Advanced Manufacturing Processes

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Module - 3
Advanced Machining Processes
Lecture - 7
Micro USM and advances in USM

Welcome to this session on electro discharge machining under the course advance manufacturing processes. In the last few sessions we have discussed about mechanical abrasive based manufacturing processes like abrasive jet machining, water jet machining, water abrasive jet machining, ultrasonic machining etcetera. All these processes work under principal of mechanical abrasion. These processes their features, their parameters, their advantages, limitations, their working principal and their new trends we have discussed already.

In this session will discuss about a new category of the processes, machining processes that is thermal based process, electric discharge machining also called EDM process. We will look a little bit about the history of EDM and then the process features and different process parameters that affects this process, the advantages and limitations of this process that also we will try to look at. Then the applications of electric discharge machining process, the mechanisms involved in material removal in this process, then a die sinker process slightly specialized process in this category itself, and then the features of the die sinker process and its applications will be discussed.

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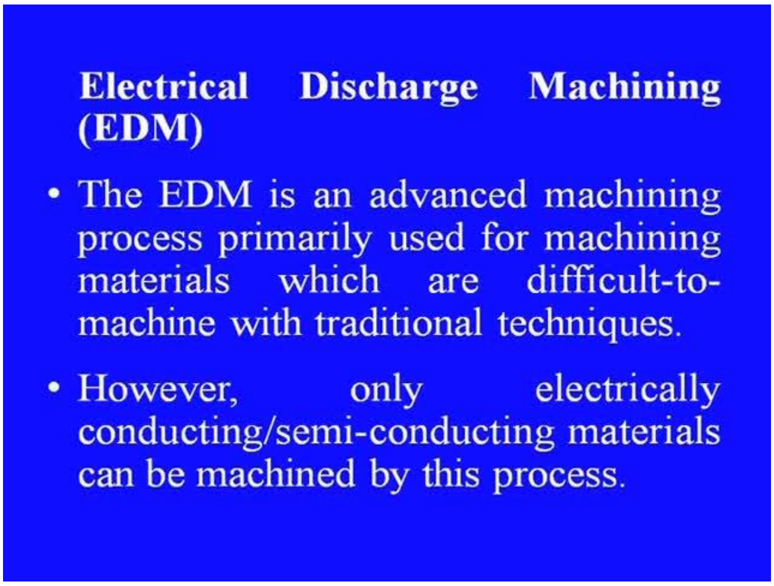

Now, let us move into the electrical discharge machining process. A brief introduction to this process is like this, this is an advance machining process primarily used for machining materials which are difficult to machine with traditional techniques. There are certain materials like having very high hardness and having very high toughness. So, these materials are indeed very difficult to machine with the help of traditional machining processes like turning, milling, drilling and so on, but the applications, kind of applications need that these type of materials to be used in the processes or applications.

So, where is the solution? How to go about their machining? So, here comes the effectiveness of such process like electric discharge machining where there is no conventional tool as such, some unconventional tools are there, but there is no physical contact between the tool and the work piece and as such there will will not be a problem as far as the hardness of the tool material is concerned with respect to the hardness of the work material as we encountered in conventional machining processes. In conventional machining processes what we do usually is we select a tool material which is having higher hardness than that of the work material.

We select this materials from the Mohs scale what is known as Mohs scale, but in this process, this category of manufacturing processes we never consider that aspect, that is the relative hardness of the tool material and the work material. So, here we go by some other principal which is predominant in material removal, but the only limitation of this process is major limitation I must say only electrically conducting or semi conducting materials can be machined by this process.

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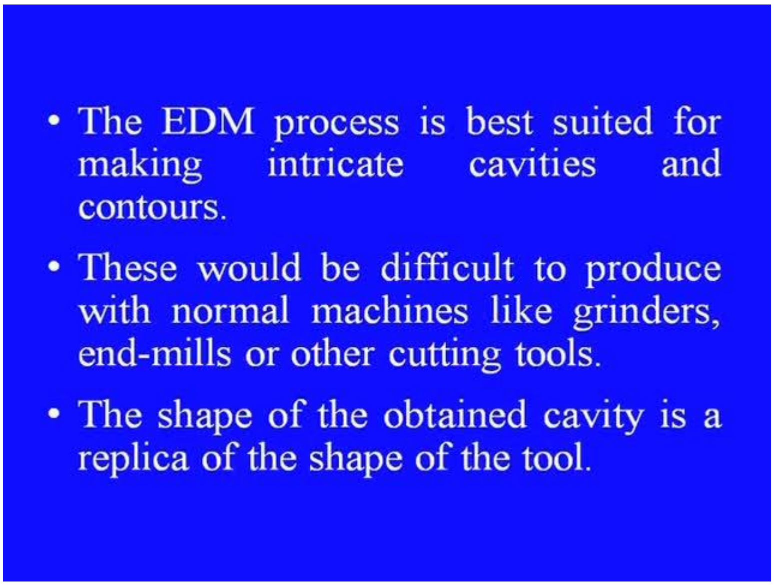

