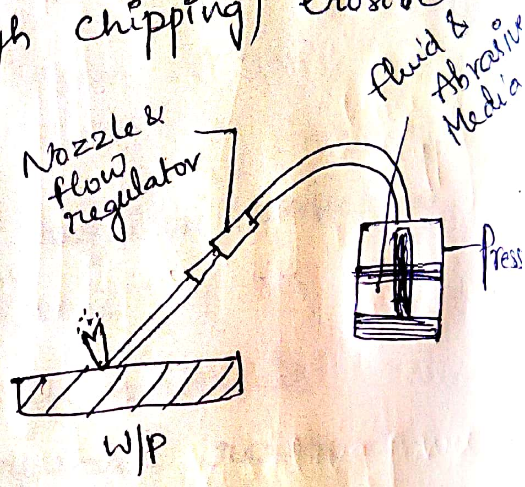
Abrasive jet Machining

Basic Principle :-

A jet of inert gas consisting of very fine abrasive particles strikes the workpiece at high velocity (usually between 200-400 m/s) resulting in material removal through chipping/ erosive action.

→ The erosive action has been employed for cutting, cleaning, etching, polishing & deburring



→ It can be used to cut hard/ brittle materials (glass, silicon, tungsten, ceramics etc) but not so effective on soft materials like aluminium, rubber etc.

Operating elements

The operating elements are Abrasive, Carrier gas and the nozzle as shown in above figure.

Abrasives

The following abrasives are used

1) Aluminium oxide
2) Silicon carbide
3) Sodium bicarbonate
4) Glass beads

→ The abrasive particles should be hard and should have high toughness.

→ It should be irregular in shape and the edges should be sharp for effective metal removal.

→ Bigger grains will remove metal at faster rate.

→ The maximum size of the particles is limited by the inside diameter of the nozzle.

Carrier gas :-

The following are the gases used as carrier for the abrasive particles in AJM.

carbondioxide, Air, nitrogen

→ The pressure of the carrier gas also affects the metal removal rate.

→ It is usually kept between 2 to 8 kg/cm^2.

Operating principle of AJM

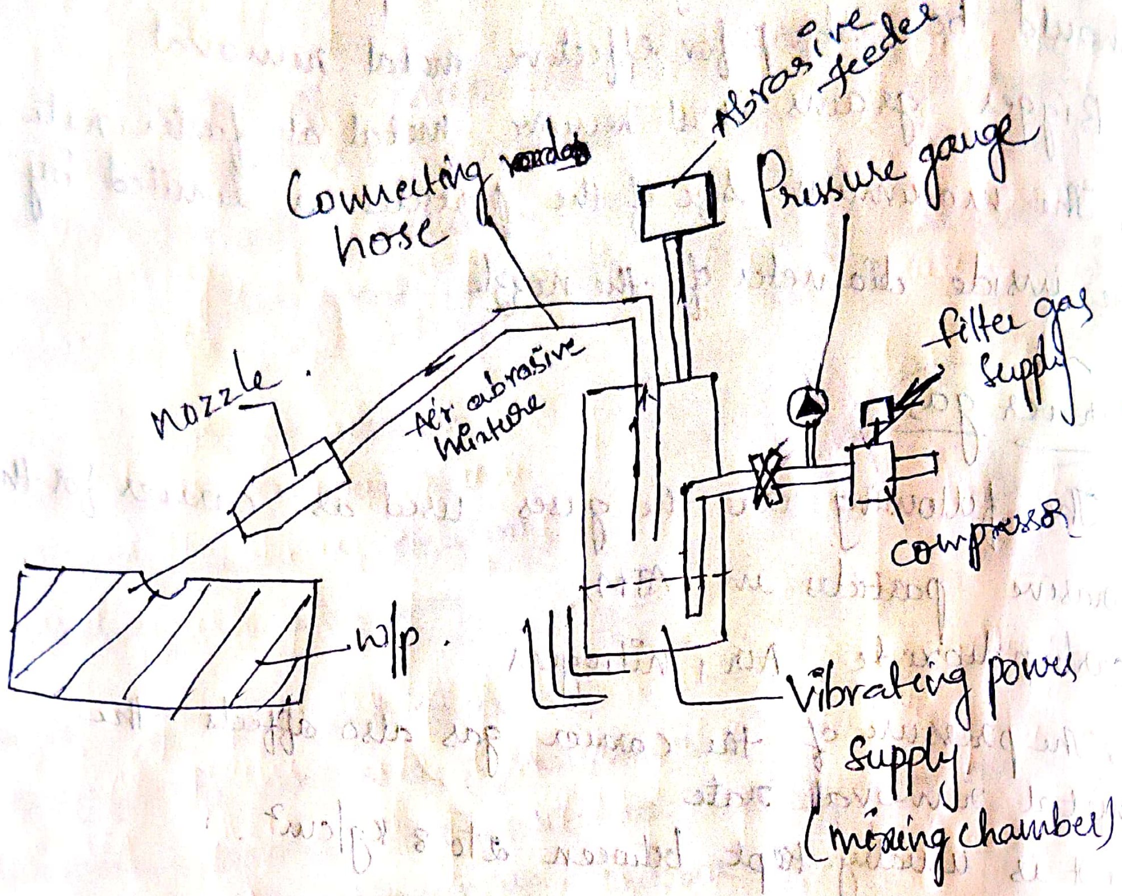
→ The fundamental principle of AJM involves the use of a high speed stream of abrasive particles carried by a high pressure gas or air on the work surface through a nozzle.

→ The metal removal occurs due to erosion caused by the abrasive particles imparting the work s/f at high speed

→ with repeated impacts, small bits of material get loosened and a fresh s/f is exposed to the jet

Construction

Schematic Representation of AJM



Equipment of AJM :-

→ It consists of Abrasive feeder, gas supply unit, filter, pressure regulator, mixing chamber, nozzle assembly and the dust collecting chamber along with the work holding device, Machining chamber.

Abrasive feeder :-

→ Required quantity of abrasive particles are supplied by abrasive feeder

→ Abrasive quantity is controlled by inducing vibration to the feeder

→ The particles propelled by carrier gas to a mixing chamber.

→ The air abrasive mixture moves further to the nozzle.

Machining chamber / ~~Mixing~~ chamber :-

→ It is well closed so that the concentration of the abrasive particles around the working chamber does not reach to the harmful limit.

→ Machining chamber is equipped with a vaccum dust collector.

