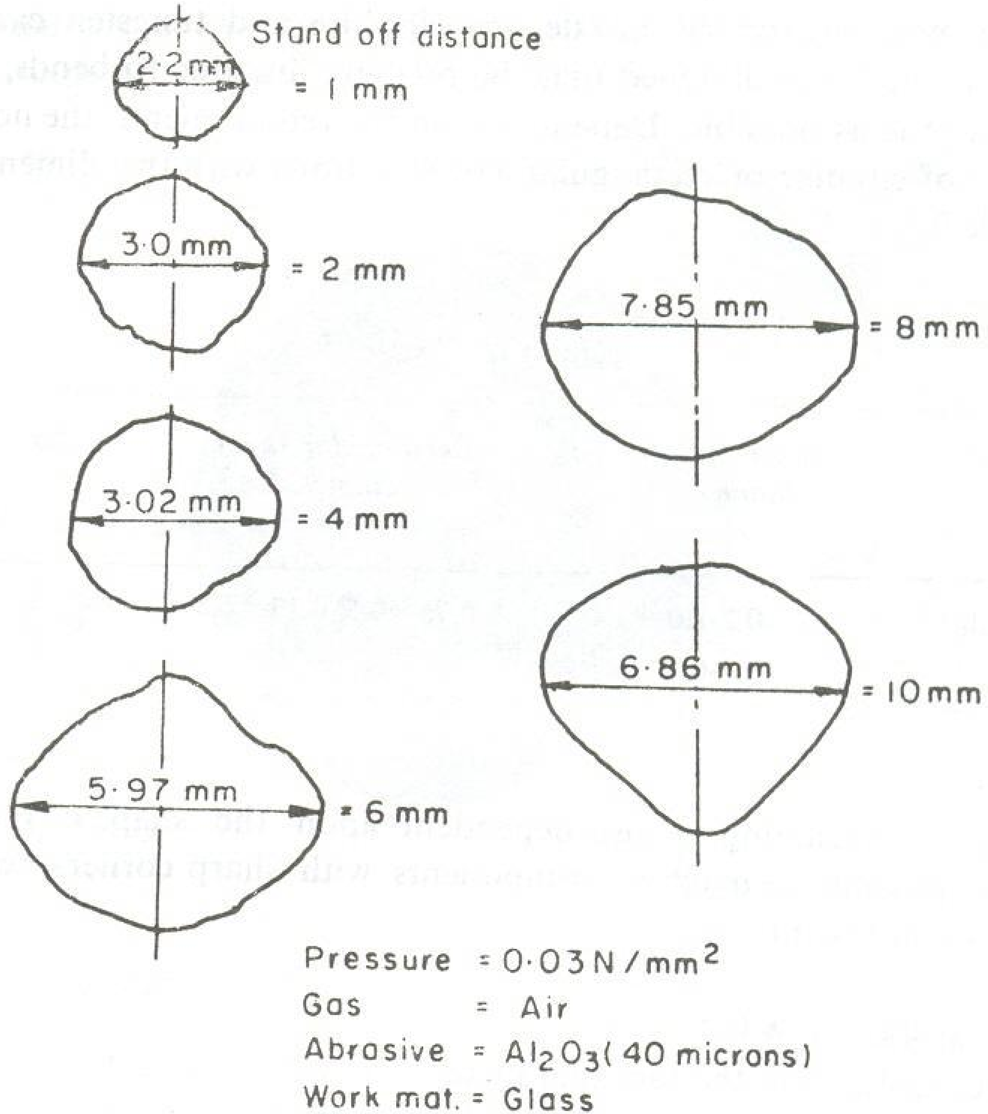


Fig. 2.22 Effect of stand off distance on the accuracy of shape produced

Nozzle design

- Has to withstand the erosive action of abrasive particles and hence, must be made of materials that can provide high resistance to wear
- Common materials for the nozzle are sapphire and tungsten carbide
- Should be designed so that the pressure loss due to bends, friction etc., is as little as possible
- Depending upon the requirements, the nozzles may be either of circular or rectangular cross sections

Shape of cut

- Accuracy of machining is also dependant upon the shape of the cut
- It may not be possible to machine components with sharp corners because of stray cutting