The EDM process is thus best suited for making intricate cavities and contours. This would be difficult to produce with normal machines like grinders, end-mills and other cutting tools. The shape of the obtained cavity is a replica of the shape of the tool. The EDM process is best suited for machining the following materials like hardened tool steels, carbides, titanium, some super alloys like inconel, etcetera which is indeed very difficult to be machined with using conventional machining techniques, but inconel is a very good material to be processed using this electric discharge machining process.

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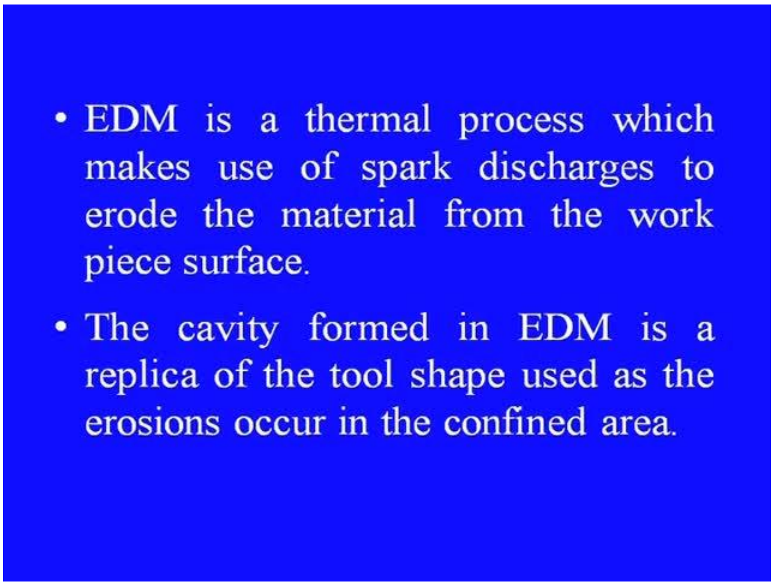

Basically EDM is a thermal process as I have already indicated which makes use of spark discharges to erode the material from the work piece material. The cavity formed in the EDM is a replica of the tool shape used as the erosions occur in the confined area. We will see in details the mechanism involved in this process little later. Since, spark discharges occur in EDM it is also called as spark machining or discharge machining. The material removal takes place through a rapid series of electrical discharges.

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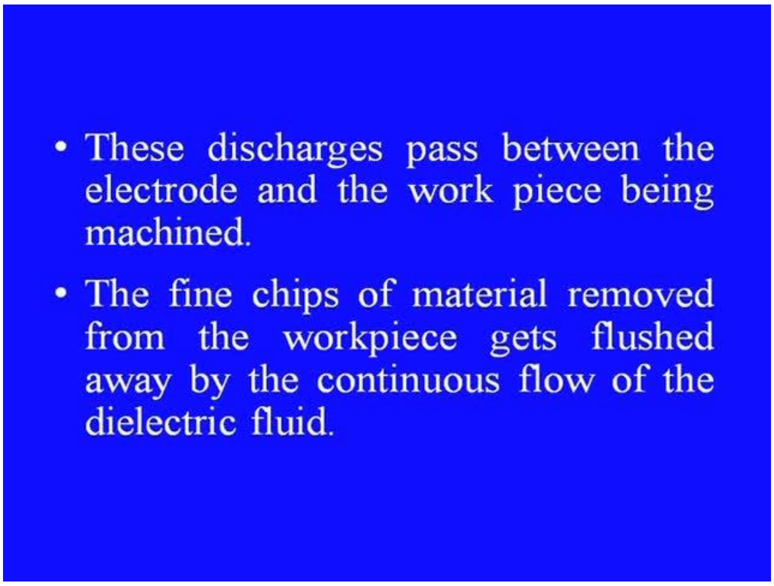

These discharges pass between the electrode and the work piece being machined. The fine chips of material removed from the work piece gets flushed away by the continuous flow of the dielectric fluid. The repetitive discharge creates a set of successively deeper craters in the work piece until the final shape is reduced. The dielectric fluid is commonly used in the form of kerosene.

