UNIT- 5

UNCONVENTIONAL MACHINING PROCESSES

INTRODUCTION :-

* Conventional Machining methods involves removal of metal by Compression shear chip formation, in which stress is beyond the yield point. and requires harder tool Material than workpiece material. But for those materials which are harder than tool material, conventional machining is impossible.
* The materials (Alloys with alloy elements as tungsten, Mo, etc.) which have low machinability are become difficult for conventional Methods and for that two approaches are there:
  (i) Modification of Conventional Methods (Eg: hot Machining)
  (ii) Development of new methods which are generally non-mechanical and don't produce chips, no direct contact b/w tool and workpiece therefore tool need not to be harder than W/p. This newer methods are known as "Unconventional Methods/ Or Non-Traditional".
* Un Conventional Machining processes refer to processes in which non-traditional energy ~~transfer~~ transfer are involved for material removal.
  Eg: Machining a complicated turbine made of Superalloys.

Need and Benefits of Unconventional Machining Processes :-

These process are depend on a number of factors as vaporization of metal, electrolytic displacement, chemical reaction and Mechanical erosion. The main reasons for using Unconventional methods, are :-

- **High Strength alloys :**
  When the hardness of work material is more than tool material and necessary to machining on hardened material then electro-chemical processes are used.

- **Complex Surfaces:-**
  When very complex surface in 3-D need to be produced (eg: dies & mould) it is where w/p material is hardened than steel tool, would be difficult by conventional process. Unconventional process to be required.
- **Higher accuracy & Surface finish:-**
  Higher accuracy and surface finish of desire in hard w/p required conventional methods to be done very slowly as adding. no. of finishing processes, making process very slow & uneconomical.
- **Difficult Geometries:-**
  Sometimes, it is required to produce difficult geometries such as long holes with high l/d ratio that of 100 or very small size holes as less than 0.1mm in diam^n which are difficult to be produced by conventional methods.
- **Automation:-**
  In NCM (Non-conventional machining), no contact b/w w/p & Tool due to which using of Numerically Controlled System more efficient machining is performed with low tool consumption.

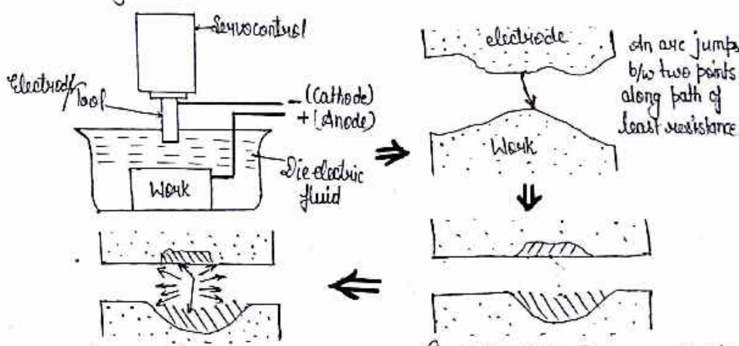
→ **Classification:-**

NCM methods are classified according to main energy source used:-

Unconventional / NCM Machining
- Thermo-electric Energy method (heat produce by arc)
  - EDM
  - LBM
  - EBM
  - PAM
- Electro-chemical Energy (involves electrolytic dissolu^n)
  - ECM
- Chemical Energy
  - CM (Chemical Machining)
- Mechanical Energy (erosion)
  - AJM
  - USM

* Electrical Discharge Machining [EDM]

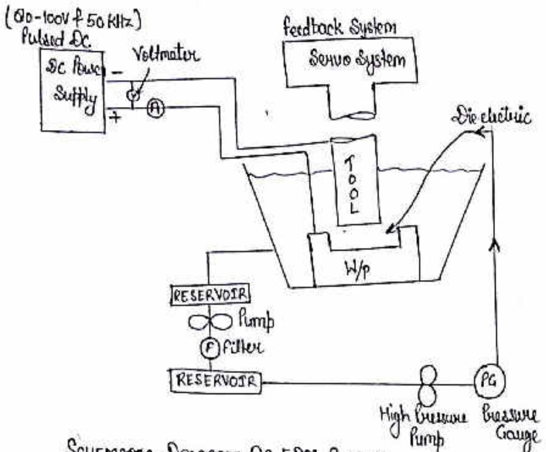
- **Introduction:-**
  - EDM is a thermoelectric process in which heat energy of a spark is used to remove material by a controlled erosion through a series of electric spark. The w/p and tool should be made of electrically conductive materials. The cavity produced in w/p is approximately the replica of tool.
  - The rate of metal removal and resulting surface finish can be controlled by proper variation in energy & duration of spark discharge in presence



The metal if dielectric fluid are partly vaporized, causing sudden expansion.

The energy of arc is so concentrated that it causes the electrode & work to melt But electrode is chosen so that it melts less.

- **Working Principle:-**
  - ↳ When a discharge takes place b/w two points of the anode and cathode, the intense heat generated near the zone melts and evaporates the materials in the sparking zone.
  - ↳ For improving the effectiveness, the workpiece & tool are submerged in a dielectric fluid (hydrocarbon or mineral oils). It has been observed



SCHEMATIC DIAGRAM OF EDM SYSTEM

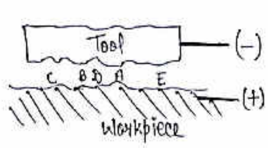
that if both electrodes are made of same material, the electrode connected to '+'ve terminal generally erodes at a faster rate. For this reason, w/p is normally made the anode.

↳ A suitable gap, (Intermolecular gap/spark gap) is maintained b/w tool & (0.025-0.05 mm) W/p surfaces which is controlled by Servomotor control unit (gap is sensed through average voltage across it and compared with preset value).

↳ The sparks are made to discharge at a high frequency (5 kHz) with a suitable source. Since spark occurs at the spot where the tool and w/p surfaces are the closest and since spark changes after each spark, the spark travells all over the surface. This results in a uniform material removal all over the surface & finally work face conforms to the tool surfaces. Thus tool produces the required impression in W/p.

NOTE :- Peak Voltage across the gap is kept in range of 30-250 Volts. And Material removal rate (MRR) is upto 300 mm^3/min
- Tool is generally made of Cu alloy or Brass.

➔ MECHANISM OF EDM :-



↳ Asperities and irregularities are always present in material surfaces. In EDM, gap b/w W/p and tool varies and it is minimum at point A.

↳ When a suitable voltage is built up across W/p & Tool, an electrostatic field of sufficient strength is developed, causing emission of electrons from cathode at A.

↳ These electrons accelerates towards the anode, after gaining a velocity electrons collide with molecules of dielectric fluid and break them into e^- and positive ions. Ultimately a narrow column of ionized dielectric fluid molecules is established at A (Conductivity of ionized column is very high and seens as a spark).

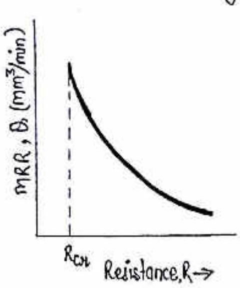
↳ As result of this spark, a compression shock wave is generated & very very high temp is established (10,000-12,000°C) which cause melting & vaporization of electrode materials by a mechanical blast, resulting in small craters on both surfaces at A and gap b/w electrods at A is increased.

↳ As this cycle is repeated at next nearest points and resulting uniform machining at all over surfaces.

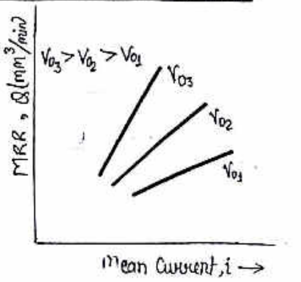
✱ MRR from cathode is comparatively less than anode due to following reasons :-

1. Electron stream strikes the anode is much more than that due to stream of positive ions strikes on cathode.
2. The hydrocarbons of dielectric fluid creates a thin film of carbon on cathode.
3. A compressive force is developed on cathode surface. Therefore tool is normally connected to negative terminal of DC source.

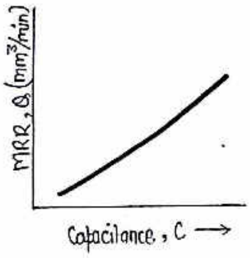
General characteristics of the Material removal rate (MRR):-



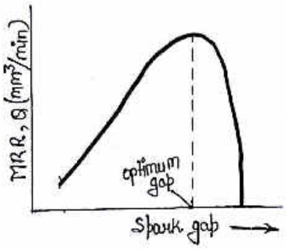
[i] Variation with resistance



[ii] Variation with mean Current



[iii] Variation with capacitance



[iv] Variation with Spark gap

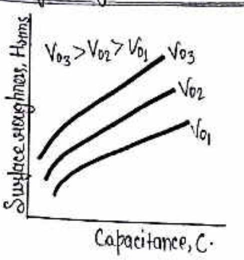
[i] As resistance b/w spark gap is increase, MRR is decreased but at below the Critical resistance (R_{cr}), burning is started instead of spark.

[ii] As voltage b/w gap is increased, current (i) is increased due to stream of e^-, therefore MRR increased.

[iii] As value of Capacitance is increase, stored charges, which tends to spark, is increased so MRR is also increased.

[iv] As spark gap is increased, ability of e^- acceleration is increases that is why MRR is increased but after a value of gap e^- loose energy in dissolving dielectric fluid molecules & MRR is decreased. Also at min value of gap e^- generation principle doesn't exist so MRR is decreased.

* Surface finish and dimensional/Machining Accuracy :-



- Since material removal in EDM is achieved through the formation of craters due to sparks, it is obvious, that large crater sizes (depth) result in a rough surface.
- So Crater size controls the quality of surface. H_{rms} (root mean square value of surface roughness) depends on C & V_o.