Masks

- Masks are used to control overspray or to produce large holes and intricate detail without having to move the nozzle and trace the shape
- First the mask is produced with open areas where material removal is desired, and then it is placed on the part
- When the AJM stream is passed over the exposed areas, cutting or etching takes place on a selective basis
- Masks can be fabricated from rubber or metal, each having its advantage and disadvantage. While the rubber masks are easy to fabricate, they give poor edge definition. The metal masks give much better definition but erode faster

Abrasives - 1

- Selected by application

Abrasives	Applications
Aluminum oxide	Cleaning, cutting, deburring
Silicon carbide	As above but for harder materials
Glass beads	Matt polishing, cleaning
Crushed glass	Peening, cleaning
Sodium bicarbonate	Cleaning, cutting for soft materials

Abrasives - 2

- Because abrasive particle size is important, abrasives are available in many sizes ranging from 10 to 50 μ
- Smaller sizes are most useful for polishing and cleaning, while the larger sizes are best for cutting and peening
- Abrasives are not reused because chips from the workpiece material clog the nozzle and also because the cutting action of used particles is degraded
- Very little savings would result from reusing powders because prices range from $3-20/kg and the consumption rate is typically only 300g/hr

Advantages

- Machining of very hard materials
- Heat sensitive materials can be machined – the gas stream dissipates generated heat when cutting heat-sensitive materials
- Fragile materials can be machined – the small loads transmitted to the workpiece allow the cutting of fragile pieces
- Very low capital cost and low power consumption
- No part shatter or vibration
- The nozzle can be directed towards small, difficult-to-reach areas

Limitations

- Low material removal rate
- Stray cutting can occur and hence accuracy is not good
- Excessive taper on deep cuts may also be a disadvantage, although the amount of taper can be reduced by tilting the nozzle
- Short nozzle standoff when used for cutting
- Possibility of abrasive particles becoming embedded in the workpiece
- Nozzle wear rate is high
- Process tends to pollute the environment

Applications - 1

- Removing flash and parting lines from injection moulded parts
- Deburring and polishing plastic, nylon and teflon components
- Cleaning metallic mould cavities which otherwise may be inaccessible
- Cleaning oxides from metal surfaces
- Cleaning metallic smears from ceramics
- Removing smudges and films from documents and museum artifacts
- Trimming, bevelling and cleaning electronic components

Applications - 2

- Drilling, cutting thin sectioned fragile components made of glass, refractories, ceramics, mica etc.,
- Producing high quality surface
- Frosting interior surfaces of glass tubes
- Etching part numbers onto metal and plastic components
- In research laboratories for testing abrasion resistance of different materials, prepare surfaces for strain gauge applications and to create artificial flaws in materials for calibration of testing equipments