→ Special consideration should be given to the dust collection system if the toxic material (like beryllium) are being machined.

AJM Nozzle :-

→ It is made of tungsten carbide or sapphire (usual life = 300 hr) which has high resistance to wear.

→ It is made up of either circular or rectangular cross section.

→ It is so designed that a loss of pressure due to bends, friction etc is mini. possible.

→ The nozzle pressure is generally maintained b/w 2-8.5 kgf/cm^2.

→ Its value depends upon the material of w/p and desired characteristics of the machined s/f (accuracy etc)

Abrasives :-

→ Aluminium oxide (Al_2O_3), silicon carbide (SiC), glass beads, crushed glass and sodium bicarbonate are some of the abrasives used in AJM.

→ Selection of abrasives depends upon the type of work material, MRR and machining accuracy desired.

→ Al_2O_3 is good for cleaning, cutting and deburring.

→ SiC is used for similar applications like Al_2O_3 but for harder work materials.

→ For obtaining matte finish, glass beads are good

→ Crushed glass performs better for giving sharper edges

→ Cleaning, deburring, cutting of softer materials are better performed by Sodium bicarbonate.

→ The size of the abrasive particles available in market is 10 to 50 um

→ Small abrasive particles are used for cleaning and polishing

→ large particles perform better during cutting

→ fine grains are less irregular in shape, hence their cutting ability is poor

→ Reuse of abrasives is not recommended because of two reasons

→ Firstly, abrasive jet contaminated with metallic chips which may block the nozzle passage.

→ Secondly, cutting ability of the used abrasive particles goes down]

~~Working~~ Gas propulsion System

→ It supplies clean and dry gas (air, nitrogen or CO_2) to propel the abrasive particles

→ The gas may be supplied either by a compressor or a cylinder

→ In case of a compressor, air filter cum drier should be used to avoid water or oil contamination of the abrasive powder.

→ The gas should be non toxic, cheap and easily available.

→ It should not excessively spread when discharged from nozzle into atmosphere

Working:-

The above figure shows a schematic diagram of working of the process.

→ The filtered gas supplied under a pressure of 2 to 8 kgf/cm^2 to the mixing chamber containing the abrasive power and vibrating at 50 Hz entrains the abrasive particles and is then passed into a connecting hose

→ This abrasive and gas mixture emerge from a small nozzle mounted on a fixture at high velocity ranging from 150 to 300 m/min.

→ The abrasive powder feed rate is controlled by the amplitude of vibration of the mixing chamber.

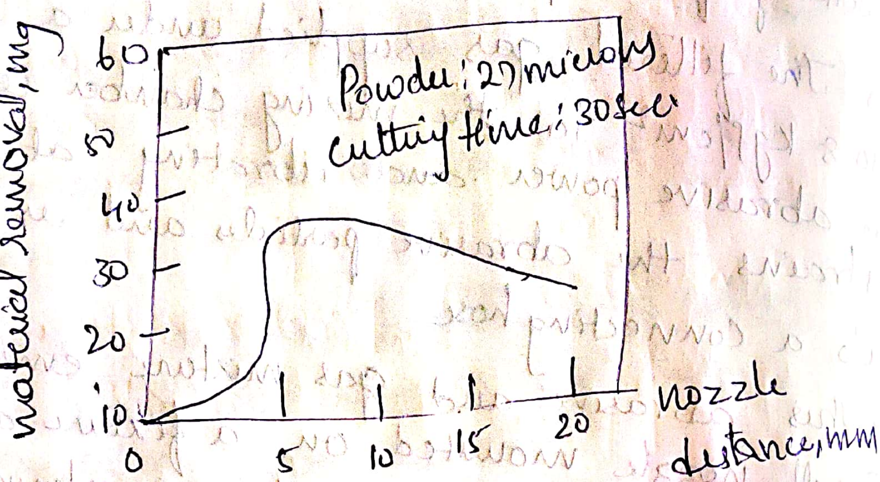
→ A pressure regulator controls the gas flow and pressure

→ To control the size and shape of the cut either the w/p or the nozzle is moved by cams, pantographs or other sustainable mechanism