NOTE:- During EDM operation, electrode (tool) gets eroded due to sparking action. Material of Tool should have good wear characteristic that difficult to Machine and for this, principal materials used which as graphite which goes directly to vapour phase without melting.

$$\text{* Wear Ratio} = \frac{\text{Material removed from W/P}}{\text{Material removed from tool.}}$$

ELECTRODE MATERIALS:-

Selection of electrode material depends on the :-

- Material removal rate
- Ease of shaping the electrode
- Wear Ratio
- Cost.

* Various materials of electrode are used :-
  - Graphite, Tungsten
  - Copper, Copper Tungsten
  - Brass, Zinc alloys etc.

DIELECTRIC FLUIDS :-

Basic requirements for Ideal dielectric fluids are :-

- low viscosity
- low Cost
- Absence of Toxic vapours.
- Chemical neutrality.

- The most commonly used fluid is hydrocarbon (Petroleum) oil. Kerosene, liquid Paraffin & silicon oils are used as dielectric fluids.

Advantages :-

- EDM is based on melting temp^{re}, not hardness so very hard materials can be machined. No effect on toughness & brittleness.
- Complicated shapes can be produced.
- It reduces fixtures & tooling cost due to no contact b/w tool & w/p.
- Production rate is comparable with conventional methods as can be automated easily.
- Higher accuracy and surface finish can be produced.
- Doesn't produce any chips or burrs on W/p surface.

Disadvantages :-

- Higher specific energy consumption (50 times of conventional machining)
- MRR is low in condition of not possibility of force circulation of dielectric fluid.
- For larger MRR, surface tends to be rough.
- Not applicable to non conducting materials.
- High current can lead to premature fatigue failure.
- Perfect square corners can't be made.

Applications :-

- Making stamping tools, wire drawing & Extrusion dies, forging dies, etc.
- Machining of refractory metals, hard carbids used in aero-space industries.
- Narrow slot can be made of Turbine blades.
- Making orifices in nozzles of diesel fuel injection valves, aircraft engines etc.

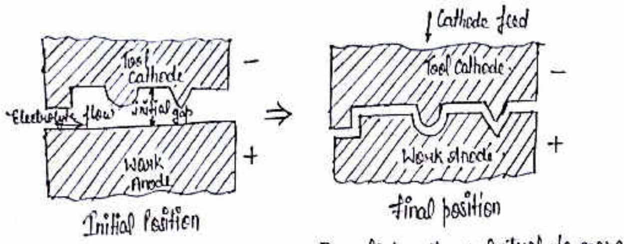
*** SUMMARY OF EDM CHARACTERISTICS :-**

Mechanism of material removal	⇒ Melting & evaporation aided by cavitation.
Medium	⇒ Dielectric fluid
Tool Materials	⇒ Cu, Brass, Cu-W alloy, Ag-W alloy, graphite.
Wear ratio	⇒ 0.1 – 10
Gap (spark gap)	⇒ 10 – 125 μm
Max MRR	⇒ 5×10^3 mm^3/min
Specific power consumption	⇒ 1.8 W/mm^3/min.
Critical parameters	⇒ Voltage, C, spark gap, dielectric circulation, melting temp^{re}.
Material Application	⇒ All conductive metals & alloys.
Shape application	⇒ Blind complex cavities, micro holes, non-circular holes, narrow slots.
Limitations	⇒ High specific energy consumption, MRR is quite low, surface is rough for high MRR, Not applicable to non conductive materials.

ELECTRO-CHEMICAL MACHINING (ECM)

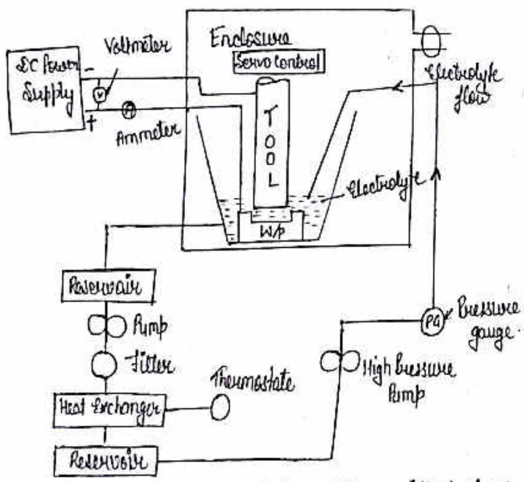
*** Introduction :-**

- ECM is the most potential Unconventional Machining process, may be considered as reverse electroplating to erode away the W/p material. It is based on principle of electrolysis. In a metal, electricity is conducted by free e⁻, but in electrolyte, conduction of electricity is achieved by movement of ions. Thus flow of current through electrolyte is always by movement of matter.
- The electrolyte principle use for electroplating which objective is to deposit metal on W/p But ECM, objective is to remove metal so W/p is connected by '+'ve terminal & tool connected to '–'ve terminal.



↳ Electrolyte acts as current carrier, high rate of electrolyte movement in gap washes metal ions away from W/P (Anode) before they have chance to plate onto the tool (Cathode). Thus dissolution rate is more where gap is less and vice versa as current density is inversely proportional to gap. Finally shape of tool is produced in job.

* Working Principle :-



↳ An electrolytic cell is created in electrolyte medium, with tool as cathode and W/p as anode. A high amperage & low voltage current is flow to dissolve the metal.

↳ The tool-to-work gap needs to be maintained at a very small value of order of 0.25mm for satisfactory MRR. Then electrolytes need to be pumped through this gap at high pressure ranging from 0.70-3.0MPa.

↳ In presence of current, on anode side (+ve) metal molecules ionized (loose e^-) and break free of W/p, and travel through electrolyte to cathode electrode (-ve, a surplus of e^-). Both ions form hydroxides, which are removed by centrifugal seperation.

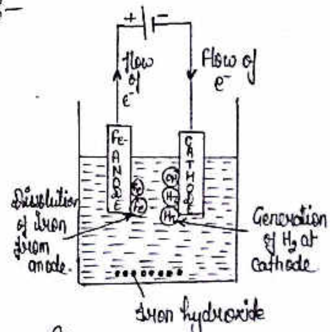
↳ This impurity is filtered before it is re-pumped into system. Also a large amount of heat is generated during electrolysis and needs to be cooled by heat exchanger. Process is recycled in constant gap. For maintaining Equilibrium gap, servo drive is provided.

↳ Finally, tool is given downward motion, work surface tends to take same shape as that of tool. Parallely H_2 gas is generated at cathode. No change in shape of electrode.

↳ In ECM, MRR is function of ion exchange rate, it is not affected by strength, hardness, or toughness of W/P (Conductive Materials).

* Electrochemistry of ECM Process :-

↳ When metallic body is submerged in an electrolyte, metallic atoms leave the body become ions and ions move to body become atom. This process goes continuously & equilibrium is maintained.



Principle of Electrolysis

↳ A potential difference exist b/w anode and cathode, there are number of possible reactions :-

- A reaction takes place at anode is dissolution of anode by electrolyte:

$$Fe \rightarrow Fe^{++} + 2e^-$$

- Similarly at cathode, Hydrogen gas released from water contains in electrolyte:

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$$

Scanned by CamScanner

- Iron and hydroxyl ions combine to form iron hydroxide:

$$Fe^{++} + 2OH^- \longrightarrow Fe(OH)_2$$

Net reaction can be as:

$$Fe + 2H_2O \longrightarrow Fe(OH)_2 + H_2$$

- It is further possible that iron hydroxide may further react with water and oxygen forming ferric hydroxide:

$$4Fe(OH)_2 + 2H_2O + O_2 \longrightarrow 4Fe(OH)_3 + H_2$$

↳ Net result is that iron gets dissolved from anode and form $Fe(OH)_3$ and H_2 gas as following observations.

- Metal is removed from W/p based on faraday's law which is will depend upon atomic weight, valency, current passed and time for which time is passed and on no other parameter.
- H_2 gas is evolved at cathode only, so no reaction takes place, shape of tool is unaffected.

NOTE :- Faraday's law :-

(i) Amount of chemical change produced by an electric current (amount of any material dissolved or deposited) is proportional to quantity of electricity passed.

(ii) Amount of different substances dissolved by same quantity of electricity are proportional to their chemical equivalent weights.

i.e.; $m \propto It\epsilon$

$m = F It\epsilon$

* $m = \frac{It\epsilon}{F}$

where m = weight (in gm.) of material dissolved.

I = Current (in Amp)

t = time (in sec.)

ϵ = gram equivalent weight of Material.

F = Faraday's Constant (96500 Coulombs).

*** Material Removal Rate of ECM :-**

According to faraday's law, weight of a material (in g) is.

$$m = \frac{It\epsilon}{F}$$

where $\epsilon = \frac{A}{Z}$ (gram equivalent weight of material)

A = Atomic weight of metal (in gram)

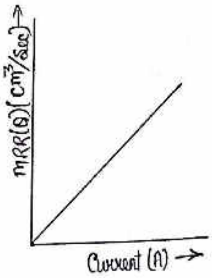
Z = Valency

Therefore Volumetric material removal rate (Q):

$$\boxed{Q = \frac{AI}{ZF\rho}} \; ; \text{cm}^3/\text{sec}$$

where ρ = density of metal (in g/cm³)

- As current b/w w/p and electrode is increased due to chemical reactions, the value of MRR is also increased.



*** Surface Finish :-**

↳ Surface finish in ECM process is very good. But due to flow separation or eddies formation there are uneven surfaces introduced. Also due to evolution of H_2 gas because when H_2 gas is involved near cathode, no reaction takes place and conductivity of electrolyte is reduced.

*** ELECTROLYTES :-**

↳ The main functions of an electrolyte in ECM are:-

- To create condition for anodic dissolution of W/p material
- To complete electric circuit and carry large current.
- To remove impurities of electro-chemical reactions from gap.
- To maintain constant temperature in machining region.

