Non-traditional abrasive machining processes : Ultrasonic, Abrasive jet and abrasive water jet machining

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Reference Books

1. Modern Machining Processes by P C Pandey & H S Shan, Tata McGraw-Hill.
2. Nonconventional Machining by P K Mishra, Narosa Publishing House.
3. Manufacturing Science by Amitabha Ghosh & A K Mallik, Affiliated East-West Press.
4. Manufacturing Engineering and Technology by Serope Kalpakjain and Steven R. Schmid, Pearson Education.

What is conventional machining ?

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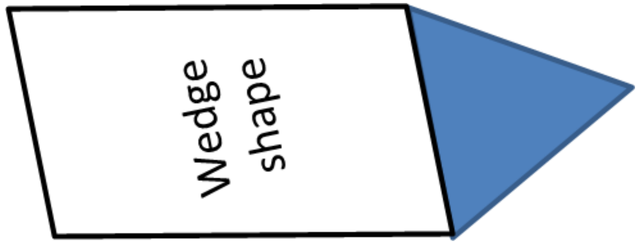
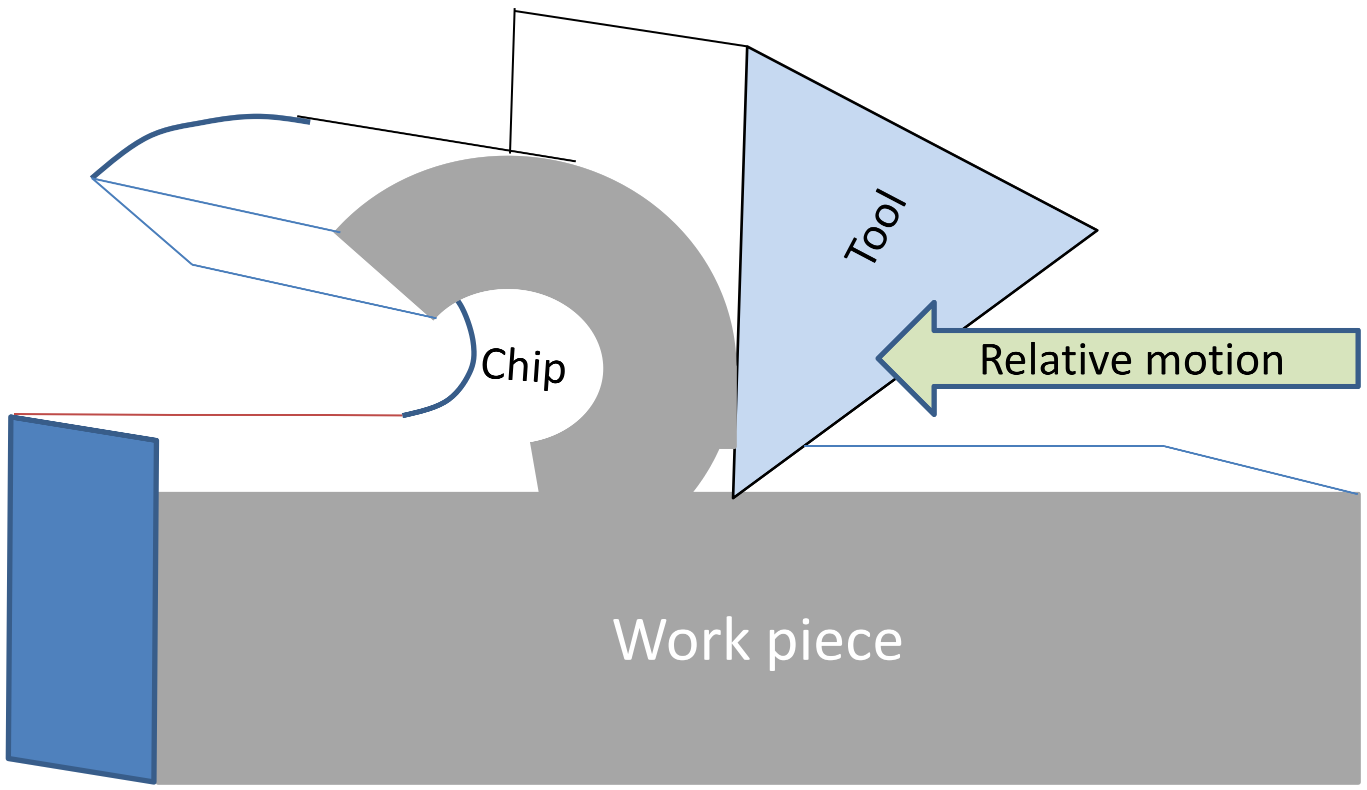


o Conventional method of machining is :

- ➢ Material will get removed in the form of chips (subtractive process)
- ➢ Sharp tool, in the shape of a wedge and is sufficiently harder than the work piece (for penetration).
- ➢ Hold the tool and the work piece rigidly
- ➢ Embed the tool to a particular depth inside the work piece by penetration
- ➢ Provide a relative motion to the tool with respect to the work piece

Conventional machining – a pictorial view



Relative motion sometimes referred as cutting speed

Why Non-traditional / non-conventional machining

In many cases

- Parts might be very hard and brittle and fracture prone – Conventional methods of machining are not possible Or might be too expensive.
  a. Glass
  b. Ceramics – metallic carbides, oxides, borides. Example : Tungsten Carbide

- The machining of complex geometrical features might not be possible by conventional means

  E.g. : Sinking operations with non-circular sections

Why Non-traditional / non-conventional machining

- In many cases of machining

  - The work material might be heat sensitive or too delicate

    - Non-conventional machining with no contact or with minimal pressure

Why Non-traditional / non-conventional machining

In many cases of machining

- Accessibility might be a problem
- Remote cutting and grooving
- Surface texture may be a problem. E.g. There might be a requirement to get a surface free of laylines.