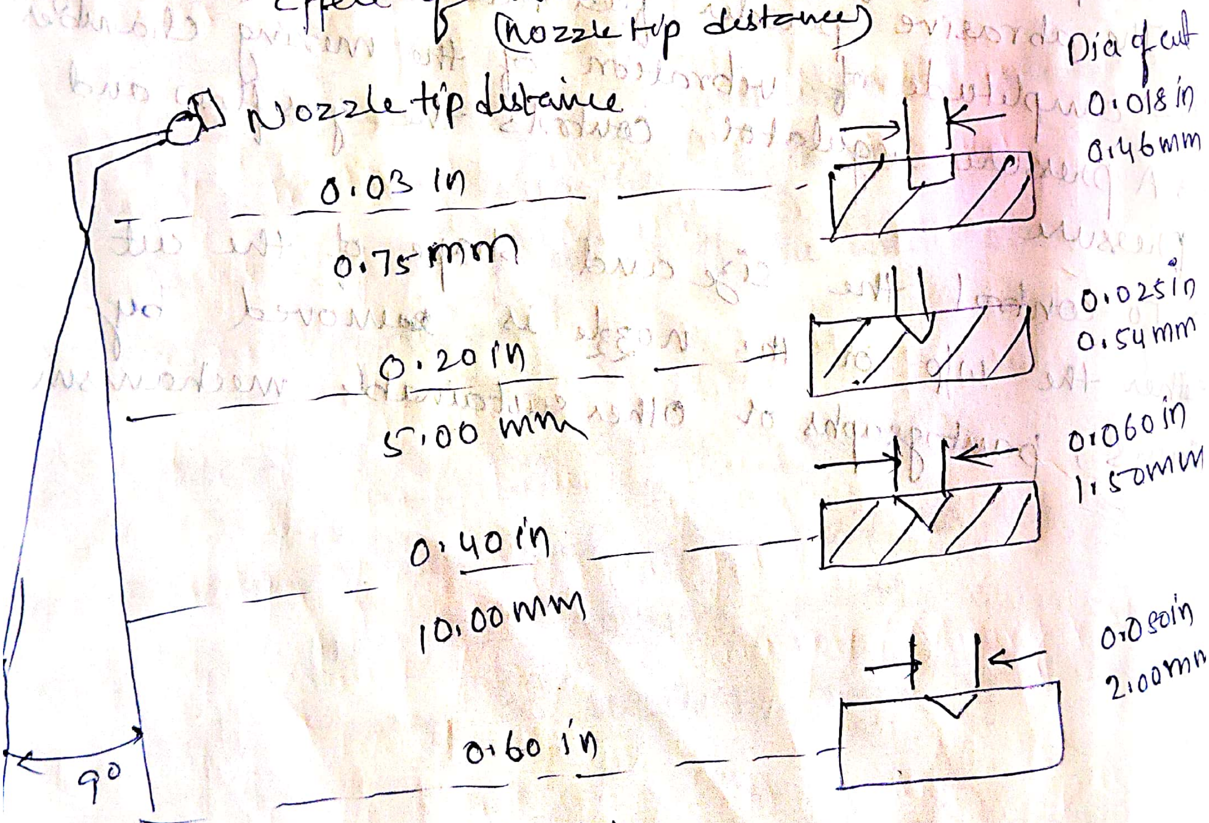
Material Removal Rate

→ The material is removed from w/p due to impact erosion of the high velocity particles.

→ The kinetic Energy of the particle is utilised to cause the microidentation in the work material and the material removal is a measure of theidentation.



Effect of NTD on Material Removal (nozzle tip distance)



Effect of NTD on machining accuracy

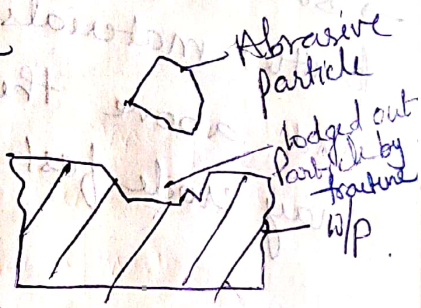
The model is based on the following assumptions

1. The abrasive particles are considered to be rigid and spherical bodies of diameter equal to the avg. grit size.
2. In case of a ductile work material, the material removal is equal to the volume of the indentation.

→ In case of a brittle work material, the volume of material is hemispherical whose diameter is equal to the chord length of indentation.

Mechanism of Metal Removal :-

When the abrasive particles impinge on the w/p or work surface at a high velocity, the impact of the particles causes brittle fracture at the places where the particles hit and the following gas or air carries away the dislodged small w/p particles.



The mathematical model of the material removal rate is based on the following assumptions

1) The abrasive particles are considered to be rigid and spherical bodies of equal diameter to the average grit size.
2) The material removed is equal to the volume of indentation in the case of a ductile work material.

It is equal to the chord length of indentation and is hemispherical in shape in the case of brittle material

$$MRR \text{ (for brittle material)} = 1.04\left[MV^{3/2}/\rho^{1/4}H^{3/4}\right]$$

$$MRR \text{ (for ductile material)} = 0.5\left[MV^{2}/H\right]$$

Where M is the abrasive mass flow rate
V is the impact velocity
P is the density of the particles,
H is material hardness of the w/p.

→ The above equation show that the velocity effects play a dominant role compared to the mass flow rate on MRR.

→ Under low velocity conditions ductile materis show lower material removal rate.

→ But at certain velocity V both (ductile & brittle) materials may exhibit similar MRR and above this velocity the ductile material may erode fast.

Process Variables of AJM

The process variables that influences the rate of material removal (MRR) and accuracy of machining in AJM are

1) carrier gas
2) Type of Abrasive
3) size of the abrasive grain
4) velocity of the abrasive jet
5) Unit volume of the carrier gas (Mixing ratio)
6) work material
7) Stand off distance (SOD) or Nozzle tip distance (NTD)
8) Nozzle design

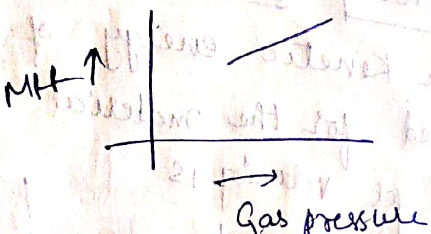
Scanned with OKEN Scanner

9) Shape of cut
10) Accuracy and Surface finish

1) Carrier gas :-
(write gas propulsion system theory)

~~2) Types of abrasives~~

The AJM Units normally operate at a pressure of 0.2 N/mm^2 To 1N/mm^2 depending upon the type of work performed
A high pressure results in rapid MRR where as a low pressure gives slow MRR.



2) Types of abrasives :-
→ The choice of abrasive depends on the type of machining operation like roughing, finishing etc, workmateri-al and cost.
→ The abrasive should be sharp, irregular in shape and be fine enough to remain suspended in the carrier gas and should also have excellent flow characterstics.
(Write Abrasives theory as continuation)

3) Size of the abrasive grain :-
→ The abrasives are available in many sizes ranging from 10μ to 50μ.
→ The best cutting have been obtained if the size of the bulk from 15μ to 40μ.
→ Fine grains are less irregular in shape and posses lesser cutting ability. They are used for polishing,

For fine deburring and cleaning operations.

→ Too fine a powder may tend to cake in the abrasive storage tank and hence reduce the rate of flow which in turn effects the MRR.

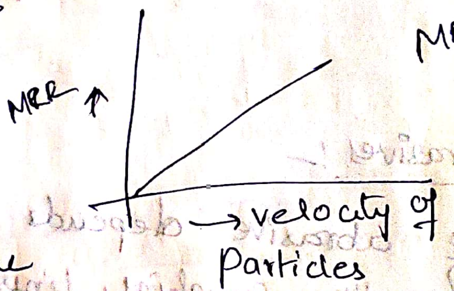
→ Over size particles also effect the MRR by plugging the orifice and reduce the velocity of the jet by means of its weight

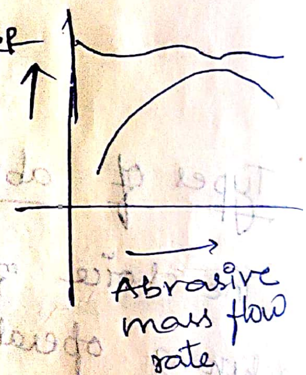
→ Coarse grains are normally recommended for cutting and peening operations

4) <u>Velocity of the abrasive jet</u> :-

→ The Kinetic energy of the abrasive jets is utilized for the material removal by erosion.

→ The jet velocity is a function of nozzle pressure, nozzle design, abrasive grain size and the mean number of the abrasives per unit volume of the carrier gas,





→ Required mini velocity for machining a particular w/p material with a particle abrasive.