↳ Electrolyte should have high electrical conductivity & low viscosity to reduce power loss. It should have nontoxic and less corrosive to machine.

* Imp: As V↑ ⇒ Gap↓ ⇒ S.F↑, Electrolyte Concentraⁿ↓ ⇒ Gap↓ → S.F↑, Electrolyte Temp↑ → Conductivity ↑ → S.F↑.

↳ Most commonly used electrolytes in ECM are NaCl and Sodium Nitrate ($NaNO_3$)

Alloy	Electrolyte
• Iron based chloride	Soln in Water (mostly 20% NaCl
• Ni based	HCL or mixture of brine + H_2SO_4
• Cu-Cr-W based	NaCl.
• WC based	Strong alkaline soln.

* ECM Tools :-
↳ Selection of material of Electrode is based on :-
  - High electrical & thermal conductivity.
  - Good stiffness & Easy Machinability.
  - High corrosion resistance.

↳ Generally, Al, Cu, Brass, Ti, nickel alloy & stainless steel are used.

* **Advantages :-**
  - Complex 3-D Surfaces can be Machined accurately.
  - Since there are no cutter marks, surface finish is higher (25 μinch).
  - Tool wear is nil so large no. of product is produced per tool.
  - It does not thermally affect the W/p.

* Limitations :-
  - Use of Corrosive medium is difficult to handle.
  - Sharp edge and corners (<0.2mm radius) are difficult to produce.
  - Very expensive.

* Applications :-
  - Blind complex cavities.
  - Turbine wheels with integral blades.
  - Jet engine blade cooling holes.
  - Curved surfaces.

* Summary of ECM Characteristic :-

• Mechanics of Material removal	⇒ Electrolysis.
• Medium	⇒ Conducting electrolyte
• Tool Materials	⇒ Cu, Brass, Steels.
• Wear ratio	⇒ ∞
• Gap	⇒ 50-300 μm.
• Max. Material removal rate	⇒ 15×10^3 mm^3/min.
• Specific Power Consumption	⇒ 7 $W/mm^3/min$
• Critical Parameters	⇒ Voltage, current, feed rate, electrolyte, electrolyte conductivity
• Materials applications	⇒ All conducting metals & alloys.
• Shape Application	⇒ Complex Cavities, curved surfaces.
• Limitations	⇒ High specific Power consumption (150 times of conventional), not applicable to nonconducting materials, expensive machine.

LASER BEAM MACHINING [LBM]

* INTRODUCTION :-

↳ Laser beam machining is a thermoelectric process, in which a very strong monochromatic beam of light known as LASER (Light Amplification by stimulated emission of Radiation) is direct strike on target surface. Due to thermal energy of beam, material surface get heated and after Melting and vaporization required products are produce.

↳ In this process, vaccum is not necessary, it works in any condition of surrounding. The wavelength of beam is around 0.1-70μm which produced power of 20000 W.

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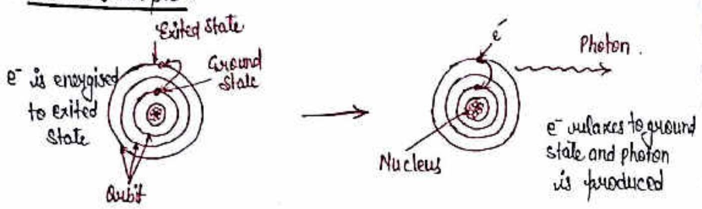
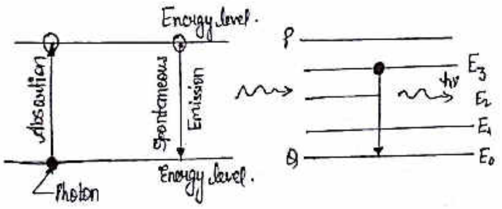
* Laser Principle :-



↳ Ground state e⁻ get some external energy source as flash, due to which they tried to jump in outer orbit. After reaching at outer orbit, no. of e⁻ in outer orbit is more, which is unnatural so every e⁻ are tried to get their original place for relax condition (equilibrium condⁿ) and released their energy in form of photon (radiations) and create a narrow laser beam.



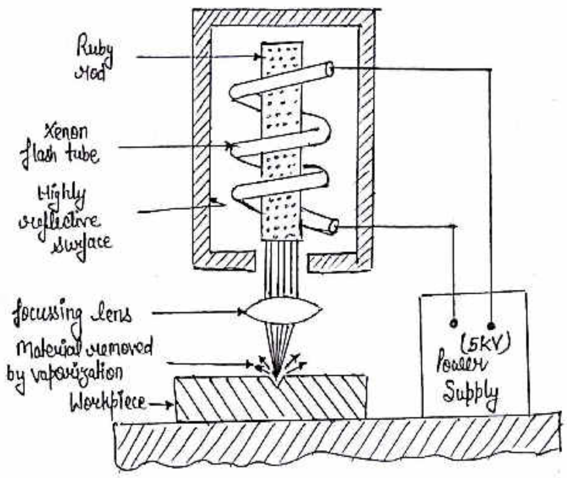
* Working Principle :-

↳ A coiled xenon flash tube is placed around the ruby rod, which is used as lasent medium. and internal surface of a container wall is made highly reflective so that maximum light falls on ruby rod for pumping operation (Pumping of e's)

↳ The capacitor is charged which is connected to coil and a very high voltage is applied to triggering electrode for initiation of flash.

↳ The emitted laser beam is focused by a lens system and focused beam strikes on w/p surface, removing a small portion of material by melting and vaporization. A very small fraction of molten metal is quickly vaporized so that a substantial mechanical impulse is generated, throwing out a large portion of liquid metal.

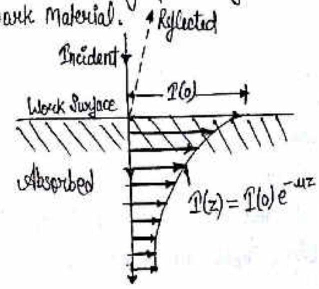
↳ The efficiency of the LBM process is very low about 0.3 – 0.5 %. Using a lens with a focal length of 25mm, the spot diameter becomes about 50 μm.



* Mechanics of LBM :-

Machining by a laser beam is achieved through following Phases :-

- Intraction of laser beam with work material.
- Heat conduction & tempʳ rise.
- Melting, vaporizaⁿ.



↳ Cutting depth (t);

$$t = \frac{P}{vd}$$

where, d = diamᵗʳ of laser Beam

* Types of Laser :-

↳ There are two types of lasent medium is used for producing laser beam.

1. Solid-State laser :-
   - Ruby which is a Cr-Alumina alloy having a wavelength of 0.7 um
   - Nd-glass (Nd: Needimium) laser having a wavelength of 1.64 um
   - Nd-YAG (Neodimium Yittrium-Aluminium Garnet) having wavelength of 1.06 um.

2. Gas-laser :-
   - Helium-Neon.
   - Argon.
   - CO_2 etc.

↳ Laser can be operated in continuous mode or pulsed mode. Typically CO_2 gas laser is operated in continuous mode & Nd-YAG laser is operated in pulse mode.

↳ Advantages :-
- More precise
- Faster process.
- Smooth and clean cut.
- Decreased Heat affected zone.
- Usefull with variety of materials : metals, composites, plastics, ceramics.
- Laser can operate in air, inert gas, vaccume and in certain liquids.

* Disadvantages :-
- Laser beams are dangerous to retina of eye.
- It can't be used for cutting of high heat conductive and high reflective materials. (Al, Cu and their alloys)
- Taper holes are produced.
- Output energy from laser is difficult to control.

* Applications :-
- Cutting of sheet plates as thick as 30mm.
- Manufacturing of metal sheet for truck bed plates.
- Lubrication holes.
- Cooling holes in vanes of Boeing jet engines.

* Summary of LBM Characteristics :-

Mechanics of material removal	⇒	Melting, Vaporization
Medium	⇒	Normal atmosphere.
Tool	⇒	High power laser Beam.
Max. MRR	⇒	$5 mm^3/min$.
Specific Power Consumption	⇒	$1000 W/mm^3/min$.
Critical Parameters	⇒	Beam Power intensity, beam diam^er, Melting Temp^r.
Material Application	⇒	All materials.
Shape Application	⇒	Drilling fine holes.
Limitations	⇒	Very large Power Consumption, Can't cut material with high conductivity & reflectivity

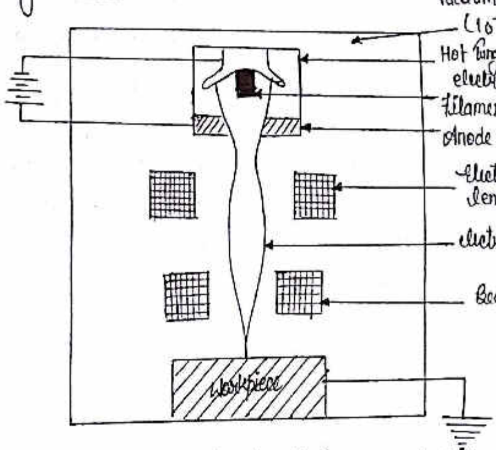
ELECTRON BEAM MACHINING[EBM]

* **Introduction :-**

↳ EBM is a thermoelectric process in which no. of electrons is produced by an accelerating voltage of 150,000V with high velocity of 300×10^{6} m/sec.

↳ This e^- beam can be focussed on a point with 10-200 um dia, the power density can go upto 6500 billion W/mm^2. Such power density can vaporized any substance immediately. Thus EBM is used generally for drill holes of 25-125 um dia.

* **Working Principle :-**



↳ An e^- beam gun is used for producing no. of electrons. It works at cathode and produced free electrons under high voltage condition.

