

Machining Science and Technology (RME6C002)

Module 3

MODULE – 3 (13 hrs)

Non-traditional Machining processes

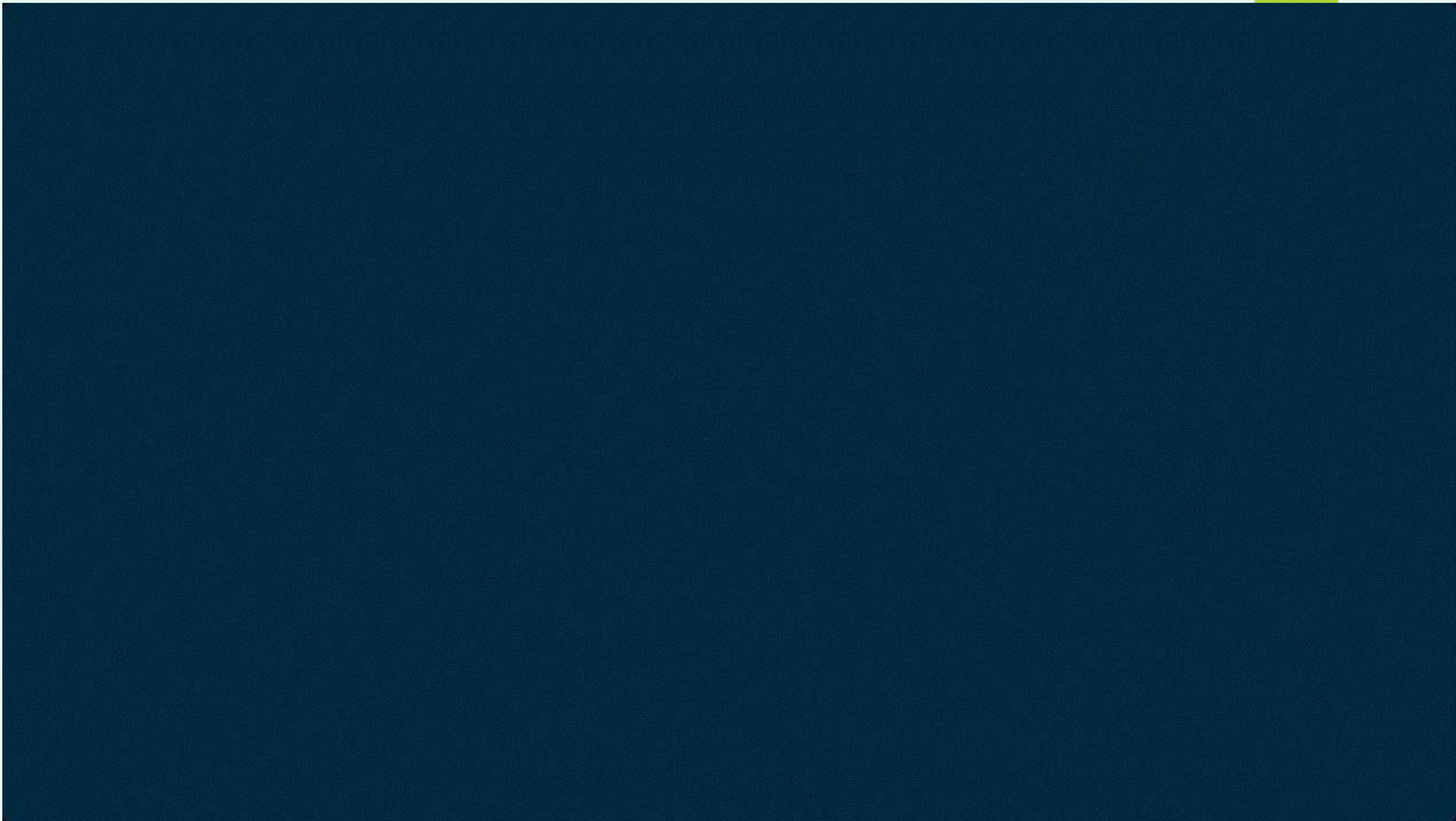
- ❖ Ultrasonic Machining, (USM)
- ❖ Laser Beam Machining (LBM)
- ❖ Plasma Arc Machining (PAM)
- ❖ Electro Chemical Machining (ECM)
- ❖ Electro Discharge Machining (EDM)
- ❖ Wire EDM
- ❖ Abrasive Jet Machining (AJM)

Advantages of PAC are

- ❖ Most applications of PAC involve cutting of flat metal sheets and plates. Operations include hole piercing and cutting along a defined path.
- ❖ Plasma arc cutting can be used to cut nearly any electrically conductive metal. Metals frequently cut by PAC include plain carbon steel, stainless steel, and aluminum. The advantage of NC in these applications is high productivity.
- ❖ It is equally effective on any electrically conductive material regardless of its hardness or refractoriness.
- ❖ It does not directly contact the work piece thereby simplifying the setup process.
- ❖ It does not require any special surface preparations or use any dangerous chemicals for cleaning after machining.
- ❖ Feed rates must be reduced for thicker stock.

Disadvantages of PAC are

- ❖ The cut surface is rough.
- ❖ Metallurgical damage at the surface is the most severe among the nontraditional metalworking processes.



Electro Chemical Machining (ECM)

❖ Electrochemical machining removes metal from an electrically conductive workpiece by **anodic dissolution**, in which the shape of the workpiece is obtained by a formed electrode tool in close proximity to, but separated from, the work by a **rapidly flowing electrolyte**.

Figure 5: Electrochemical Machining Process

Principle of ECM

- ❖ ECM is based on electrolysis. A typical arrangement of an electrolytic cell is shown in Fig. 6.
- ❖ When a potential difference is applied across the cathode and anode, there are a number of possible reactions that can take place.
- ❖ The following are some of those that are relevant for ECM.

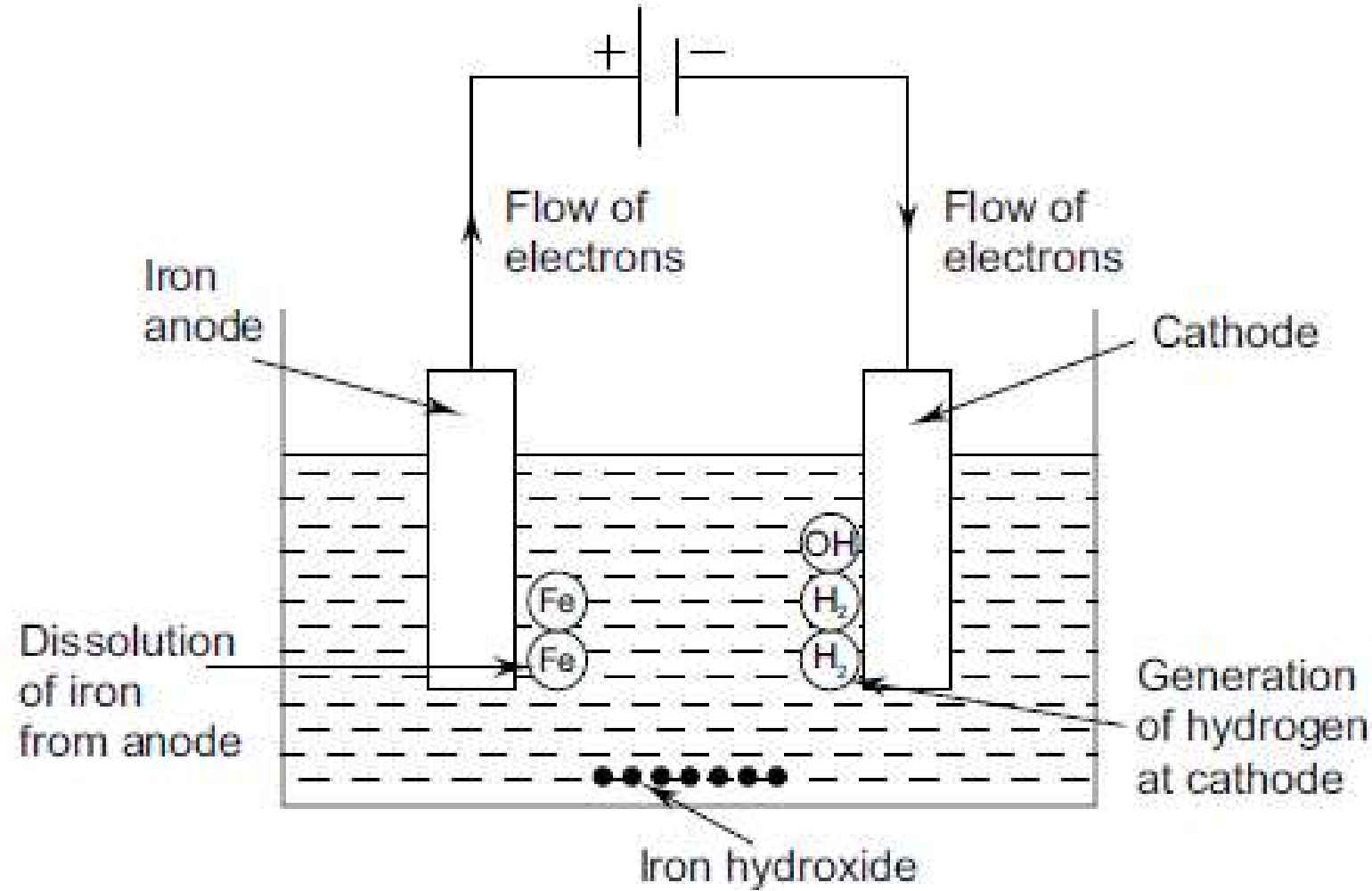
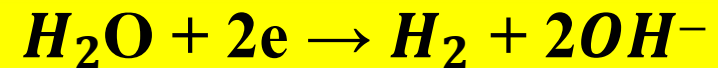