→ The velocity of the abrasive jet ranges from 15 to 335 m/s

→ A high velocity obviously causes high MRR. even if the mass flow rate of the abrasive jet is kept constant.

5) <u>Mixing ration</u> :-

It is denoted as M

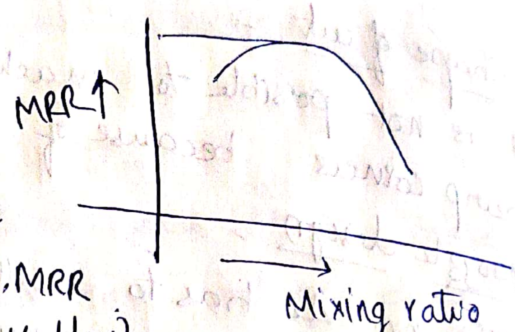
$$M = \frac{\text{Volume flow rate of abrasive per unit time}}{\text{Volume flow rate of the carrier gas per unit time}}$$

→ A large value of M results in higher rate of material removal upto a certain limit and then it gets reduced because a large abrasive flow rate decreases the jet velocity

→ which is responsible for causing the impact of the abrasive on to the w/p material.

and also it presents the problem of clogging the nozzle

→ Thus for a given condition there is an optimum mixing ratio that results in a max. MRR



→ But when the abrasive mass flow rate increases the MRR also increases.

b) Stand off distance:-

→ It is defined as the distance b/w the face of the nozzle and the working surface of the w/p material.

→ It is not only affects the MRR but also the shape and size of the cut or cavity produced

→ The MRR initially increases, then it is stable for some distance and after a particular distance it ↓ because of as the SOD ↑, it results in the flaring up of the jet in the atmosphere with a reduced jet velocity

→ Lesser material removal rate at low SOD is due to the reduction of nozzle pressure with decreasing distance.

→ SOD normally maintained b/w 0.25 mm to 15 mm

7) W/p material:-

It is best suited for machining hard, brittle and heat sensitive metals, alloys and non metallic materials like quartz, germanium, silicon, glass, ceramics etc.

8) Shape of cut :-

It is not possible to machine or cut parts with sharp corners because of stray cutting

9) Nozzle design :-

The nozzle has to withstand the erosive action of abrasive particles & must be made of a material which offers high resistance to wear.

9) Accuracy and s/finish :-

→ The control of the various parameters results in a tolerance in the region of ±0.05mm

→ accuracy of ±0.1mm.

→ The surface finish ranges from 0.4-1.2mm in most of the applications.

Advantages:-

1) Ability to cut fragile, brittle, hard and heat sensitive materials without damage.

2) Ability to cut intricate hole shapes in the materials of any hardness and brittleness.

3) No heat is generated

4) Very low capital cost

5) No vibrations

6) The energy transfer media (water) is cheap, non toxic and easy to dispose off.

7) Intricate contours can be cut

8) The system has no moving parts, its operating & maintenance costs are low & the process is very sa

Disadvantages:-

1) Low material removal rate
2) Due to stray cutting accuracy is affected
3) Particles can imbed in w/p
4) Abrasive powder cannot be reused.
5) Requires a seperate dust collecting system.

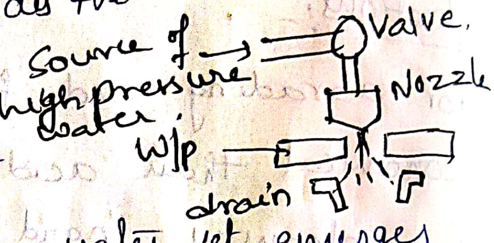
Applications:-

1) For abrading and frosting glass. It is more economical than acid etching and grinding
2) for cleaning hard surfaces, safe removal of smears on ceramics, oxides on metals, resistive coating etc.
3) Delicate cleaning such as removal of smudges from antique documents
4) Machining semiconductors such as germanium, gallium etc.
5) For drilling holes of different shapes & cutting fine lines on surfaces and thin sections.
6) Used for deburring, scribbing, grooving, polishing.

Water jet Machining.

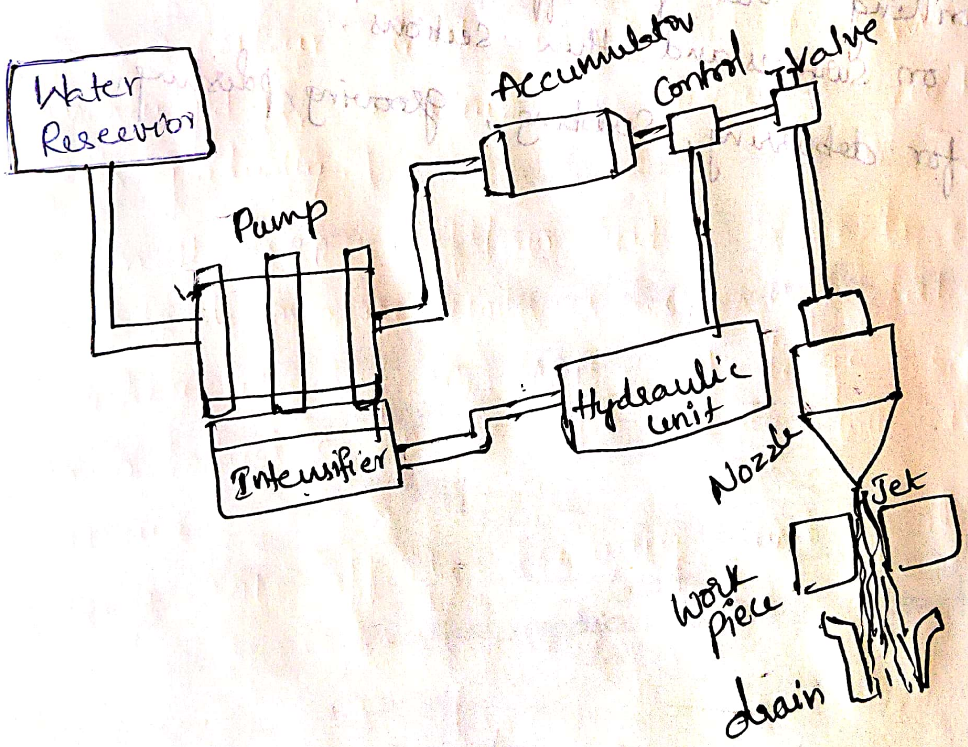
Introduction

The key element in WJM is a jet of water. This employs a fine, high pressure (1500-4000 MN/cm²), high velocity (upto twice the speed of sound) jet of water, which when bombarded on the w/p erodes the material.