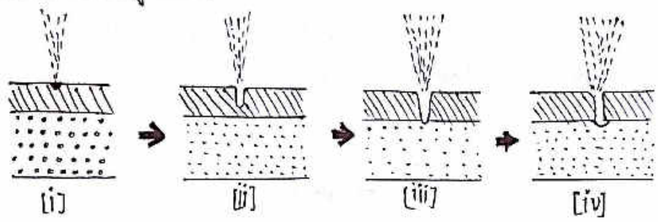
↳ The cathode generally made of tungsten or tantalum and this tungsten filament is heated upto a temp of around 2500°C.

↳ This heating leads emission of e^-s. These electrons are shaped by an anode and they are accelerated by large potential difference b/w cathode and anode.

↳ Then the beam is focussed with help of electromagnetic lenses. The deflecting coils are used to control the beam movement in any required manner. Finally e^- beam strikes on W/p surface and materials are melted and vaporized in required amount.

↳ This process is done under vaccume chamber (10^{-5} mm Hg) as e^- don't loose their energy before striking W/p surface.

* **Mechanism of EBM :-**

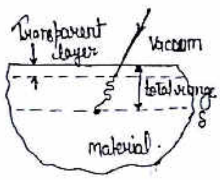


[i] Localised heating by focussed electron beam.
[ii] Gradual formation of hole by penetration of melt vaporization front
[iii] Penetration till auxilliary support.
[iv] Expulsion of any molten material at top by high vapour pressure.

* **Process Parameters :-**

- Accelerating Voltage (100kV)
- Beam Current (250uA − 1A)
- Pulse duration (50us − 50 ms)
- Energy per Pulse (100 J/Pulse)
- lens current.
- Spot size (10um − 500um)
- Power density.

Effect of EBM in Material :-



S = distance of penetraⁿ of e⁻

↳ When fast moving e⁻ impinges on a material surface, it penetrates through a layer undisturbed. Then starting colliding with molecules, and brough to rest.

↳ The layer through which the electron penetrates undisturbed is called transparent layer, so generation of heat takes place inside material.

* **Advantages :-**
- Very high drilling rate when small holes are to be drilled.
- Doesn't depend on properties of material except Melting Point tempᵉʳ.
- Fixture cost is low.
- HAZ is less due to shorter pulse.
- Brittle materials can also be machined.

* **Disadvantages :-**
- High capital cost by using vacuum system.
- HAZ is rather less but recast layer formation can't be avoided.
- Expensive, if accuracy is required.
- High specific energy consumption.
- Thin parts may distort.

* **Applications :-**
- Drilling small holes.
- Cutting of small slots
- Also used in welding of any material.
- Used in annealing process.

* **Summary of EBM characteristics :-**

Mechanics of material removal	⇒	Melting, vaporization
Medium	⇒	Vacuum
Tool	⇒	High velocity e⁻ Beam.
max. MRR	⇒	$10 mm^3/min$.
Specific Power consumption	⇒	$450 W/mm^3/min$.
Critical Parameters	⇒	accelerating Voltage, Beam Current & diameter, work speed, Melting Tempᵉʳ.
Material application	⇒	All Materials
Shape Application	⇒	Drilling fine hole, narrow slot.
Limitations	⇒	High Specific power consumption, necessity of Vacuum, expensive.

ULTRASONIC MACHINING (USM)

* **INTRODUCTION :-**

↳ USM is the finishing processed by the electrospark machines, in which material is removed from surface by microchipping and erosion with abrasive grains in slurry. Slurry driven b/w tool and w/p at high velocity by a tool oscillating normal to work surface at high frequency about 19-25 kHz. Friction of abrasive particles gradually cut the w/p.

↳ Ultrasonic waves are sound waves of frequency higher than 20,000 Hz. and it is generated by using mechanical, thermal energy sources. They can be produced in gases (air also), liquids & solids.

↳ Hardened materials can be produced Machined by USM. (as hardened steel, carbides, diamond, glasses).

↳ This process is used as finishing and polishing.

↳ Hard abrasive particles are mixed with water in slurry.

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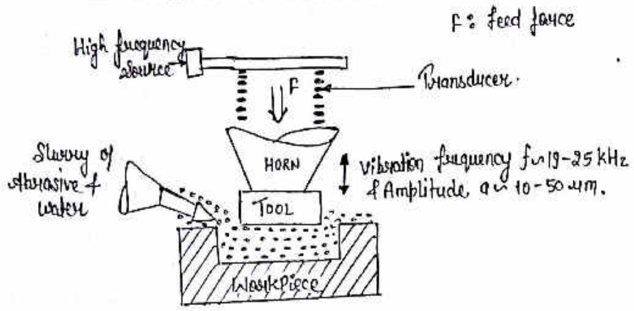
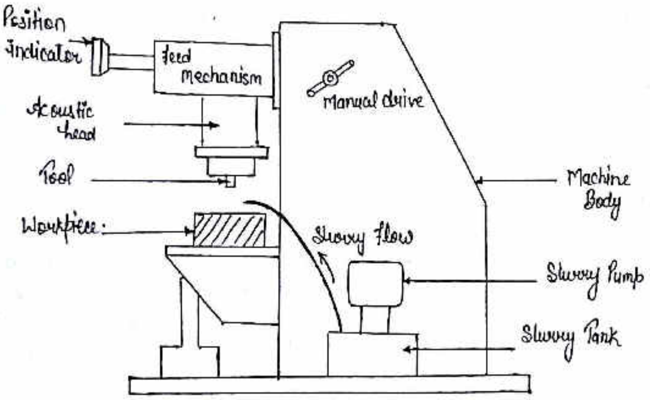


* Working Principle:-



↳ In USM, a tool of desired shape vibrates at a ultrasonic frequency (19-25 kHz) with an amplitude of around 15-50 μm over Workpiece.

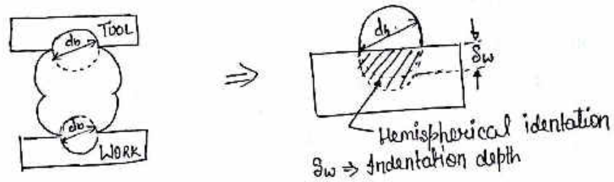
↳ Generally tool is pressed with a feed force F, between tool and w/p. The machining is zone is flooded with hard abrasive particles generally in form of water based slurry.

↳ As tool vibrate over w/p, abrasive particles act as indenters and indent both tool and work material. The abrasive particles, as they indent the w/p material would remove the same.

↳ If work material is hard, brittle, due to crack initiation, propagation and finally get fracture of material. Hence it is used for machining of brittle materials (have poor conductivity).

↳ Hard and ductile tools are used as steel, stainless steel.

* Mechanism of USM :-

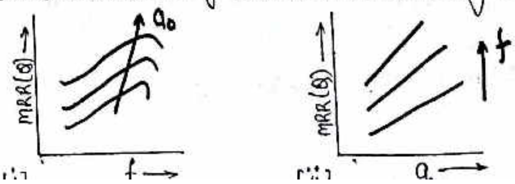


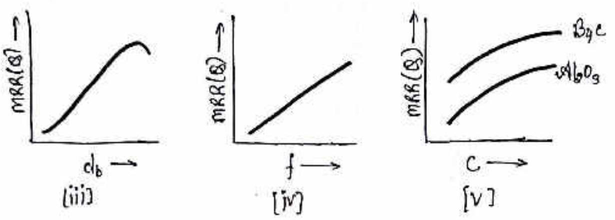
↳ Basic three steps of mechanis is there as:-

1. Direct hammering of abrasive into work by tool.
2. The Impact of abrasive on tool.
3. Cavitation induced erosion & chemical erosion caused by slurry.

* Process Parameters:-

- Amplitude ($a = 15$-$50\mu m$)
- Frequency ($f = 19$-25 kHz)
- Feed force & pressure : related to tool dimensions.
- Abrasive size (15μm – 150μm)
- Abrasive Materials (Al_2O_3, SiC, B_4C & Diamond)
- Flow strength of w/p and tool materials.
- Contact area of Tool (A)
- Volume concentration of abrasive in water slurry (C).





[i] & [ii] As frequency increases, indentation is also increased i.e MRR increased but after reaching peak value of f, MRR started to decreased.

[iii] If diam^{r} of abrasive is large, MRR is increased but after a value it starts cutting.

(iv) f ↑ → MRR ↑

[V] Concentration of B_4C (Boron Carbide) is have high MRR than Al_2O_3.

* **Advantages :-**
  - Good surface finish.
  - Can drill circular/non circular holes in very hard material.
  - Semiconductors can also be machined.
  - Less stress because of non-thermal characteristics.

* **Disadvantages :-**
  - Low MRR
  - Rather high tool wear.
  - Low depth of hole.

* **Applications :-**
  - Drilling and finishing of drawing, blanking & punching dies.
  - Grinding, profiling.
  - Coining, lapping, deburring & broaching.

* **Summary of USM characteristics :-**

• Mechanism of material removal	⇒	Brittle fracture caused by impact of grains. due to tool vibrating at high frequency.
• Medium	⇒	Slurry.
• abrasives	⇒	B_4C, SiC, Al_2O_3, diamonds.
• Vibration frequency	⇒	19-25 KHz
• Tool Material	⇒	Soft Ductile & hard steel.
• Wear ratio	⇒	1.5 for WC W/p, 100 for glass W/p
• Gap	⇒	25-40 μm
• Critical Parameters	⇒	frequency, amplitude, tool material, abrasive size, feed force, slurry concentration.
• Material application	⇒	Hard & Brittle metals & alloys, semi-conductors.
• Shape application	⇒	Round & irregular holes, impression.
• Limitations	⇒	Low MRR, tool wear, low depth.