Why Non-traditional / non-conventional machining

In many cases of machining

- The size range of geometrical features to be produced might not be possible by conventional means.

- Micro and nano machining are possible both by conventional and non-conventional means or hybrid methods

Main non-traditional manufacturing methods

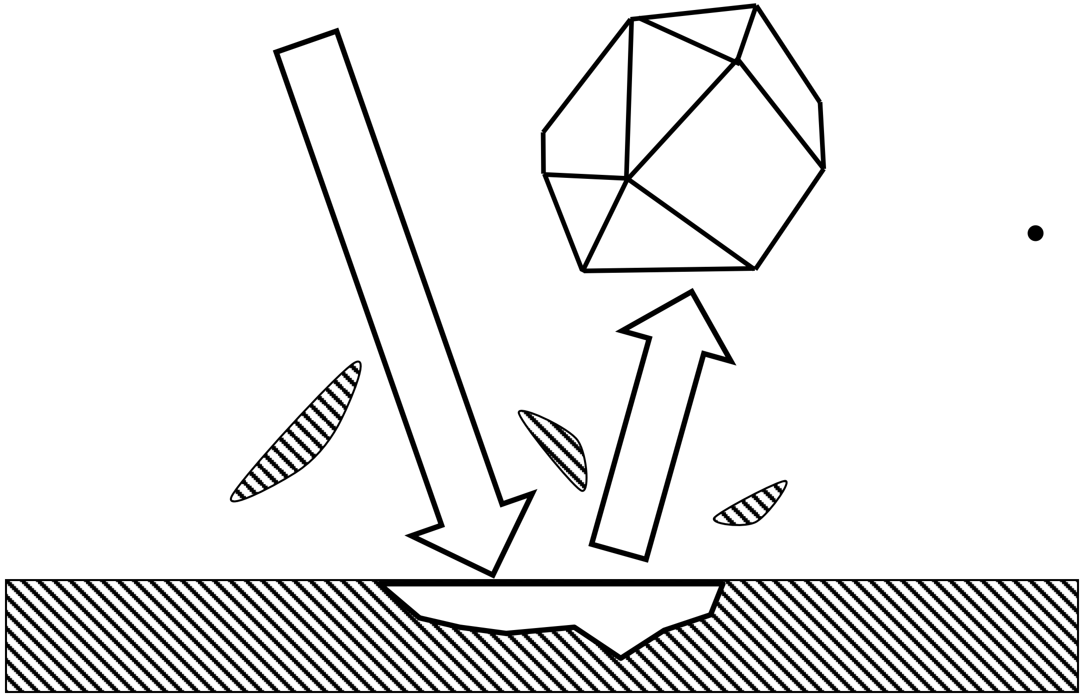
- Thermal
  - Laser beam machining (LBM), Electron Beam Machining (EBM), Plasma Arc machining
  - Electrical Discharge Machining (EDM)

- **Mechanical (Abrasive)**
  - **Ultrasonic machining (USM), Abrasive jet machining (AJM), Abrasive water jet machining (AWJM)**

- Chemical and Electrochemical
  - Electrochemical Machining (ECM)
  - Chemical machining (CM)