Operating principle of WJM :-

When the high pressure water jet emerges out of the nozzle, it attains large kinetic energy. When this high velocity jet strikes the workpiece, its kinetic energy is converted into pressure energy inducing high stresses in the work material. When the induced stress exceeds the ultimate shear stress of the material, rupture takes place



Schematic diagram of WJM

Equipment

1) Intensifier
2) Accumulator.
3) Hydraulic pump
4) Nozzle.

Working

→ The pumping unit or intensifier to raise the pressure of water.
→ pressures normally used in the System are in the range of 1500 to 4000 N/mm².
→ from the pump, the water goes to an accumulator.
→ The accumulator helps in eliminating pulsation and also acts as an energy reservoir since the cutting action may not be continuous.
→ from the accumulator the water is lead to the nozzle through a high pressure thick tube which may be carbon Steel jacketed stainless steel tube.
→ The material of the nozzle may be sintered diamond, sapphire or tungesten carbide.
→ The exit dia of the nozzle is in the range of 0.05 to 0.35 mm.
→ Thin jets of high pressure and high velocity have been used to cut materials such as wood, coal, textiles, rubber, rocks, concerete and leather.

Process parameters of WJM :-

for successful utilisation of WJM process, it is necessary to analyse the following process criteria

1) Material Removal rate (MRR)
2) Geometry & surface finish of w/p
3) Wear rate of the nozzle.

The process criteria are influenced by various process parameters.

1) MRR depends on the reactive force F of the jet

Reactive force = Mass flow rate (m) × Jet velocity(v)

~~Base~~ ~~MRR~~.

2) MRR influenced by SOD (stand off distance)

→ MRR increases with the increase of SOD up to a certain limit after which it remains unchanged for a certain tip distances and then falls gradually.

→ Small MRR at low SOD is due to a reduction in nozzle pressure with decreasing distance.

→ where as drop in MRR at large SOD is due to a reduction in the jet velocity with increasing distance.

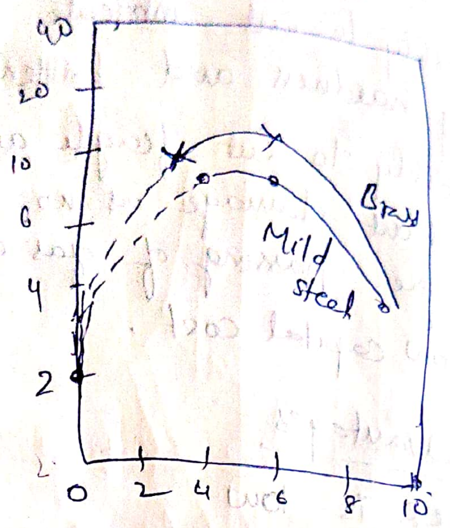
→ large SOD affects accuracy and quality

3) MRR effect due to feed rate

→ The removal rate increases with feed rate and reaches peak value and then the tendency is to fall

→ It is due to the erosion and removal process lagging behind the impacting phenomenon.

→ The depth of groove has also been reported ~~to~~ to decrease with increase in feed rate



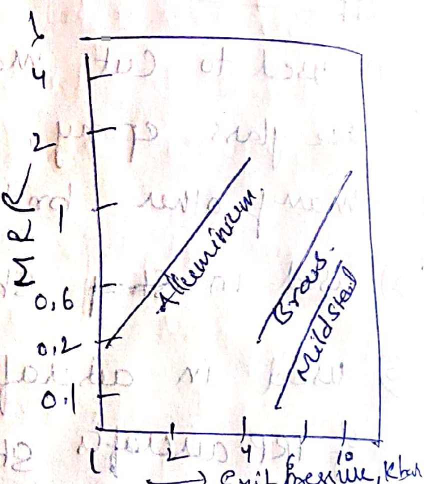
MRR at different feed rates

4) Effect of exit pressure

→ The liquid jet represent a fairly effective cutting tool for some non-metallic materials

→ There is a threshold pressure below which little or no cutting can be achieved for example, mild steel requires about 6kbar (6120 kg/cm²) pressure to produce any effect.

→ Variation of MRR with P indicating that MRR varies approximately proportionately with $P^{3/2}$ to the working power and consequently of jet.



MRR at different exit pressures.

Advantages.

1) Ability to cut intricate hole shapes in materials of any hardness and brittleness
2) Ability to cut fragile and heat sensitive materials without damage as no heat is generated due to the passing of gas or air
3) Low capital cost.

Disadvantages

1) MRR is low
2) The Machining accuracy is poor.
3) Nozzle wear rate is high
4) Additional cleaning of the work surface may occur as there is a possibility of sticking abrasive grains in softer materials.

Applications:-

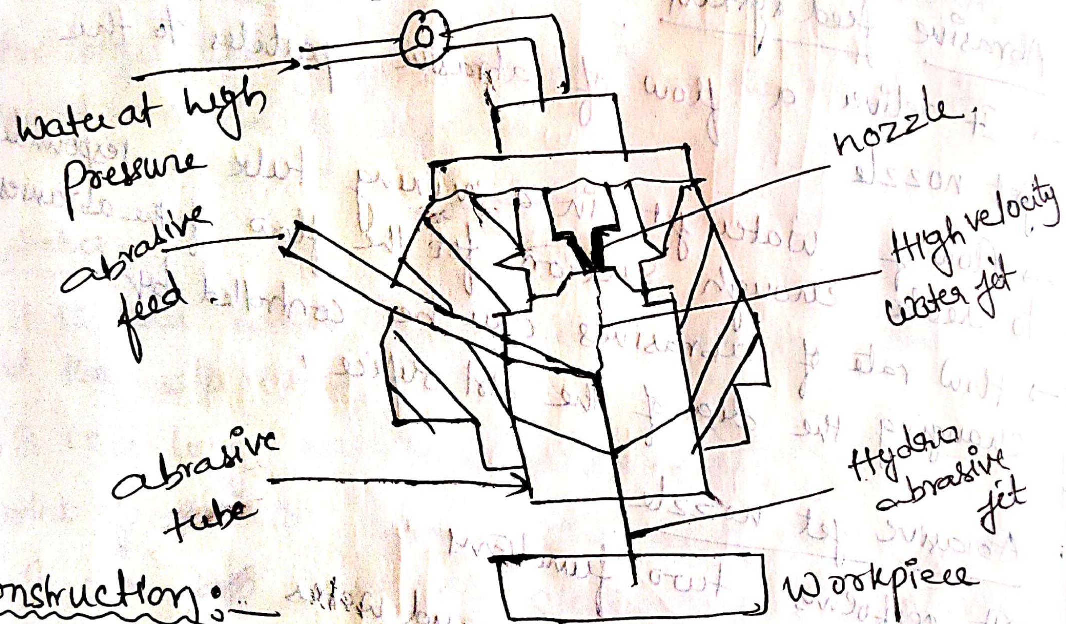
1) used to cut many non metallic materials like glass epoxy, graphite, boron, leather and many other brittle materials
2) used in ~~Shop~~ Shoe making industry
3) used in aircraft industries to profile cutting of FRP aircrafts structures even glass windows

