Advanced Manufacturing Technology & Prototyping
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Lecture 4_Part 2
Ultrasonic Machining Process

DR. Moustafa Mahmoud
Associate Professor
Design & Production Dept.,
Faculty of Engineering, Ain Shams University
m_m_sayed@eng.asu.edu.eg

Mechanical Processes

- **Mechanical non- traditional machining processes**, material removal is achieved through the action of a ***high-velocity stream of abrasives and/***or ***fluid***, allowing for the precise removal of excess material.

- The **mechanical impact** and **erosion** **facilitate** the removal of material, producing a surface finish that is often free of **heat-induced distortions** or **micro-cracking**.

Mechanical Processes

Mechanical NTM processes include:

- Ultrasonic Machining (USM),
- Abrasive Jet Machining (AJM),
- Waterjet Machining (WJM)
- Abrasive Waterjet Machining (AWJM).

ULTRASONIC MACHINING PROCESS

Contents

- Introduction to USM
- Schematic diagram
- Principle & Working
- Mechanism
- USM system & subsystem
- Process Variables & their effect
- Process Output
- Application
- Advantages & disadvantages
- Products

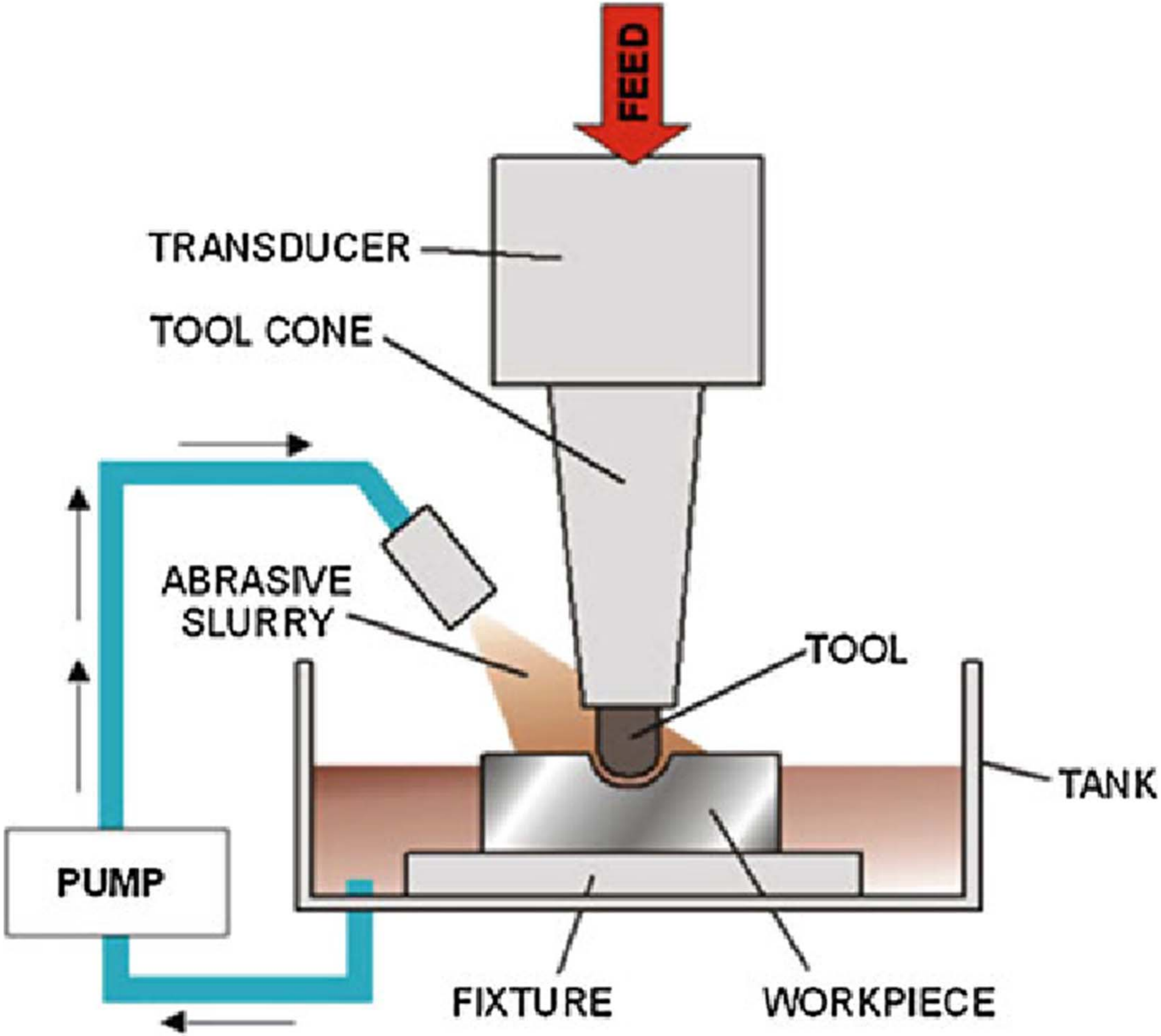
Introduction

- Ultrasonic machining is a **non-traditional** mechanical means of uniform stock material removal process.
- Its applicable to both conductive and nonconductive materials.
- Particularly suited for very hard and/or brittle materials such as graphite, glass, carbide and ceramics.

Introduction, cont.

- It is a mechanical material removal process, used to **erode** material in the form of fine holes and cavities in hard or brittle workpiece.
- It uses formed tools, vibrations of high frequency and a suitable abrasive slurry mix.
- Frequency > 20,000 Hz.

Schematic diagram

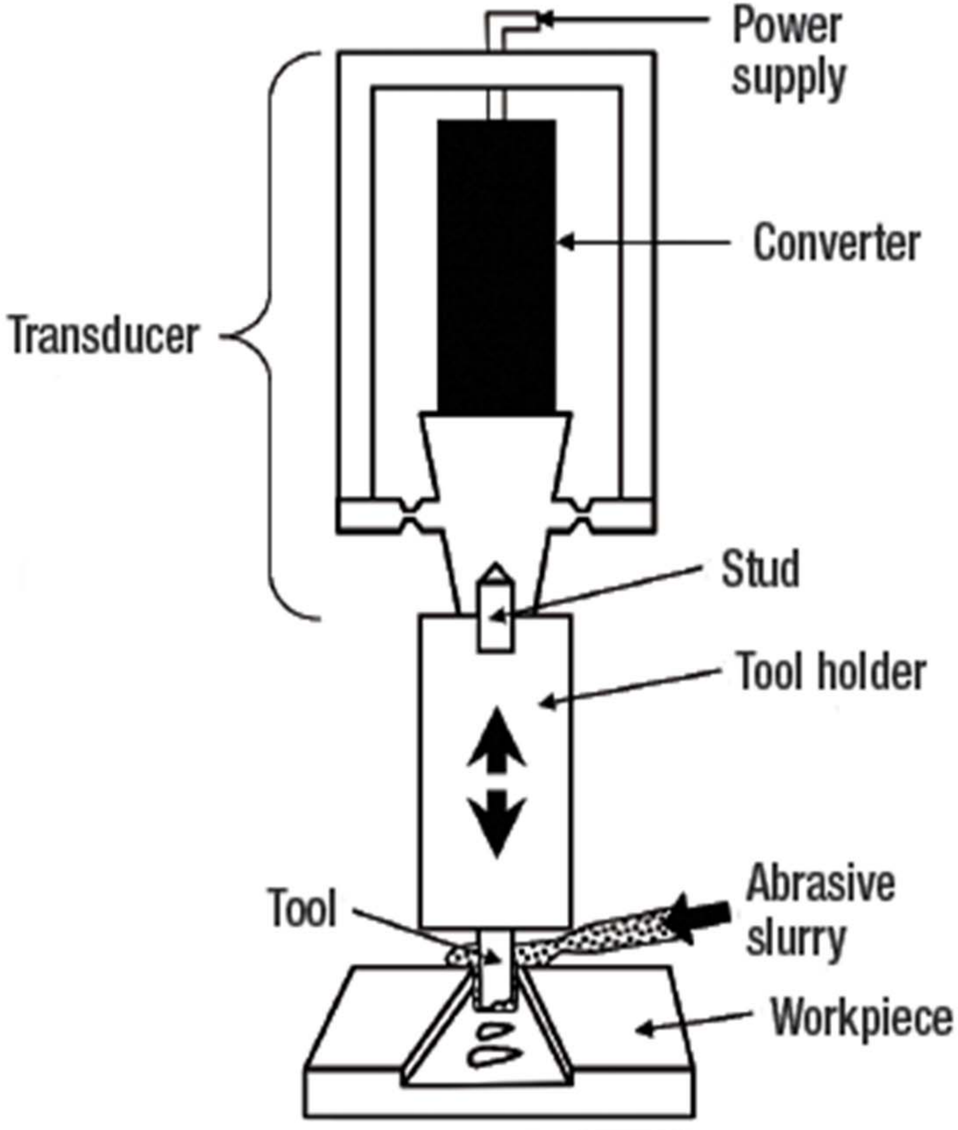


Process

- **Impact erosion process** - abrasive particles.
- **Cutting** → abrasive particles in the slurry (fluid).
- **Material removal → abrading action → “shaped tool”** and the workpiece.

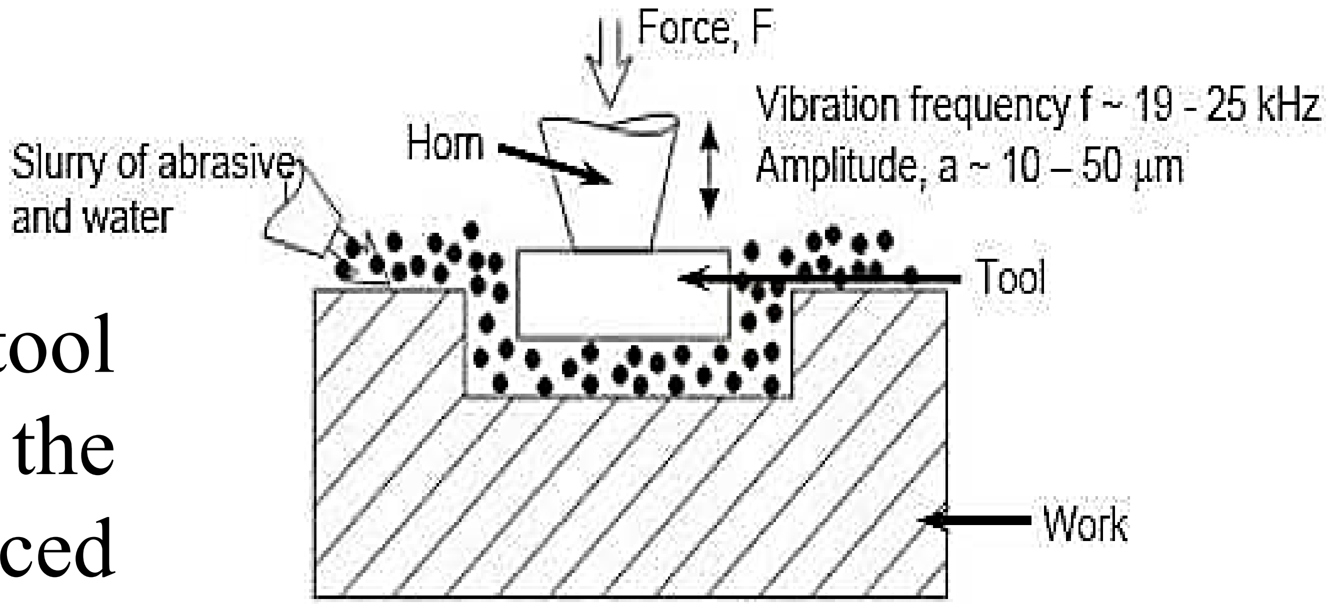
Working Principle

- The process is performed by a cutting tool, which oscillates at high frequency, typically 20-25 kHz, in abrasive slurry.
- The tool is gradually fed with a uniform force.
- The high-speed reciprocations of the tool drive the abrasive grains across a small gap against the workpiece .