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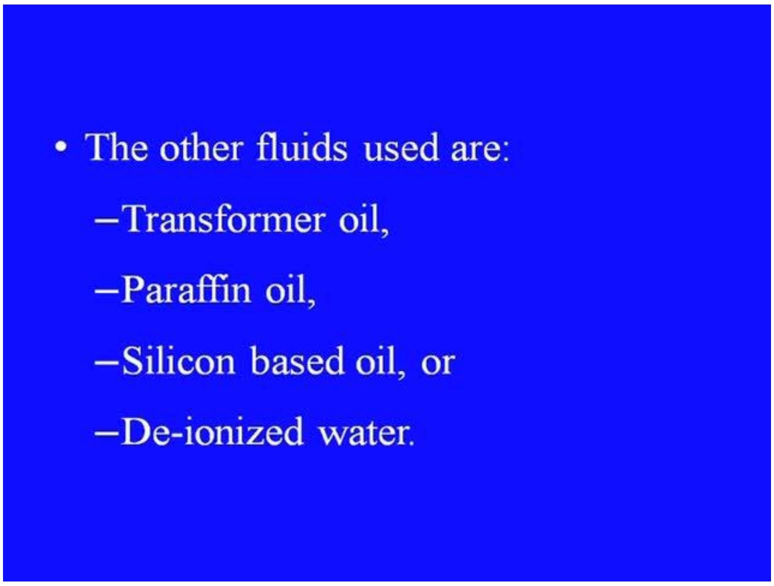

Of course, there are other fluids also used as dielectric fluids in this process. These include transformer oil, paraffin oil; silicon based oil or de-ionized water. The dielectric system performs the following task.

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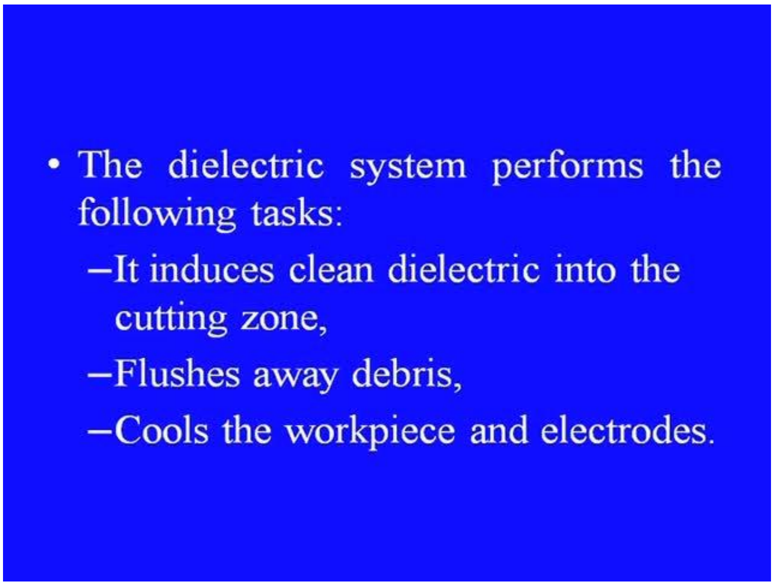

Number one, it induces clean dielectric into the cutting zone which is very much required for getting ionized and thus, thereby creating a plasma column as we will see in a later on during the mechanism of material removal or what is the working principal of this process. Then this dielectric is also responsible for flushing away the debris, those are produced in the cutting zone and of course they cools the work piece and electrodes. Otherwise they will continuously get heated and the appropriate dimensions of the work piece will not be achieved.