Figure: 6 Principle of electrolysis

The reaction taking place at the anode is the dissolution of anode by the electrolyte.

Similarly at the cathode, hydrogen gas is released from the water contained in the electrolyte.



Combining the above two reactions, the iron and hydroxyl ions would combine to form the iron hydroxide as follows:



The net reaction of all the above three reactions can be shown as



It is further possible that the iron (ferrous) hydroxide may further react with water and oxygen forming the ferric hydroxide as shown below:



Based on this it is possible to make the following observations:

- ❖ The metal from the anode is dissolved electrochemically and hence the metal removal rate based on the Faraday's laws will depend upon atomic weight, valency, the current passed and the time for which the current is passed, and on no other parameter.
- ❖ At the cathode only hydrogen gas is evolved and no other reaction takes place, so the shape of the cathode is unaffected.

- ❖ Based on the above observations, the ECM process can now be conceived as a process involving a tool cathode which has the complimentary shape of the part to be produced and the work to be done as anode, as shown in Fig. 7.

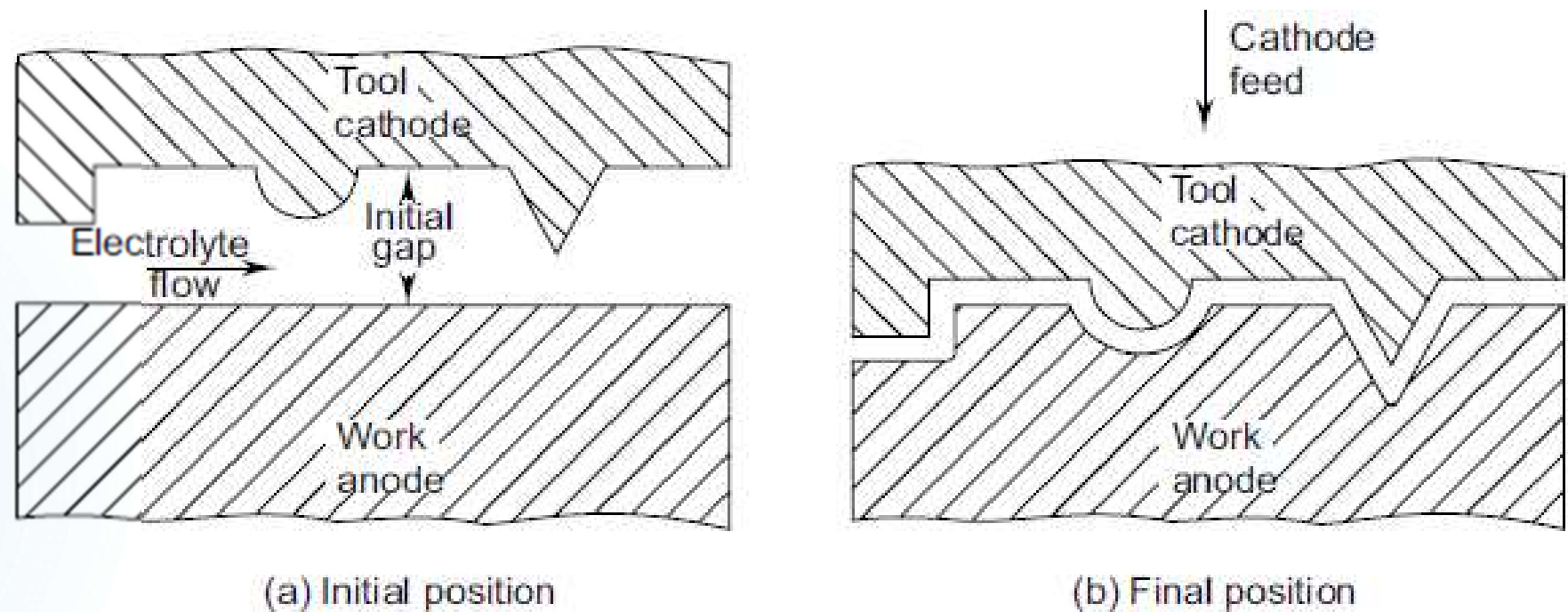


Figure: 7 Complimentary shape produced by ECM

ECM System Analysis

The electrolysis process is governed by the following two law's proposed by Faradays:

- ❖ The amount of chemical change produced by an electric current that is the amount of any material dissolved or deposited is proportional to the quantity of electricity passed.
- ❖ The amount of different material dissolved or deposited by the same quantity of electricity are proportional to their chemical equivalent weights.

In the quantitative form, Faradays two las states that

$$m \propto I t \varepsilon \dots\dots\dots(1)$$

where

m = weight (in grams) of a material dissolved or deposited,

I = Current (In Amp),

t = time (in seconds)

ε = gram equivalent weight of the material

Now Introducing the constant of proportionality F, commonly called Faraday (=96500 coulombs) so rewrite the equation (1)

$$m = \frac{I t \varepsilon}{F} \dots\dots\dots(2)$$

The gram equivalent weight of the metal is given by

$$\varepsilon = \frac{A}{Z} \dots\dots\dots(3)$$

where

A = atomic weight

Z = valency of the ion produced

Using eq (2) we get the rate of mass removal in the form

$$m = \frac{AI}{ZF} \dots\dots\dots(4)$$

If the density of the anode material is ρ , the volumetric removal rate is given by

$$Q = \frac{AI}{\rho ZF} \dots\dots\dots(5)$$

where

A = gram atomic weight of the metallic ions

Z = valency of the ion produced

I = current (In Amp),

F = Faraday (=96500 coulombs)

ρ = density of the anode (g/m³)

Electrolyte

Functions of ECM are:

- Completes the electrical circuit between the tool and the work piece,
- Allow desirable machining reactions to take place,
- Carry away heat generated during the operation,
- Carry away products of reaction from the zone of machining.

Properties are:

- High electrical conductivity
- Low viscosity and high specific heat
- Chemical stability
- Resistance to formation of passivating film on work piece surface
- Non corrosive and non-toxic
- Inexpensive and readily available

Electrolytes such as : Sodium chloride or potassium chloride up to 0.25 kg/litre, Sodium nitrate up to 0.50 kg/litre, etc.

- ❖ **Feed rate:** High feed rate results in higher material removal rate. It also decreases the equilibrium-machining gap resulting in improvement of surface finish and tolerance control.
- ❖ **Voltage:** Low voltage decreases the equilibrium-machining gap and results in better surface and finer tolerance control.
- ❖ **Current:** Increased current leads to electrolyte heating, the limiting condition being the boiling point of the electrolyte. More metallic ions react with the electrolyte causing higher hydrogen evolution. Also it leads to polarised ionic layers forming at the electrodes causing voltage drops.
- ❖ **Electrolyte concentration:** Low concentration of the electrolyte decreases the machining gap and results in better surface and finer tolerance control.
- ❖ **Electrolyte temperature:** Low temperature of the electrolyte is conducive to better surface finish and tolerances.