Working Principle, cont.

- The impact of the abrasive is the *energy principally responsible* for material removal in the form of small wear particles that are carried away by the abrasive slurry.



- The shape of the tool corresponds to the shape to be produced in the workpiece.

Mechanism for material removal

- USM is generally used for machining brittle work material.
- Material removal primarily occurs due to the **indentation of the hard abrasive grits** on the brittle work material.
- As the tool vibrates, it leads to indentation of the abrasive grits.

Mechanism for material removal

- Occurs when the abrasive particles, suspended in the slurry between the tool and workpiece, are struck by the down-stroke of the vibration tool.
- The impact propels the particles across the cutting gap, hammering them into the surface of both tool and workpiece. Collapse of the cavitation bubbles in the abrasive suspension results in very high local pressures.
- Under the action of the associated shock waves on the abrasive particles, microcracks are generated at the interface of the workpiece – brittle fracture.
- The brittle fracture lead to chipping of particles from the workpiece.

Mechanism for material removal, cont.

- During indentation, due to Hertzian contact stresses, **cracks** would develop just below the contact site, then as indentation progresses the cracks would propagate due to increase in stress and ultimately lead to brittle fracture of the work material under each individual interaction site between the abrasive grits and the workpiece.

Material Removal Mechanism, cont.

$$MRR_w = \frac{2}{3}\pi\left(\delta_w d_b\right)^{3/2} nf \quad \ldots\ldots (\mu m^3/sec)$$

δ_w : indentation depth (μm)
d_b : abrasive grit size (μm)

n : average number of grits
f : frequency (Hz)

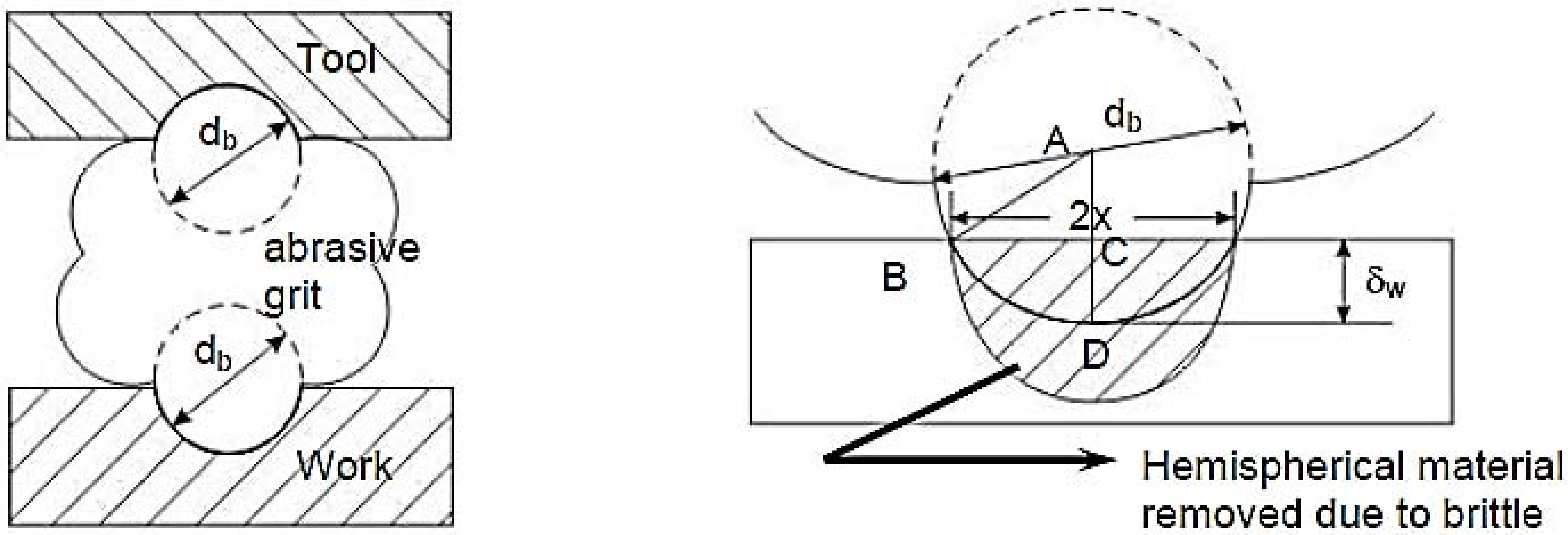
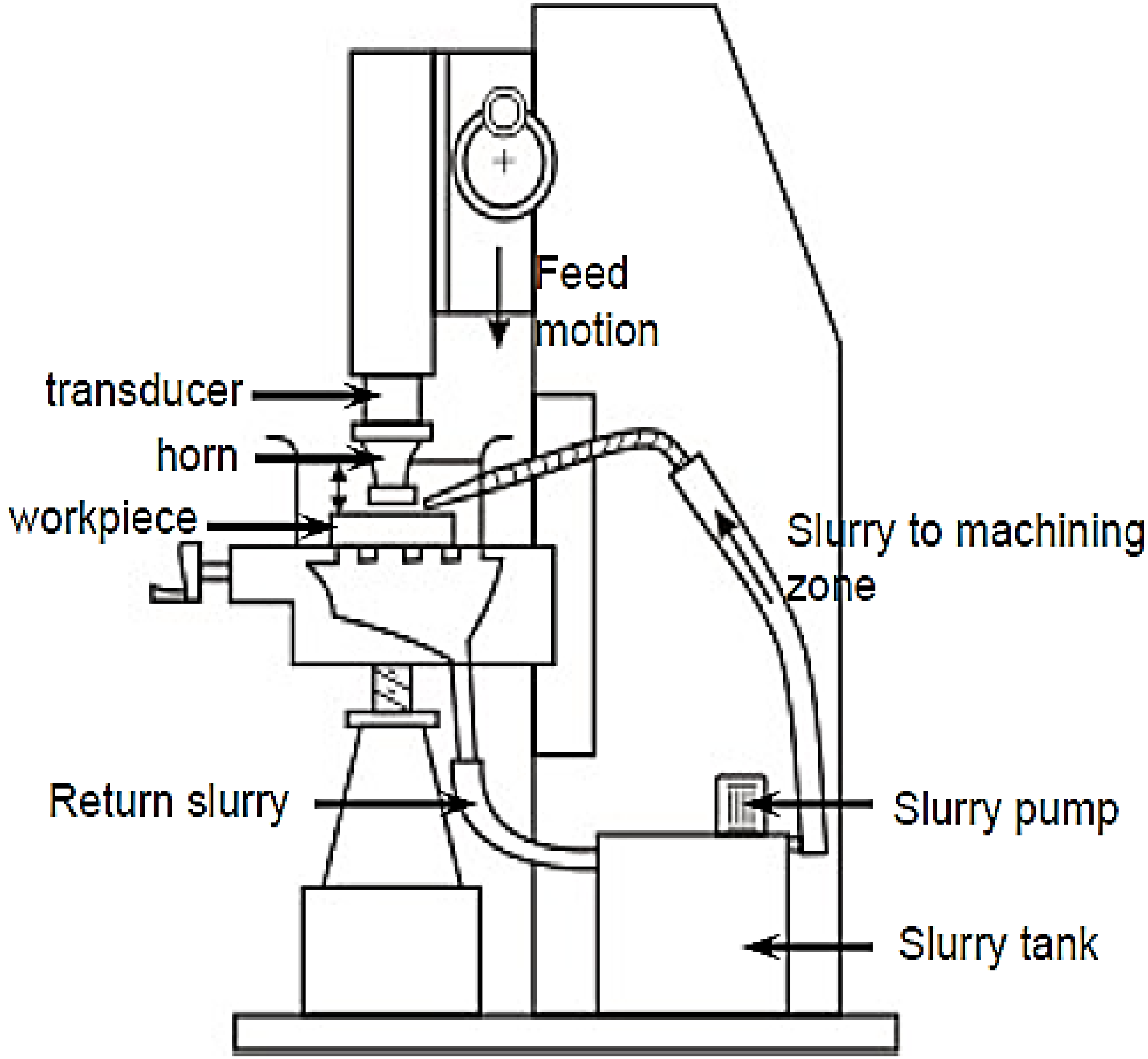