Parts identification using AJM and rubber mask

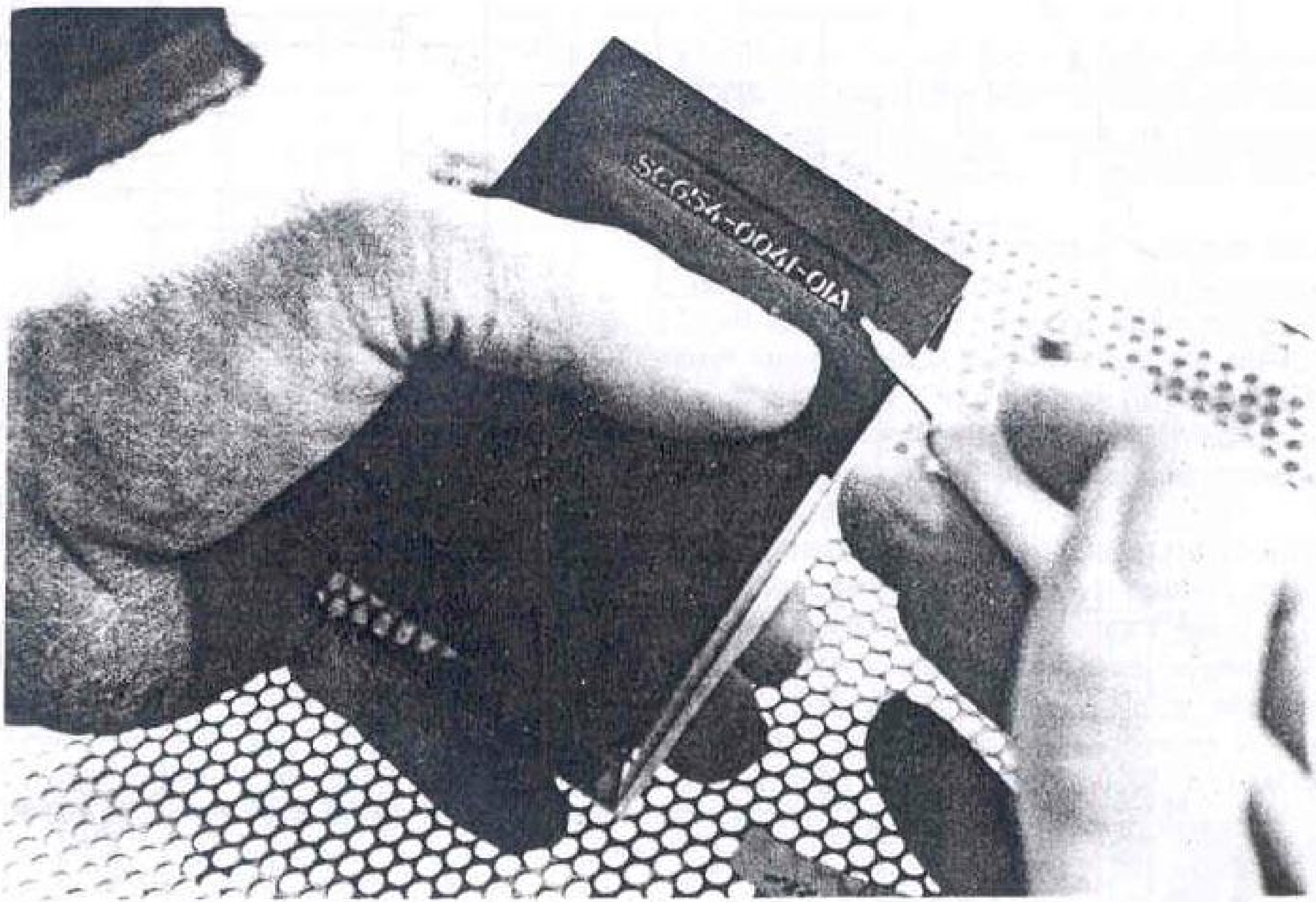


Fig. 1 Identification of hard plastic embedded voltage regulator using AJM equipment and rubber mask