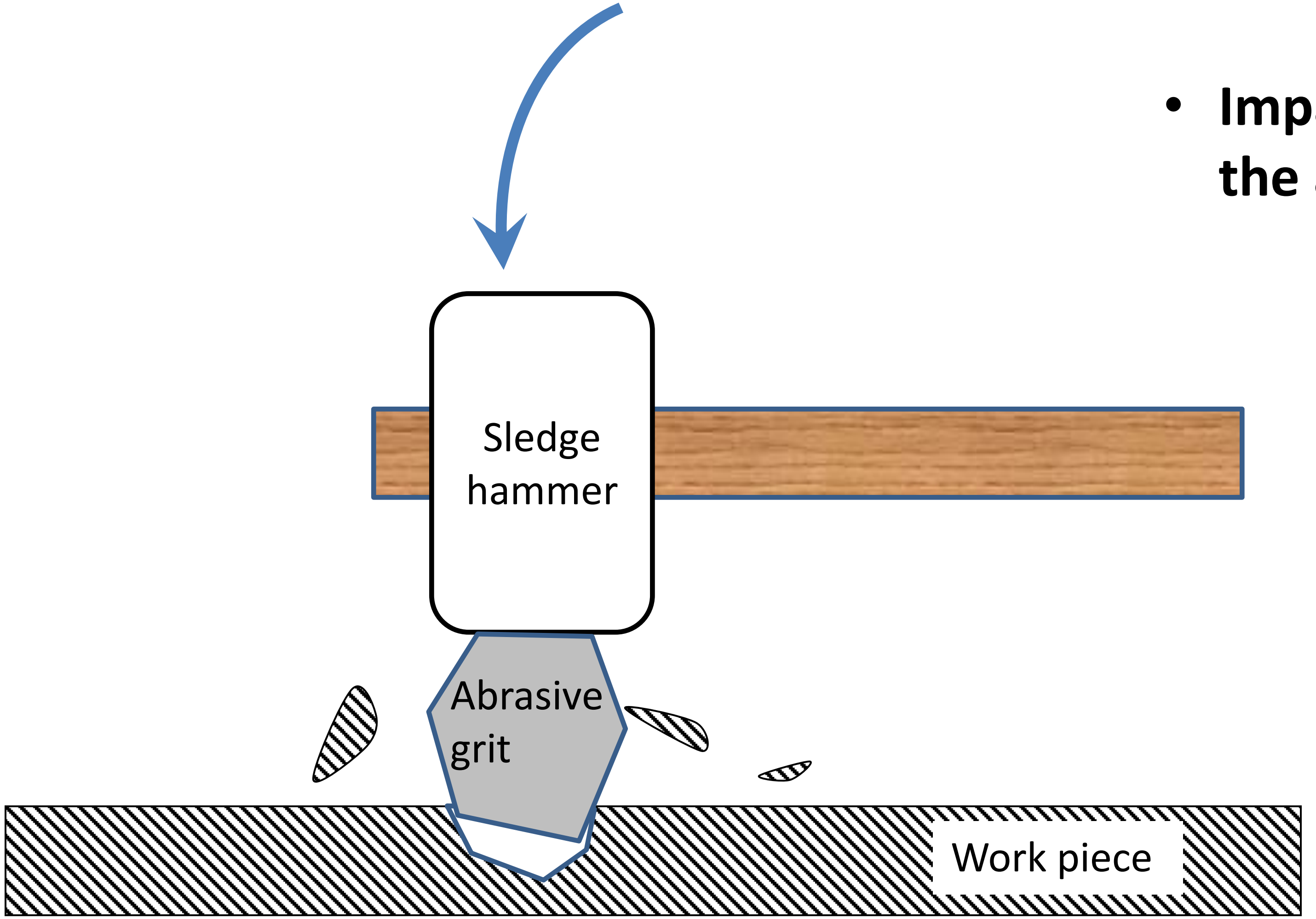
How is material removed in abrasive based non-traditional methods of machining ?

- By free impacts



- **Abrasive particle accelerated to very high speed and made to impact against brittle work piece.**
- **Abrasive : Hard and rigid.**

By percussion (hammering)

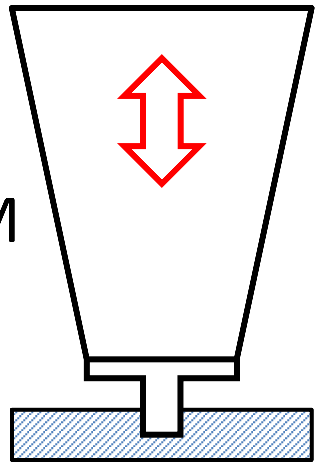


- **Impacts of hammer are on the abrasive.**

Non-traditional abrasive machining methods

Ultrasonic machining - USM

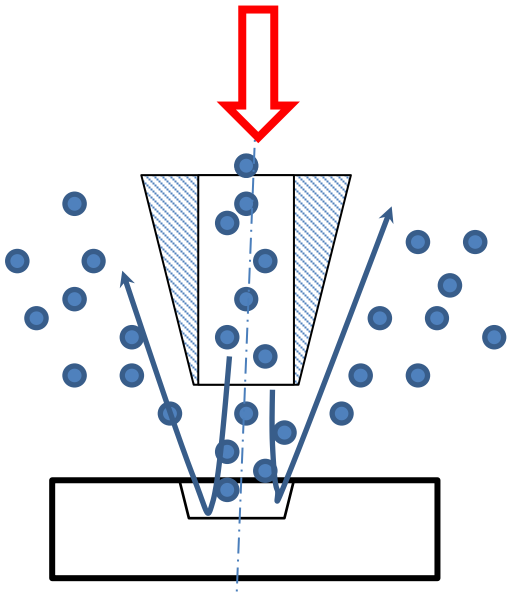
Rotary ultrasonic vibration machining - RUM



Vibrates at Ultrasonic Frequencies.