Fig. 9.2.3 Interaction between grit and workpiece and tool

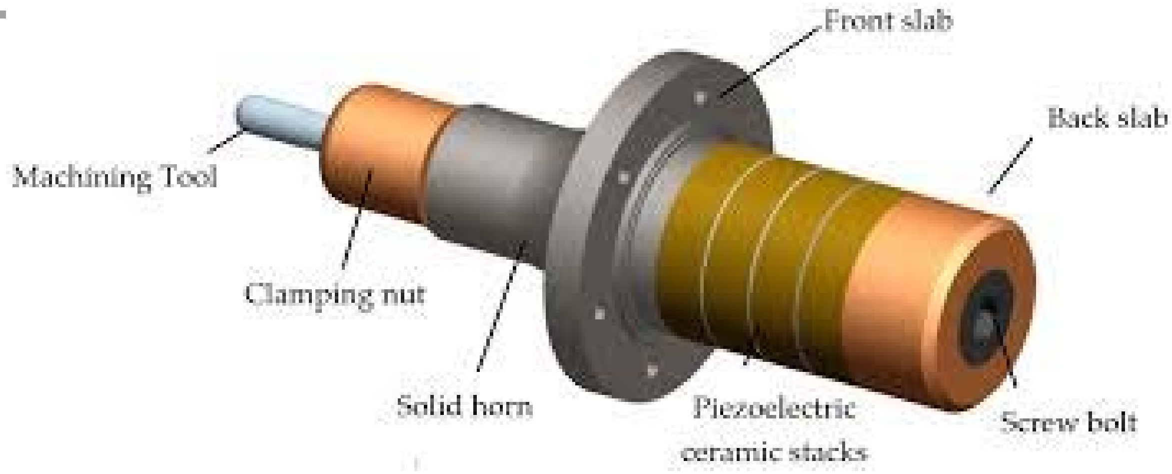
USM System Component

1. Power supply
2. Transducer
3. Tool holder
4. Tool
5. Abrasive slurry



USM System Component

1. Transducer:



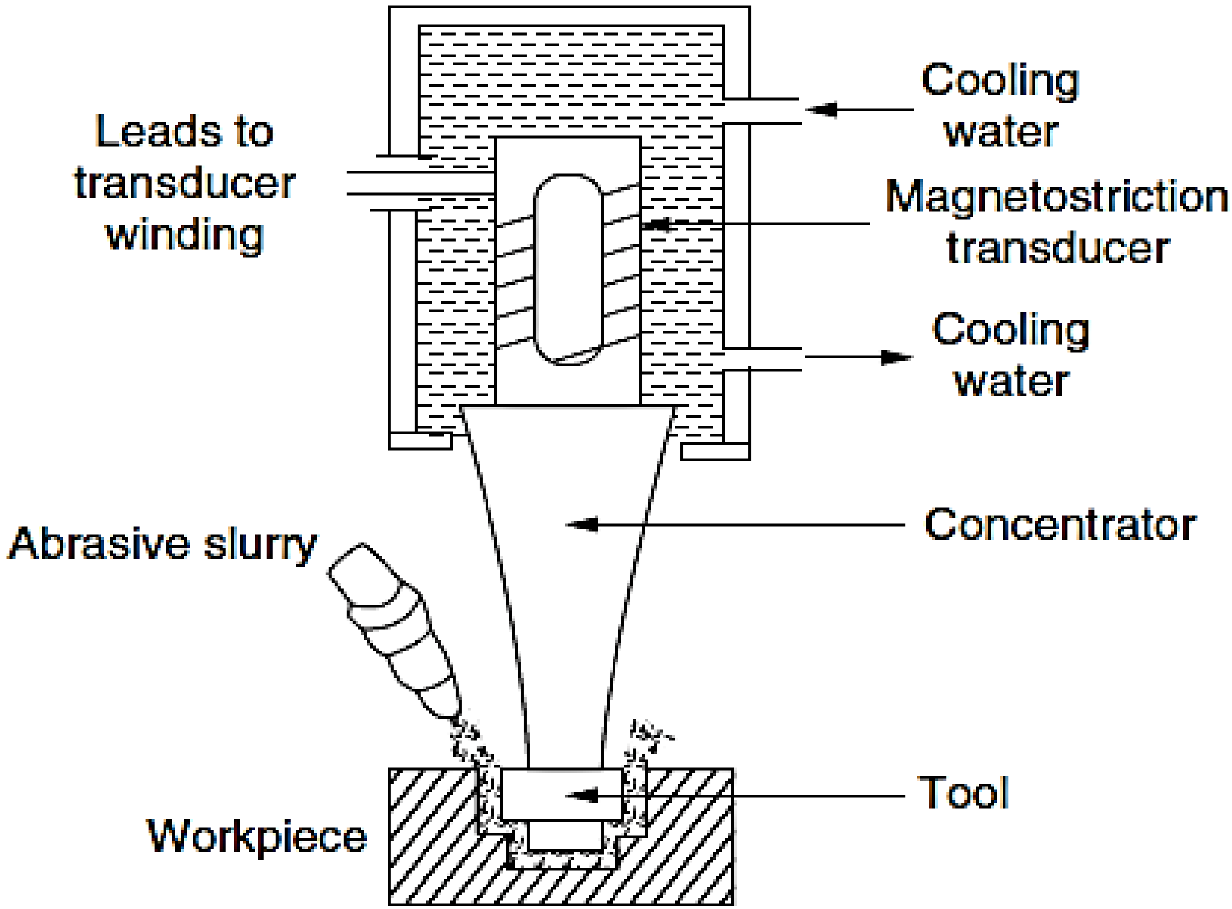
- Piezoelectric transducers utilize crystals like quartz whose dimensions alter when being subjected to electrostatic fields.
- The charge is directionally proportional to the applied voltage.
- To obtain high amplitude vibrations the length of the crystal must be matched to the frequency of the generator which produces resonant conditions.

USM vibration

- The ultrasonic vibrations are produced by the **transducer**.
- The transducer is driven by suitable ***signal generator*** followed by ***power amplifier***.
- The transducer for USM works on the following principle:
  - Piezoelectric effect
  - Magnetostrictive effect
  - Electrostrictive effect

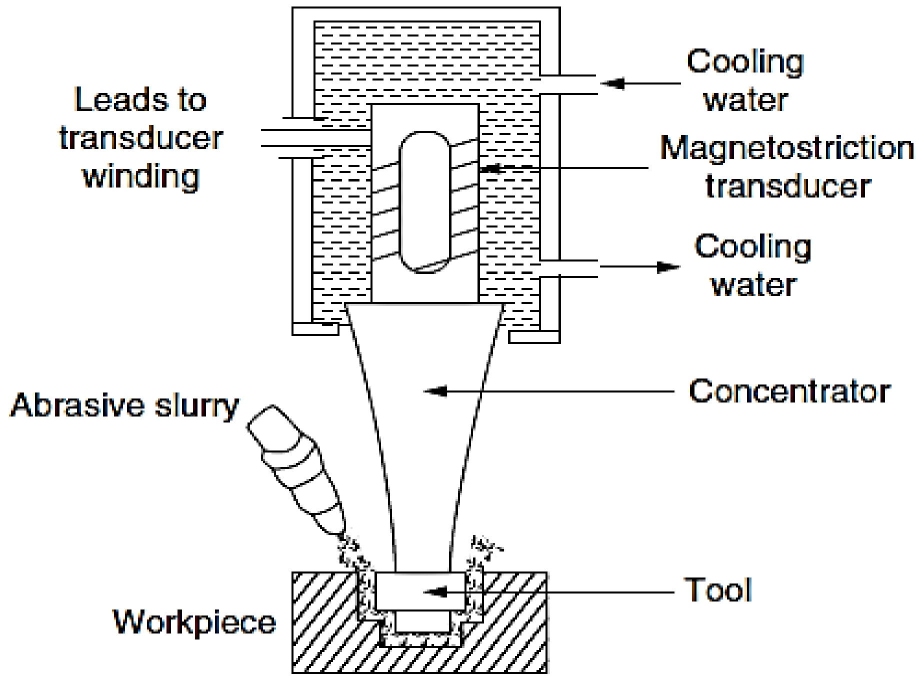
Magnetostrictive transducer

- Magnetostrictive transducers are most popular and robust amongst all.



Magnetostrictive transducer

- Magnetostrictive transducer is made from ferromagnetic materials, such as nickel and nickel alloys.
- Applying high-frequency electrical energy to the coils surrounding the ferromagnetic material leads to vibration at the applied frequency.



USM System Component, cont.

2. Abrasive Slurry:

- **Abrasive:**

  Common types of abrasive:

  - Boron carbide (B4C) good in general, but expensive
  - Silicon carbide (SiC) glass, germanium, ceramics
  - Corundum (Al2O3) - Diamond (used for rubies , etc)
  - Boron silicon-carbide (10% more abrasive than B4C)

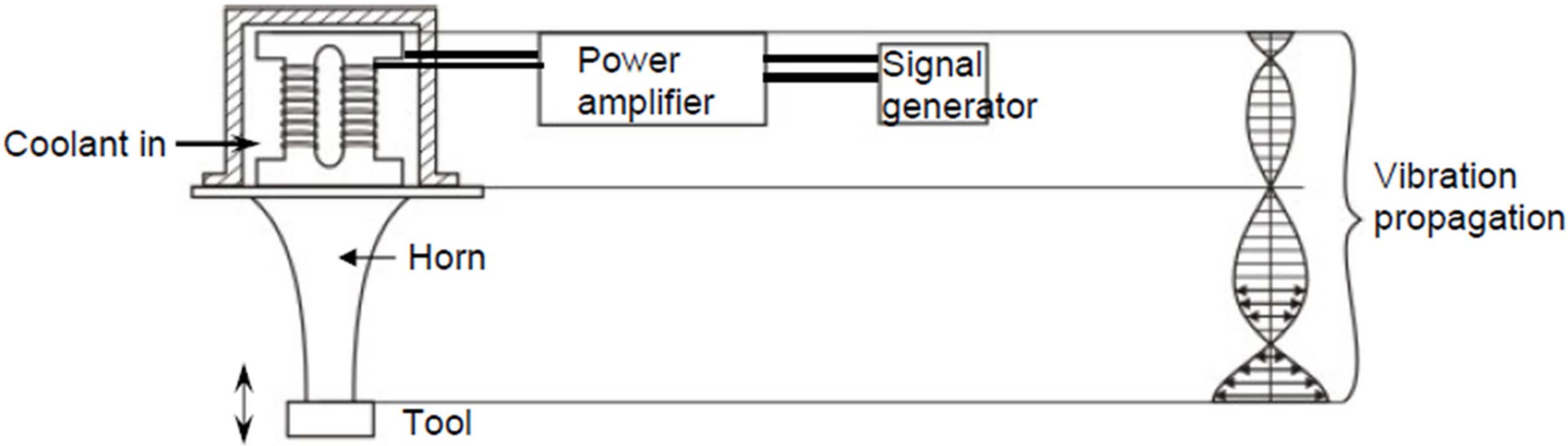
- **Liquid:**

  - Water: most common
  - Benzene
  - Glycerol
  - Oils - High viscosity decreases MRR

USM System Component, cont.

3. Tool Holder/Acoustic head/Horn

- Its function is to increase the tool vibration amplitude and to match the vibrator to the acoustic load. Therefore it must be constructed of a material with good acoustic properties and be highly resistant to fatigue cracking.



USM System Component, cont.

3. Tool Holder/Acoustic head/Horn

- Monel and titanium have good acoustic properties and are often used together with stainless steel, which is cheaper.