ABRASIVE JET MACHINING [AJM]

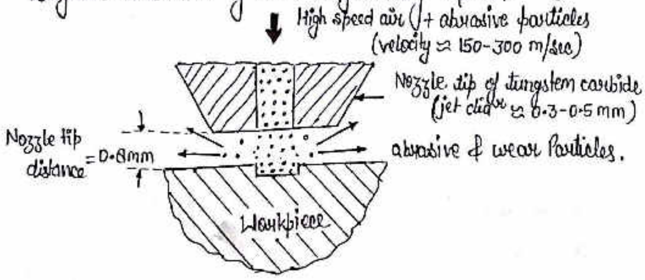
* **Introduction :-**

↳ In AJM, material removal takes place due to impingment of the fine abrasive particles. These particles move with a high speed air (or gas) stream. (around 300m/sec)

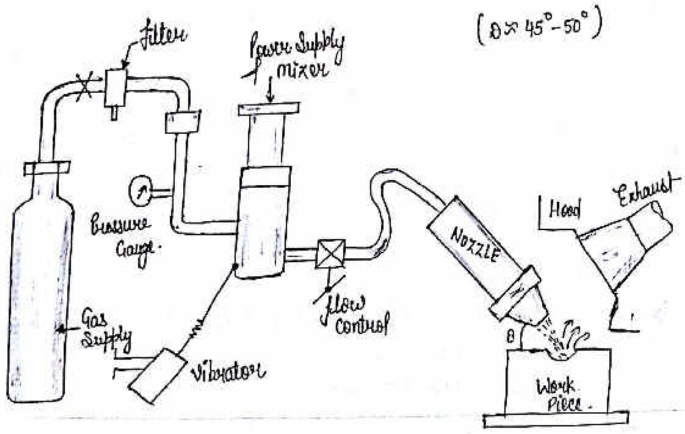
↳ The abrasive particles are typically of 0.025mm diam^{r} and air discharges at a pressure of several atmosphere through a nozzle under controlled conditions.

↳ Abrasive particles act as a cutting tools and required impact force is provided by kinetic energy of gas.

↳ It is used for cutting small holes & slots in metallic and non-metallic materials, deburring of parts, trimming and for removing oxides from surface. Holes made by AJM is generally tapered.



* **Working Principle :-**



↳ Cylinder of gas is provided proper gas supply pressure in order of 850 kPa and amount of gas controlled by valve and filtered the impurities of gas.

↳ Abrasive paticles are also controlled by valve and mixed with gas in mixer in uniform ratio due to vibrator.

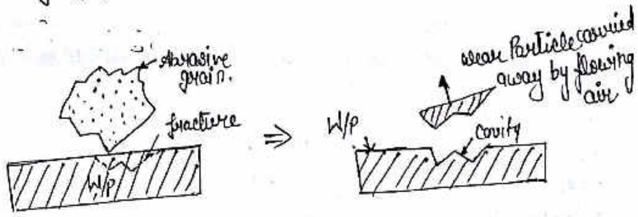
↳ This mixer is flow through pipe and enters in nozzle. Abrasive particles have tendency to erode/wear the contact material, therefore shapphire material is used for nozzle material (or Tungsten Carbide)

↳ Abrasives are flow from nozzle (diam of 0.075 - 0.4 m) and strike on w/p surface with high velocity, they fracture off other particles. Flow of fine abrasives tends to round off corners, so AJM avoids for sharp corners.

↳ As particle cause a small fracture, gas stream carries both abrasive particles (10-50 μm) and fractured particles away. (wear)

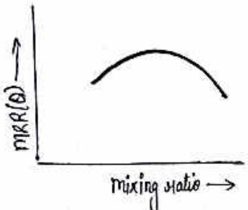
* **Mechanism :-**

- Fine particles (0.025 mm) are accelerated in gas stream.
- Particles are directed towards focus of machining (< 1mm from tip).
- As Particles impact surface, they fracture off other Particles.
- Impact of particles cause a fracture and both particles are flow away by gas stream.

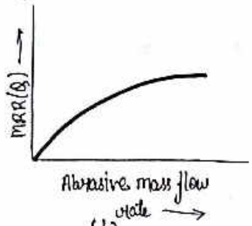


* **Process Parameters :-**

(i) The abrasive (Composition, strength, size, mass flow rate)
(ii) The Gas (Composition, pressure & velocity)
(iii) The nozzle (Geometry, Material, distance & inclination)



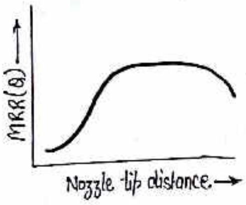
(i) (a)



(b)

a) As mixing ratio increased, MRR is also increased but after a ratio MRR becomes decreased.

(b) mass flow rate ↑ ⟶ MRR ↑ (due to high velocity.



↳ As standoff distance ↑ → MRR ↑ but at a specific distance MRR is constant and after a value it will be decreased.

* **Advantages :-**

- Abrasive jet can be used to cut any material.
- Free from chattering, vibrations.
- No heat generation, so very thin brittle materials can be cut.

* **Disadvantages :-**

- Low MRR & limited to brittle and hard materials.
- Abrasive Powders can't be reused.
- Wear rate of nozzle is high.
- Poor Machining accuracy & Not ecofriendly.

* **Applications.**

- Suitable for hard, brittle metals, alloys (Eg: Si, Germanium, Glass, Ceramics)
- Suitable for thin section, deburring.

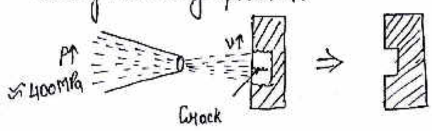
* **Summary of AJM characteristics :-**

• Mechanism of material removal	⇒ Brittle fracture by impinging abrasive grains at high speed.
• Medium	⇒ Air, CO_2.
• Abrasive	⇒ Al_2O_3, SiC, Glass beads, 0.025mm diam^{r}, non recirculating.
• Velocity	⇒ 150 - 300 m/sec.
• Pressure	⇒ 2-10 atm.
• Nozzle	⇒ WC, sapphire, (0.05-0.2 mm^2)
• Critical Parameters	⇒ Abrasive flow rate & velocity, grain size, jet inclination.
• Material applications	⇒ Hard & Brittle, metals, alloys.
• Shape applications	⇒ Drilling, cutting, deburring, etching etc
• Limitations	⇒ Low MRR, embedding of abrasive in W/P Tapering of drill hole.

WATER JET MACHINING [WJM]

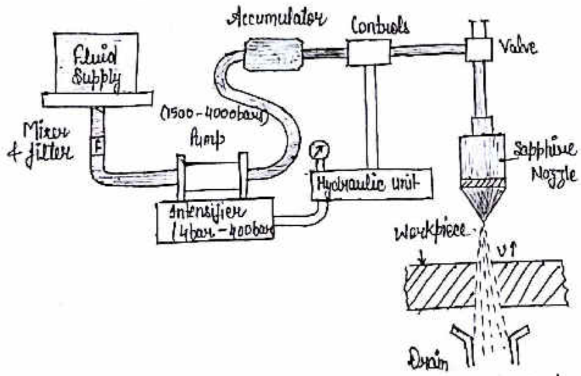
* **Introduction :-**

↳ It is also called "hydro-dynamic maching" in which pressure energy in converted into mechanical energy of water which is used for cutting, deburring operation.



↳ In this process, water is greatly accelerated and further concentrated and used for fabrication of any material.

* Working Principle :-



- In WJM, fluid is supplied after getting filtered to the pump at high pressure of (1500-4000bars). An itensifier is used to increase the pressure of fluid (4-400bar). After intensifying high pressure fluid flow toward accumulator.
- Accumulator decreases the turbulency in fluid and fluid jet becomes continuous stream jet with high pressure. Control system and hydraulic units are used for controlling and maintaining the properties of q, or quantity of water jet.
- High pressure water jet enter into nozzle and may cause erosion, sapphire material is used for nozzle. At small orifice of nozzle high pressure energy is converted into mechanical energy ie V↑.
- High velocity water jet is direct strike on W/P surface, cause crack. Cracks propogates continuously and remove material in desired shape.
- Water circulation is reused in WJM, with a drainage system.
- Water is generally used as working fluid jet.
- Because it is an efficient & clean operation, it is used in food processing industry for cutting and slicing the food product.

* Advantages :-
  - No heat is produced.
  - No environmental problems.
  - Burr production is minimal and provide good surface finish.
  - Relatively small volume of fluid is required.
  - Any contour can be cut.

* Disadvantages :-
  - Noise level is high
  - Water ejecting from nozzle may be completely evaporated.
  - Water recirculation at high pressure is difficult.

* Applications :-
  - Variety of materials can be cut as Plastics, fabrics, rubber, wood, etc.
  - Also cut ceramics, steel, Ti.
  - Used in food industry.