Abrasive Water jet Machining

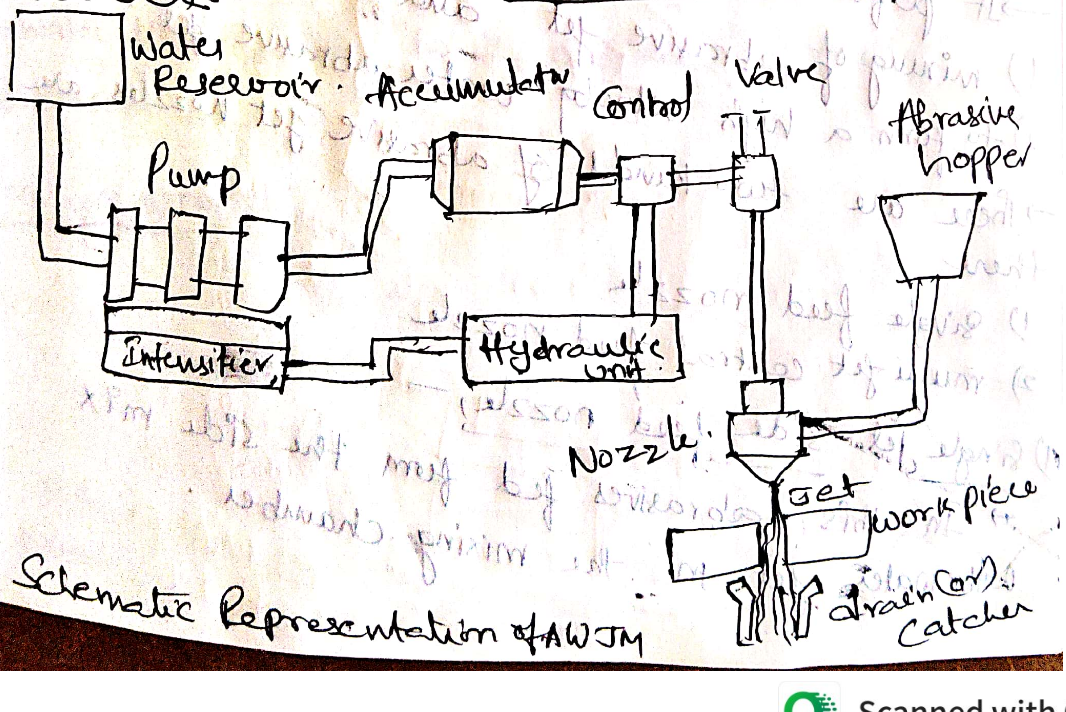
In this process abrasives are used for machining of materials. These processes offer advantage of cutting electrically non conductive as well as difficult to machine materials comparatively more rapidly and efficiently than other processes.

Principle of AWJM

In this process a high stream of abrasive jet particles is mixed with pressurized water and injected through nozzle on the workpiece.



Construction:



Schematic Representation of AWJM

Equipment

1) pumping system
2) abrasive feed system
3) abrasive jet nozzle
4) Catcher.

Pumping system.

It produces a high velocity water jet by pressurizing water to as high as 415 mpa by means of an intensifier.

Abrasive feed system.

→ It deliver a flow of abrasive particles to the jet nozzle.
→ Flow of water jet in a mixing tube is responsible to create enough suction for the flow of the abrasives
→ Flow rate of abrasives can be controlled by changing the dia of the ctrl orifice.

Abrasive jet nozzle

→ It performs two functions
1) mixing of abrasive jet and water
2) to form a high velocity water abrasive jet
→ There are two kinds of abrasive jet nozzles are there
1) single feed nozzle
2) multi jet central feed nozzle

1) Single jet side feed nozzle,—
→ In this, abrasives fed from the side mix with water jet in the mixing chamber.

→ The nozzle is less expensive.
→ It has rapid wear at the exit part of the nozzle.

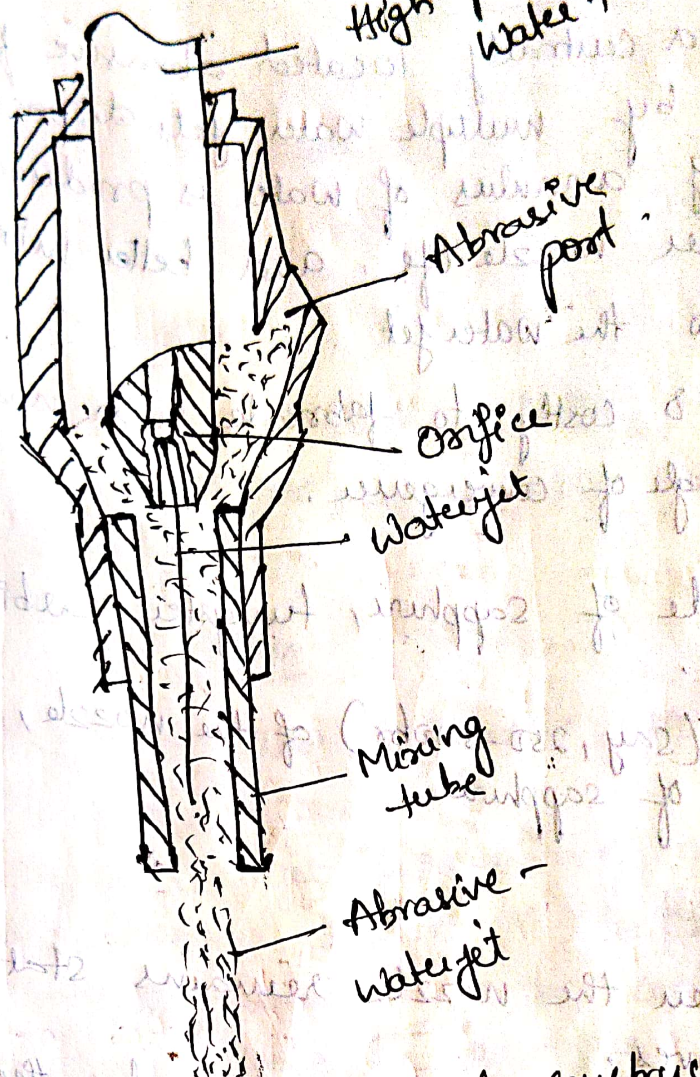
Multiple jet central feed nozzle
→ It consists of a centrally located abrasive feed system surrounded by multiple water jets disposed such as converging annulus of water is produced
→ It gives higher nozzle life. and better mixing of abrasives into the water jet
→ It is difficult & costly to fabricate such nozzles becoz of the angle of convergence.

