Advanced Manufacturing Processes
Prof. Dr. Apurbba Kumar Sharma
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Module - 3
Advanced Machining Processes
Lecture - 14
Electrochemical Machining (ECM)

Welcome to this session on electrochemical machining under the course advance manufacturing processes. In one of the previous sessions we have discussed about the electrochemical discharge machining process, its principles and features, different variants and new developments in this process. Moving ahead we will now discuss about another advanced manufacturing process, namely the electrochemical machining process. Let us study its basics and basics of electrolysis.

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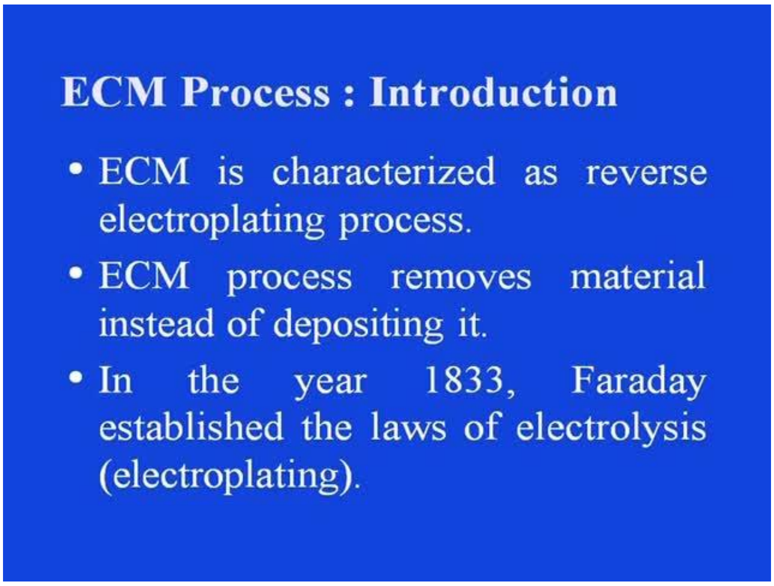

The electrochemical machining process: The electrochemical machining also in short very popularly known as ECM is characterized as reverse electroplating process. This ECM process removes material instead of depositing it. In the year 1833, Faraday established the laws of electrolysis or for electroplating. So, this is the basis for this process which is very, very popular not only in these industries, but outside these industries also for some other purposes like for electroplating of different materials.

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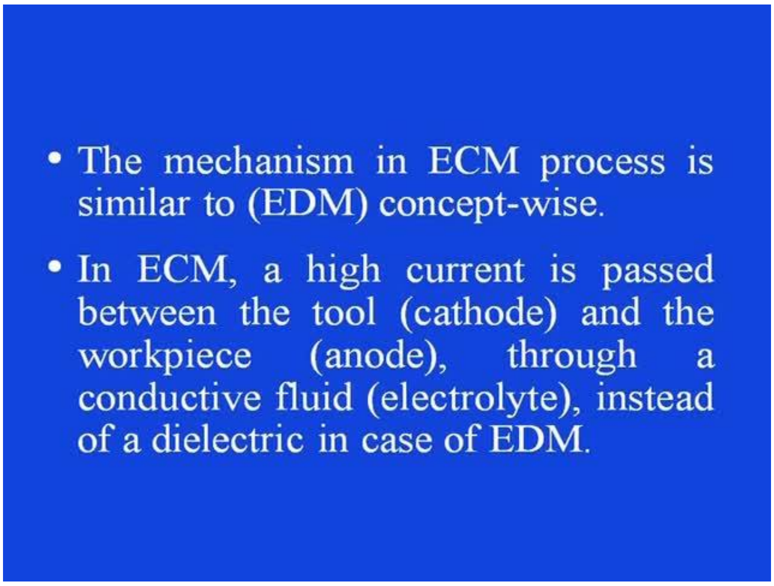

The mechanism in electrochemical machining process is similar to EDM process concept wise. In ECM a high current is passed between the tool which is the cathode, and the work piece which is made anode through a conductive fluid which is also called electrolyte instead of dielectric in case of EDM. That means basically in ECM and EDM in both the cases; one electric power supply is required in which in both the cases the tool is made generally the cathode, and the work is generally made the anode and both are separated by a fluid - working fluid.

In case of EDM it is called the dielectric which is a non conducting fluid and which is responsible for creation of the plasma which ultimately helps in evaporating the material from the work piece. However, in contrast in EDM in ECM we use one fluid which is capable of conducting current and is called electrolyte through which the current passes.

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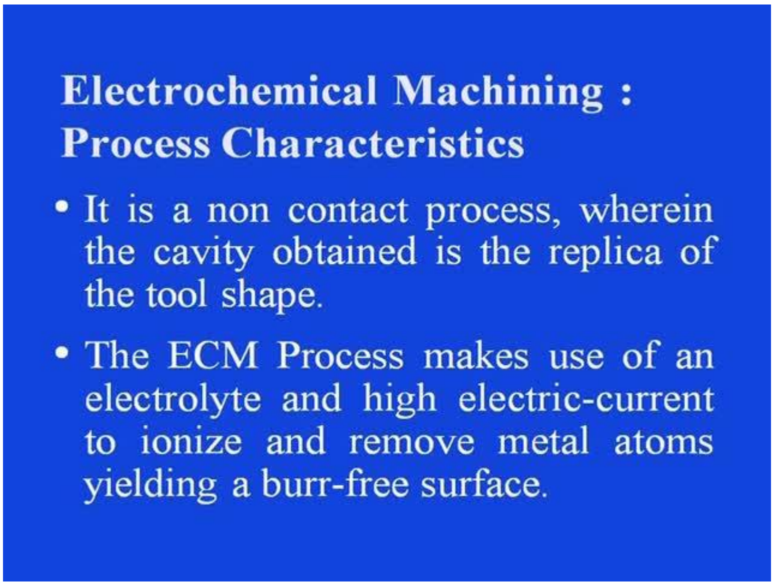

Let us discuss about the process characteristics of this electrochemical machining. It is again a non contact process wherein the cavity obtained is the replica of the tool shape. The ECM process makes use of an electrolyte as we have already spoken and high electric current to ionize and remove metal atoms yielding a burr free surface. One of the very striking features of this ECM process is that it is not affected by the strength, hardness or toughness of the work material.

Machining of conductive, any conductive material is possible irrespective of their hardness, toughness or strength. This is a very, very positive point in case of ECM whereas, in conventional machining we have to select a tool material which is harder than the work piece material. And in case of tough material it is very difficult to machine those work materials easily. The ECM process is also capable of machining complex cavities in high strength materials. The basic setup is like this.

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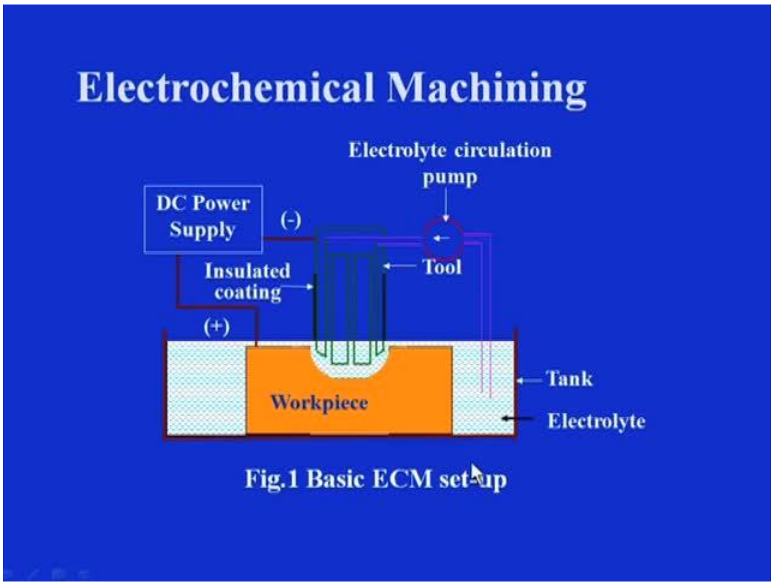

In which the work piece will be dipped in a fluid, working fluid also called the electrolyte and the electrolyte will be continuously flown through the gap between the tool and the work piece. This is the tool and this is the work piece through which there will be a gap that is also called the inter electrode gap. This gap will be maintained and this gap will be continuously filled by the electrolyte present. We will come in details about the electrolyte, how the, what what are the characteristics of this electrolyte and what are the conventionally used electrolytes in this process.