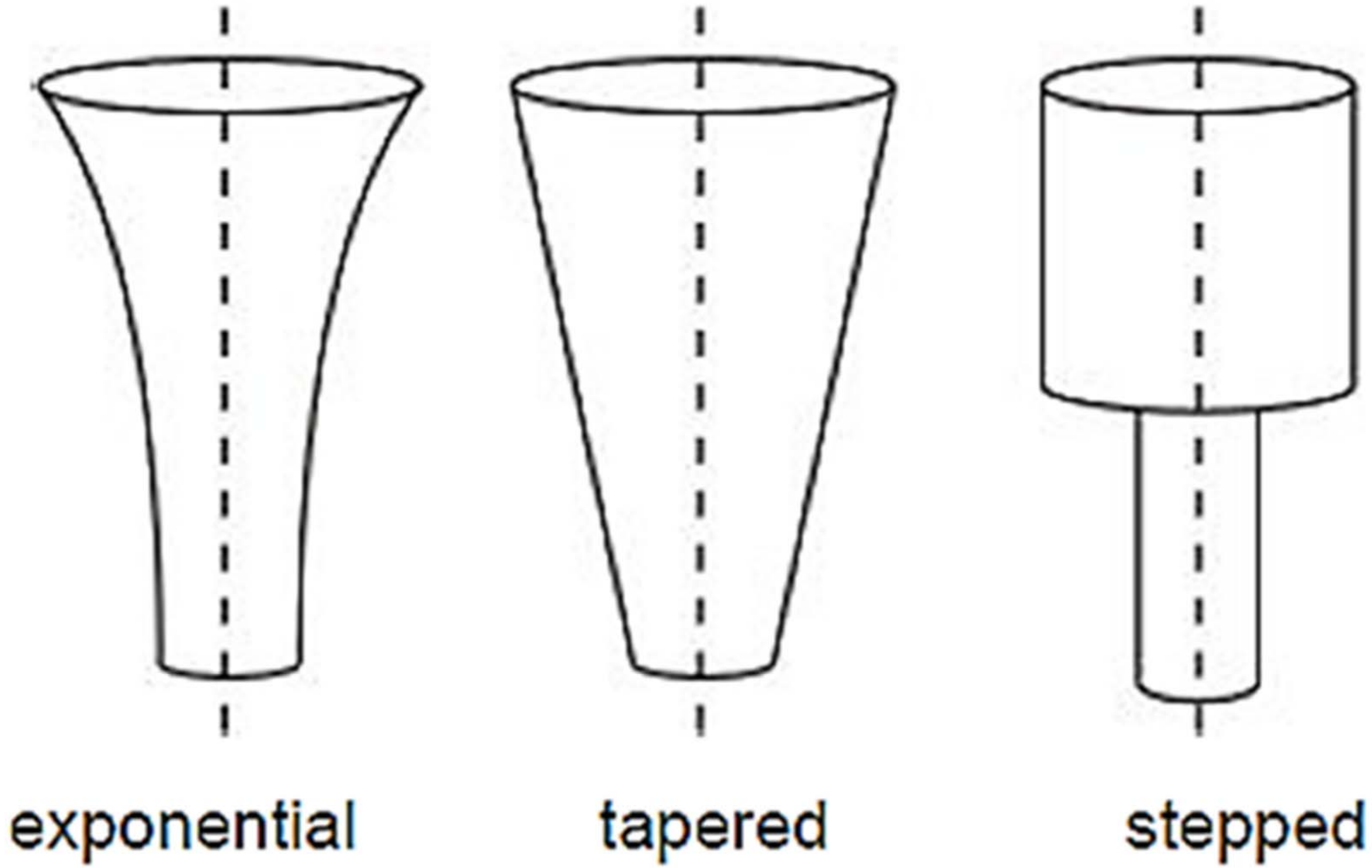
USM System Component, cont.

3. Tool Holder/Acoustic head/Horn

- The shape of the tool holder is cylindrical or conical, or a modified cone which helps in magnifying the tool tip vibrations.
- Shapes are:
  - ✓ Exponential
  - ✓ Tapered
  - ✓ Stepped

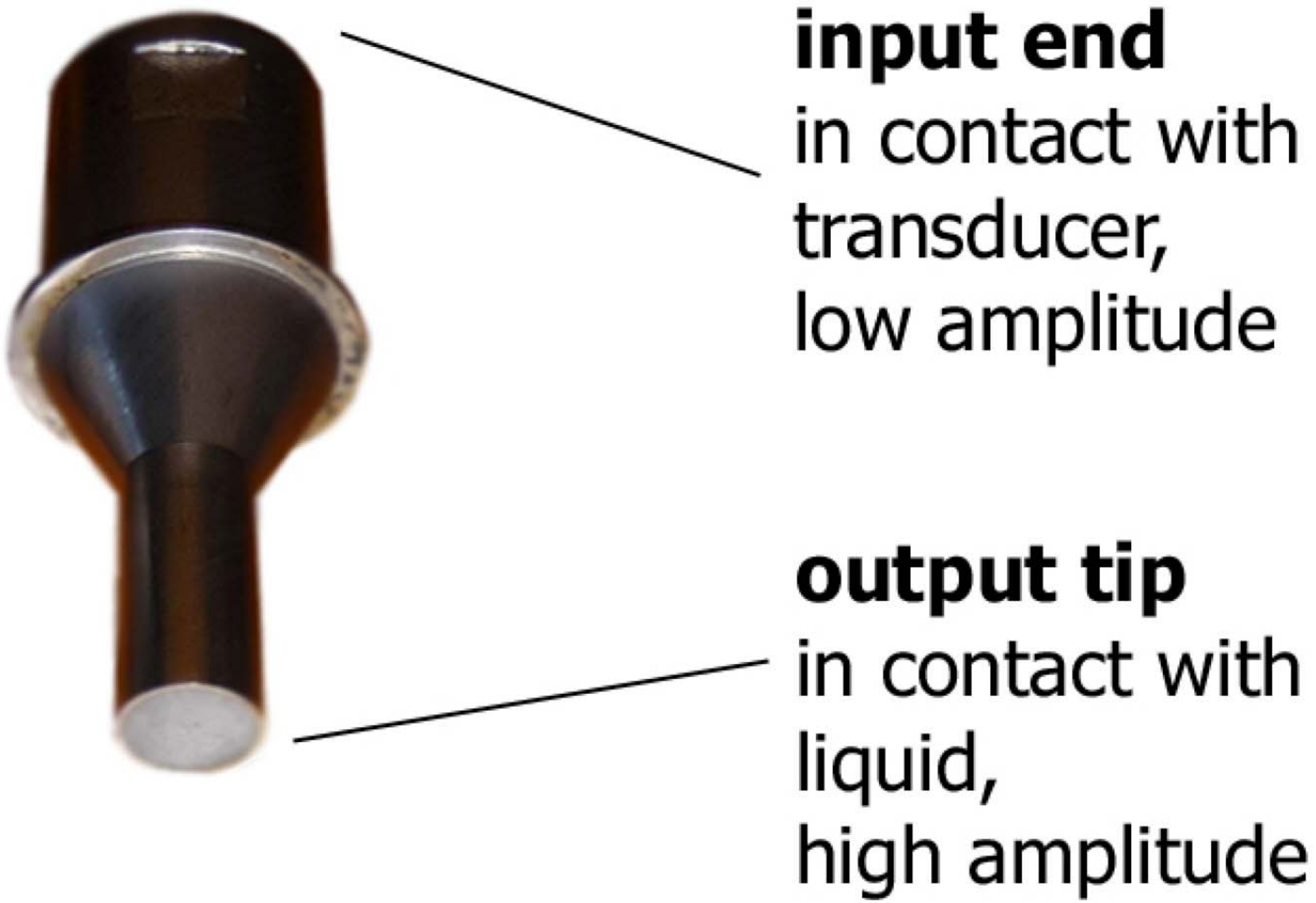
USM System Component, cont.

Horn Shapes:



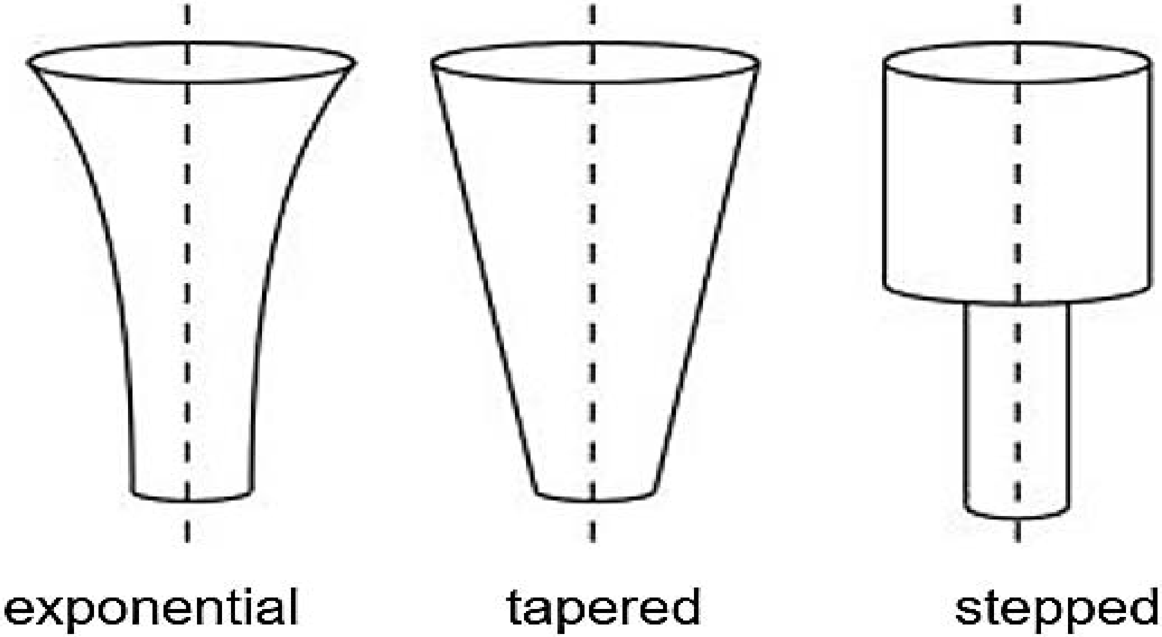
USM System Component, cont.

- **Taper Horn**



USM System Component, cont.

Horn Shapes characteristics:



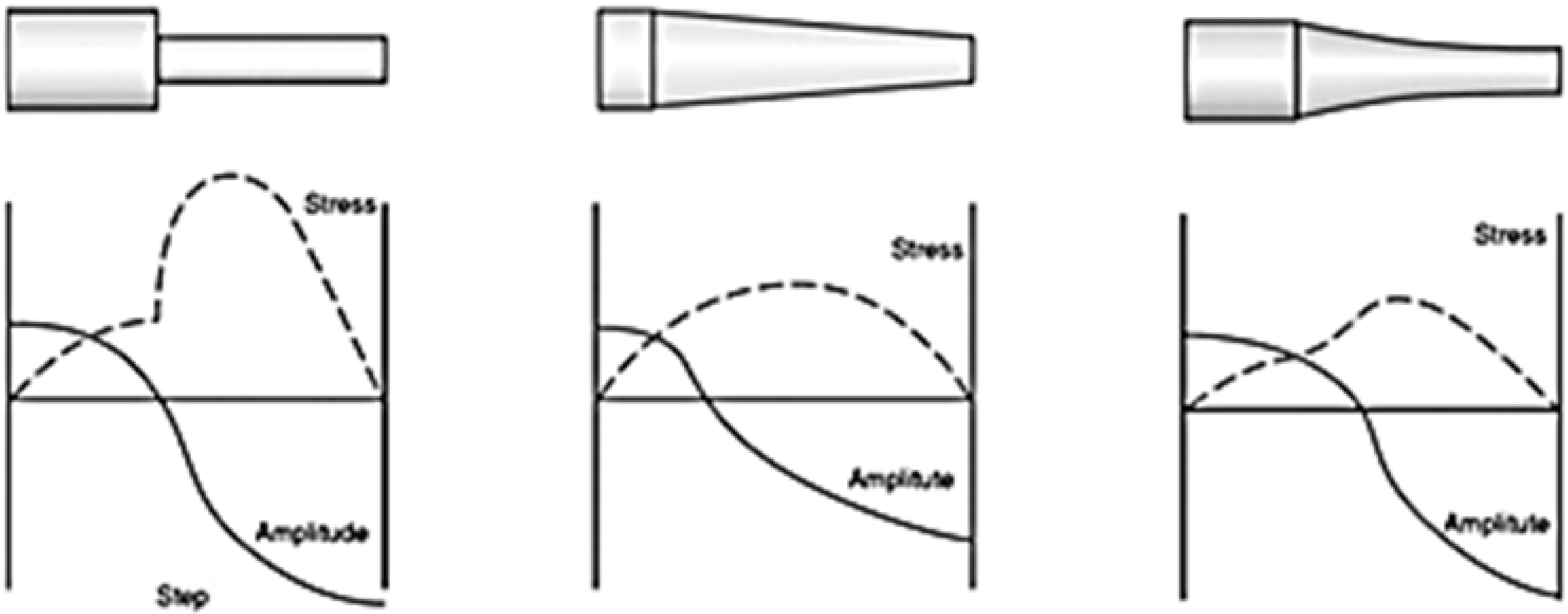
- *Uniform Stress Distribution
- *Small amplitude,
- *high frequency
- *Expensive

- *Low Cost
- *Small Amplitudes

- *Large Amplification
- *Stress Concentration

USM System Component, cont.