Difference between EDM & ECM

	ELECTRICAL DISCHARGE MACHINING (EDM)	ELECTRO CHEMICAL MACHINING [ECM]
• Mechanism of material removal.	Melting and evaporation aided by cavitation.	Electrolysis
• Medium	Dielectric fluid	Conducting electrolyte
• Tool materials	Cu, brass, Cu-W alloy, graphite.	Cu, brass, steel.
• Wear Ratio	0.1 – 10	∞
• Gap	10–125 μm	50 – 300 μm.
• Max. Removal Rate	5×10^3 mm^3/min	15×10^3 mm^3/min.
• Specific Power Consumption	1.8 W/mm^3/min	7 W/mm^3/min.
• Critical parameters	Voltage, capacitance, spark gap, dielectric circulaⁿ, M.P Tempʳ.	Voltage, Current, feed rate, electrolyte,
• Material applications	All conducting metals & Alloys.	All conducting metals & alloys.
• Shape applications	Complex cavities, micro holes in nozzle, narrow slots.	Curved surfaces, large cavities, Blind complex cavities.
• Limitations	• MRR is low when dielectric circulaⁿ is not possible. • High energy consumption (50 times of CM)	• High specific energy consumption (150 times of CM) • Non-applicable for non-conductive Materials • Expensive

Difference between EBM & LBM

	ELECTRON BEAM MACHINING (EBM)	LASER BEAM MACHINING (LBM)
Mechanism of material removal.	Melting & vaporization	Melting & Vaporization
• Medium	Vacuum	Normal Atmosphere
• Tool	High velocity electron Beam	High power laser Beam.
• Max. MRR	10 mm^3/min.	5x mm^3/min.
• Specific Power Consumption	450 W/mm^3/min	1000 W/mm^3/min.
• Critical Parameters	Accelerating voltage, beam current, Beam diamʳ, work speed, M.P Tempʳ.	Beam Power intensity, Beam diamʳ. Melting Tempʳ.
• Material applications	All materials.	All materials (except reflectivity = Al)
• Shape Applications	fine drill holes, cutting contours in sheets, Cutting narrow slot	Drilling fine holes.
• Limitations	• very high specific Power Consumption • Necessity of Vacuum • Expensive	• Very large Power Consumption, • Can't cut materials with high heat conductivity and high reflectivity

Difference between AJM & WJM

	ABRASIVE JET MACHINING (AJM)	WATER JET MACHINING (WJM)
• Mechanism of material removal	Brittle fracture by impinging abrasive grains at high speed.	Brittle fracture by impinging water jet at high speed.
• Medium.	Air, CO_2	Air
• Abrasives	Al_2O_3, SiC, non-recirculating	Re-circulating water
• Velocity	150 - 300 m/sec.	150 - 350 m/sec.
• Pressure	2 - 10 atm.	≈ 4000 bars.
• Nozzle	WC, sapphire with orifice (0.05 - 0.2 mm^2)	WC, sapphire.
• Critical Parameters	Abrasive flow rate, velocity, nozzle tip distance, grain size, jet inclination	Water flow rate & velocity, nozzle tip distance.
• Material Applications	Hard & brittle metals & alloys, non metallic.	Hard & Brittle, thin section of non-metallic (Si, ceramics etc)
• Shape Applications	Drilling, Cutting, deburring, etching.	drilling, deburring.
• Limitations	• Low MRR. • embedding of abrasive in W/p.	• low MRR • Tapering of drilled holes.

SOLID STATE WELDING

Solid state welding is a group of **welding** processes which produces coalescence at temperatures essentially below the melting point of the base materials being joined, without the addition of brazing filler metal. Bonding of the materials is a result of diffusion of their interface atoms.

This includes cold welding, diffusion welding, explosion welding, friction welding, hot pressure welding and ultrasonic welding.
In all of these processes time, temperature, and pressure individually or in combination produce coalescence of the base metal without significant melting of the base metals.

Advantages of Solid State Welding:

- Weld (bonding) is free from microstructure defects (pores, non-metallic inclusions, segregation of alloying elements)
- Mechanical properties of the weld are similar to those of the parent metals
- No consumable materials (filler material, fluxes, shielding gases) are required
- Dissimilar metals may be joined (steel - aluminum alloy steel - copper alloy).

Disadvantages of Solid State Welding:

- Thorough surface preparation is required (degreasing, oxides removal, brushing/sanding)
- Expensive equipment.

The following processes are related to Solid State welding:

1. **Forge Welding (FOW)**- Forge Welding is a Solid State Welding process, in which low carbon steel parts are heated to about 1800°F (1000°C) and then forged(hammered).
   Prior to Forge Welding, the parts are scarfed in order to prevent entrapment of oxides in the joint.
   Forge Welding is used in general blacksmith shops and for manufacturing metal art pieces and welded tubes.

2. **Cold Welding (CW)-** Cold Welding is a Solid State Welding process, in which two work pieces are joined together at room temperature and under a pressure, causing a substantial deformation of the welded parts and providing an intimate contact between the welded surfaces.
   As a result of the deformation, the oxide film covering the welded parts breaks up, and clean metal surfaces reveal. Intimate contact between these pure surfaces provide a strong and defectless bonding.
   Aluminum alloys, Copper alloys, low carbon steels, Nickel alloys, and other ductile metals may be welded by Cold Welding.

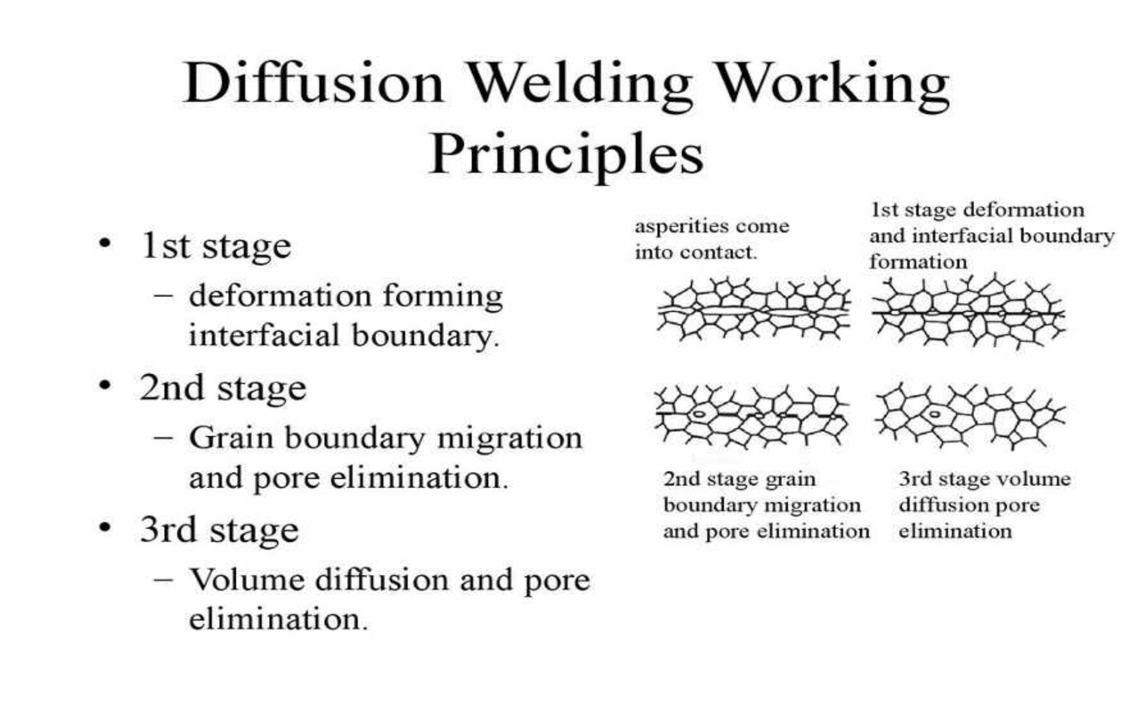
3. **Friction Welding (FRW)-** Friction Welding **is** a Solid State Welding process, in which two cylindrical parts are brought in contact by a friction pressure when one of them rotates. Friction between the parts results in heating their ends. Forge pressure is then applied to the pieces providing formation of the joint. Carbon steels, Alloy steels, Tool and die steels, Stainless steels, Aluminum alloys, Copper alloys, Magnesium alloys, Nickel alloys, Titanium alloysmay be joined by Friction Welding.

4. Explosive Welding (EXW)
5. Diffusion Welding (DFW)
6. Ultrasonic Welding (USW)

Diffusion Welding (DFW)

Diffusion Welding is a Solid State Welding process, in which pressure applied to two work pieces with carefully cleaned surfaces and at an elevated temperature below the melting point of the metals. Bonding of the materials is a result of mutual diffusion of their interface atoms.

7. Diffusion involves migration of atoms across joint due to concentration gradient.
8. The two atoms are pressed together at an elevated temperature (50%-70% of M.P.)
9. The pressure is gradually applied and temperature is elevated to permit diffusion at atomic level.
10. Due to local deformation at the contact points permits longer areas to be in touch and with time grains diffused closing interfacial voids, remaining voids are shrinks and then disappear slowly.
    In order to keep the bonded surfaces clean from oxides and other air contaminations, the process is often conducted in vacuum.
    No appreciable deformation of the work pieces occurs in Diffusion Welding.



Diffusion Welding is often referred more commonly as Solid State Welding (SSW).
Diffusion Welding is able to bond dissimilar metals, which are difficult to weld by other welding processes:

- Steel to tungsten, Steel to niobium, Stainless steel to titanium, Gold to copper alloys.

Diffusion Welding is used in aerospace and rocketry industries, electronics, nuclear applications, manufacturing composite materials.

Advantages of Diffusion Welding:

Dissimilar materials may be welded (Metals, Ceramics, Graphite, glass);
Welds of high quality are obtained (no pores, inclusions, chemical segregation, distortions).

No limitation in the work pieces thickness.