This work piece will be as I already indicated, this work piece will be connected to this positive terminal of this power supply DC power supply and the tool will be connected to the negative end of this power supply and a very high current at low voltage will be supplied or passed through this gap. Since, the high current is used generally this electrode and the work piece both will be insulated from the system. So, that there is no short circuiting or leakage of the current does take place and as far as possible this electrolyte will be filtered and kept on flowing through the electrodes continuously.

This rate of pumping and the pressure at which this electrolyte will be pumped should be decided before hand depending on the applications or the requirement of the process. Therefore, the pump for flowing or pumping this electrolyte should be decided accordingly. Now, let us see the fundamentals of this process. The electrolysis process being the most fundamental activity in ECM, its characteristics need to be understood before proceeding into the process details.

The the term electrolysis as the name suggest is a chemical phenomenon that occurs between two conductors dipped in a suitable solution when electric current is passed between them. For example, if two copper wires are dipped in a copper sulphate solution and they are connected to a source of direct current as shown in this figure the basic ECM cell will be formed. This solution of copper sulphate is termed as the electrolyte which is electrically conductive.

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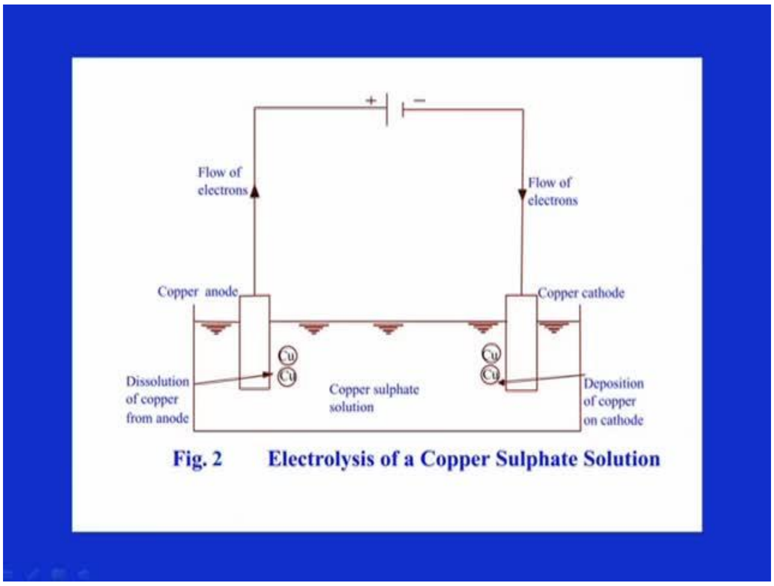

Fig. 2 Electrolysis of a Copper Sulphate Solution

This is shown here. So, this is the, this is the copper sulphate solution which is a conductive liquid and the current can pass through this. And these are the two electrodes partially submerged or dipped into this solution and are connected to the electrical energy source which is a DC source and the positive terminal will be connected to the work piece from which the material will go into the solution, whereas the other one the negative terminal will be connected to the plate or the electrode in which metal will get deposited.

However, in case of machining as required in the industrial purposes, for the industrial purposes, material removal purposes will discourage this material getting deposited on the electrode. Rather, these materials which come into the solution will be taken away getting being deposited on this electrode so that the electrode geometry or the characteristics remain same. And in, the selection of the electrode material is also very very important. So, there should be a parity between the electrolyte used and the electrodes used.

Therefore, in this copper sulphate solution copper electrodes give the best result and accordingly selected. The entire system of electrolyte and electrodes is called the electrolytic cell. As a part of polarity the chemical reactions occurring at the anode and cathode are called as anodic or cathodic reactions respectively .

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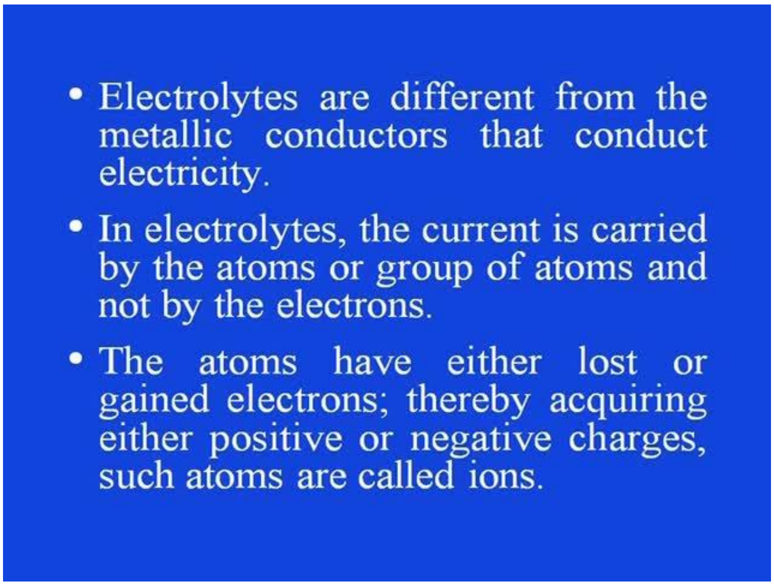

Electrolytes are different from the metallic conductors that conduct electricity. In electrolytes the current is carried by the atoms or group of atoms and not by electrons as in the case of conductors, solid conductors where the electrons move and as a result we get the current. The atoms have either lost or gained electrons; thereby acquiring either positive or negative charges. Such atoms are called ions.

The ions that carry positive charges are attracted by the cathode and they move through the electrolyte in the direction of the positive current and are referred to as the cations. The negatively charged ions on the other hand get attracted to the positive electrode that is the anode and they are referred to as the anions.

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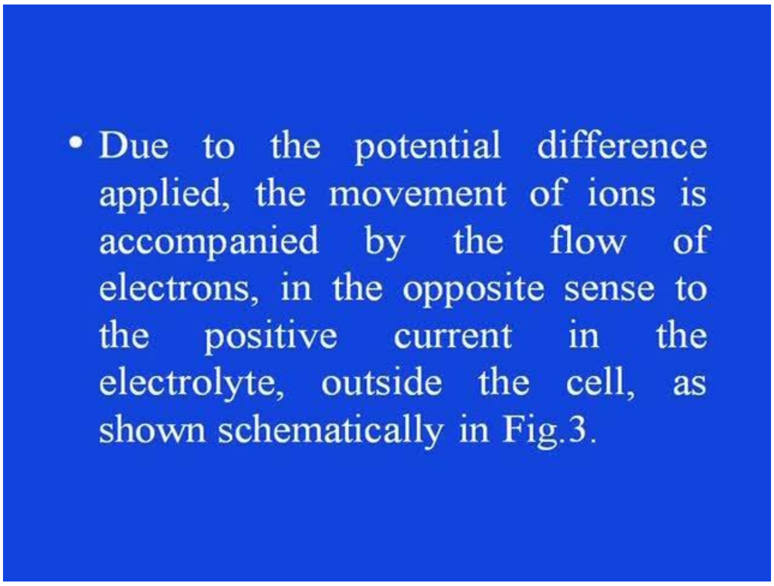

Due to the potential difference applied, the movement of ions is accompanied by the flow of electrons, in the opposite sense to the positive current in the electrolyte, outside the cell as this is shown in this figure schematically.