Plastic connector body showing condition before and after finish removal by AJM

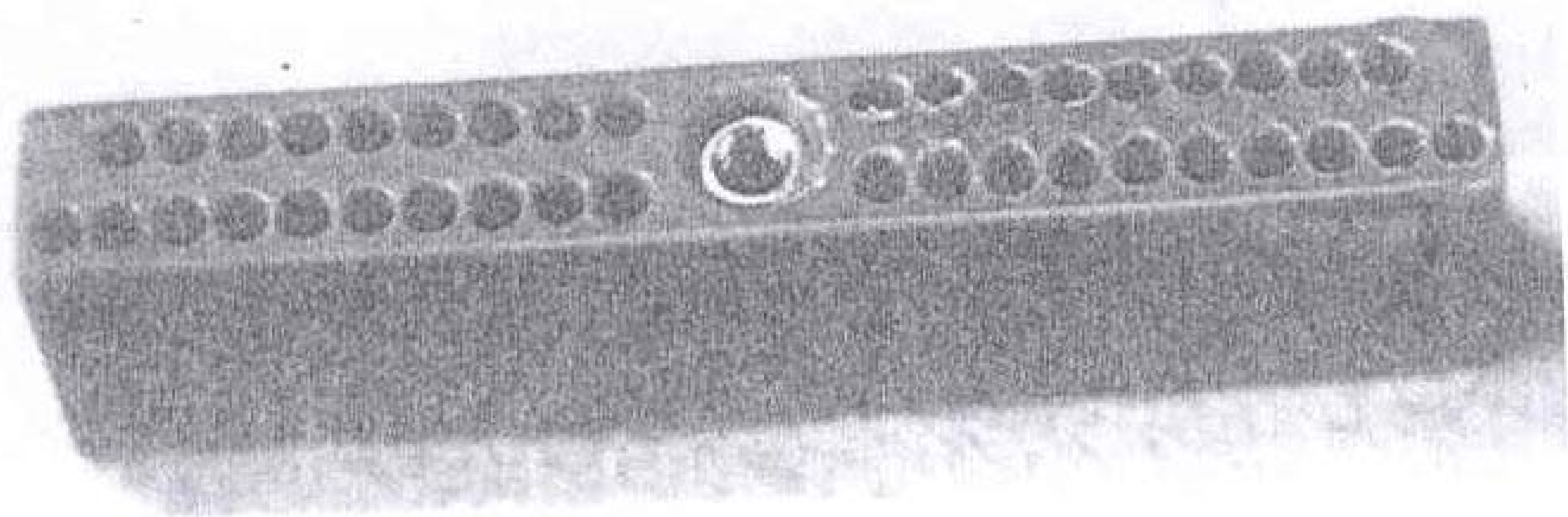


Figure 2.12 Plastic connector body showing condition before and after flash removal by AJM (Source: Comco, Inc., Burbank, Calif).

Technique used for AJM trimming of silicon/tungsten disks

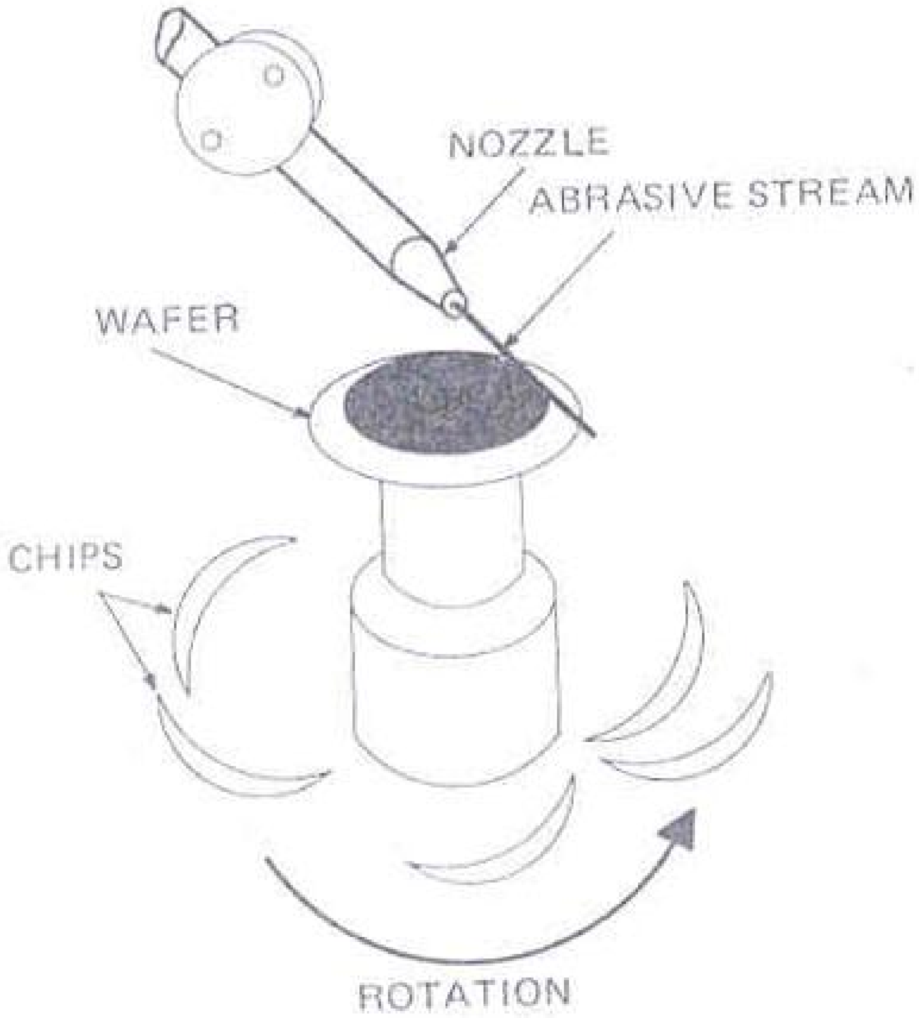


Figure 2.11 Technique used for AJM-trimming of silicon/tungsten disks.