Horn Shapes characteristics:



USM System Component, cont.

4. Tool

- Tool material should be tough and ductile. **Low carbon steels and stainless steels** give good performance.
- Tools are usually 25 mm long ; its size is equal to the hole size **minus twice the size of abrasives**.
- Mass of tool should be minimum possible so that it does not absorb the ultrasonic energy.
- It is important to realize that finishing or polishing operations on the tools are sometimes necessary because their surface finish will be reproduced in the workpiece.
- Tool and tool holder are often attached by silver brazing.

USM System Component, cont.

USM Tool properties

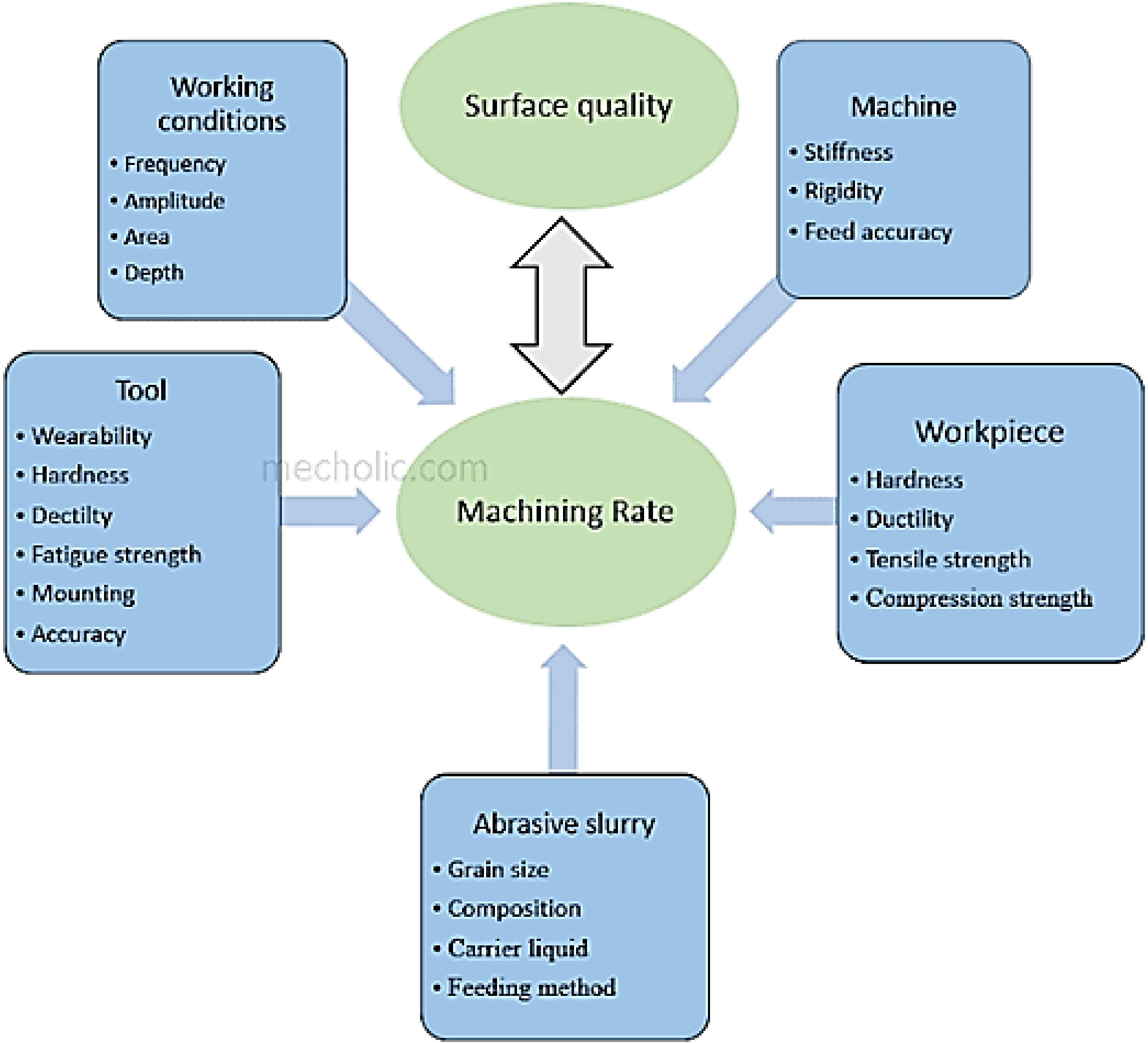
- Hard but ductile metal
- Stainless steel and low carbon soft steel
- Aluminum and brass tools wear near 5 to 10 times faster
- Surface finish of the tool is important (it affects the surface finish of w/p).

Process Variables (adjusted)

1. **Amplitude of vibration (a): 15- 50 µm.**
2. **Frequency of vibration (f): 19-25 kHz**
3. **Feed force (F)**
4. **Feed pressure (p)**
5. **Abrasive size: 15-150 µm**
6. **Contact area of the tool (A)**
7. **Volume concentration of abrasive in slurry (C)**

Process Outputs (parameters)

- Material Removal rate (MRR)
- Surface Quality


Working conditions
• Frequency
• Amplitude
• Area
• Depth
Surface quality
Machine
• Stiffness
• Rigidity
• Feed accuracy
Tool
• Wearability
• Hardness
• Dectilty
• Fatigue strength
• Mounting
• Accuracy
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Machining Rate
Workpiece
• Hardness
• Ductility
• Tensile strength
• Compression strength
Abrasive slurry
• Grain size
• Composition
• Carrier liquid
• Feeding method

EFFECT OF MACHINING VARIABLES ON MRR

Effect of Amplitude on MRR

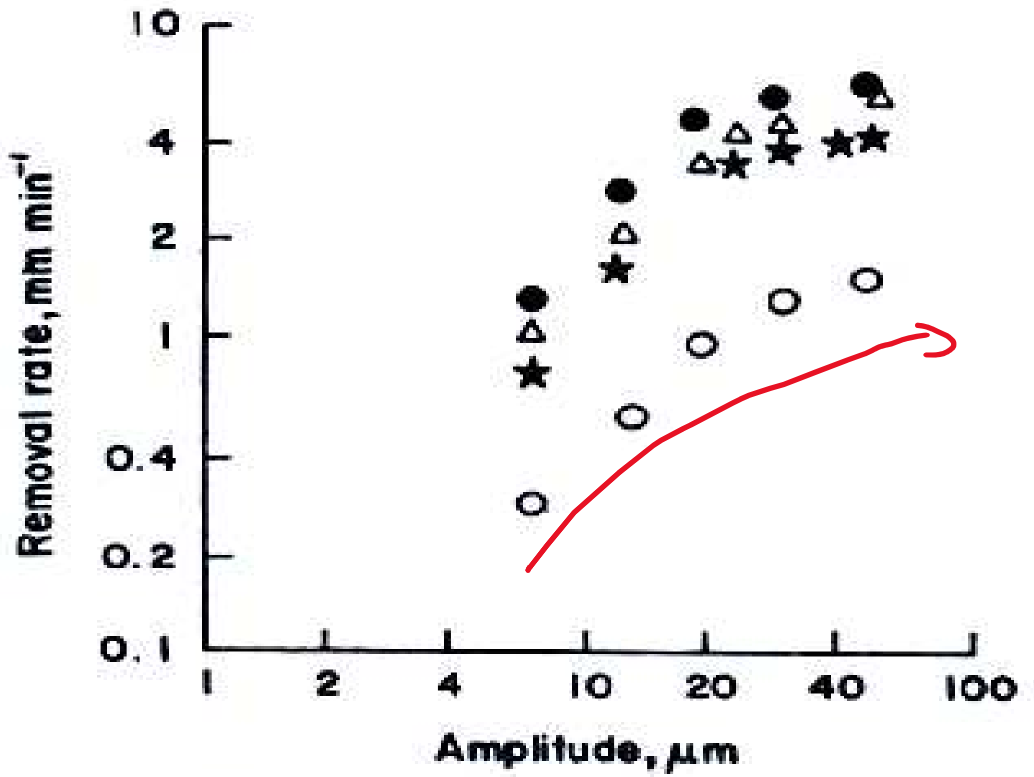
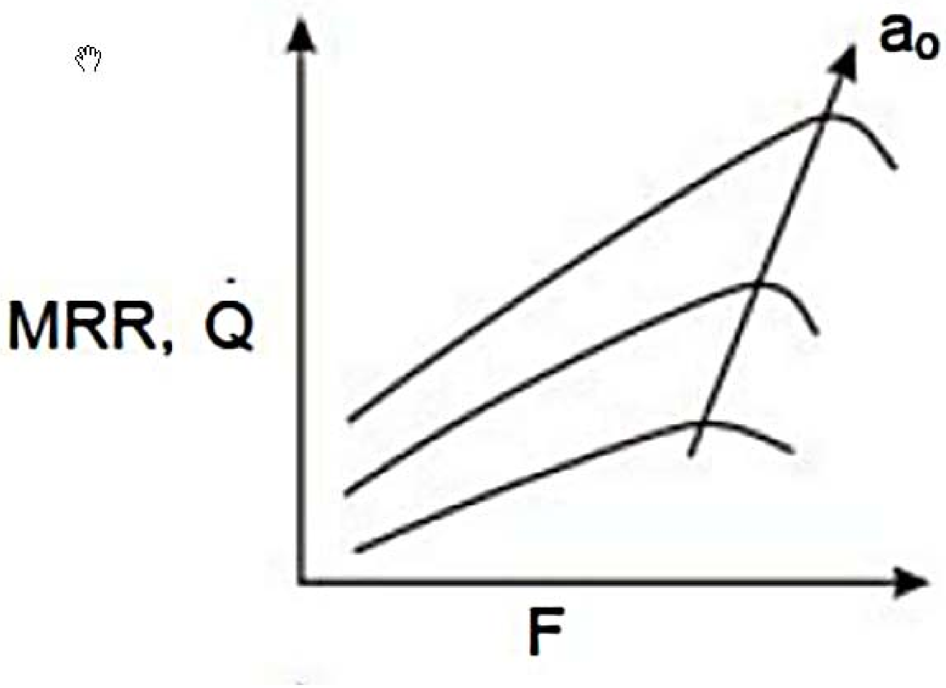
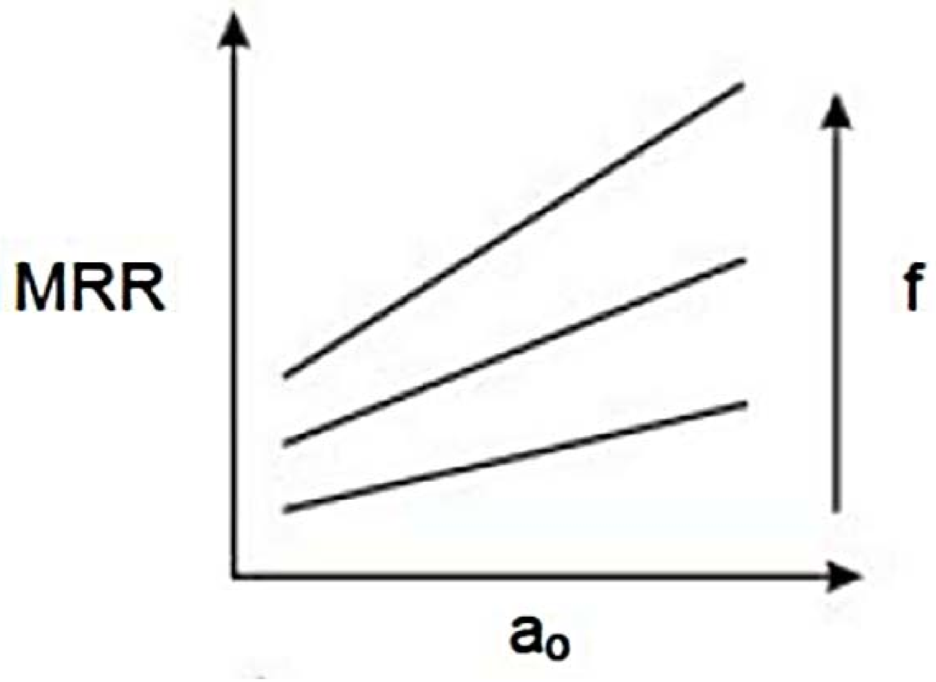