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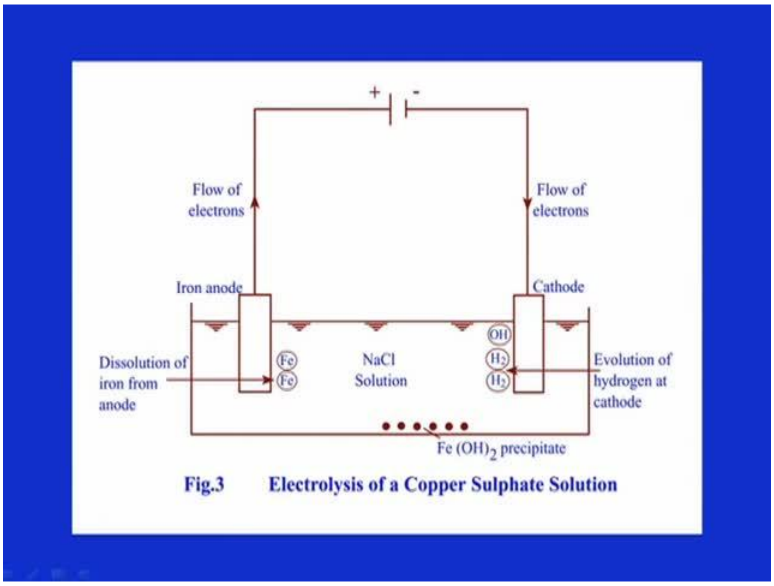

In which here is an electrolytic, electrochemical cell in which iron anode and cathodes are used, dipped partially on the solution of common salt solution that is sodium chloride solution which acts as the electrolyte in this case. And here this cell is connected to one energy source and iron is connected to the positive terminal. In this external circuit the flow of electrons is from this iron anode to this cathode like this. However, in the solution there are flow of ions that is the iron from this anode goes into the solution in the form of ions, and they react with this solution forms ferric hydroxide and they gets precipitated as shown in this particular figure as you can see in the screen.

And on the cathode the water gets disassociated into OH ions and hydrogen ions, hydrogen gas bubbles are evolved and they gets, they goes away and then the current flows in the form of ions, positive ions from this and the negative ions from this cathodes. Negative ions from this cathode will be attracted towards this positive anode in this direction. Whereas, the positive ions from this anode will be attracted towards this cathode at this point and the hydrogen gas will be evolved.

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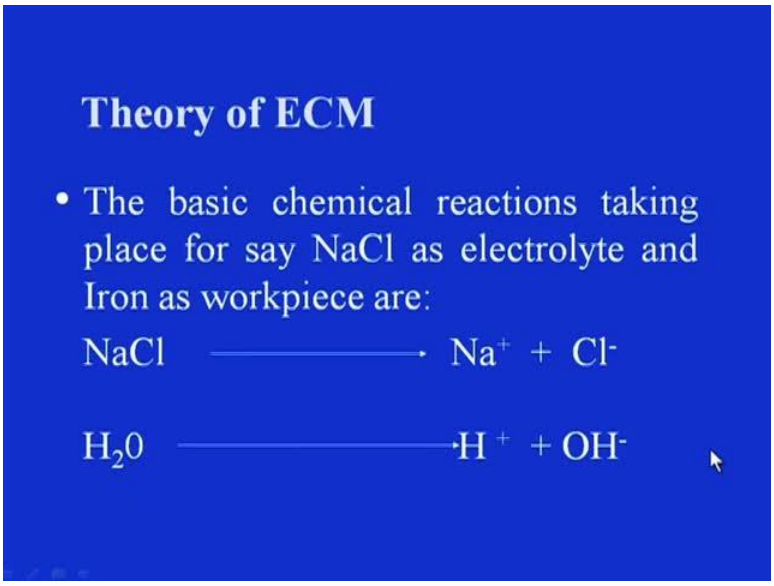

So, this is shown like this. So, in the electrolyte, sodium chloride electrolyte, sodium chloride will be disassociated into the ions of sodium as well as chlorine, the sodium ion and chlorine ion. And H 2 O which is water will be disassociated into hydrogen and OH ions, hydrogen is positively charged and OH ions are negatively charged.

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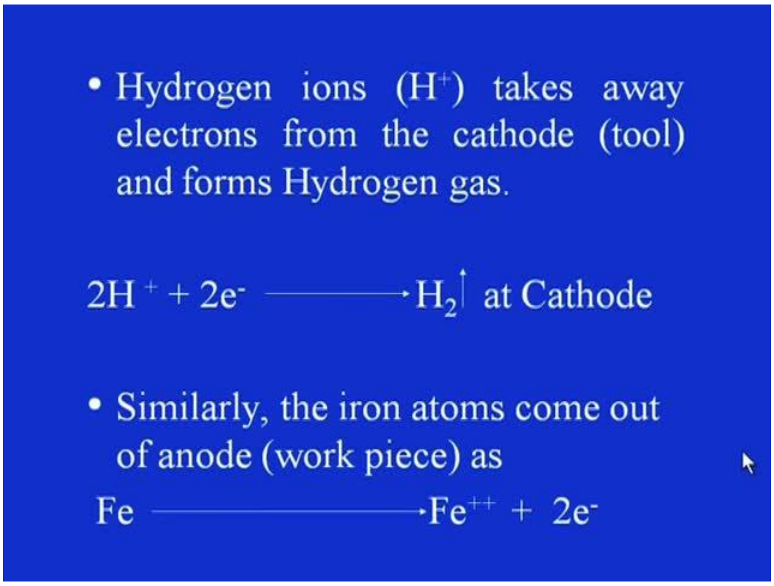

Now, these hydrogen ions take away electrons from the cathode which is a tool here and forms hydrogen gas like two hydrogen ions combines with two electrons, form one hydrogen molecule which comes out of the from the solution at the cathode. At the same time the iron atom, atoms come out of the anode which is a work piece here and they loses, they lose two electrons to form two iron ions, positively charged iron ions. Within the electrolyte iron ions combine with chloride ions to form iron chloride and sodium ions combine with hydroxyl ions to form sodium hydroxide.

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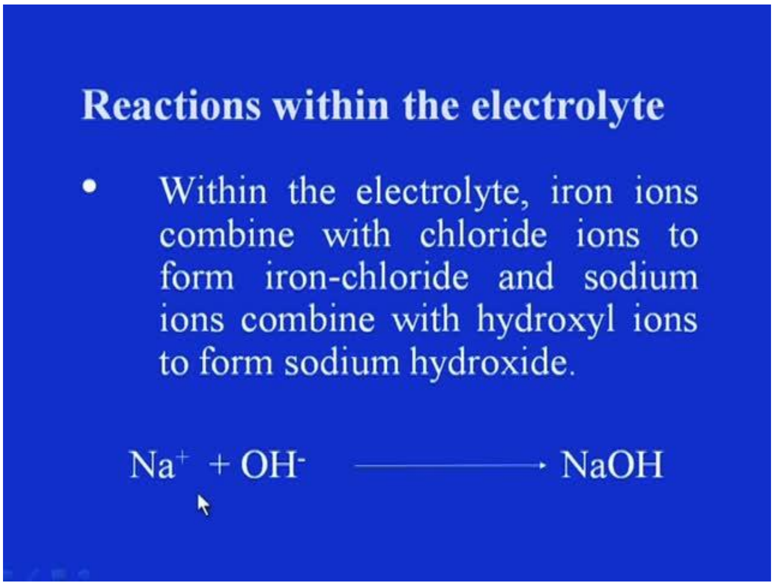

As we have seen already sodium ions are positively charged whereas, hydroxyl ions are negatively charged. Therefore, they combine to form sodium hydroxide.

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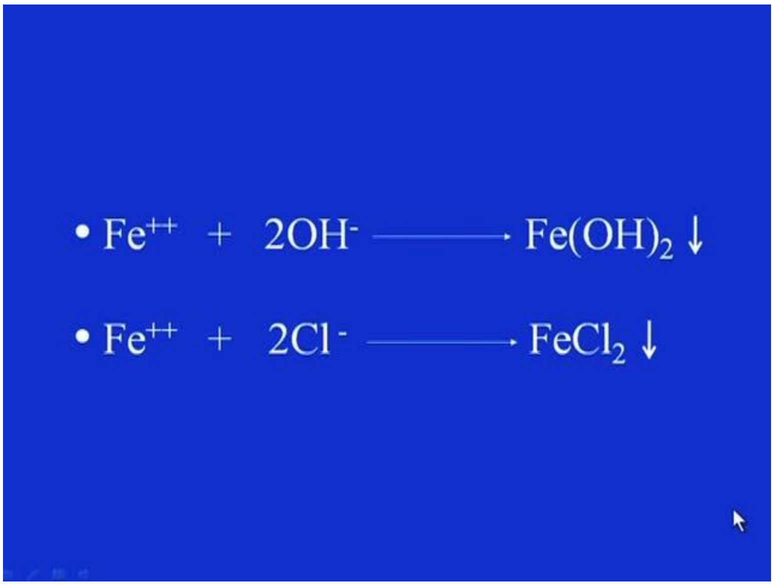

And iron ions will combine with negatively charged hydroxyl ions to form ferric hydroxide and they will get precipitated. Similarly, chlorine ions that is present in the sodium chloride solution as part of the disassociation of sodium chloride in the solution will form ferric chloride with iron ions which are positively charged. This ferric chloride also will get precipitated as in the case of ferric hydroxide. Hence, in practice Fe CL 2 and Fe OH 2 are formed and get precipitated in the form of sludge and the work piece gets gradually machined due to atomic level disassociation.