1. Tool doesn't come in contact with the work piece or any other friction So wear and tear of the tool is negligible.
2. Toughness and brittleness of a material has no effect on the machining process.
3. In this method , metal removal is an atom by atom resulting in higher surface finish and crack free surface.
4. No heat affected zone.
5. Very accurate and relatively fast

Disadvantages :

1. Large power consumption
2. Sharp internal corner cannot be achieved.
3. Work material used must be good conductor of electricity.
4. More expensive than conventional machining.
5. Need more area for installation.

- ▶ The most common application of ECM is high accuracy duplication. Because there is no tool wear, it can be used repeatedly with a high degree of accuracy.
- ▶ It is also used to make cavities and holes in various products.
- ▶ Sinking operations (RAM ECM) are also used as an alternative to RAM EDM.
- ▶ It is commonly used on thin walled, easily deformable and brittle material because they would probably develop cracks with conventional machining.

- ❖ The shape of the finished work surface is produced by a formed electrode tool.
- ❖ The sparks occur across a small gap between tool and work surface.
- ❖ Electrical discharge machining (EDM) removes metal by discharging electric current from a pulsating DC power supply across a thin interelectrode gap

FIGURE 8 Electric discharge machining (EDM): (a) overall setup, and (b) close-up view of gap, showing discharge and metal removal.

- ❖ The region in which discharge occurs is heated to extremely high temperatures, so that a small portion of the work surface is suddenly melted and removed.
- ❖ The flowing dielectric then flushes away the small particle (call it a “chip”).
- ❖ Because the surface of the work at the location of the previous discharge is now separated from the tool by a greater distance, this location is less likely to be the site of another spark until the surrounding regions have been reduced to the same level or below.
- ❖ Although the individual discharges remove metal at very localized points, they occur hundreds or thousands of times per second so that a gradual erosion of the entire surface occurs in the area of the gap

- Discharge current and
- Frequency of discharges.

❖ As either of these parameters is increased, metal removal rate increases. Surface roughness is also affected by current and frequency, as shown in Figure 9.

❖ The best surface finish is obtained in EDM by operating at high frequencies and low discharge currents.

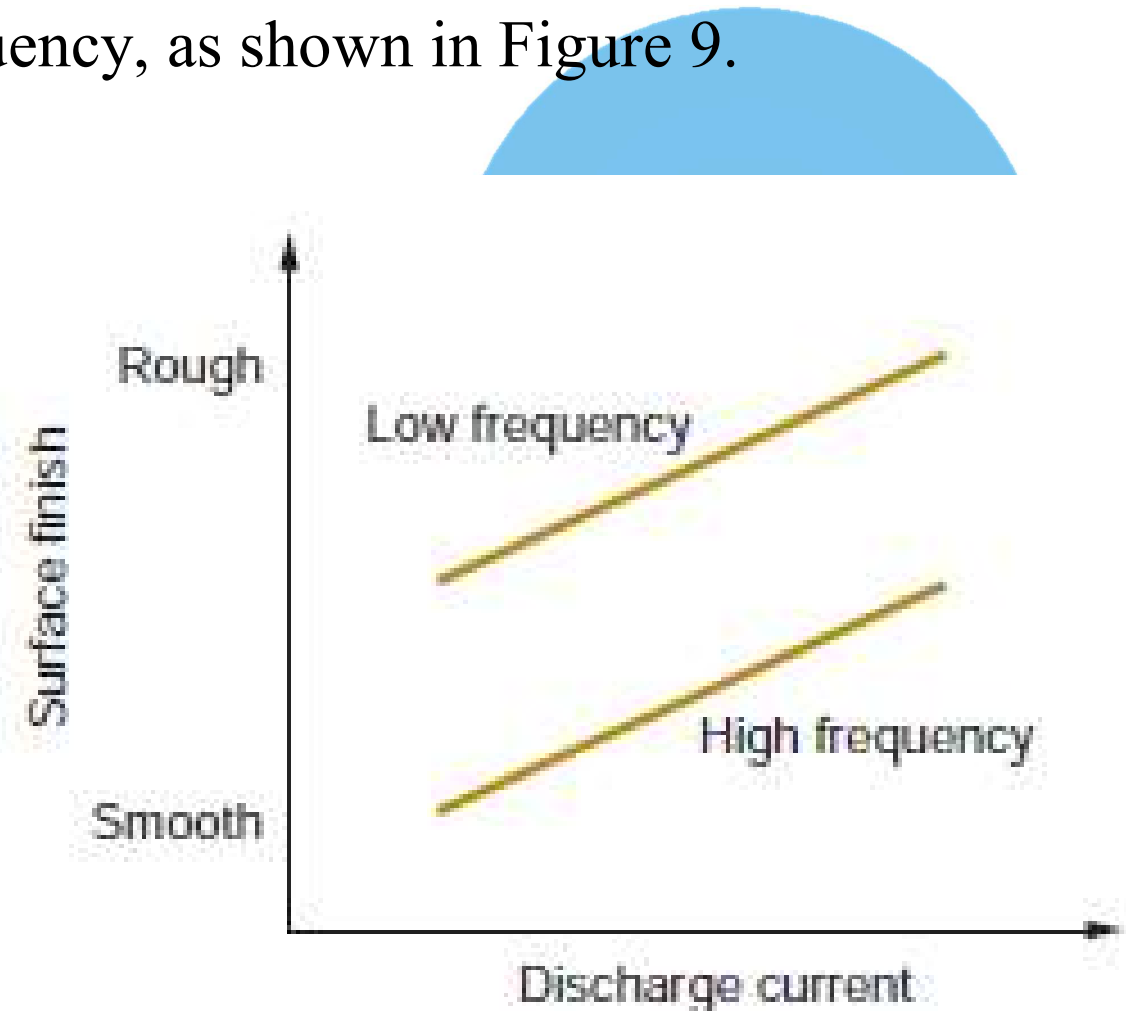


FIGURE 9 Surface finish in EDM as a function of discharge current and frequency of discharges.

- ❖ As the electrode tool penetrates into the work, overcutting occurs.
- ❖ **Overcut** in EDM is the distance by which the machined cavity in the work part exceeds the size of the tool on each side of the tool, as illustrated in Figure 8(a).
- ❖ It is produced because the electrical discharges occur at the sides of the tool as well as its frontal area. Overcut is a function of current and frequency, as seen in Figure 10, and can amount to several hundredths of a millimeter.