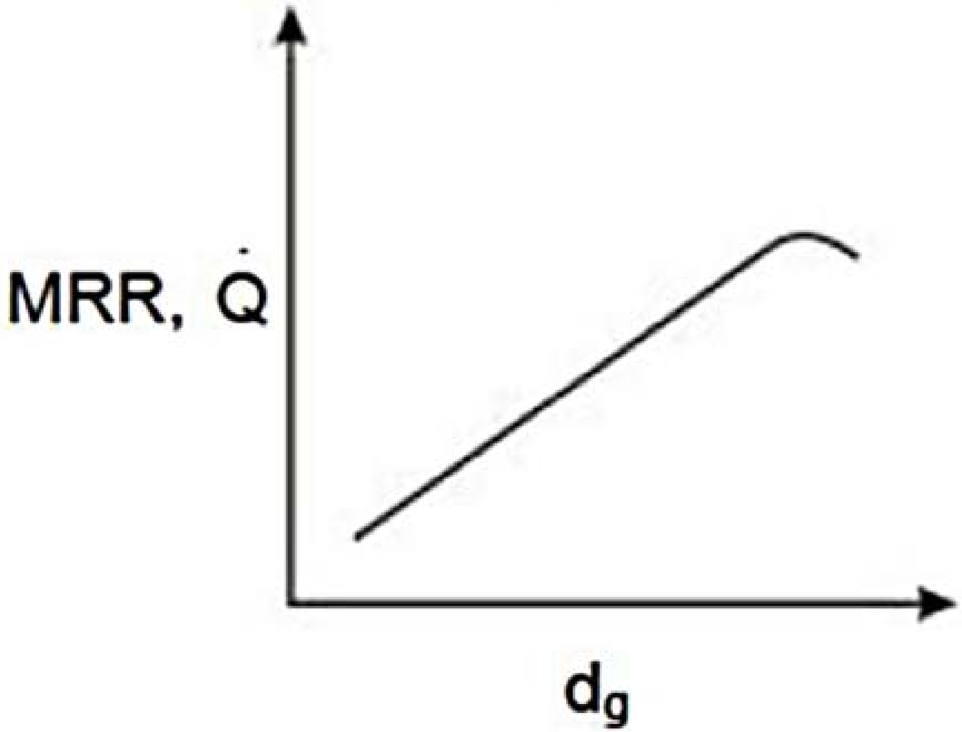
Fig. 5.6 Effects of amplitude of vibration on material removal rate during USM. Workpiece: glass; tool: steel; abrasive: B_4C (120 mesh size); pressure: • 0.20 MPa; Δ 0.16 MPa; * 0.10 MPa; ○ 0.04 MPa. [*Kremer et al.*, 1981].