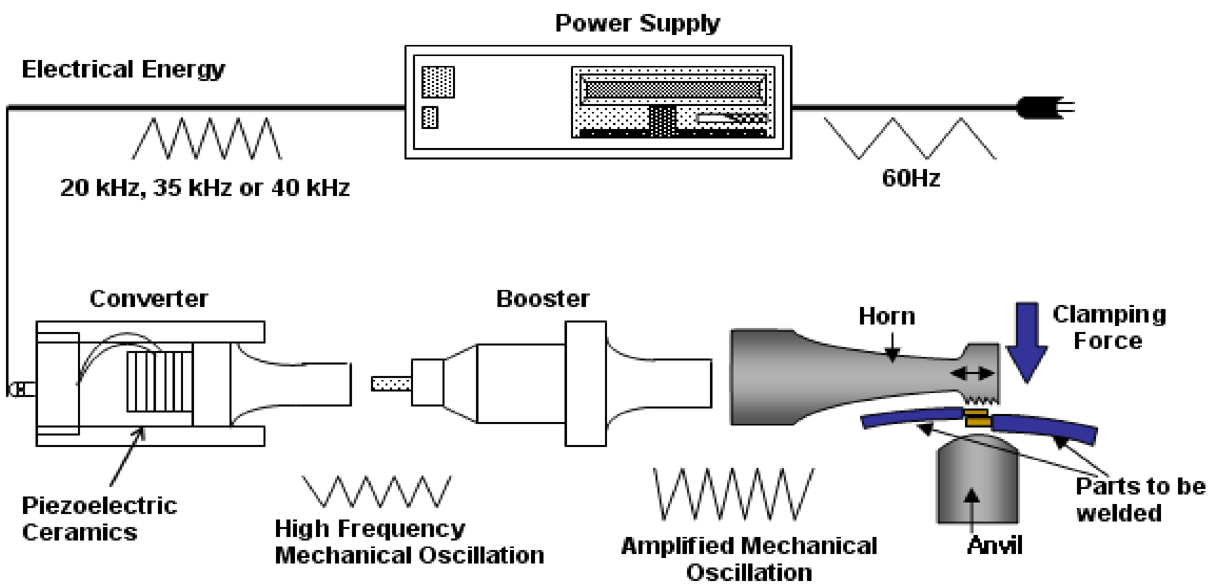
Disadvantages of Diffusion Welding:

Time consuming process with low productivity;
Very thorough surface preparation is required prior to welding process;
The mating surfaces must be precisely fitted to each other, Relatively high initial investments in equipment.

Ultrasonic Welding (USW)

Ultrasonic Welding is a Solid State Welding process, in which two work pieces are bonded as a result of a pressure exerted to the welded parts combined with application of high frequency acoustic vibration (ultrasonic).

Ultrasonic vibration causes friction between the parts, which results in a closer contact between the two surfaces with simultaneous local heating of the contact area. Interatomic bonds, formed under these conditions, provide strong joint.
Ultrasonic cycle takes about 1 sec. The frequency of acoustic vibrations is in the range 20 to 70 KHz.
Thickness of the welded parts is limited by the power of the ultrasonic generator.
Ultrasonic Welding is used mainly for bonding small work pieces in electronics, for manufacturing communication devices, medical tools, watches, in automotive industry.

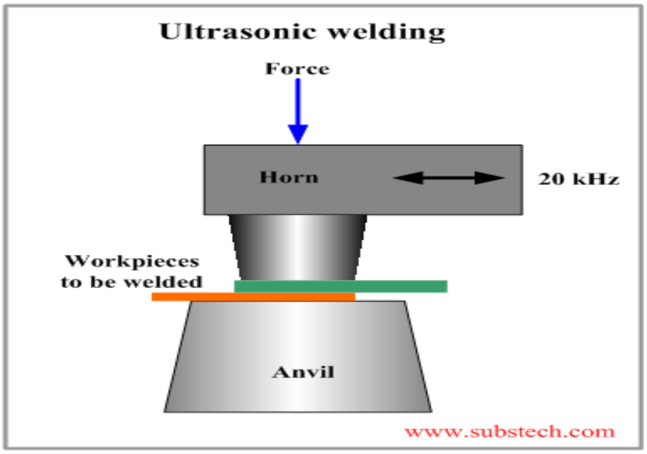


Advantages of Ultrasonic Welding:

- Dissimilar metals may be joined, Very low deformation of the work pieces surfaces;
- High quality weld is obtained, The process may be integrated into automated production lines.
- Moderate operator skill level is enough.

Disadvantages of Ultrasonic Welding:

- Only small and thin parts may be welded;
- Work pieces and equipment components may fatigue at the reciprocating loads provided by ultrasonic vibration, Work pieces may bond to the anvil.


Ultrasonic welding
Force
Horn
20 kHz
Workpieces
to be welded
Anvil
www.substech.com

Plasma Arc Welding (PAW)

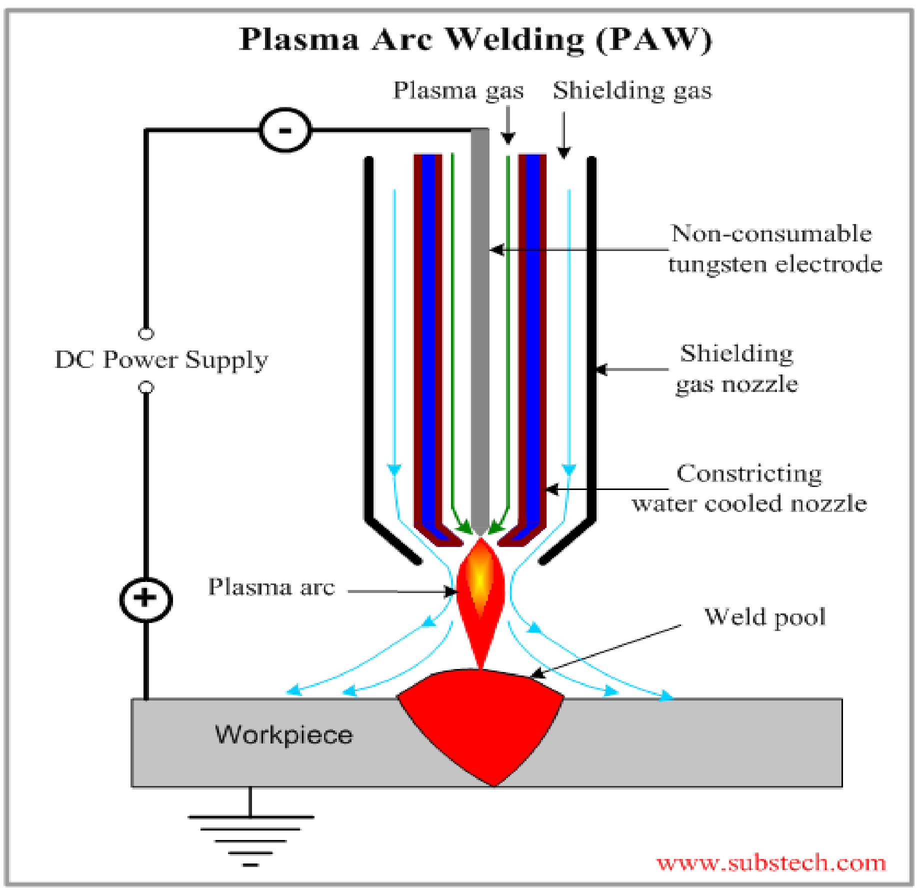
Plasma Arc Welding is the welding process utilizing heat generated by a constricted arc struck between a tungsten non-consumable electrode and either the work piece (**transferred arc process**) or water cooled constricting nozzle (**non-transferred arc process**).

Plasma is a gaseous mixture of positive ions, electrons and neutral gas molecules.

1. Arc is setup between electrode and Anodic nozzle, forced to pass through nozzle.
2. Now plasma gas passing through arc dissociated and ionized resulting in high velocity plasma (Plasma formation)
3. Constriction reduces arc area so increasing velocity and energy density arc thereafter high temperature about 2800 ^{0}C. This heat is used for melting.
4. High energy plasma makes deeper penetration with successful welding of thick sheets.

   Transferred arc process produces plasma jet of high energy density and may be used for high speed welding and cutting of Ceramics, steels, Aluminum alloys, Copper alloys, Titanium alloys, Nickel alloys.

   Non-transferred arc process produces plasma of relatively low energy density. It is used for welding of various metals and for plasma spraying (coating). Since the work piece in non-transferred plasma arc welding is not a part of electric circuit, the plasma arc torch may move from one work piece to other without extinguishing the arc.



Advantages of Plasma Arc Welding (PAW):

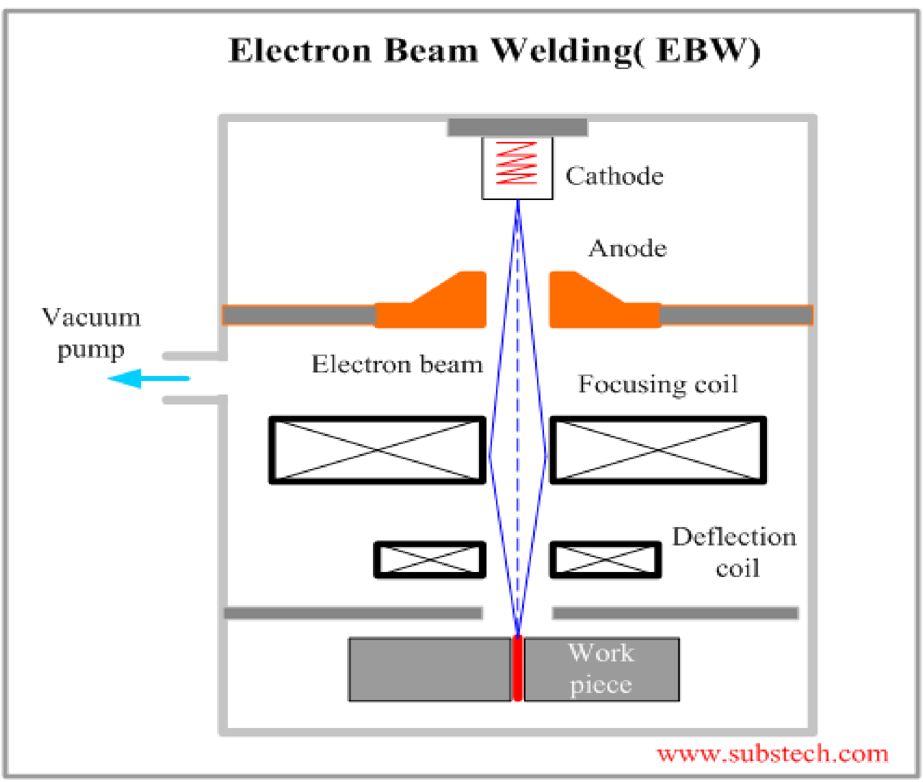
1. Requires less operator skill due to good tolerance of arc to misalignments;
2. High welding rate, High penetrating capability (keyhole effect.