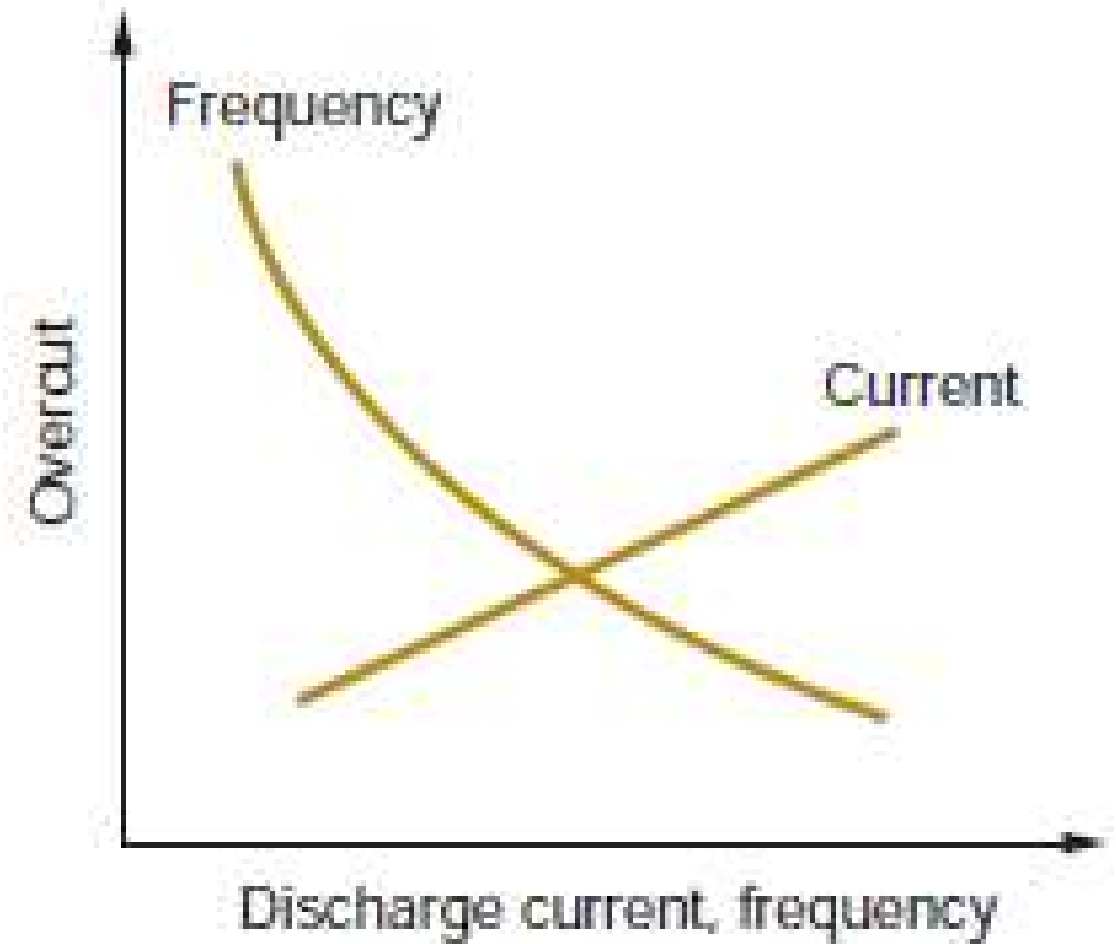


FIGURE 10: Overcut in EDM as a function of discharge current and frequency of discharges.

Schematic Diagram of EDM

A typical schematic of the various elements present in a commercial EDM machine is shown in Fig. 11.

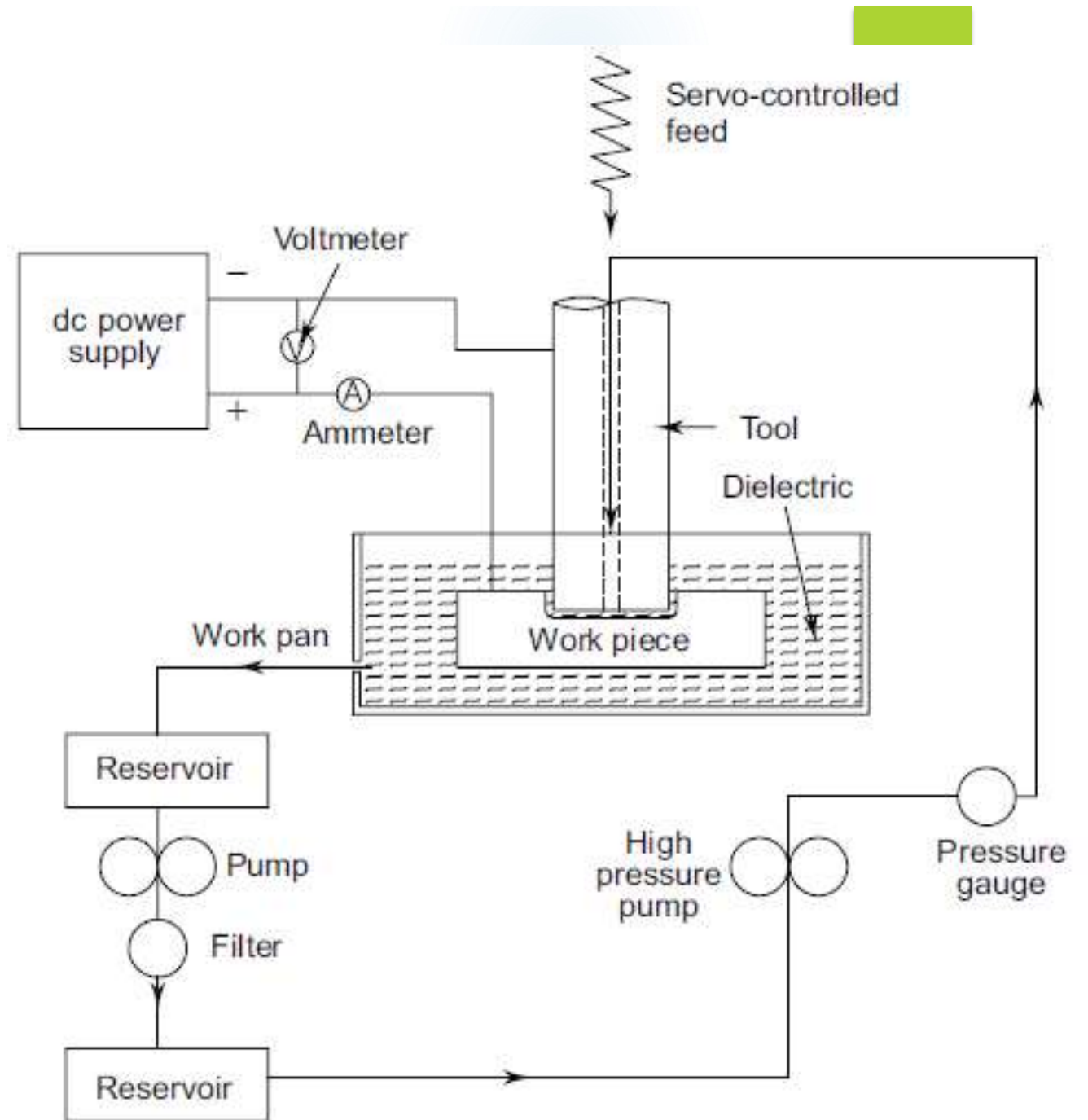


Figure 11: Typical schematic of the components that form a typical EDM machine

Dielectric Fluid

The requirements are:

- The dielectric fluid should have sufficient and stable dielectric strength to serve as insulation between the tool and work till the breakdown voltage is reached.
- It should de-ionise rapidly after the spark discharge has taken place.
- It should have low viscosity and a good wetting capacity to provide effective cooling mechanism and remove the swarf particles from the machining gap.
- It should flush out the particles produced during the spark out of the gap. This is the most important function of the dielectric fluid. Inadequate flushing can result in arcing decreasing the life of the electrode and increasing the machining time.
- It should be chemically neutral so as not to attack the electrode, the work piece, the table or the tank.
- Its flash point should be high so that there are no fire hazards.
- It should not emit any toxic vapours or have unpleasant odours.
- It should maintain these properties with temperature variation, contamination by working residuals and products of decomposition.
- It should be economical and easily available

Properties of dielectric fluids

- ❖ **Flash point** : It is the lowest temperature at which a dielectric gives off sufficient vapours to produce an inflammable mixture of air and gases in a standardized apparatus. The higher the flash point, the better it is for use in EDM. Generally any temperature higher than 80°C should be considered good for the operation.
- ❖ **Dielectric strength** : This is the ability of the fluid to maintain high resistivity before spark discharge and in turn the ability to recover rapidly with a minimal amount of OFF time. Fluid with a high dielectric strength offers finer degree of control. This will ensure better cutting efficiency.
- ❖ **Viscosity** : Fluids with lower viscosity are better for producing accurate and finer surfaces. Dielectrics of 2 to 3.5 cSt at a temperature of 20° C are suitable for polishing work while 4 to 6.5 cSt at 20° C is suitable for rough cut operations.

- ❖ **Specific gravity** : Dielectrics normally have a specific gravity of 0.750-0.820. The heavier chips settle down in the lighter dielectric reducing the gap contamination and possibilities of secondary discharge and/or arcing.
- ❖ **Odour** : The unused dielectric should normally be odourless and should not begin to smell, even when heated.
- ❖ **Effect on health** The effect of the dielectric on the health of the operator is of paramount importance. Of particular importance are its effects on skin irritation, toxicity, and smoke generation.

Flushing

- ❖ Flushing refers to the method in which the dielectric fluid flows between the tool and the work gap.
- ❖ The efficiency of machining depends to a greater extent on the efficiency of the flushing.
- ❖ The wear debris present in the spark gap should be removed as quickly as possible.
- ❖ With poor flushing there is a possibility of build-up of the machined particles in the gap resulting in the short-circuiting and lower material removal rates.