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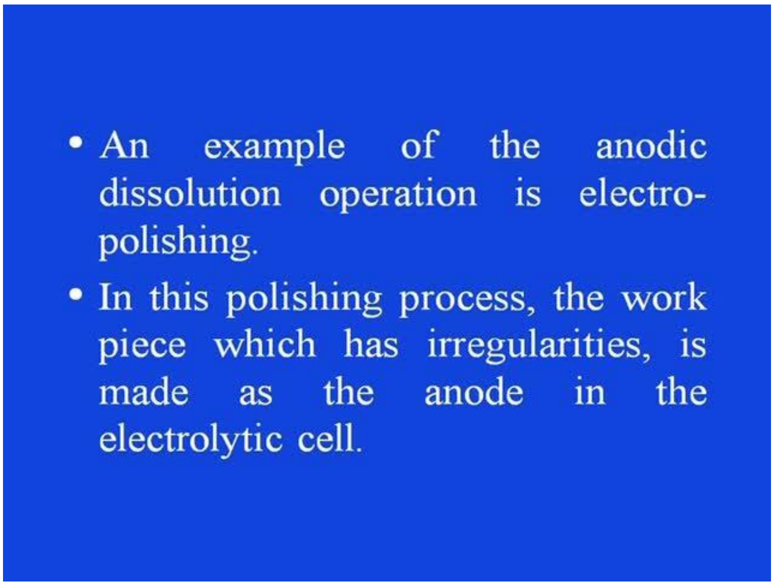

An example of the anodic dissolution operation is electro polishing. In this polishing process the work piece which has irregularities is made as the anode in the electrolytic cell. The work piece gets polished and irregularities on its surface are dissolved preferentially, so that after the process the item gets shining and becomes flat. The ECM and electro polishing processes are similar such that both are anodic dissolution processes.

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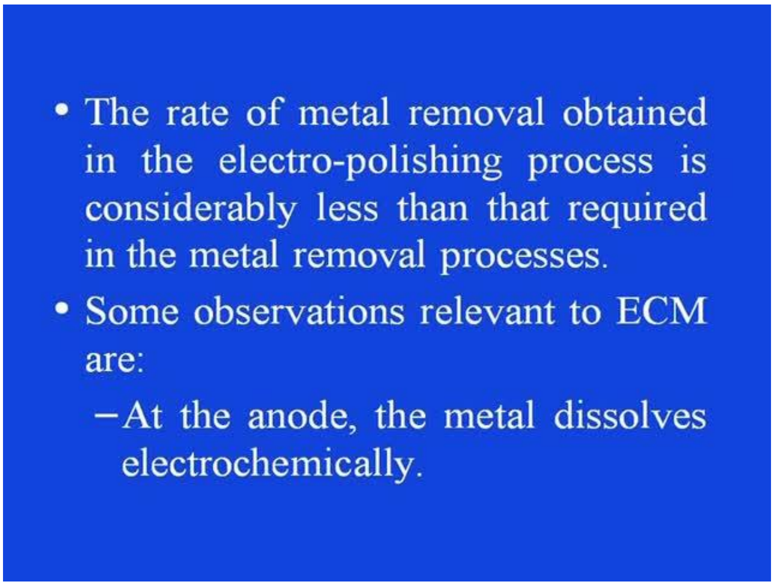

The rate of metal removal obtained in the electro polishing process is considerably less than that required in the metal removal processes. Some observations relevant to ECM are at the anode the metal dissolves electrochemically. The rate of dissolution depends upon number of factors.

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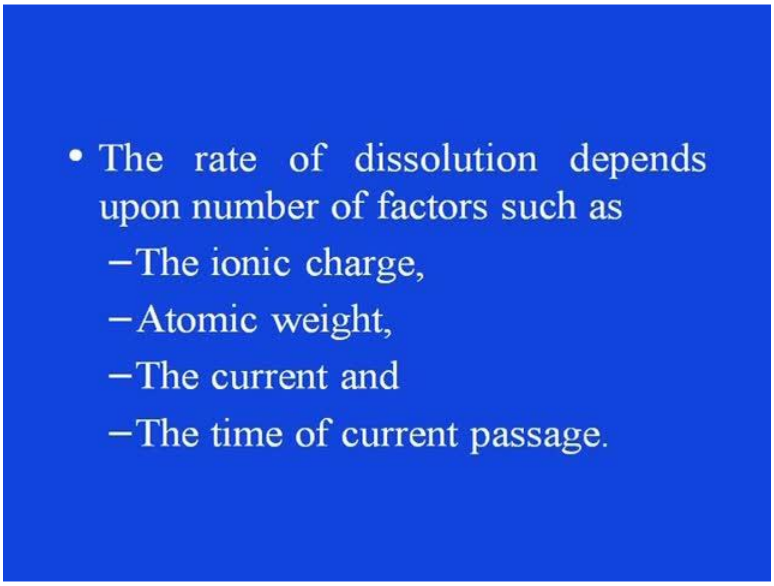

Such as ionic charge, atomic weight, the current and the time of current passage. The rate of dissolution is not influenced by the hardness of the work piece material or any other material characteristics. At the cathode only the hydrogen gas is evolved, the electrode shape remains unaltered during the electrolysis process. The unaltering nature of the electrode is the most significant feature of the ECM process among the material removal processes being used.

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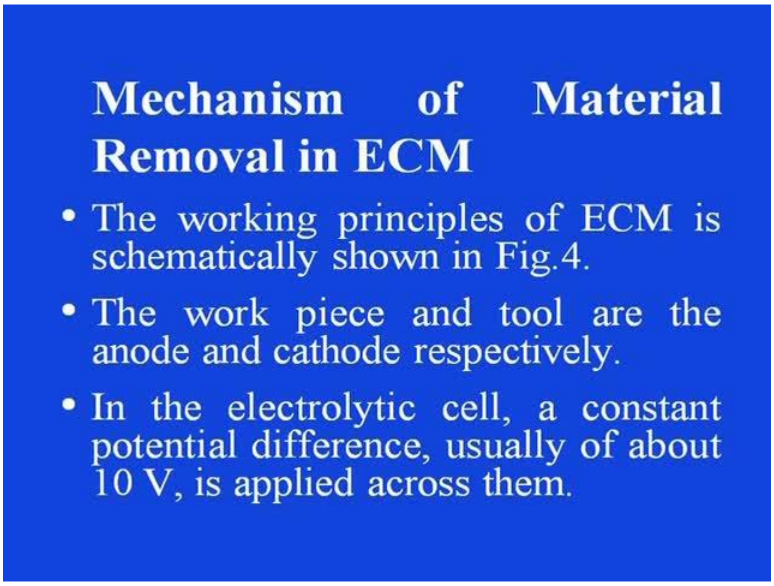

Now, let us look at the mechanism of material removal in ECM. The working principle is schematically shown in the next figure. The work piece and tool are the anode and cathode respectively. This has been already indicated. In the electrolytic cell a constant potential difference usually of about 10 volt is applied across them. This can schematically shown here.