* Nozzle is made of sapphire, tungsten carbide or boron carbide.
* For longer life (say, 250-500hr) of the nozzle, it should be made of sapphire.

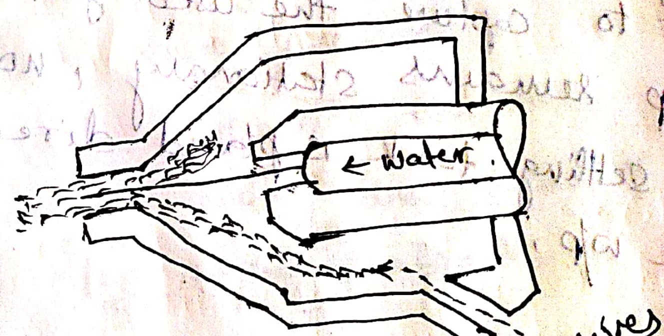
Catcher :-
→ It is used when the nozzle remains stationary and the w/p moves.
→ It is a long narrow tube placed under the point of cut to capture the used jet.
→ In case w/p remains stationary, nozzle moves a water filled settling tank is placed directly underneath the w/p.

Working of AWJM :-

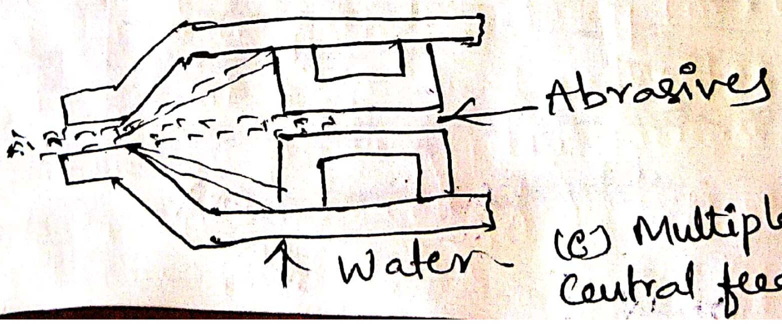
Abrasive water jet nozzle



(a) details of construction



(b) Single jet side feed nozzle



(c) Multiple jets Central feed nozzle

→ Water is sourced from the reservoir and distributed throughout the system, beginning ~~with the~~ journey from reservoir to the drainage system.

→ Initially, the water undergoes pressurisation in the hydraulic intensifier before being directed to the accumulator for temporary storage.

→ Control valves with in the system manage water pressure and control its directional flow.

→ Subsequently, abrasive particles are introduced in to the mixing chamber, forming a mixture with water in the ratio of 30% Abrasive particles to 70% water.

→ When these high velocity abrasive particles impact hard workpieces, they can induce plastic deformation and fracture in the hard materials.

Process Variables :-

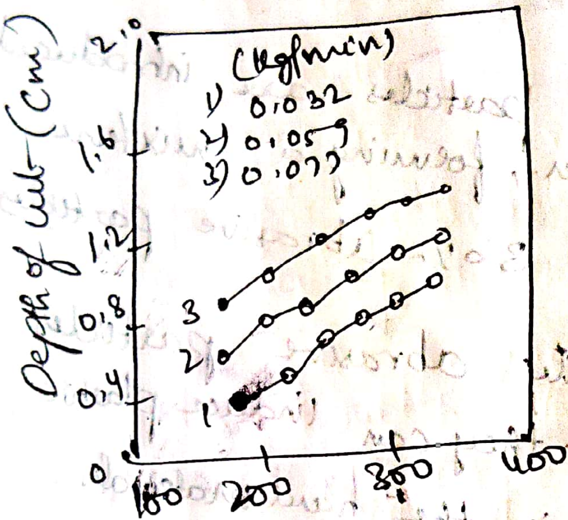
Parameters which effect performance of AWJM process are

- Water (flow rate & pressure)
- abrasives (type, size and flow rate)
- Water nozzle and abrasive jet nozzle (design)
- Cutting parameters (feed rate, stand off distance)
- ~~water~~ Work material

1) Water

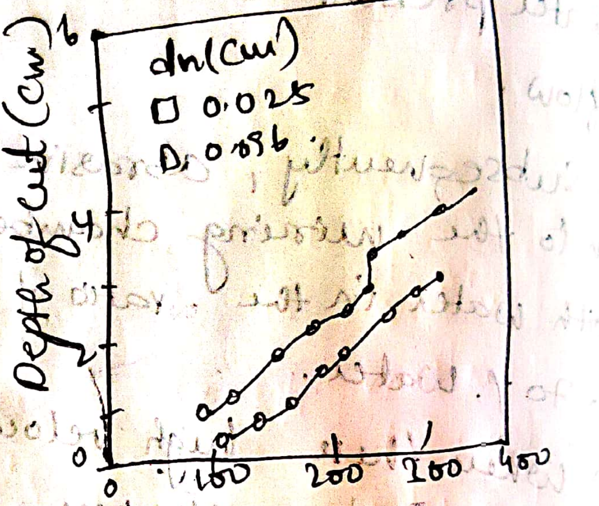
Water jet pressure during slotting

Relations b/w pressure and depth of cut for different abrasive flow rates and nozzle diameter are shown in fig.



Pressure (Mpa)

In mild steel w/p for various abrasive flow rates



Water jet pressure (Mpa) for various nozzle diameters (dn)

→ There is a minimum pressure (i.e., critical pressure or threshold pressure, Pc) below which no machining would take place.

→ The critical pressure (Pc) exists because a minimum abrasive particle velocity (or KE) is required to cut a particular material.