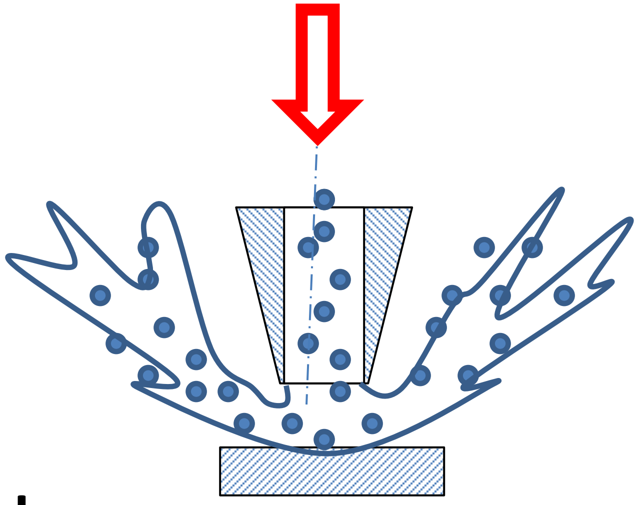
Percussion method of material removal

Free impact of abrasive particles (150-300 m/s)



Abrasive Jet machining – AJM

Abrasive water jet machining - AWJM



Medium : Water ; Speeds : ~800 - 1000 m/s
Practically any material can be removed/machined.

Area of application of Non-traditional abrasive machining methods

- USM and AJM would be most suitable for machining **hard** and **brittle, electrically non-conductive** materials : Glasses, ceramics, semi-conductors etc.

- If the material is electrically conductive, Electrical discharge machining (EDM) would be more suitable. Electro-chemical machining may also be carried out.

- AWJM can machine practically all materials : Metals, ceramics, rocks, glass, composites etc. The cut materials are free from heat affected zones.

Area of application of Non-traditional abrasive machining methods

Every process has its characteristic drawbacks as well

- EDM tends to produce recast layer (material removed will be melted and resolidified), surface cracks, material transfer from cutting element to work piece, and thermal effects.

- Laser cutting may produce clinging dross (on the underside of cut, material resolidified from the cut material will be hanging and producing unusable product), striations (parallel marks – rough texture), tapered cut and thermal effects

- So other methods have their respective problems – so that non-traditional abrasive machining methods have a fair chance to compete in the various machining applications of today.

Applications for Non-traditional abrasive processes

- Machining of 2-D and 3-D profiles
- Laminated object (sheets) manufacturing
- Machining of grooves
- Cutting of sheets and plates
- Rock cutting by AWJM
- Drilling of circular and non-circular holes
- Machining of heat sensitive materials, thin fragile specimens, difficult to machine materials

Scope of non-traditional abrasive machining in the industry

- Since there is a heavy dependency on metals, EDM, Wire-cut EDM have gained tremendous momentum while USM and AJM have not. Even ECM has not, for another reason (charge passage – material removal still takes place).

- However, some niche areas have been defined for such processes

- Hybrid processes have evolved

- AWJM is unique in that it does not affect properties of material (no heat affected zone) and can cut practically all materials.

Why can't we apply conventional methods of machining for glasses, ceramics and semiconductors ?

- Glasses and ceramics will fracture if we try to machine them by conventional methods of machining.

- Non-traditional abrasive machining - They will fracture and crack up, but since the abrasive grits are small in size, the fractures produced will be small as well, so that the net effect will be production of smooth surface with material removal.

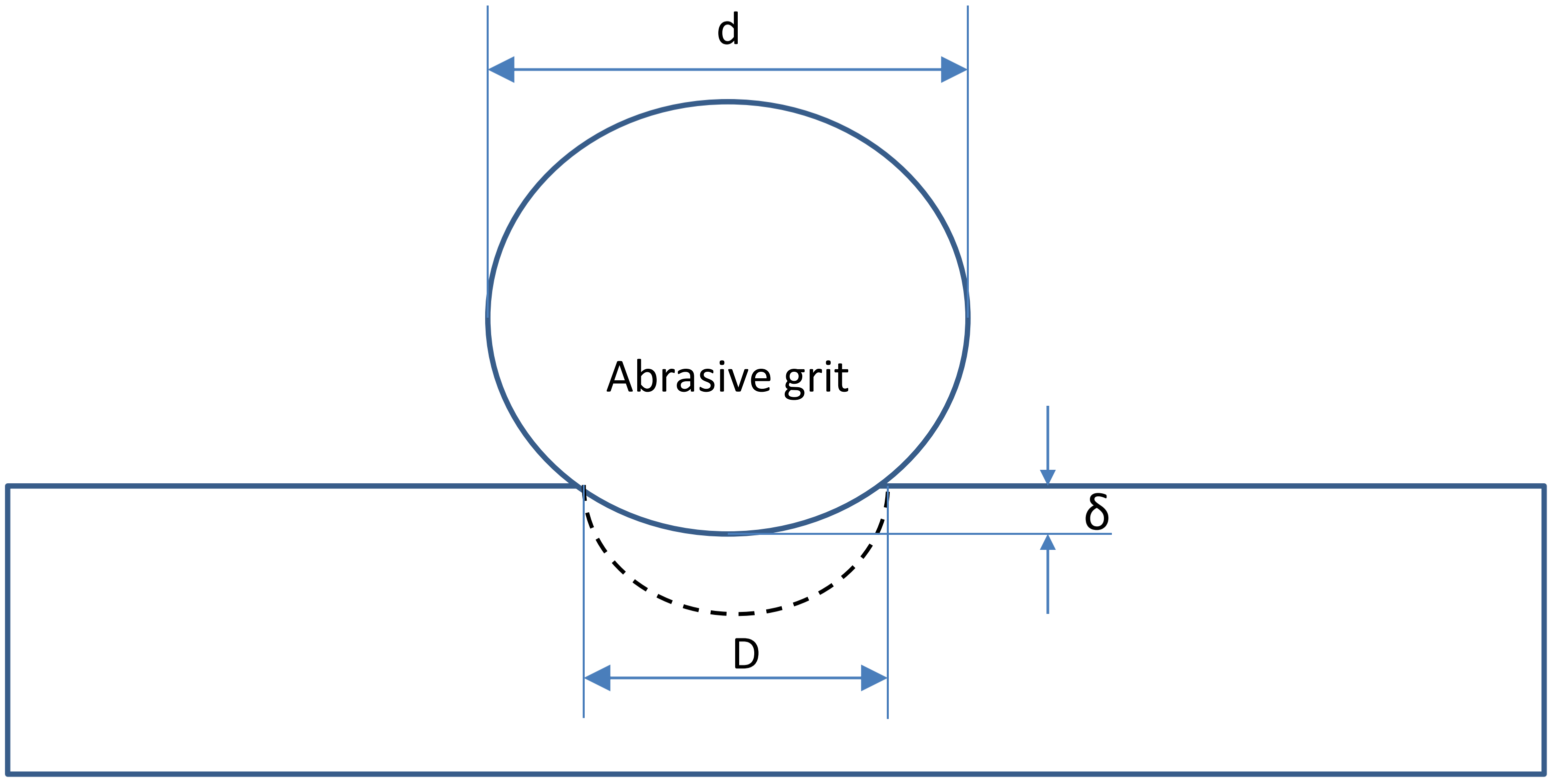
- Dynamics of these machining methods : Cutting forces are minimal. Hence delicate parts can be easily machined by these methods.