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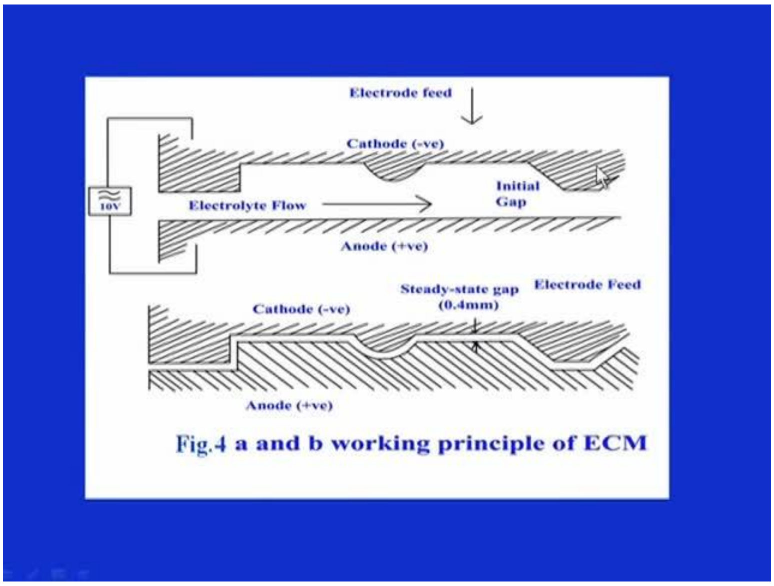

This is the cathode or the tool which is connected to the negative of this power supply something around 10 volt and this is the, this is the anode which is connected to the positive end of this power source. In between the electrolyte is kept on flowing as we have already indicated leaving a gap between this work piece, work piece and the tool that is the anode and the cathode. And the tool can have different shapes as per the requirement that means geometry of the tool that we can use has no constraint. It can be of any shape as per the requirement of the of the work piece and therefore, the same shape will be replicated or reproduced on the work piece also as we can see on the screen.

So, this is the shape of this work piece now after machining and we can see the gap also. This gap which was initially like this uneven somewhere here this was the minimum gap and somewhere here this was the maximum gap. After sometime, after this electrolysis is taking place this gap will come to be an uniform gap throughout and the process will continue further. And this is basically the working principle in ECM. This gap will be maintained by the appropriate control system for the tool advancement either for the tool advancement or for the work piece advancement at a particular rate.

And still as one can see this gap, through this gap the electrolyte will be kept on flowing continuously which will keep this, this connection between the power source or you can say cathode, and anode alive as well as which will at the same time take away the debris produced in this which are nothing but the ions, metal ions. A suitable electrolyte for example, an aqueous sodium chloride is commonly chosen. In order to remove the products of machining the electrolyte is pumped through the gap between the two electrodes. The rate at which metal is removed from the anode is approximately in inverse proportion to the distance between the electrodes. As the machining precedes there is a simultaneous movement of the cathode towards anode to maintain this gap.

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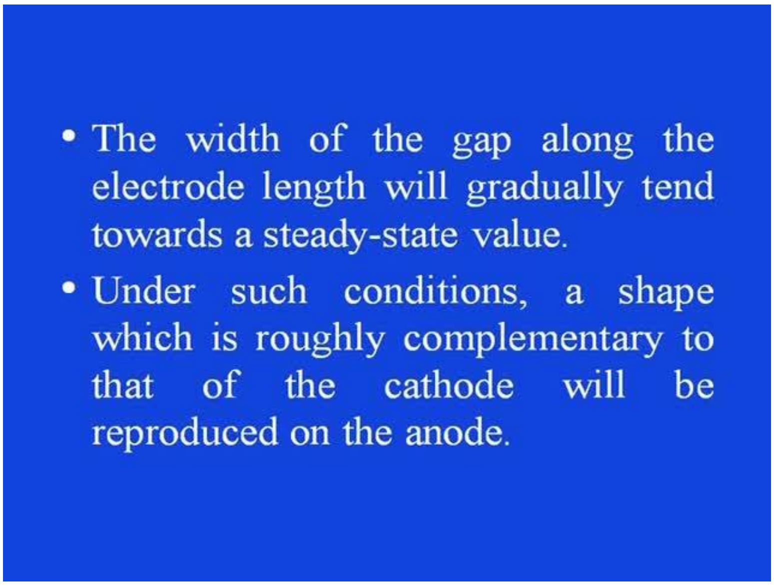

The width of the gap along the electrode length will gradually tend towards a steady state value as we have already explained. Under such conditions a shape which is roughly complementary to that of the cathode will be reproduced on the anode. Using a computer numerical controlled setup complex profiles can be generated as shown in the figure.

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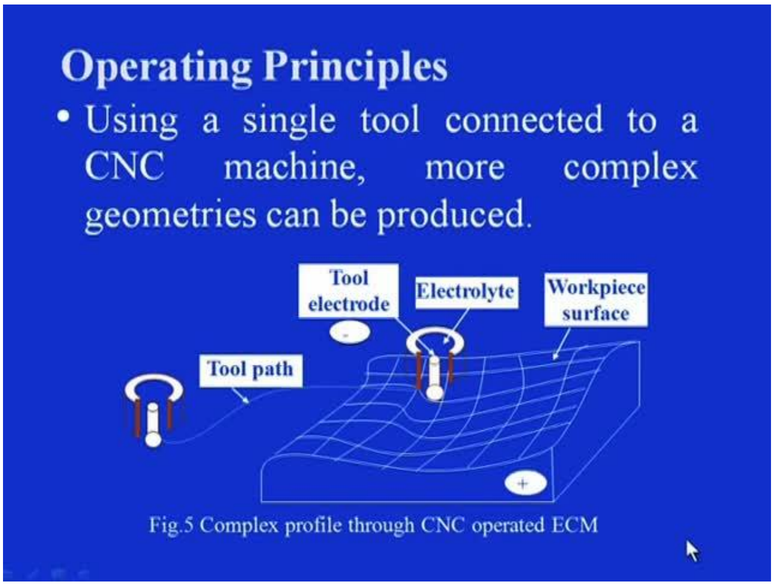

So, this is a figure. So, in which this is a complex profile. This profile can also be machined using this ECM process by suitably programming the tool part in which this has to, the tool has to move or the tool shape we have to produce beforehand so that it replicates the shape on this work piece.

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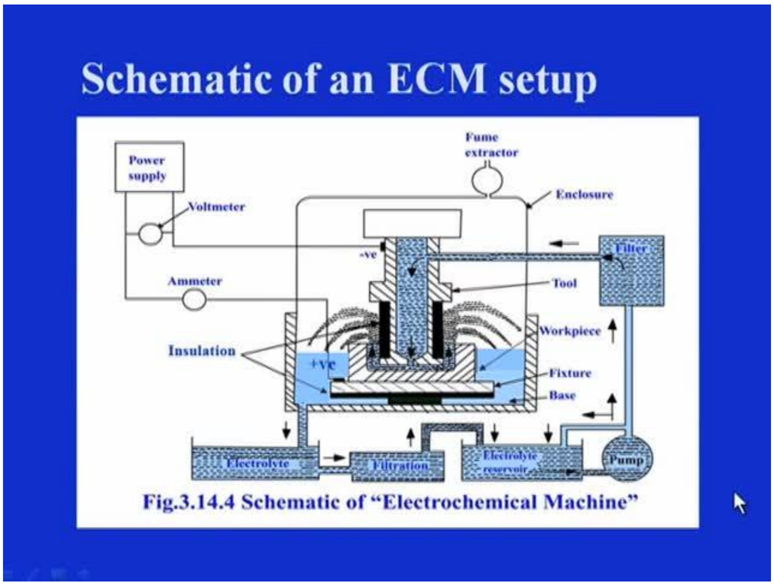

So, this is another schematic of this electrochemical machining in which this is the work piece which is of course, insulated. Similarly, the tool is also, tool is also insulated. You can clearly see on the screen this is insulated, well insulated and this is tool as well as the work piece is connected to the power supply with appropriate polarities. Then the electrolyte will be continuously kept on flowing with this pump, electrolyte pumping system which is in fact a complex system in which several stages will be there, where the electrolyte will be filtered so that this debris produced during the machining do not get circulated again into the gap. This might cause the blockage of the gap or reduce the efficiency of the process.

Therefore, there are different mechanisms like settling tank and then filtering the electrolyte and then finally, again pumping into the gap. Generally, the entire system is put under an enclosure so that any fumes, toxic fumes etcetera produced in the process does not affect the environment and the operator. The general requirements of the tool material in ECM are like this.