→ A increase in pressure also increases rate of nozzle wear and cost of pump maintenance and lower volumetric efficiency.

Water flow rate :-

→ Water is used as a propelling fluid which enables high abrasive flow rates (0.1-5 kg/min) to be achieved, and makes it possible to accelerate abrasives to high velocities (over 300 m/s).

→ Water flow rate (Q) is proportional to square root of pressure ($Q \propto \sqrt{P}$) and square of diameter of the nozzle ($Q \propto d_n^2$)

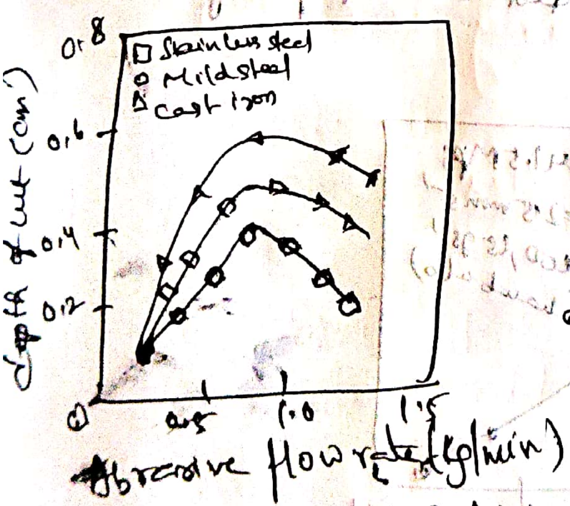
· Abrasives

1) Abrasive flow rate

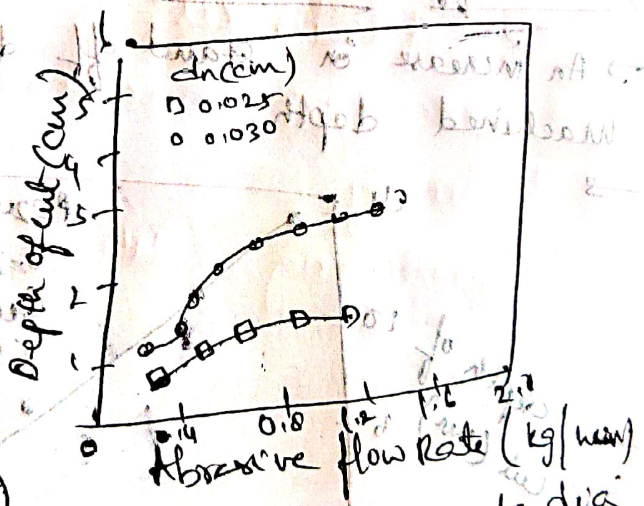
Machined depth (depth of cut) is proportional to the abrasive flow rate ($\dot{m}$) and square of particle velocity (V_p).

→ An increase in abrasive flow rate beyond the critical value (m_c) would reduce machined depth.

→ increase in abrasive flow rate enhances wear rate of mixing nozzles and reduces mixing effiency inside AWJ nozzle.



Various work materials using Garnet as Abrasive material



for various nozzle dia using aluminium as work material.

Abrasive particle size:-

→ Commonly used abrasive particle size ranges from 100-150 grit.

→ There is an optimum particular size for a particular w/p material and also for particular nozzle mixing chamber.

→ Mesh size 60 is more effective for relatively shallow depth of cut.

Abrasive materials:-

→ Garnet, Silica and Silicon carbide are commonly used abrasives

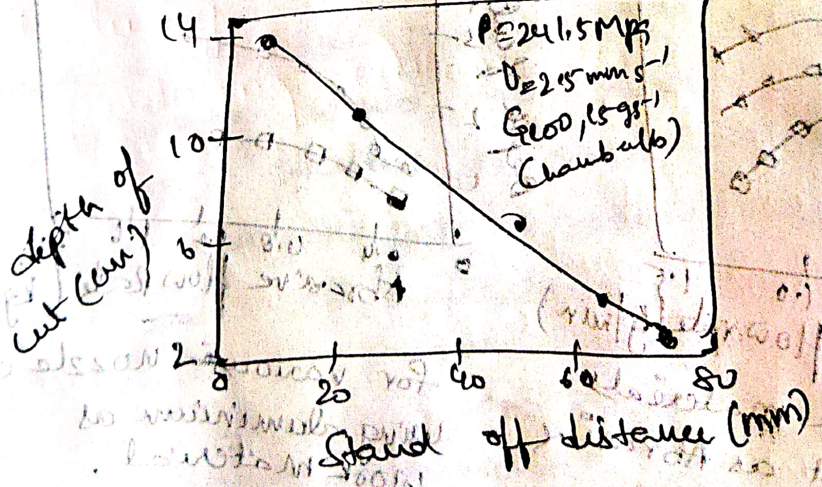
→ Type of abrasive to be used is determined after knowing hardness of the w/p material.

→ Higher the hardness of the w/p material, harder should be the abrasives to be used.

→ Complete recycling of the abrasives is not possible.

4) Stand off distance

→ An increase on stand-off distance rapidly decreases machined depth.

→ 

→ This has been explained by arguing that the liquid phase of the jet breaks up into droplets resulting in free abrasive particles.
→ These free abrasive particles rebound, upon impact that leads to a shallower penetration.
→ There is an upper value of SOD beyond which the process will no longer do the cutting.

Mechanics of metal Removal

→ It is used to cut even thick materials (200mm) with a narrow kerf.
→ width of the kerf depends upon the workpiece hardness.
→ For hard materials, the kerf narrows down towards the bottom while the reverse of is true in case of a soft materials.
→ In case of glass, stray cutting may result in frosting.

Advantages

→ cutting electrically non conductive as well as difficult to machine materials.
→ Dust free
→ High cutting speed
→ multidirectional cutting capacity
→ No fire hazards
→ No thermal deformation stresses.
→ High quality of machined edge.
→ Recycling of abrasive particles
→ low power requirements

Disadvantages

→ Higher operating costs due to abrasive material usage.

→ produces abrasive waste that require proper disposal

→ Requires regular maintance of abrasive supply and removal systems.

→ Initial equipment cost can be high

Applications

→ cutting metals (eg. steel, aluminium, titanium

→ precision cutting of ceramics & glass

→ shaping and profiling composite mater

→ cutting stone, marble and granite

→ Trimming and shaping aerospace components

→ creating intricate patterns.

→ Cutting automotive parts like gears and disc brakes

→ precision machining in aerospace industry

→ producing custom tiles