- If the abrasive grits can be kept in a confined chamber and not permitted to come in contact with the atmosphere, the processes can be considered to be environment friendly.

Hybrid processes

- Electrochemical grinding (Hybrid between ECM and Conventional grinding)
- Electrochemical-aided abrasive flow machining (Inside or hollow geometry machining - Finishing purposes)
- Chemical-assisted ultrasonic vibration machining
- Electrical discharge grinding

Abrasive grit, indentation depth and material removal



Brittle work piece

Ultrasonic machining

Ultrasonic machining

- This method of machining resorts to percussion or hammering of abrasives against the work piece.
- Hammering is done by a body (tool) which is sufficiently ductile so as not to undergo brittle fracture itself.
- It should also be fatigue resistant because the hammering is done at ultrasonic frequencies.
- Material removal – microchipping and erosion.
- The rate of machining is proportional to rate of hammering, so the frequency of hammering is in the ultrasonic range - 19 to 25 kHz

Ultrasonic machining : Materials required

- Abrasives need to be applied at the site of machining and need to be removed together with machined material from work piece and tool material, so they are carried in a slurry to and from the site of machining.

- Reusing/recycling of abrasives is generally not recommended (abrasive contamination and fracture).

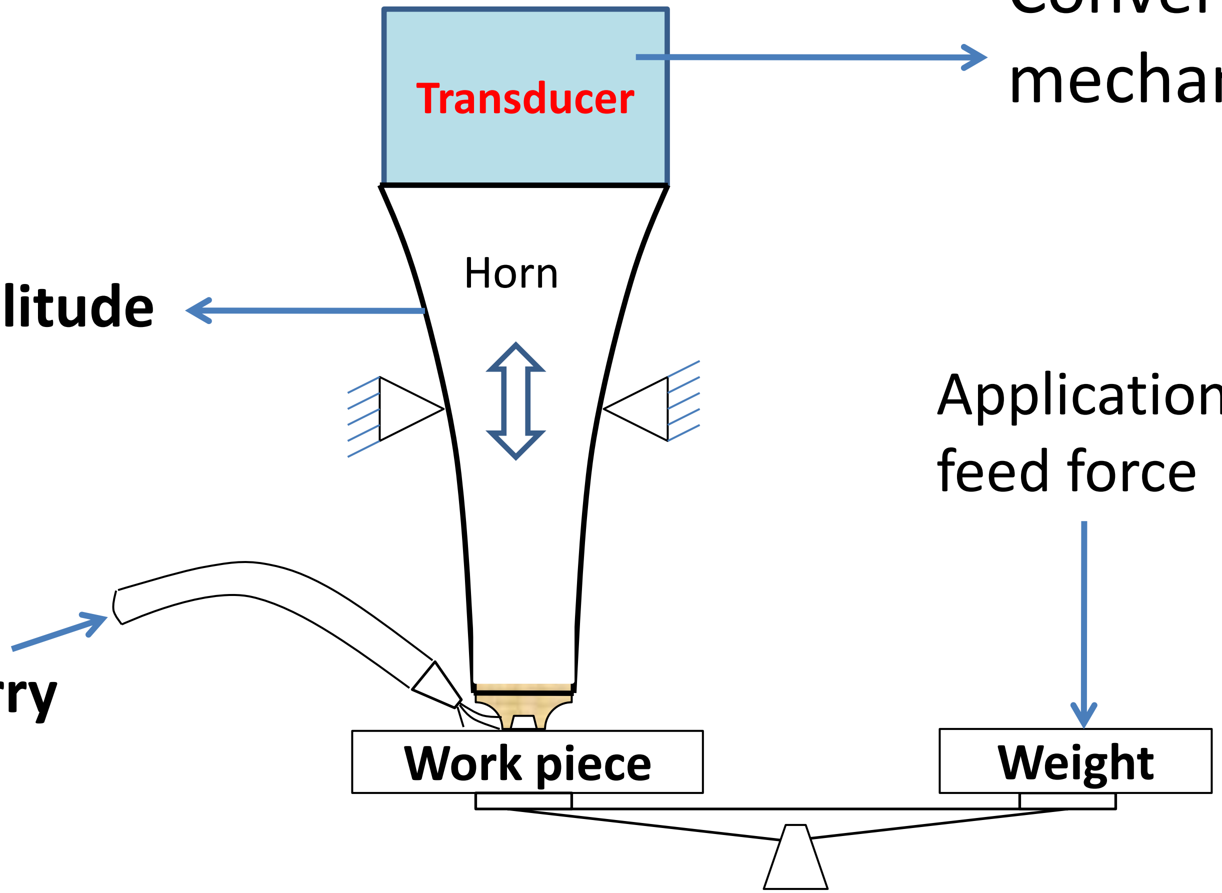
- The tool is pressed against the work piece to create a slight pressure, low enough so as not to crush abrasives and high enough so as to ensure fracturing of work piece.