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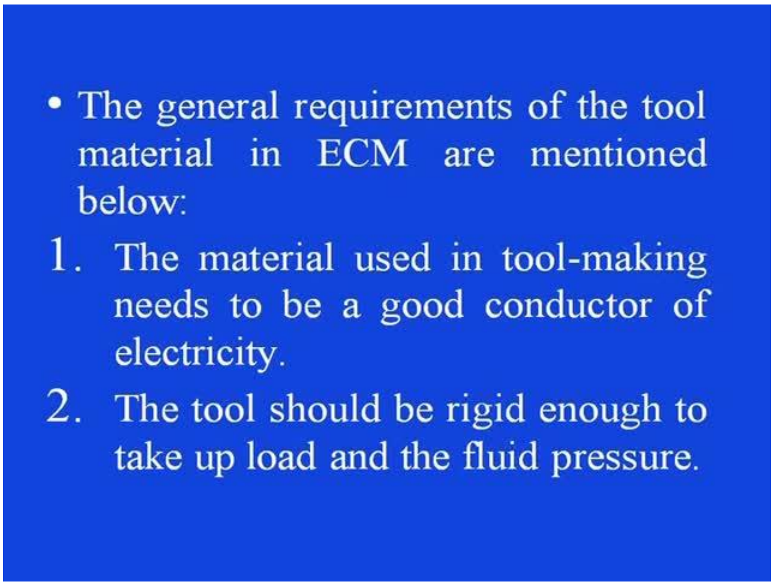

Number one, the material used in tool making needs to be a good conductor of electricity. The tool should be rigid enough to take up the load and the fluid pressure. Number three, the tool should be chemically inert with respect to the electrolyte otherwise the tool will start getting chemically reacted with a electrolyte. Number four, the tool material should be easily formable and machineable to the desired shape.

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Copper, brass, titanium, copper tungsten and stainless steels are the most commonly used electrode materials. Other materials which can be used as tool materials are aluminum, graphite, bronze, platinum and tungsten carbide. The electrolyte used is generally of sodium or potassium base. The hole or cavity produced through ECM is an exact replica of the tool shape as we have already indicated; it can have any complex shape even.

Thus the tool shape and its accuracy have a direct affect on the work piece accuracy. This is a critical aspect in ECM where the tool needs to be produced very carefully so that the accuracy of the produced part increases. Now, let us discuss few things about the accuracy in electrochemical machining.

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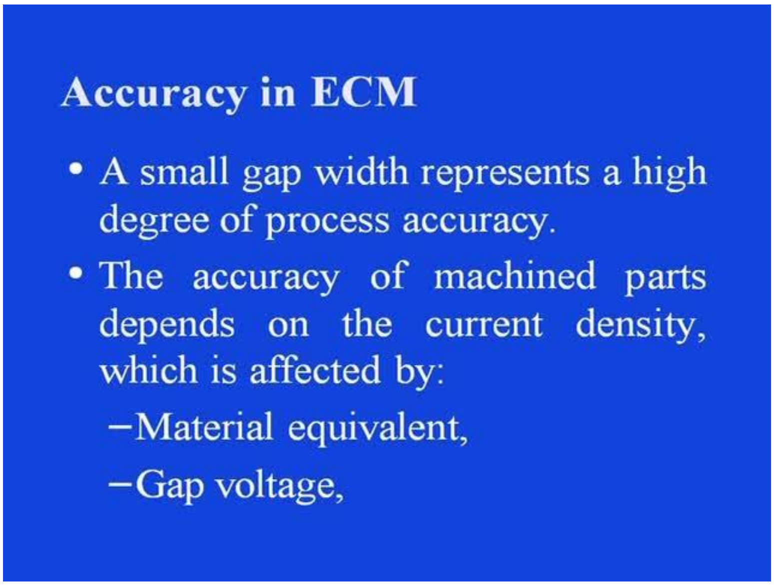

A small gap width represents a high degree of process accuracy. The accuracy of machined parts depends on the current density which is again affected by material equivalent, gap voltage…

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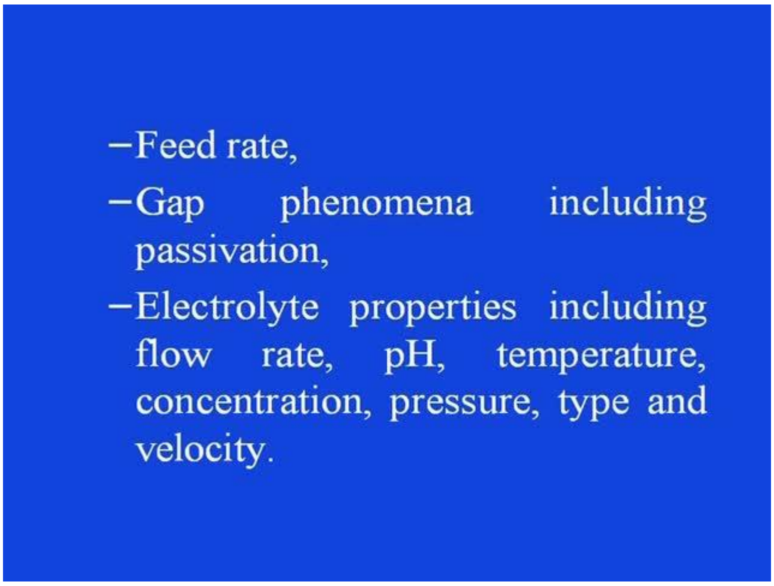

Feed rate, gap phenomena including the passivation, electrolyte properties including flow rate, pH temperature, concentration, pressure, type and velocity etcetera. For high process accuracy conditions leading to narrow machining gap are recommended. These include use of high feed rate, high conductivity electrolytes, passivating electrolytes such as sodium nitrate, tool insulation that limits the side machining action etcetera.

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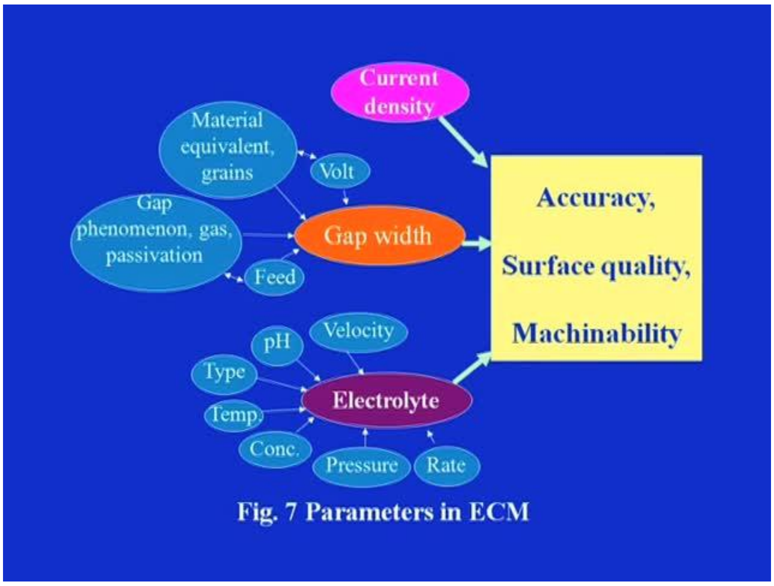

This is the schematic of the different parameters that affects the accuracy and surface quality in ECM. These are mostly the current density, then the gap width which is again affected by the voltage as well as the feed rate, the material equivalent of grains, then the gap phenomenon like gas, gases evolved and then passivation of course, we will discuss what is the passivation here.

Then the electrolyte system, in that electrolyte there are other variables that affects this electrolyte system like the velocity, pH value of the electrolyte that is the type, temperature of the electrolyte, concentration of the electrolyte, pressure at which it is kept on flown and then rate at which it is flowing. The passivation we can discuss like this, glimpse of this passivation affect, it can be explained like this.

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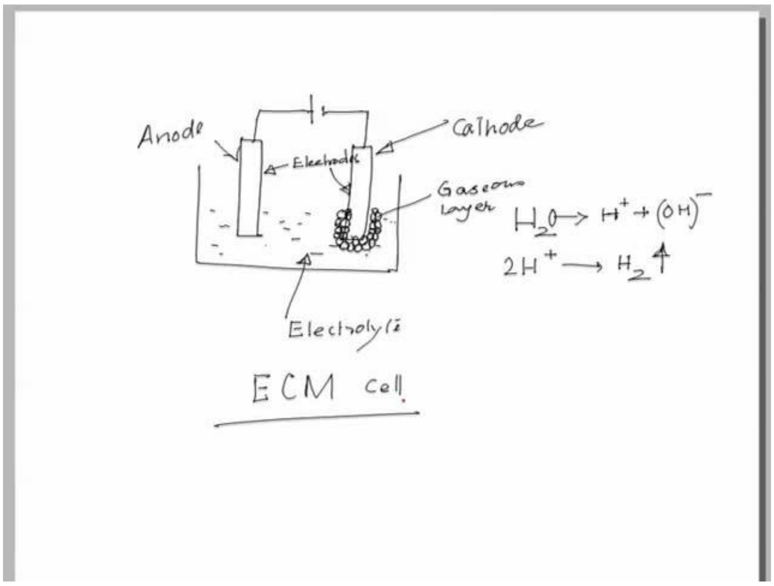

This is the electrolyte. So, there are two electrodes being connected to one cell, electrical power cell and this is the electrolyte electrolyte. These are the electrodes. Now, as we have seen already discussed in the beginning of this session there will be some hydrogen gases developed here or otherwise we can say water will be disassociated into H as well as OH anions and cations. Now, this H two ions of hydrogen will form one molecule of hydrogen gas which will come out from this solution, but at the initial stage there will be hydrogen gases or bubbles formed in this way and this will form a layer just adjacent to this electrode.