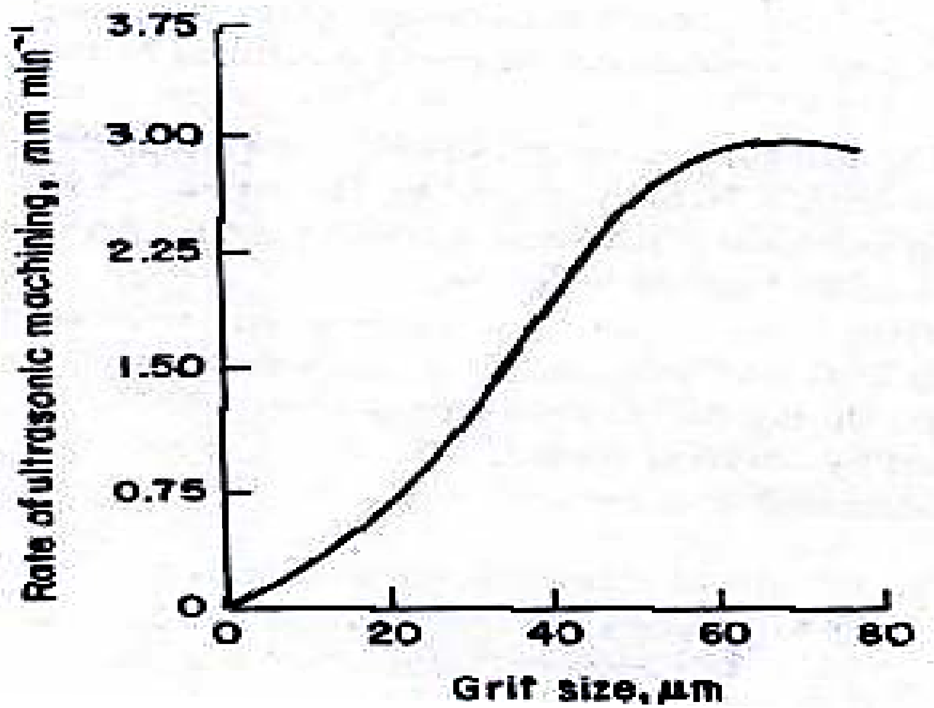
Effect of Amp. & Freq. on MRR



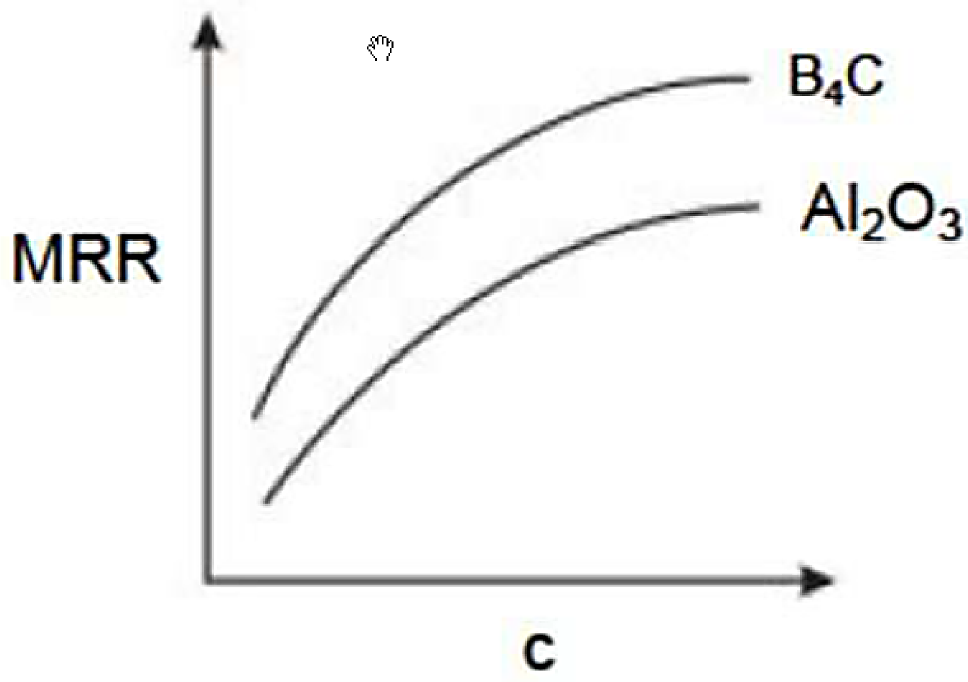


Effect of Abrasive grit size on MRR

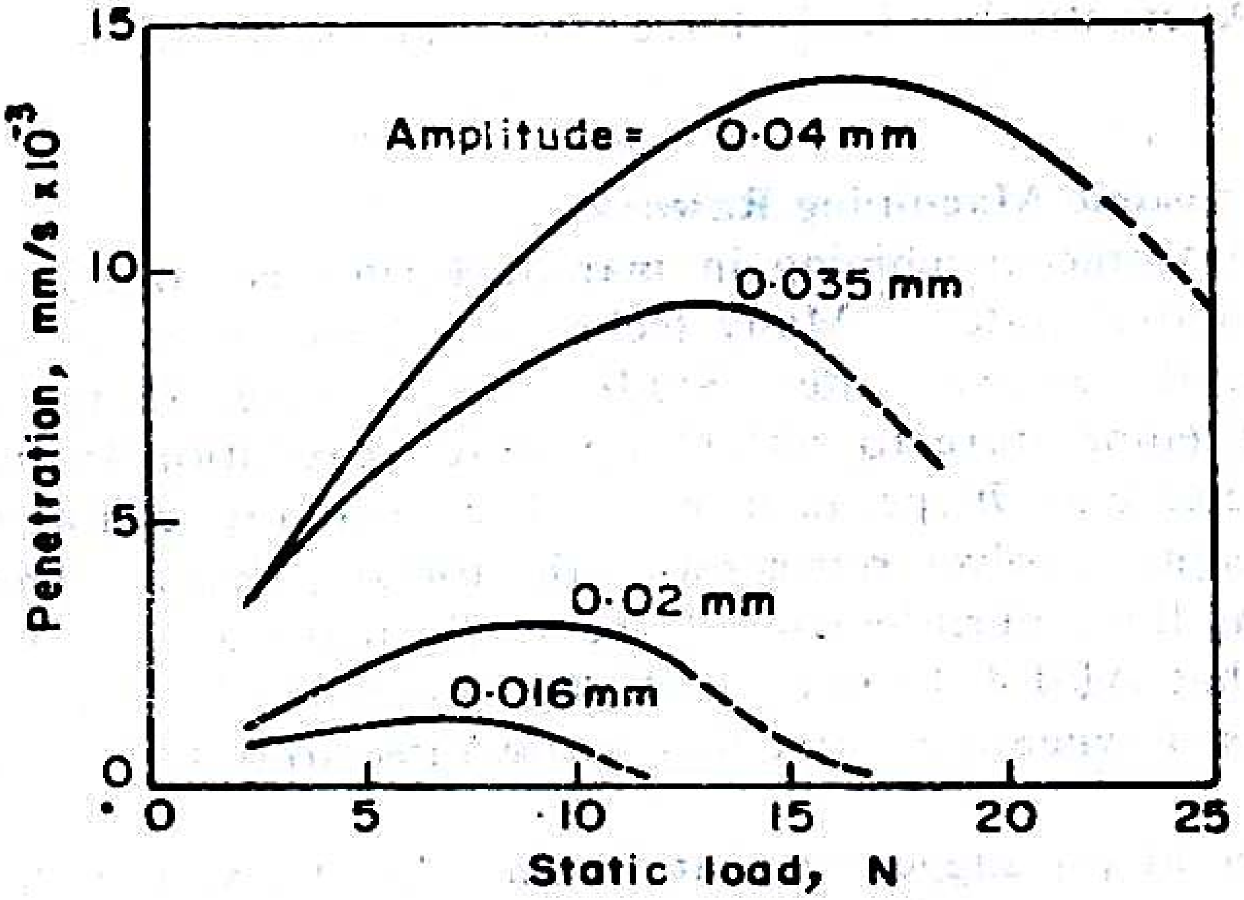




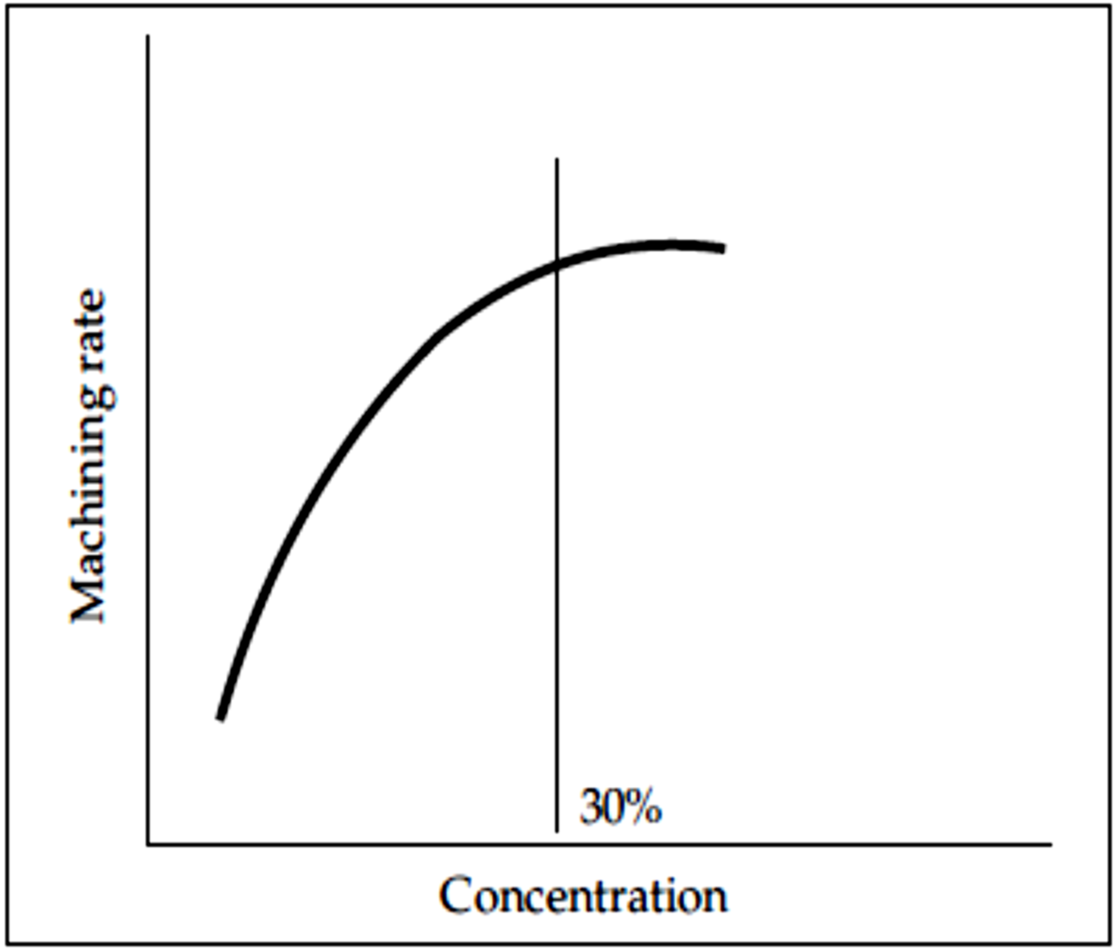
Effect of Abrasive type on MRR



Effect of applied force on MRR

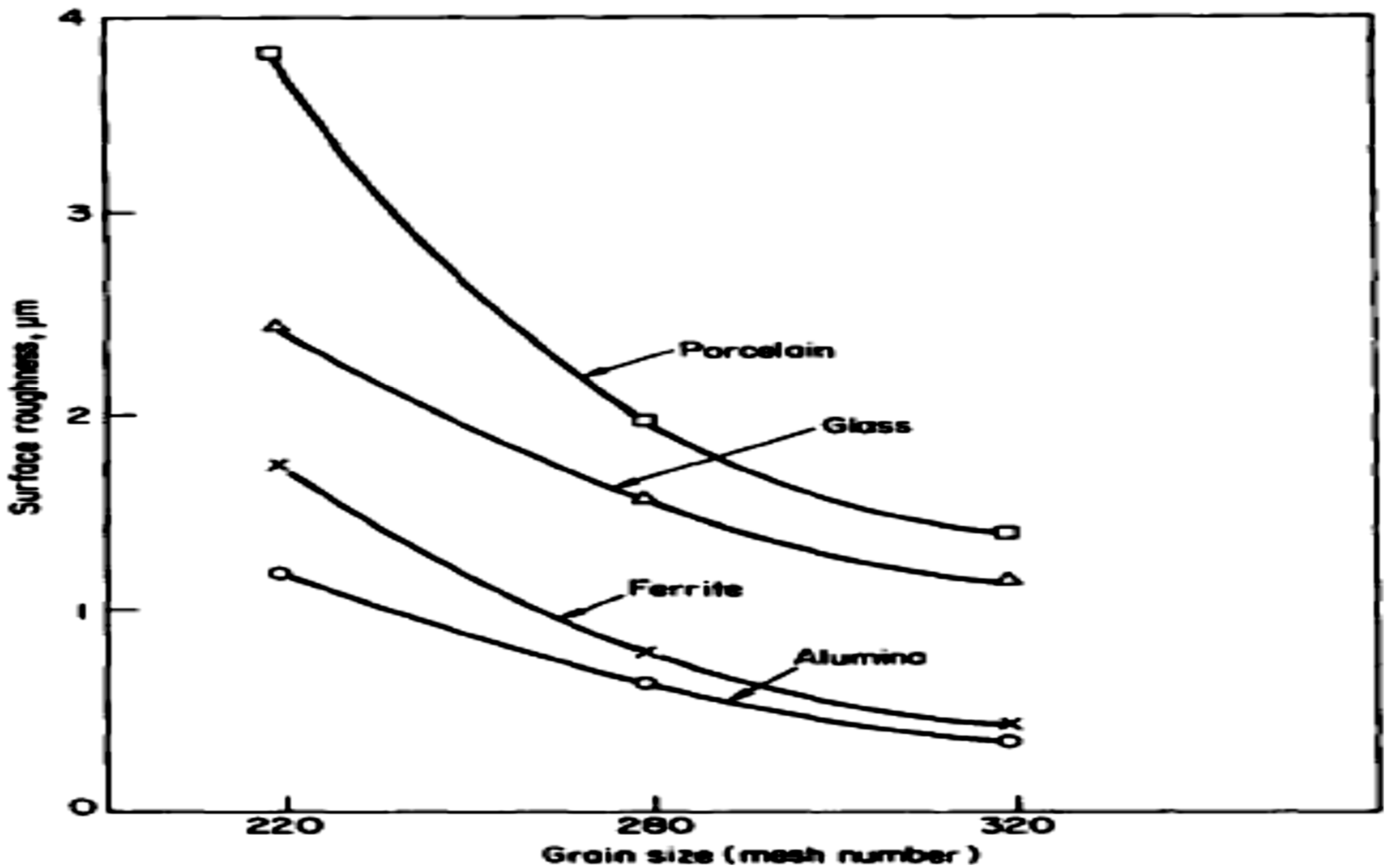


Effect of Abrasive concentration on MRR

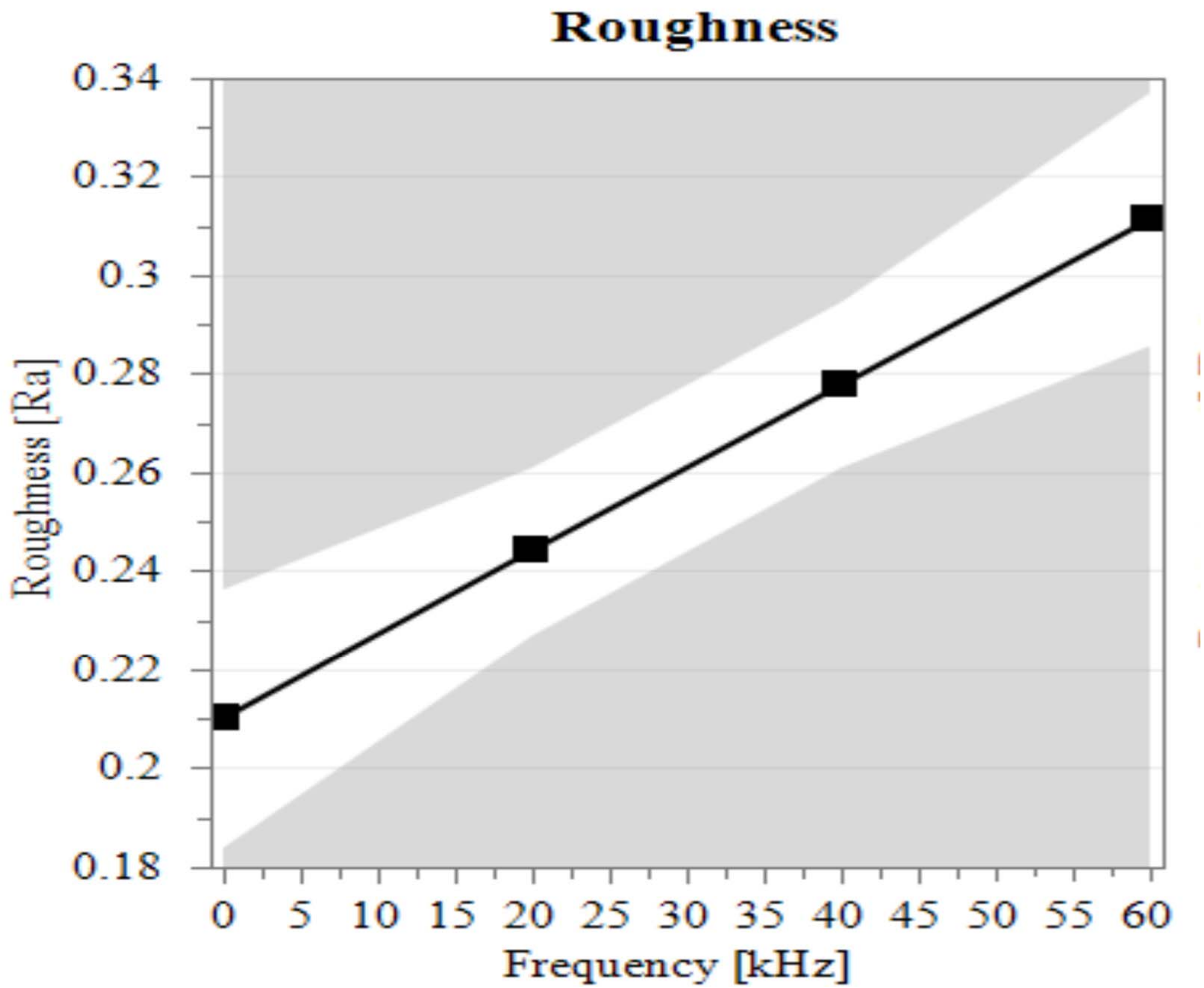


EFFECT OF MACHINING VARIABLES ON SURFACE ROUGHNESS

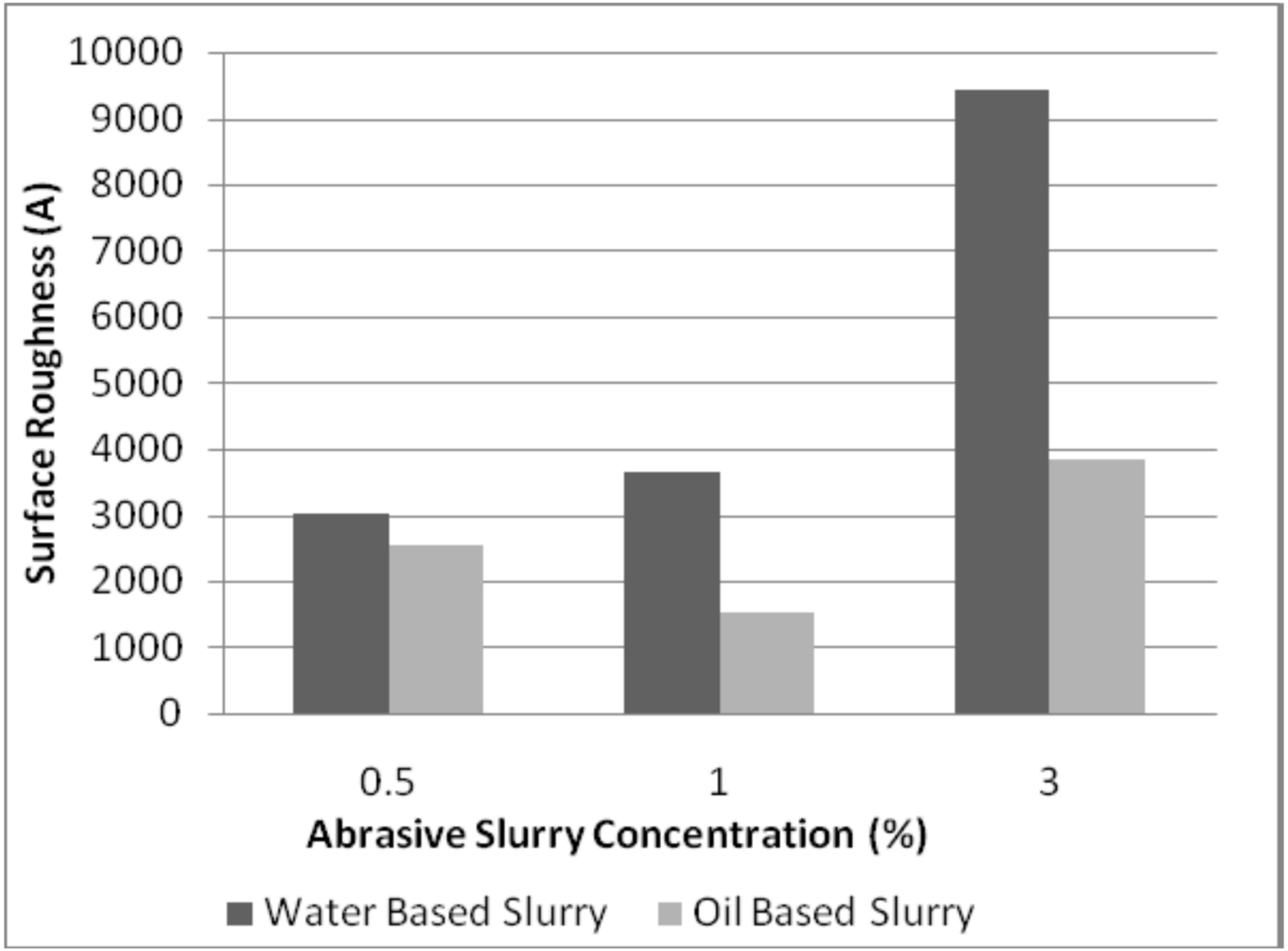
Effect of Abrasive grain size on Surface Roughness



Effect of Frequency on Surface Roughness



Effect of Abrasive concentration on Surface Roughness



Applications

- **<u>It is mainly used for:</u>**

(1) Drilling

(2) Grinding,

(3) Profiling

(4) Coining

(5) Piercing of dies

(6) Welding operations on all materials which can be treated suitably by abrasives.

(7) Used for machining hard and brittle metallic alloys, semiconductors, glass, ceramics, carbides etc.

(8) Used for machining round, square, irregular shaped holes and surface impressions

Applications

- Shapes obtained by USM include non-round holes, holes along a curved axis and coining operation, in which an image pattern on the tool is imparted to a flat work surface

Applications, cont.

1. Machining of cavities in electrically non-conductive ceramics
2. Used to machine fragile components in which otherwise the scrap rate is high
3. Large number of holes of small diameter
4. Used for machining hard, brittle metallic alloys, semiconductors, glass, ceramics, carbides etc.

Applications, cont.

5. Used for machining round, square, irregular shaped holes and surface impressions.
6. USM enables a dentist to drill a hole of any shape on teeth without any pain