- Abrasives have higher fracture strength than that of the work piece.

Ultrasonic machining : Support systems

Converts electrical energy to mechanical vibrational energy

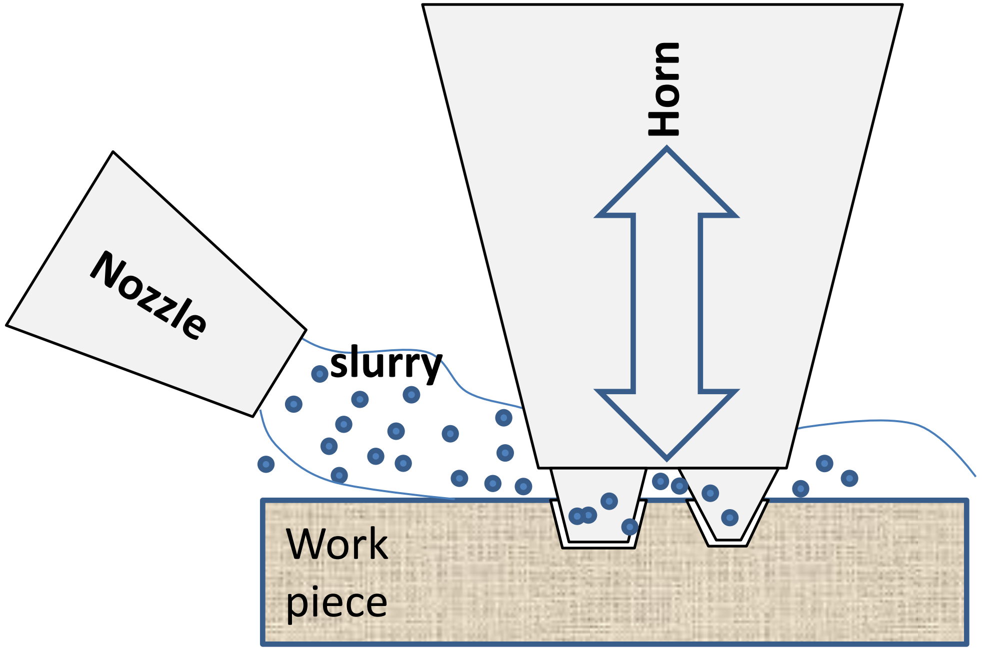
Amplifies amplitude of vibration



Application of constant feed force

Abrasive slurry

USM machining zone



Machining data