The net effect of this layer formation is that this will disconnect this electrical supply to this cathode. On, in other words we can say now this cathode is disconnected from this electrolyte through these bubbles of hydrogen or the gases, gaseous layers. So, this is we can say gaseous layer which is basically of hydrogen bubbles. Therefore, the working of the cell which depends on the continuous electrical connection between the anode and the cathode, so this is anode here and this is cathode here, is disturbed.

Therefore, the working of the cell comes to standstill. This is called the passivation effect which is nothing but is a byproduct of the dynamics of the process. Now, for having effective machining or the working of this process or the cell we need to remove this gaseous layer so that the cell again starts functioning. So, there are different methods developed for this in which these gaseous layers can be removed continuously or to some extent effectively so that the performance of the cell, ECM cell increases.

Now, let us discuss few things about the process control. During electrochemical machining many of the selected controls must be kept unchanged as they have a direct impact on the process accuracy and surface finish. The gap voltage affects the produced size which in turn alters the dimensions of the machined work piece. Surface roughness depends on current density, this in turn is affected by the tool feed rate, gap voltage, work material, gap phenomenon and electrolyte conditions including type, concentration, temperature, pressure, pH level and conductivity.

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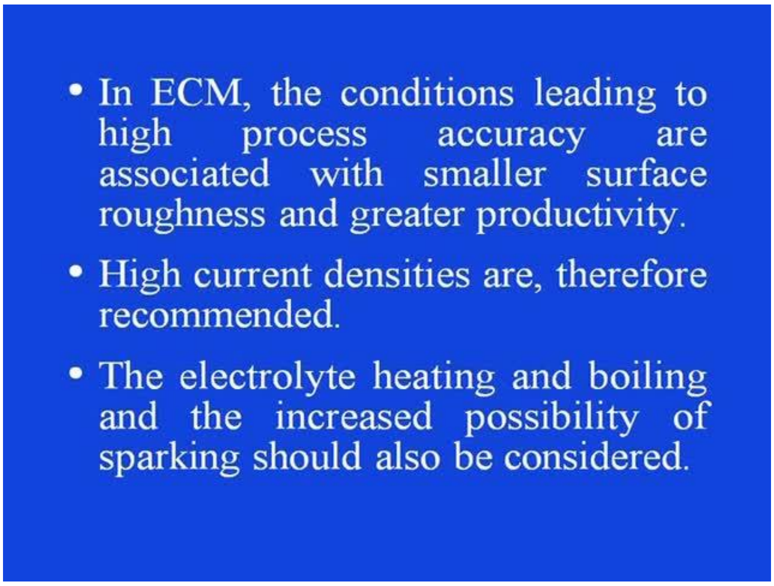

In ECM the conditions leading to high process accuracy are associated with smaller surface roughness and greater productivity. High current densities are therefore, recommended for higher productivity. The electrolyte heating and boiling and the increased possibility of sparking should be also be considered. Proper control of electrochemical machining enhances the product quality and process productivity in view of the following reasons.

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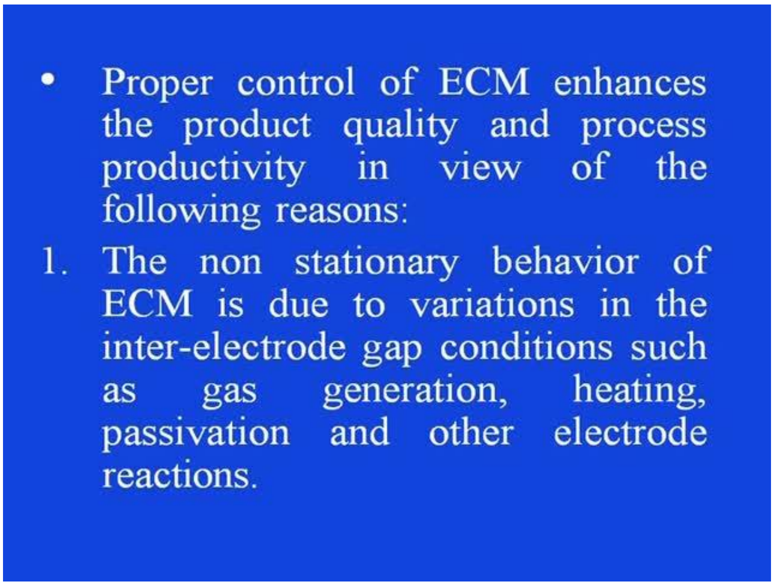

Number one, the non stationary behavior of ECM is due to variations in the inter electrode gap conditions such as gas generation, heating, passivation as we have just now discussed and other electrode reactions.

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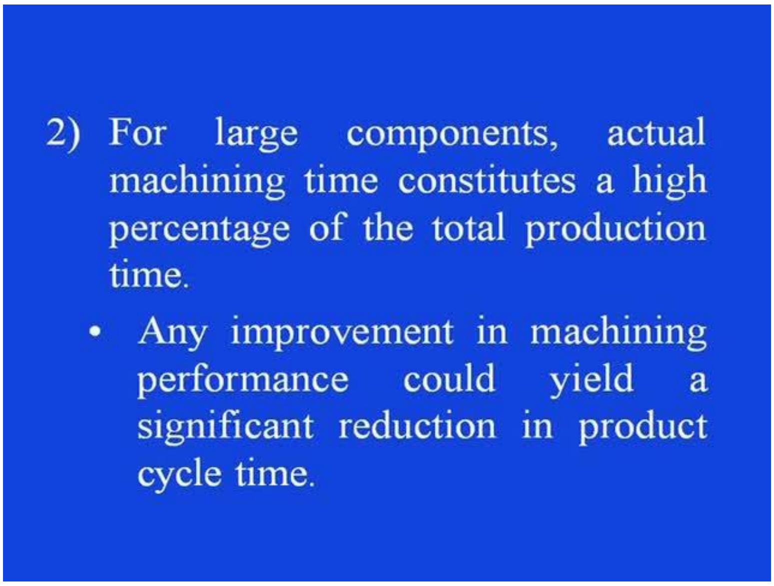

Number two, for large components actual machining time constitutes a high percentage of the total production time. Any improvement in the machining performance could yield a significant reduction in product cycle time.

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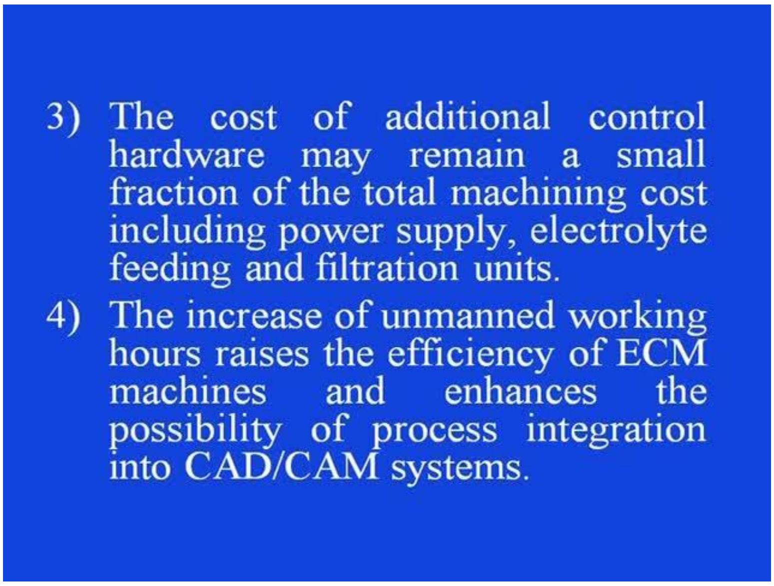

The cost of additional control hardware may remain a small fraction of the total machining cost including power supply, electrolyte feeding and the filtration unit. Number four, the increase of unmanned working hours raises the efficiency of electro chemical machining, machines and enhances the possibility of process integration into

CAD CAM systems. Number five, the ECM deterioration by sparking may cause irreparable damage to the intricate and often costly work piece or tools or completely shut down the machine prematurely. This this risk rises at high machining speeds which are normally associated with narrow intra electrode gaps.