The flushing method that can be used in EDM depends upon the work piece geometry and can be classified as:

- Normal flow
- Reverse flow
- Jet flushing
- Immersion flushing

❖ Normal flow

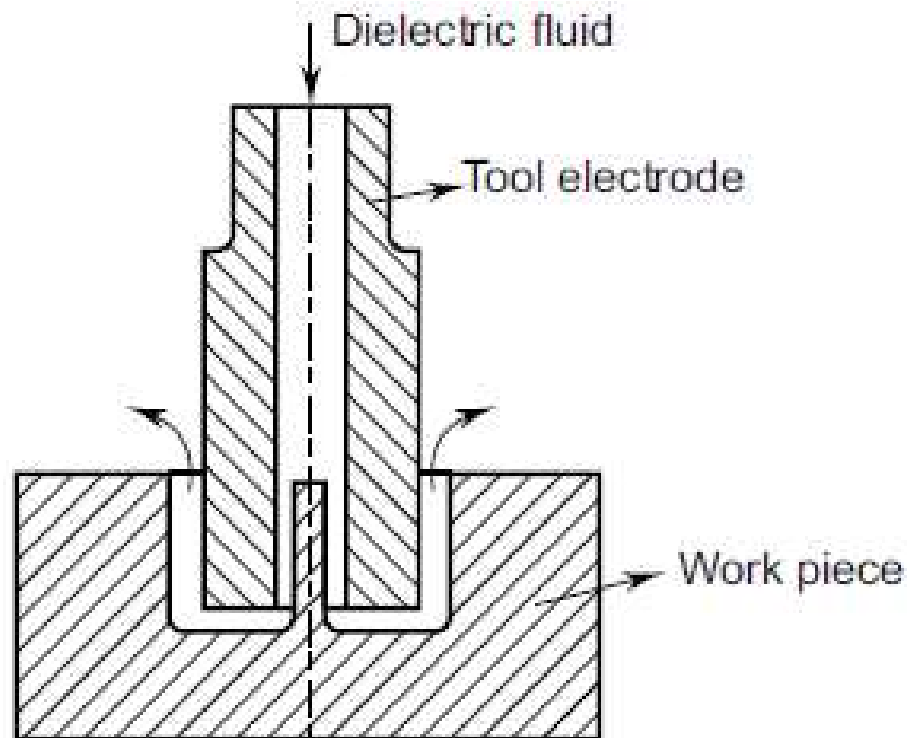


Figure 12(a): Normal flow flushing techniques used with the dielectric flow through the tool in the EDM process

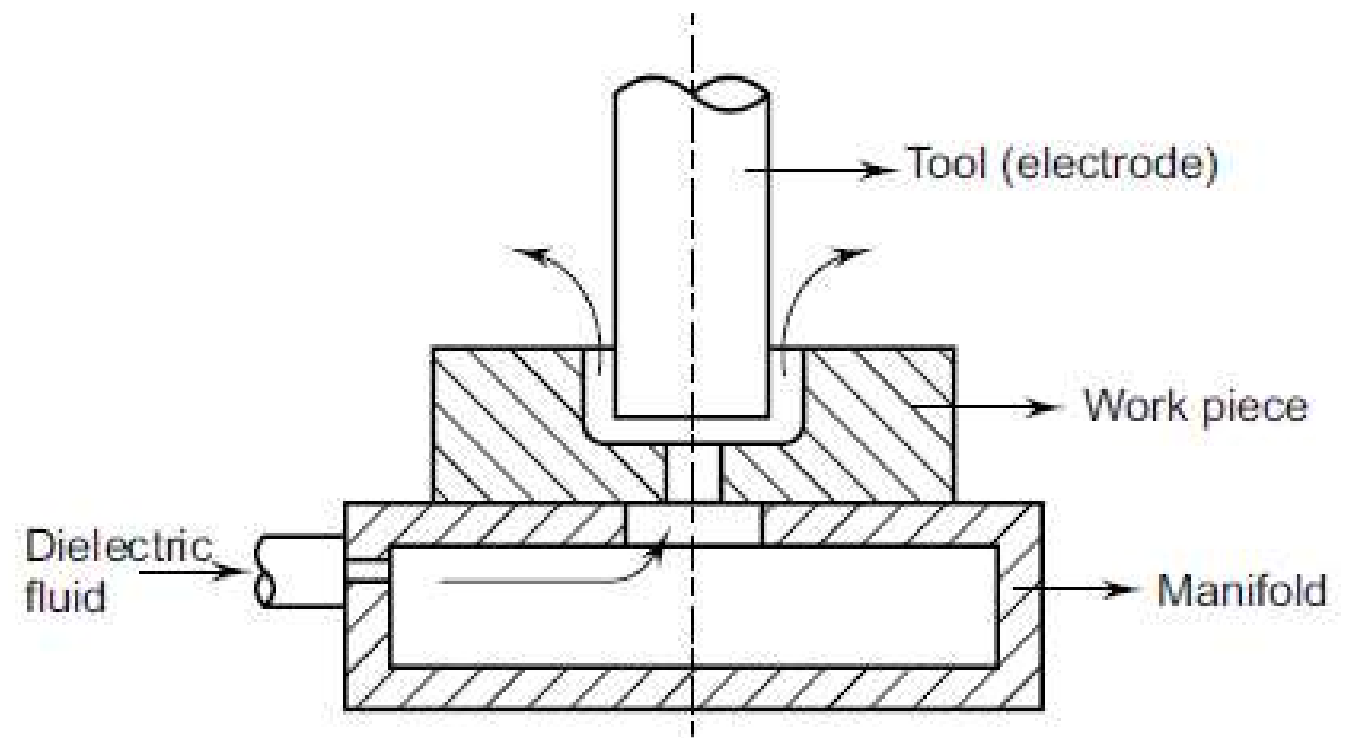


Figure 12(a): Normal flow flushing techniques used with the dielectric flow through the work piece in the EDM process

❖ Reverse flow

In this case the gap between the tool and workpiece is completely submerged in the dielectric fluid and then a vacuum is applied to the manifold