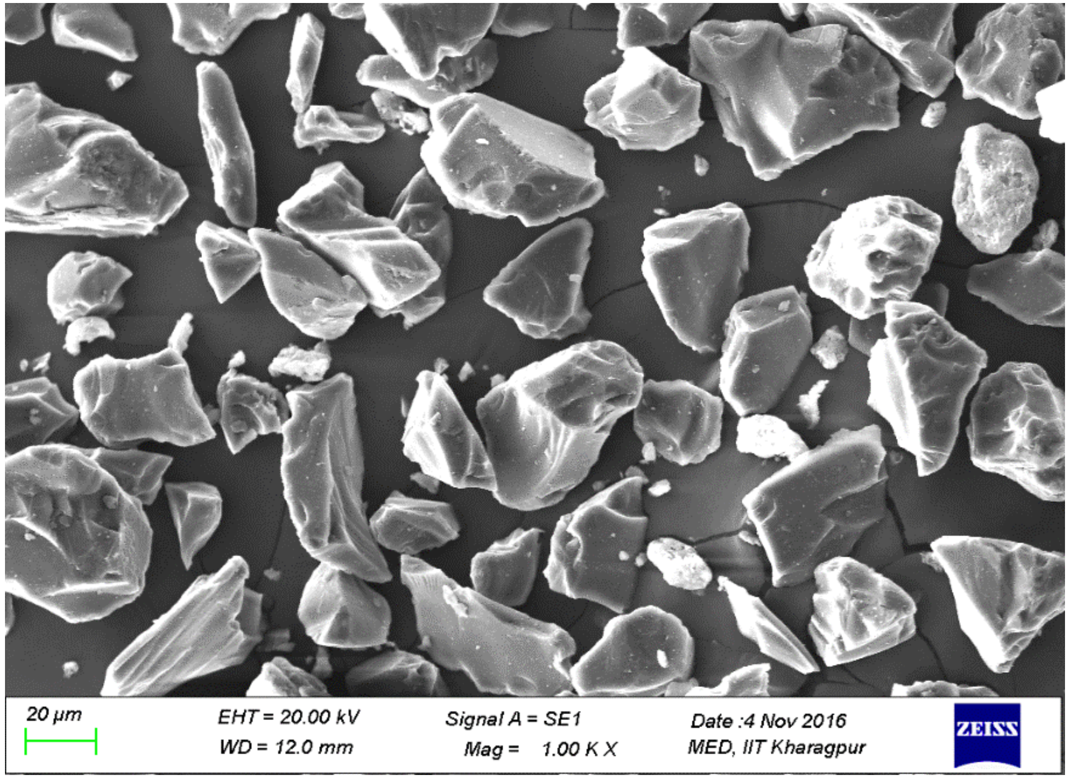
- Abrasives : Boron carbide (most common) B_4C, silicon carbide SiC, aluminium oxide Al_2O_3, Boron Silicarbide

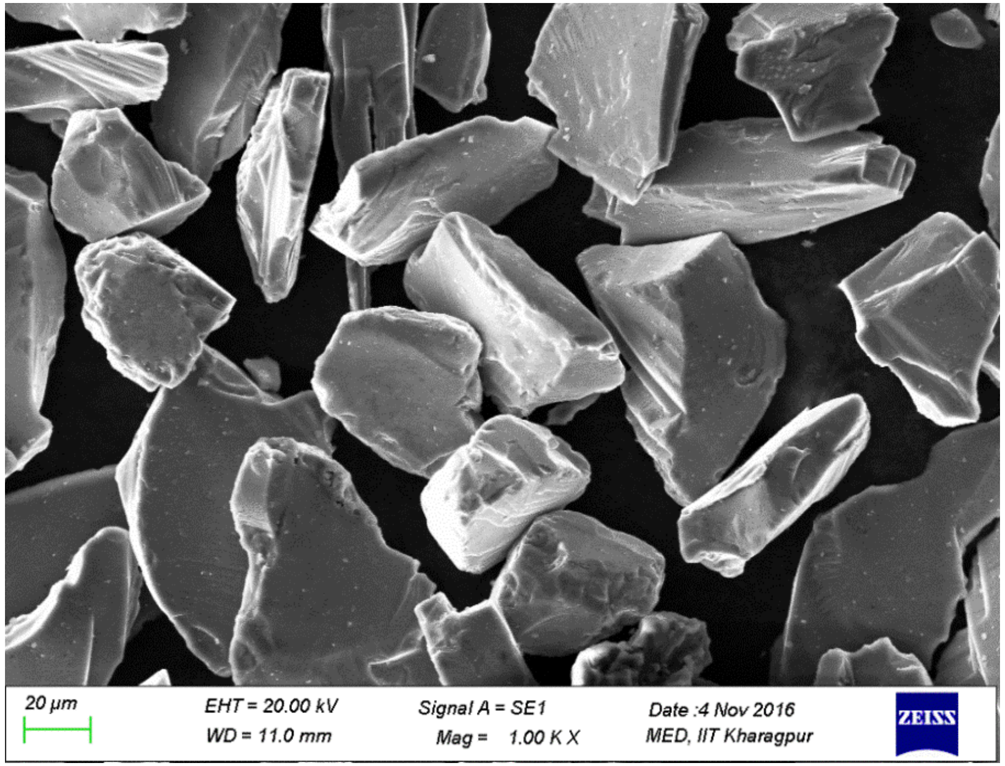
- Diamond powder or Diamond dust is used on Diamond, ruby etc.

- Abrasives are carried in a water slurry. Concentrations 20% to 60% by volume.