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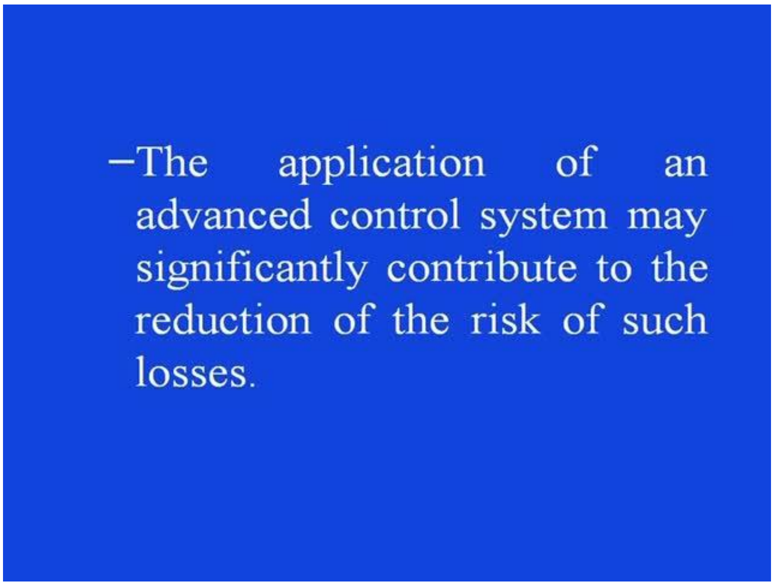

The application of an advanced control system thus significantly contributes to the reduction of risk of such losses. Let us see few points about the economics of this process.

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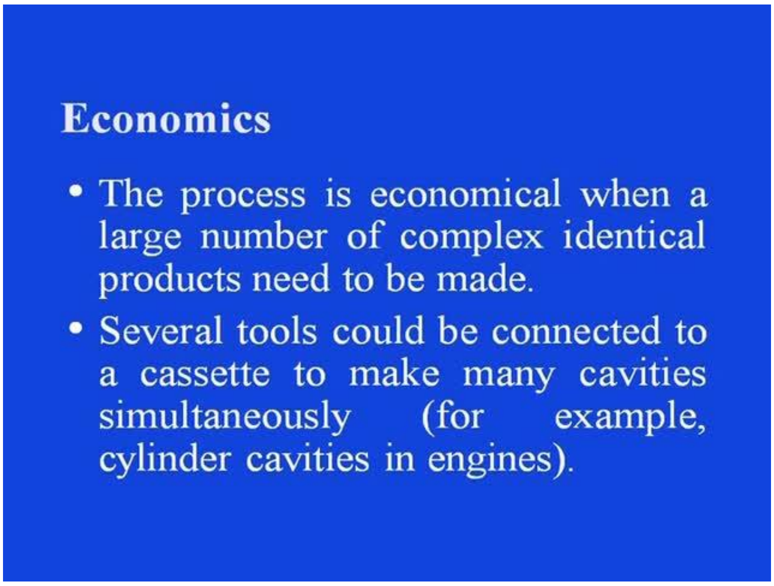

The process is economical when a large number of complex identical products need to be made. Several tools could be connected to a cassette to make many cavities simultaneously for example, cylinder cavities in engines, in which number of cavities can be made simultaneously or in a single shot. Large cavities are more economical on ECM and can be processed in one-tenth of the time that is required in EDM that means it is considered to be highly economical with respect to the EDM process.

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And the other advantages over the EDM of this ECM process are it is faster than the EDM process as we have seen just now. It could be as high as ten times. No tool wear. No heat affected zone which is very common in case of EDM, there will be a large heat affected zone in the cutting area in case of EDM. Also better surface finish and accuracy can be obtained with respect to EDM in case of ECM.

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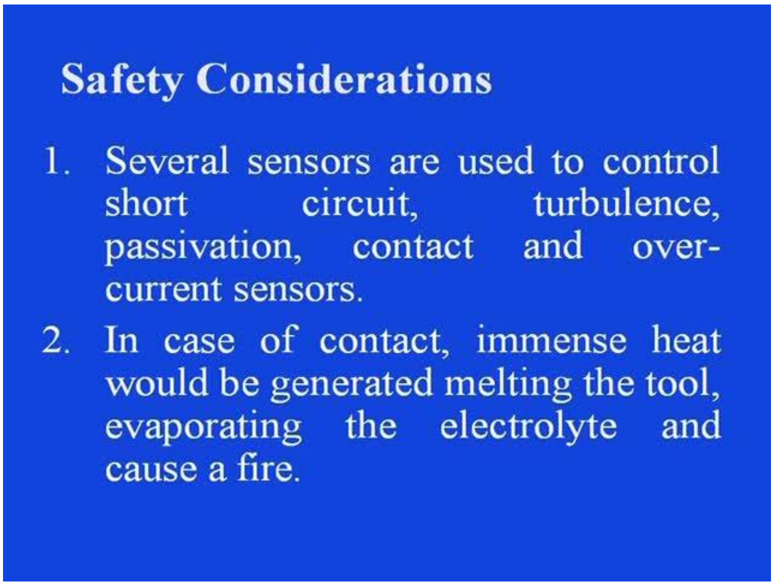

Now, let us quickly review the safety considerations in ECM. Number one, several sensors are to be used to control short circuit, turbulence, passivation, contact and over current sensors. Number two, in case of contact immense heat would be generated melting even the tool itself, evaporating the electrolyte and could cause a fire. Number three, the worker must be insulated to prevent electrocution. Number four, the tool and the work piece must be grounded before any handling is performed. Number five, electrolyte is highly pressurized and worker must check for minor cracks in piping before operating.

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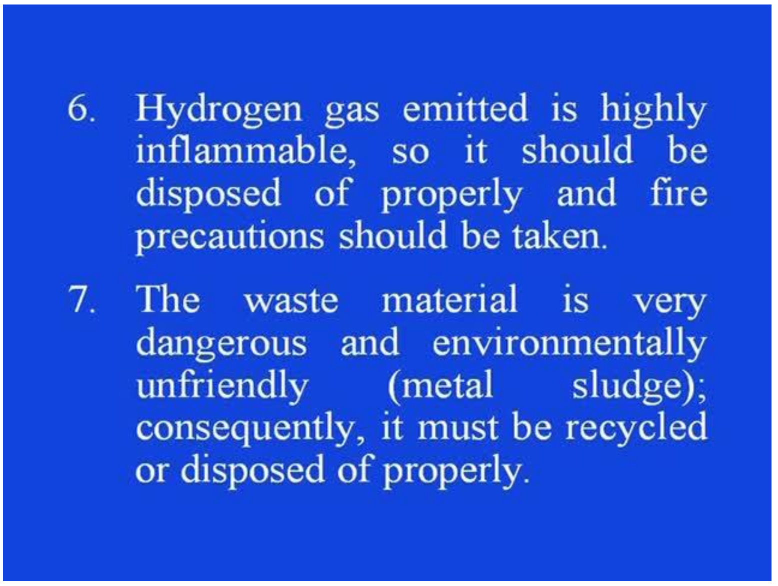

Number six, hydrogen gas emitted is highly inflammable. Therefore, it should be disposed of properly and fire precautions should be taken. Number seven, the waste material is very dangerous and environmentally unfriendly which is nothing but metal sludge. Therefore, it must be recycled or disposed of properly. Now, let us summarize what we have discussed in this particular session.

In this session we have discussed about the basic ECM process, its working principles, features, advantages and applications. The most important feature is that irrespective of the hardness of the work piece any conductive material can be machined by this process not only hardness, irrespective of its toughness and strength the material can be machine by ECM provided it is electrically conductive. We hope this session was informative and interesting.

Thank you.