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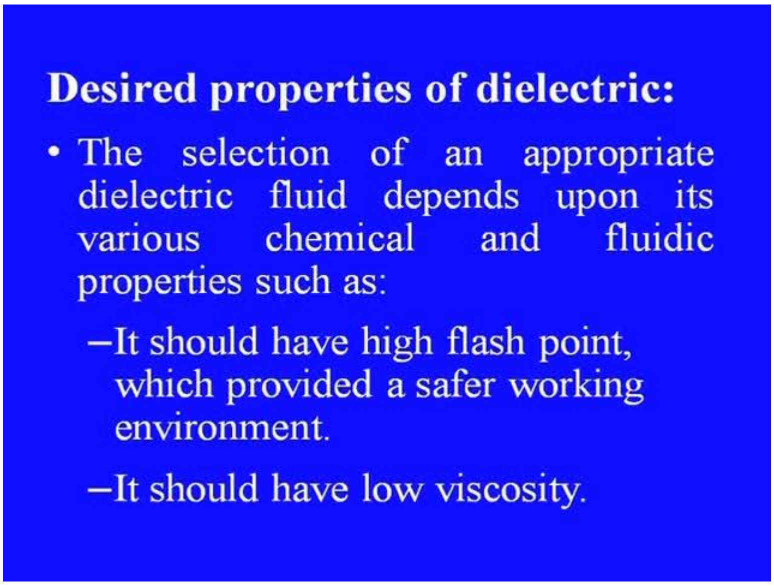

Now, let us briefly see what are the desired properties of a dielectric. The select, selection of an appropriate dielectric fluid depends primarily upon its various chemical and fluidic properties such as it should have high flush point which provide a safer working environment, then it should have low viscosity so that it can flow very easily as well as it can flush away the debris produced in that working zone.

It should also have higher dielectric strength to minimize the DC arching direct current arching that takes place during that process. It should be order less or operator friendly, should not harm the operator, no toxic gasses should be developed during the ionization process, its oxidation stability should be higher. Then the dielectric fluid should not create any skin irritation for the operator who will be handling this dielectric very frequently and moreover it should be easily available and economical or cheap also.

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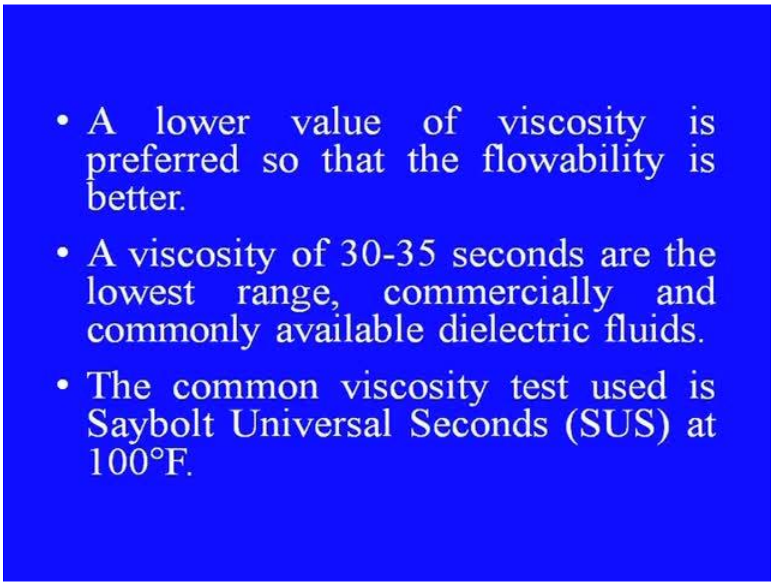

A lower value of viscosity is preferred so that the flow ability is better. A viscosity of around 30 to 35 seconds are the lowest range and commercially and commonly available dielectric fluids have these viscosity in these range. The common viscosity test used to measure the viscosity of this dielectric fluids are Saybolt Universal Seconds in short it is known as SUS at 100 degree Fahrenheit. Now, let us quickly look the origin of electro discharge machining process.