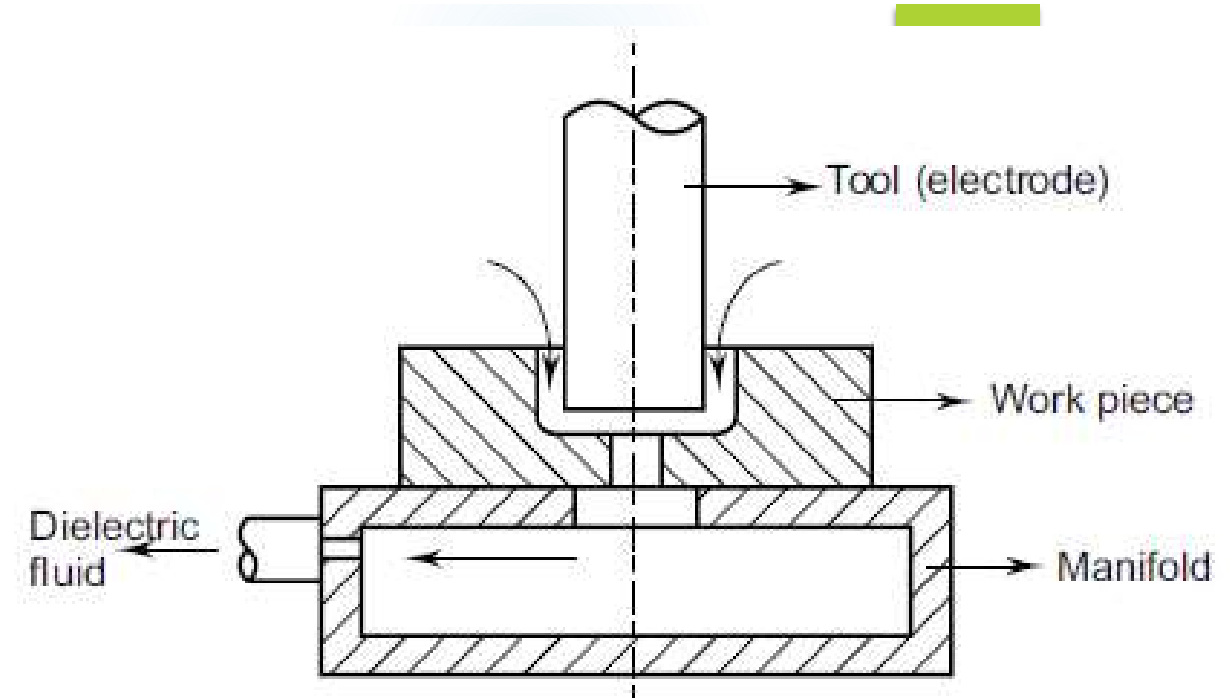
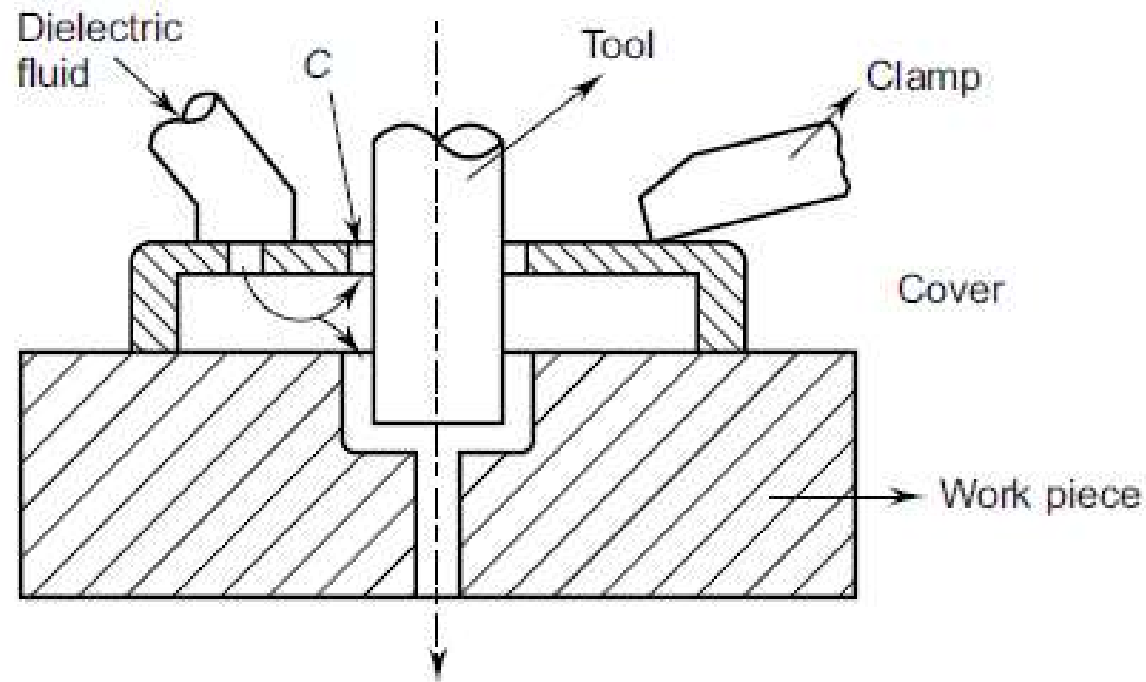


Figure 13(a): Reverse flow flushing techniques used in the EDM process



Instead of vacuum, a positive pressure can be applied to achieve reverse flow

Figure 13(b): Reverse flow flushing techniques used in the EDM process

❖ Jet flushing

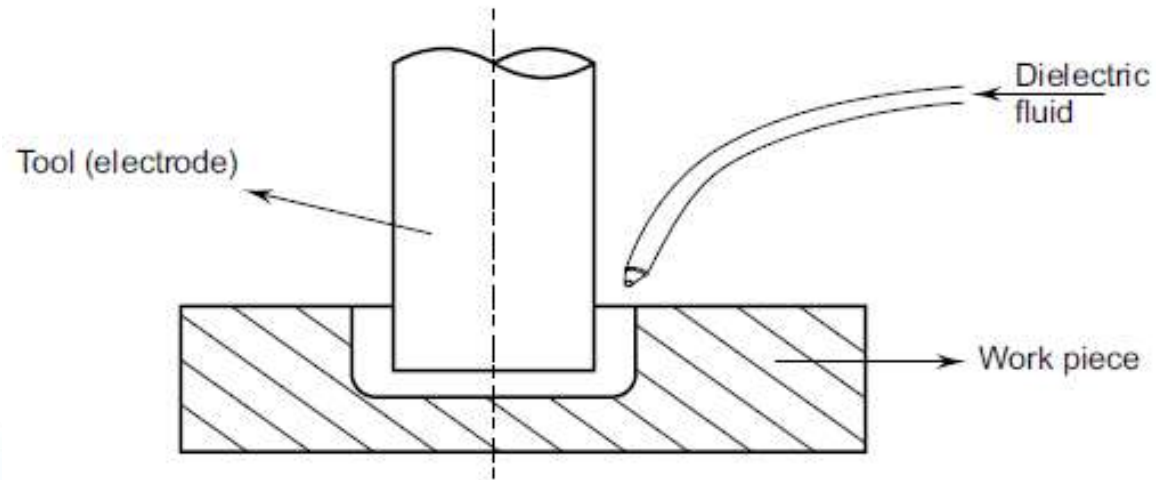


Figure 14: Jet flushing technique used in the EDM process

❖ Immersion flushing

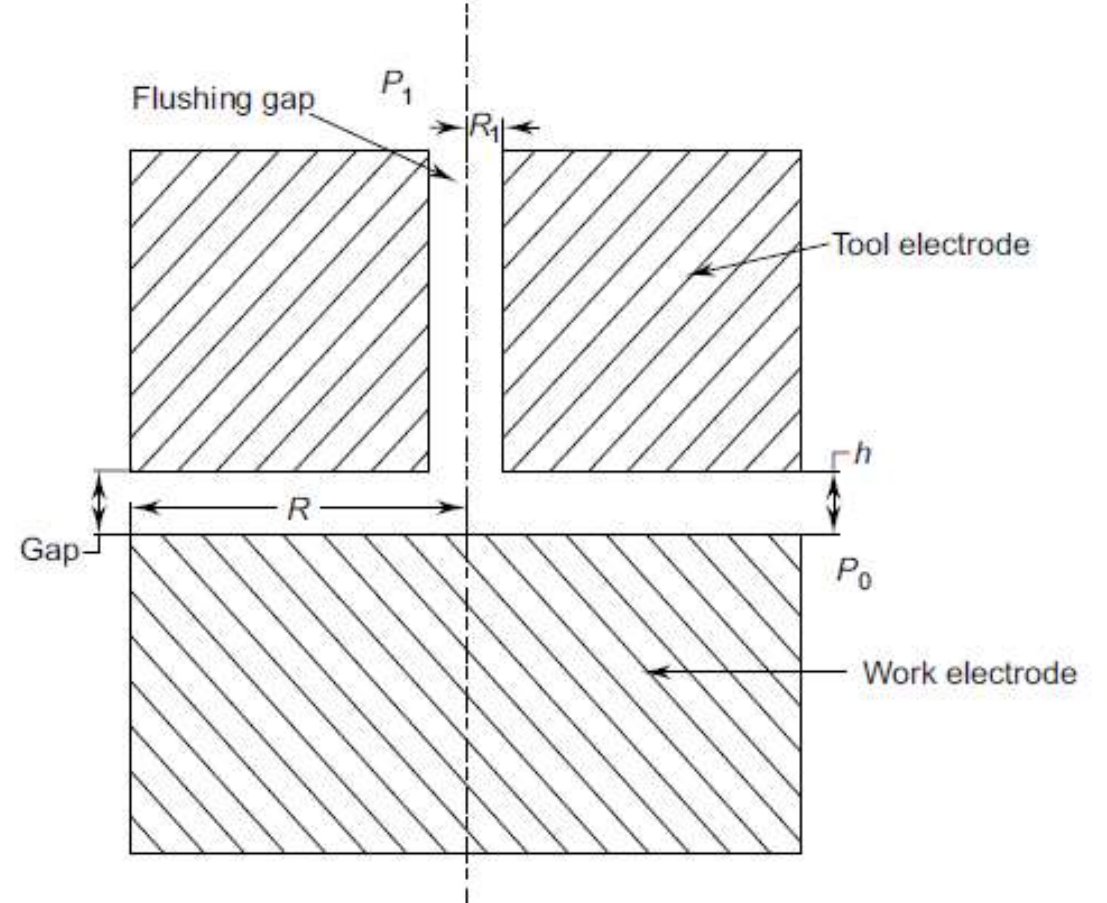


Figure 15: Fluid flow passage through the electrode in the EDM process

Electrodes

In the EDM process the shape of the electrode is impressed on the work piece in its complimentary form. The shape and accuracy of the electrode plays a very important role in the final accuracy of the work piece machined.