Scanning electron microscope images of abrasives

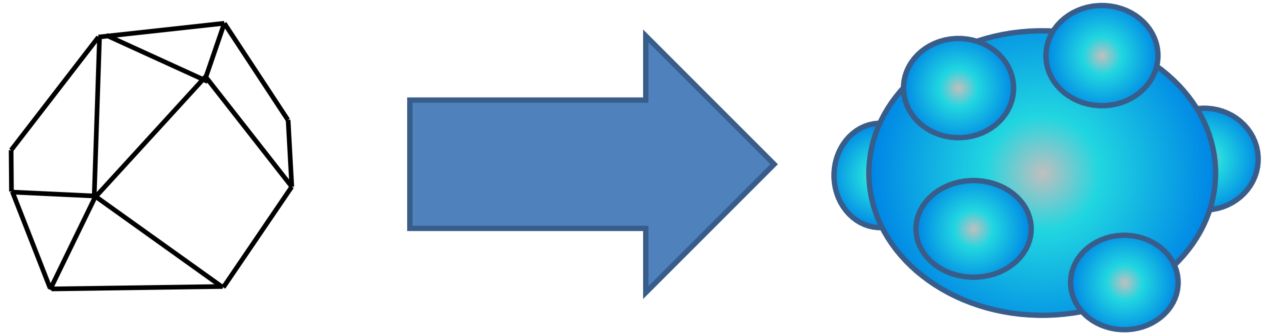
Boron carbide (~ 40 micron)



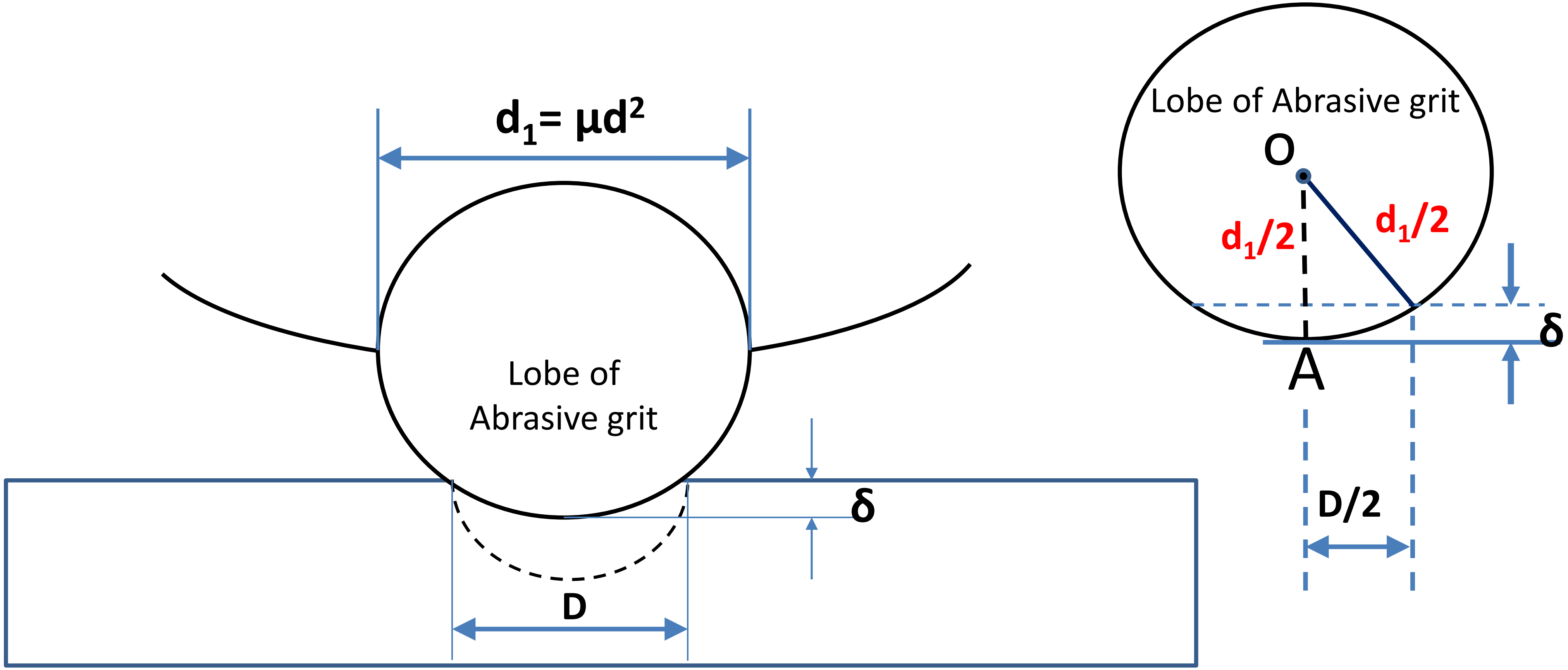


Silicon carbide

How is the abrasive considered in analysis



Abrasive grit, indentation depth and material removal



$$\left(\frac{d_1}{2} - \delta\right)^2 + \frac{D^2}{4} = \frac{d_1^2}{4} \quad \rightarrow \quad D = 2\sqrt{d_1 \times \delta}$$

Main assumptions

- The abrasive grits are perfectly rigid and hard spheres with lobes as shown

- If the work material is brittle, a hemispherical volume of material with diameter *D,* is removed per impact

- All abrasive grits are similar, and all impacts are identical

- The MRR in USM is proportional to the frequency, the number of abrasive grits making impact

Thank you