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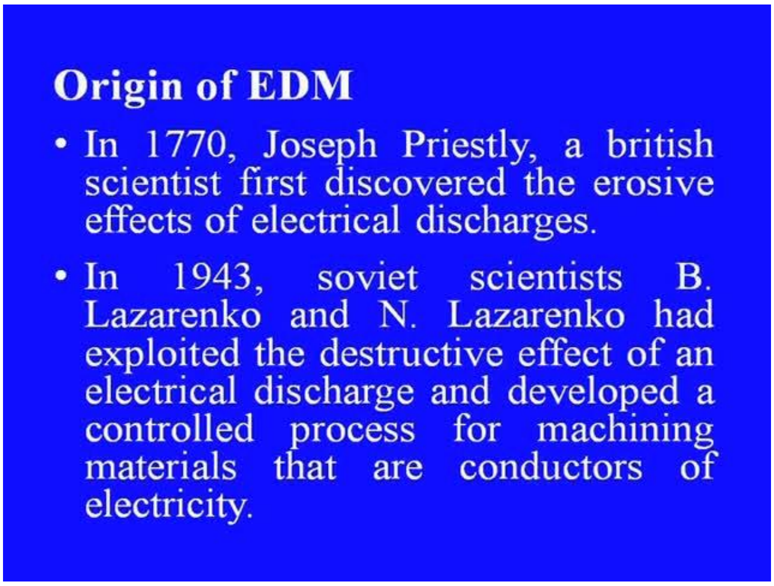

In the year 1770, Joseph Priestly, a British scientist first discovered the erosive effects of dielectric discharges. In the year 1943 soviet scientist B Lazarenko and N Lazarenko had exploited the destructive effect of an electrical discharge and developed a controlled process for machining materials that are conductor of electricity. Then what is the principal of electric discharge machining? In this process the work piece and the tool are submerged in a non conducting dielectric fluid which is separated by a small gap which is provided for sparking to take, takes place. This gap is also called spark gap. The configuration is something like this.

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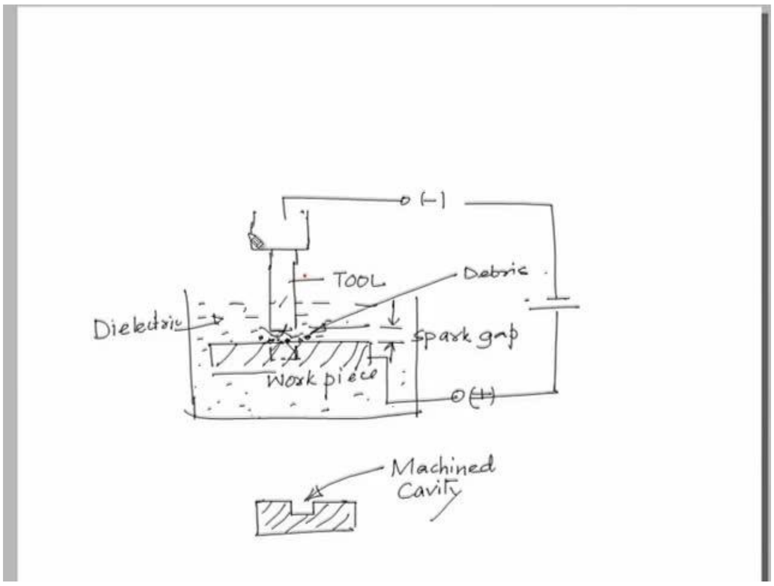

So, this is the tool and this is the work piece. This is the tool and this is work piece. This is the gap provided this is also known as spark gap. This will be generally connected to some DC connection and this will be generally negative and this work piece, work piece will be connected to the positive terminal of the power supply. So, here in between will be the power supply here. Now, the entire system will be emerged, submerged on liquid, but that is so this is the, what is known as dielectric. So, this will be continuously kept on flowing by some pump arrangement, by some pump arrangement and this dielectric fluid will be taking away the debris produced in this zone while the actual machining will take place.

So, these are nothing but the called debris and these debris will be flushed away by this flowing dielectric fluid and this gap between the tool and the work piece is provided so that the sparking can takes place in this zone. Sparking can takes place here. Because of this parking the material will get removed from the work piece and this will ultimately create an impression which is exactly similar to that of the work tool that we have used for machining this material. So, this is the machined cavity we can say after the machining is completed.

So, this cavity the size or shape of this cavity will depend on the tool we are using here. The dielectric fluid insulates the work piece from the tool and creates the resistance to flow of electricity between the electrodes as I have already shown in the schematic. There will be a spark gap which will separate both the elect electrode as well as the work piece. Otherwise, there will be a short circuiting condition and the current will flow directly instead of any spark being created.

So, that is being provided by the dielectric fluid, that gap will be maintained through some servo mechanism which will maintain this gap something around 0.2 millimeter or something like that. Of course that may vary depending on different material configuration and that may vary depending on the kind of machining required. The dialectic fluid may be typical hydro carbon oil as we have already indicated, it usually the kerosene is preferred or at times de-ionized water is also used.