The electrode material should have the following characteristics to serve as a good tool.

1. It should be a good conductor of electricity and heat.
2. It should be easily machinable to any shape at a reasonable cost.
3. It should produce efficient material removal rates from the work pieces.
4. It should resist the deformation during the erosion process.
5. It should exhibit low electrode (tool) wear rates.
6. It should be available in a variety of shapes.

Various electrode materials used: Graphite, Copper, Copper graphite, Brass, Zinc alloys, Steel, Copper tungsten, Silver tungsten, Tungsten, etc.

The material removal rate, MRR is given by

$$MRR = \frac{K_M V_c^2}{2R_c} \frac{1}{\log_e \left(\frac{1}{1 - \frac{V_c}{V_o}} \right)}$$

Where

K_M = proportionality constant.

R_c = resistance,

V_o = voltage when power supply is on

V_c = Capacitor voltage

Examples of EDM

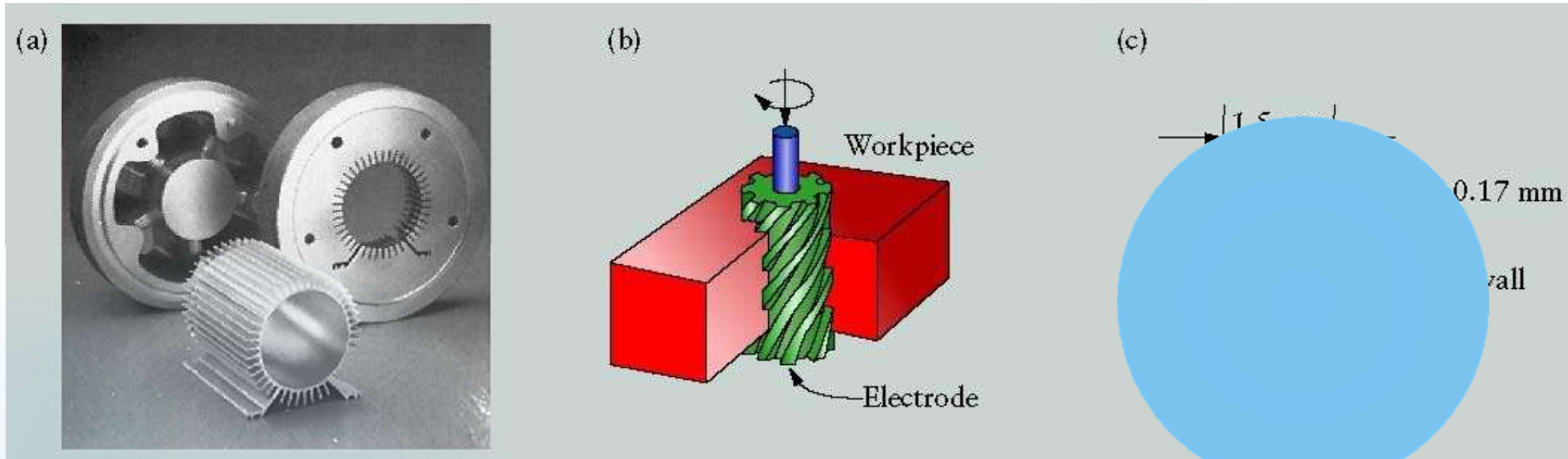


FIGURE 15 : (a) Examples of cavities produced by the electrical-discharge-machining process, using shaped electrodes. The two round parts (rear) are the set of dies for extruding the aluminum piece shown in front, (b) A spiral cavity produced by a rotating electrode, (c) Holes in a fuel-injection nozzle made by electrical-discharge machining. Material: Heat-treated steel.

Process Characteristics

The metal removal rates in EDM depend upon the following parameters, which are discussed in greater details below:

- Current in each spark
- Frequency of the discharge
- Electrode material
- Work piece material
- Dielectric flushing condition

Advantages

- ❖ There is no physical contact between the tool and the work piece and hence no cutting forces acting on the work piece. Even fragile work pieces can be machined using this process.
- ❖ Any complex shape required in dies and mould can be easily produced to the required degree of accuracy and finish.
- ❖ The process is not affected by the hardness of the work material.
- ❖ The material removal rates are almost comparable with that of the conventional machining processes.
- ❖ Since there are no cutting forces acting on the tool, high aspect ratio surfaces can be machined using EDM process.
- ❖ The process is generally highly automated with very little operator skill required.
- ❖ The actual surface produced by EDM consists of small craters, which may help in the retention of the lubricants.

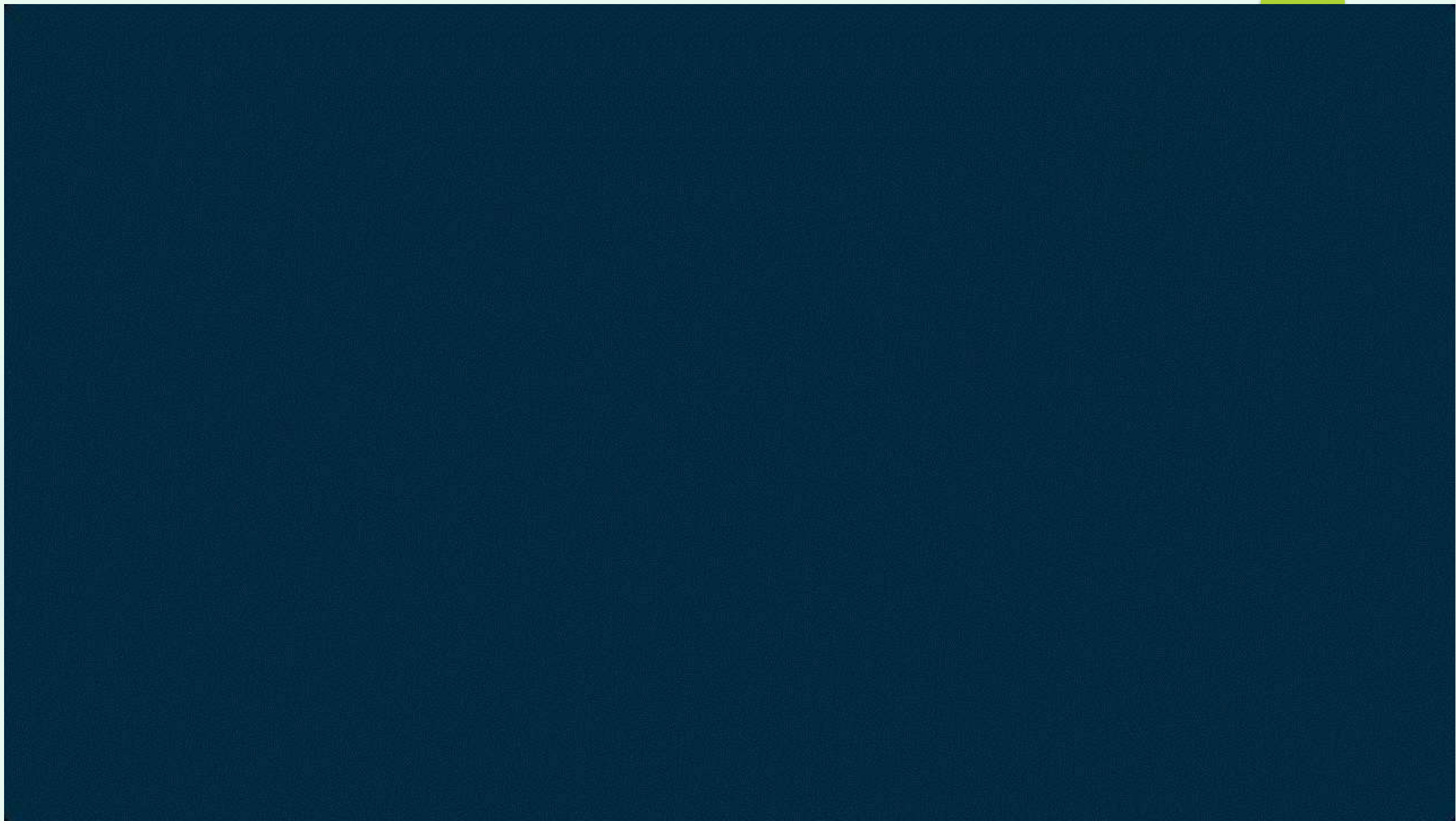
Disadvantages

- The wear rate on the electrode is considerably higher. Sometimes it may be necessary to use more than one electrode to finish the job.
- The work piece should be electrically conductive to be machined using the EDM process.
- The energy required for the operation is more than that of the conventional process and hence will be more expensive.