7. USM is used for grinding Quartz, Glass, ceramics
8. USM can be used to cut industrial diamonds

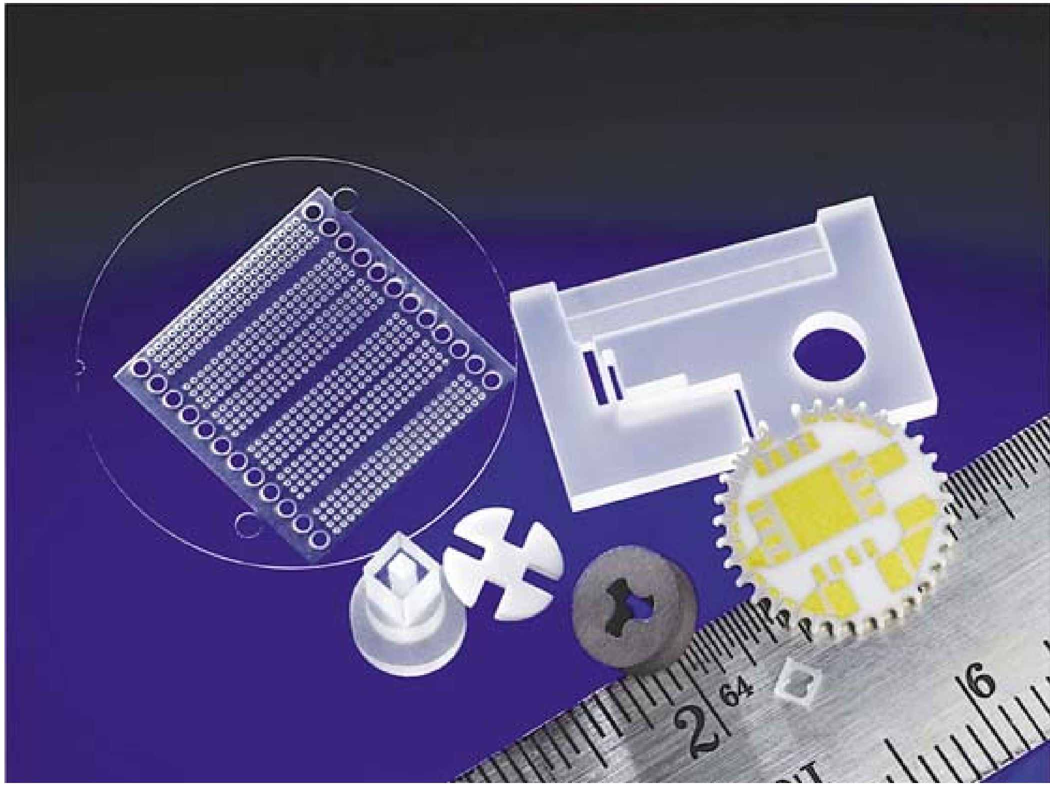
Advantages

- Machining any materials regardless of their conductivity
- USM apply to machining semi-conductor such as silicon, germanium etc.
- USM is suitable to precise machining brittle material.
- USM does not produce electric, thermal, chemical abnormal surface.
- Can drill circular or non-circular holes in very hard materials
- Less stress because of its non-thermal characteristics
- Machined parts by USM possess better surface finish and higher structural integrity

Disadvantages

- USM has low material removal rate. (3-15 mm^3/min)
- Tool wears fast in USM.
- Machining area and depth is restraint in USM.

Products



Summary of USM characteristics

- Mechanics of material removal : Brittle fracture caused by impact of abrasive grains due to vibrating at high frequency
- Medium: Abrasive slurry
- Abrasives : B_4C; SiC; Al_2O_3; diamond; 100-800 grit size
- Vibration frequency : 19-25 kHz,
- Amplitude : 25-100 micro meter

Summary of USM characteristics, cont.

- Tool feeding: Spring control, hydraulic (pneumatic) control
- Tool material : Soft steel
- Material/tool wear : 1.5 for WC workpiece, 100 for glass
- Gap: 25-40 micro meter
- Critical parameters : Frequency, amplitude, tool material, grit size, abrasive material, feed force, slurry concentration, slurry viscosity.

Summary of USM characteristics, cont.

- Material application : Metals and alloys (particularly hard and brittle), semiconductors, nonmetals, e.g., glass and ceramics
- Shape application: Round and irregular holes, impressions
- **Limitations : Very low MRR, tool wear, depth of holes, and cavities small.**

QUESTIONS??????????????

END