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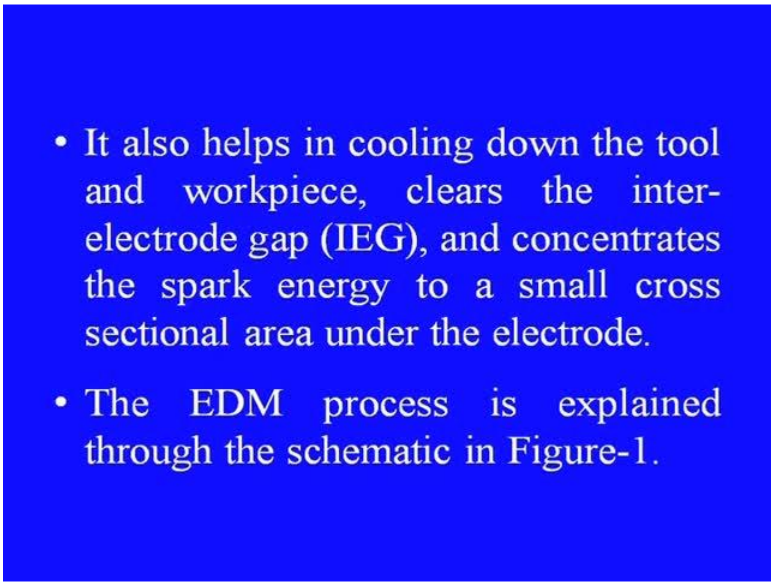

It also helps in cooling down the tool and the work piece. It clears the inter electrode gap and concentrates the spark energy to a small cross sectional area under the electrode. The EDM process is explained in this schematic. This is a clear schematic on the screen.

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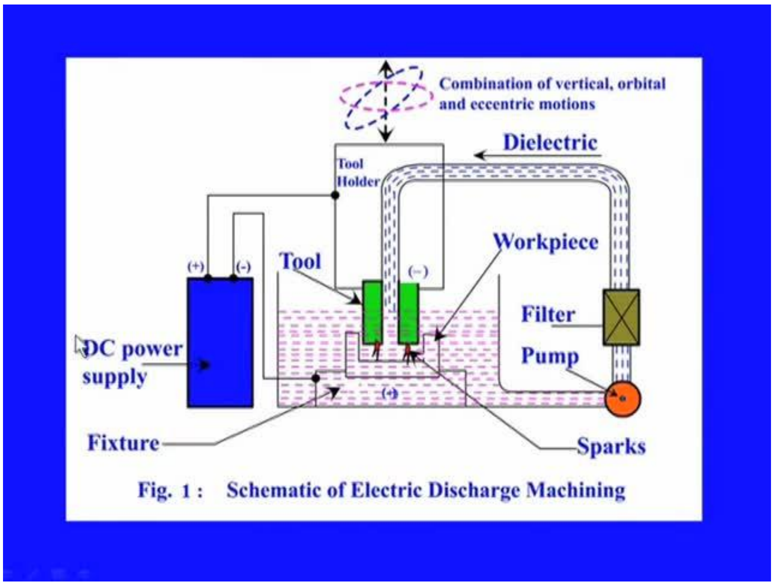

So, this is what I was talking about the power supply which provides the power to the the configuration work piece, work piece as well as the tool. The tool will be generally connected to the negative negative end of this power supply and the work piece would be given the positive polarity, positive connection and then this is the flowing fluid or the dielectric flowing system. So, this consists of one pump and then the filter. The filter is required because this dielectric fluid after working for some time will carry the debris as well and if the debris in this dielectric gets increased then the efficiency of this dielectric fluid flowing through this will come down.

Therefore, the debris need to be separated out at some stage and there are some certain filtering mechanisms and this will filter out the debris present in this dielectric fluid. Now, this is the this is the tool which will be continuously advancing through some control mechanisms that is connected to the machine tool and the sparking will take place in this zone. That is it is shown as a spark also and this is the fixture which is generally an insulated fixture because this work piece is directly connected to the power supply.

Therefore, this fixture needs to be insulated one and this holds the work piece in its position. And this tool at times can be made rotated as well and obviously this is generally made to travel in the said direction or in the height direction so that the machining can be created. As the two electrodes come closer to one another; the electric field intensity increases beyond the strength of the dielectric. This enables it to break and thereby allowed a current to flow between two electrodes. As a result of this effect intense heat gets generated near the zone which melts and vaporizes the material in the sparking zone. As the flow of current is momentarily stopped some fresh dielectric liquid particles come in position between the inter electrode gap and the cycle repeats.