Applications

The EDM process is extensively used because of its many advantages. Applications of EDM include both tool fabrication and parts production:

- ❖ Molds for plastic injection molding,
- ❖ Extrusion dies, wire drawing dies,
- ❖ Forging and heading dies,
- ❖ Sheet metal stamping dies.
- ❖ hole drilling



Wire EDM

- ❖ Electric discharge wire cutting (EDWC), commonly called *wire EDM*, is a special form of electric discharge machining that uses a small diameter wire as the electrode to cut a narrow kerf in the work.
- ❖ The cutting action in wire EDM is achieved by thermal energy from electric discharges between the electrode wire and the workpiece.
- ❖ The workpiece is fed past the wire to achieve the desired cutting path, somewhat in the manner of a bandsaw operation.
- ❖ Numerical control is used to control the work part motions during cutting.
- ❖ As it cuts, the wire is slowly and continuously advanced between a supply spool and a take-up spool to present a fresh electrode of constant diameter to the work. This helps to maintain a constant kerf width during cutting.
- ❖ As in EDM, wire EDM must be carried out in the presence of a dielectric.
- ❖ Wire diameters range from 0.076 to 0.30 mm (0.003–0.012 in), depending on required kerf width.
- ❖ Materials used for the wire include brass, copper, tungsten, and molybdenum. Dielectric fluids include deionized water or oil.

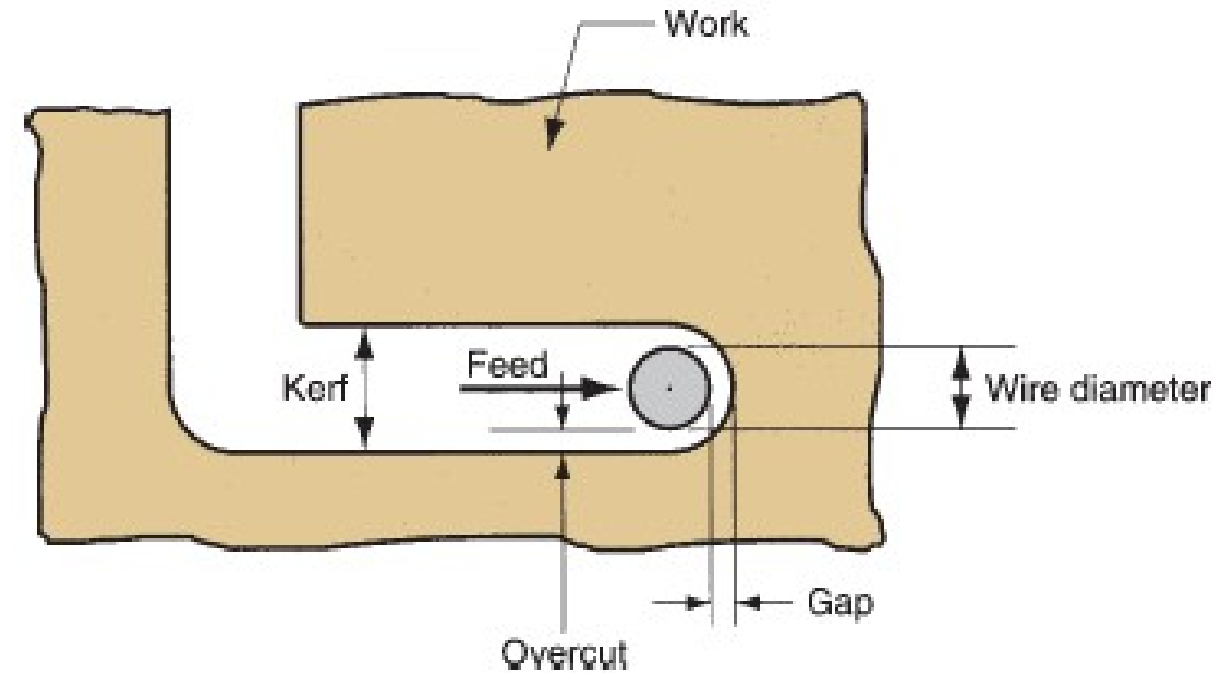
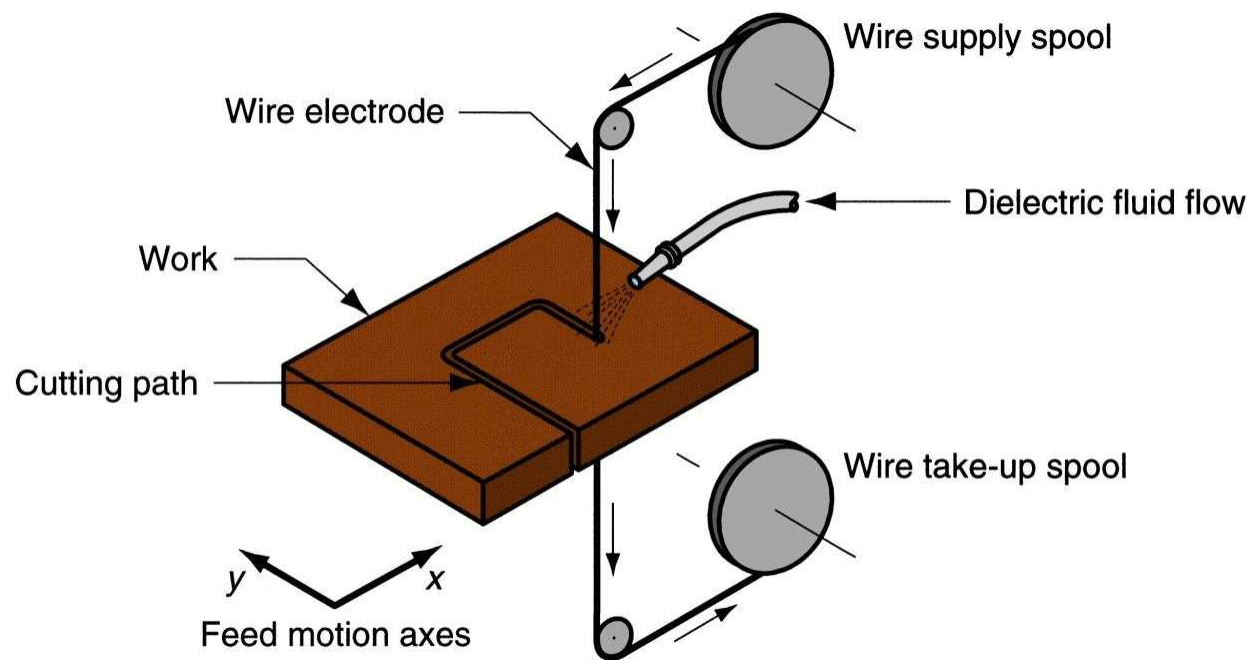


FIGURE 16 : (a) Wire EDM Process, (b) Definition of kerf and overcut in electric discharge wire cutting

- ❖ As in EDM, an overcut exists in wire EDM that makes the kerf larger than the wire diameter, as shown in Figure 16(b).
- ❖ This overcut is in the range 0.020 to 0.050 mm (0.0008–0.002 in). Once cutting conditions have been established for a given cut, the overcut remains fairly constant and predictable.

Advantages

- ❖ Although EDWC seems similar to a bandsaw operation, its precision far exceeds that of a bandsaw.
- ❖ The kerf is much narrower, corners can be made much sharper, and the cutting forces against the work are nil.
- ❖ In addition, hardness and toughness of the work material do not affect cutting performance. The only requirement is that the work material must be electrically conductive.

Applications

- ❖ The special features of wire EDM make it ideal for making components for stamping dies. Because the kerf is so narrow, it is often possible to fabricate punch and die in a single cut.
- ❖ Other tools and parts with intricate outline shapes, such as lathe form tools, extrusion dies, and flat templates, are made with electric discharge wire cutting.