Disadvantages of Plasma Arc Welding (PAW): Expensive equipment, High distortions and wide welds as a result of high heat input (in transferred arc process).

Electron Beam Welding (EBW)

Electron Beam Welding is a welding process utilizing a heat generated by a beam of high energy electrons. The electrons strike the work piece and their kinetic energy converts into thermal energy heating the metal so that the edges of work piece are fused and joined together forming a weld after Solidification.

The process is carried out in a vacuum chamber at a pressure of about $2*10^{-7}$ to $2*10^{-6}$ psi (0.00013 to 0.0013 Pa). Such high vacuum is required in order to prevent loss of the electrons energy in collisions with air molecules.
The electrons are emitted by a cathode (electron gun). Due to a high voltage (about 150 kV) applied between the cathode and the anode the electrons are accelerated up to 30% - 60% of the speed of light. Kinetic energy of the electrons becomes sufficient for melting the targeted weld. Some of the electrons energy transforms into X-ray irradiation.
Electrons accelerated by electric field are then focused into a thin beam in the focusing coil. Deflection coil moves the electron beam along the weld.
Electron Beam is capable to weld work pieces with thickness from 0.0004” (0.01 mm) up to 6” (150 mm) of steel and up to 20” (500 mm) of aluminum. Electron Beam Welding may be used for joining any metals including metals, which are hardly weldable by other welding methods: refractory metals (tungsten, molybdenum, niobium) and chemically active metals (titanium, zirconium, beryllium). Electron Beam Welding is also able to join dissimilar metals.



Advantages of Electron Beam Welding (EBW):

- Tight continuous weld, Low distortion, Narrow weld and narrow heat affected zone.
- Filler metal is not required.

Disadvantages of Electron Beam Welding (EBW):

- Expensive equipment, High production expenses.
- X-ray irradiation.

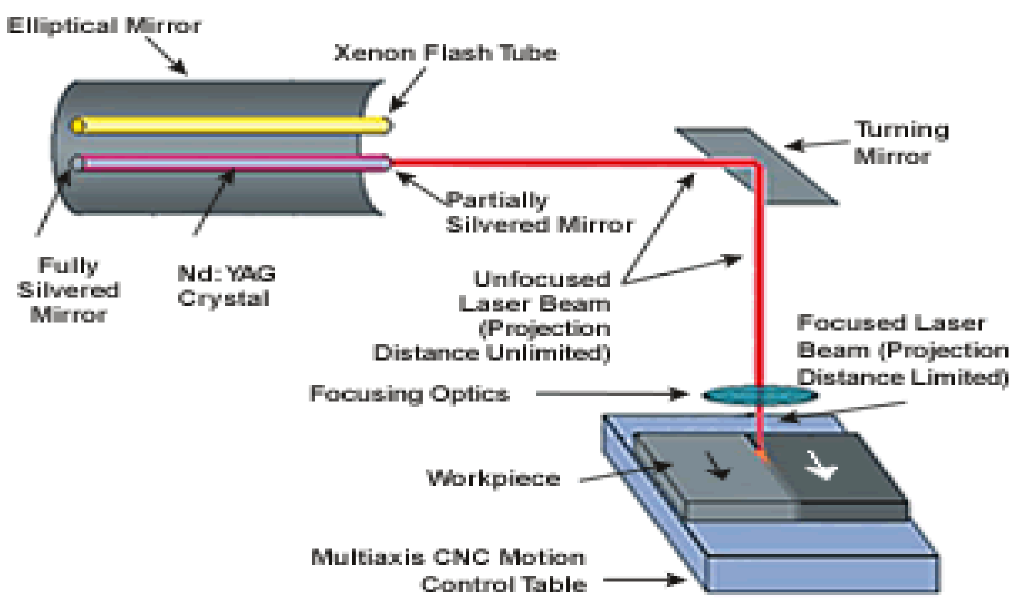
Laser Beam Welding (LBW)

Laser Welding (LW) is a welding process, in which heat is generated by a high energy laser beam targeted on the work piece. The laser beam heats and melts the work pieces edges, forming a joint.

Energy of narrow laser beam is highly concentrated: 10^8-10^{11} W/in^2 (10^8-10^{10} W/cm^2), therefore diminutive weld pool forms very fast (for about 10^{-6} sec.). Solidification of the weld pool surrounded by the cold metal is as fast as melting. Since the time when the molten metal is in contact with the atmosphere is short, no contamination occurs and therefore no shields (neutral gas, flux) are required.

The joint in Laser Welding (Laser Beam Welding) is formed either as a sequence of overlapped spot welds or as a continuous weld.

Laser Welding is used in electronics, communication and aerospace industry, for manufacture of medical and scientific instruments, for joining miniature components.



Types of LASER- Gas laser (Co_2,) and Solid state laser (Nd YAG = Neo_dymium Yttrium Aluminum Garnet)

<u>Advantages of Laser Welding:</u>

- Easily automated process, Controllable process parameters.
- Very narrow weld may be obtained, High quality of the weld structure.
- Very small heat affected zone, Dissimilar materials may be welded.
- Very small delicate work pieces may be welded, Vacuum is not required.
- Low distortion of work piece.

<u>Disadvantages of Carbon Arc Welding:</u>

- Low welding speed;
- High cost equipment;
- Weld depth is limited.

Explosion welding /Cladding

Explosion welding (EXW) is a solid state (solid-phase) process where **welding** is accomplished by accelerating one of the components at extremely high velocity through the use of chemical **explosives** (Controlled detonation).

- Even heat is not supplied but the metal at interface melts during welding because of heat that comes from several sources (shock waves associated with impact, energy expended in collision) by plastic deformation at the interface.

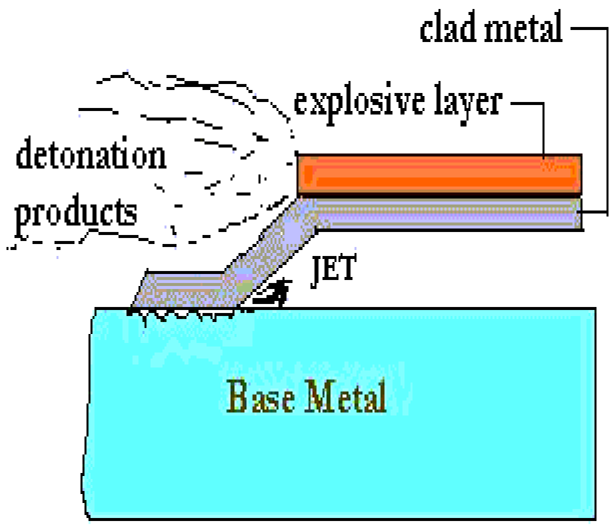
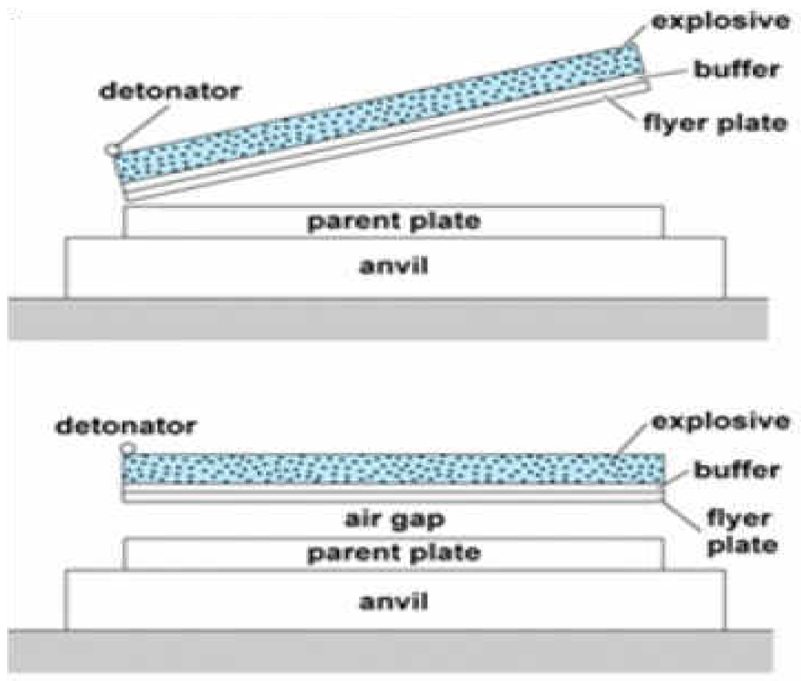


Fig. 1 Explosive Welding



- The basic mechanism is based on molecular bonding as a result of high velocity impact.
- High velocity is promoted by detonated explosives. Detonation velocity should not increased by 120 % of sonic velocity.
- After detonation the surface forms a liquid jet which directed away from welding seam.

Important parameters are critical velocity and critical angle. Well suited for brittle joint.

High velocity explosives (4572-7620 m/s)-TNT, RDX(Nitroamine), PETN(Penta Erithritol Tetra Nitrate)
Medium velocity explosives (1524-4572 m/s)-Ammonium nitrate, Dynamites, Ammonium perchlorate

Advantages- Bond dissimilar mainly unweldable metals, Portable , Inexpenssive, NO need of surface preparations. Quickly weld over large areas.

Disadvantages- Metals have high enough impact resistance, Noise and blast require workers protection, for simple geometries.

Application- Spot wellidng , cladding of base metals with thinner alloys, seam & lap welds, joining of sockets.