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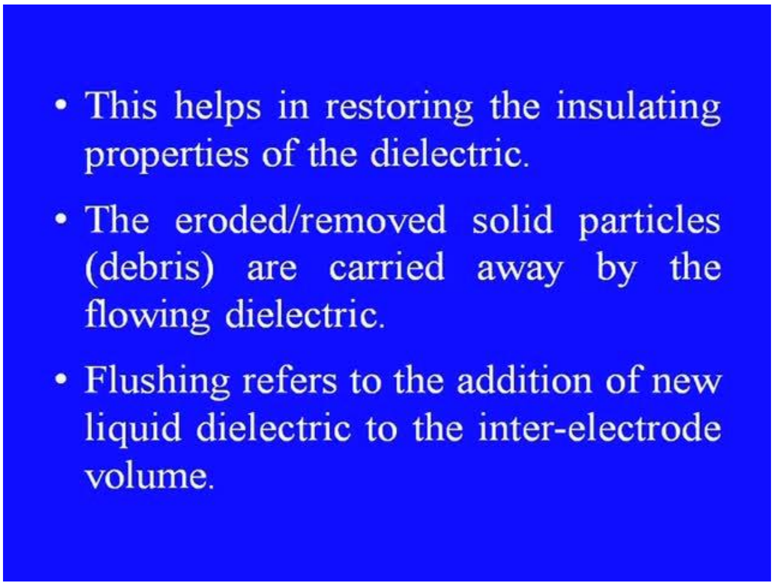

This helps in restoring the insulating properties of the dielectric. The eroded or removed solid particles which are also called debris are carried away by the flowing dielectric as I have already indicated. The flushing refers to the addition of new liquid dielectric to the inter electrode volume.

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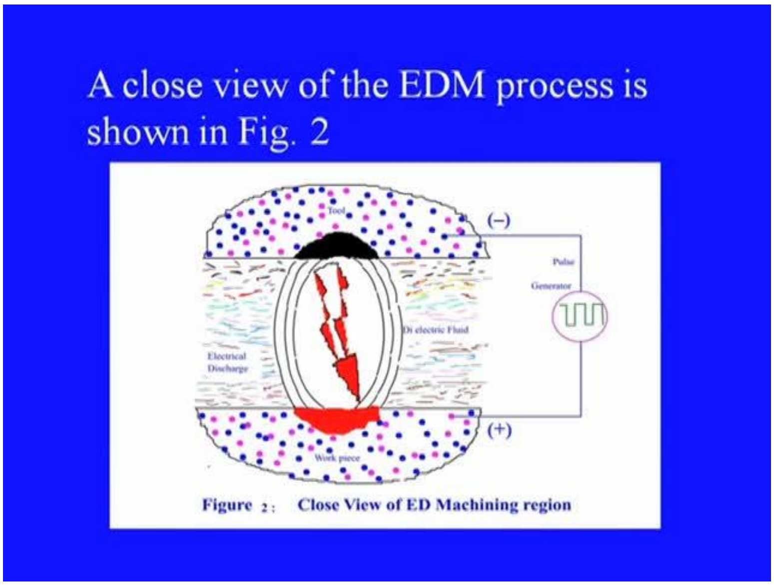

So, this picture depicts actually what happens in the sparking zone as we apply the electric field across the tool and a tool and a work piece. So, this is where the dielectric is. This is the voltage applied across them and as the voltage increases to a particular what is called discharged voltage this dielectric column or the dielectric present in this the nearest nearest point gets break down and it creates, plasma is created here and as we know this plasma is nothing but flow of electrons.

So, that means circuit is completed now through which the current flows through this small column of plasma which is nothing but a ionized column of this dielectric material. Now, this plasma creates intense heating in this zone which not only evaporates this dielectric, but it also melts and evaporates this work piece material and that causes the material to get removed from this surface as you can see from this screen.

This melted and evaporated material getting dislodged from this zone and as this dielectric will be kept on flowing continuously, this flowing dielectric will quickly carry away this molten material as debris. Of course, there are some other phenomena that takes place here. Some of the molten material or semi molten material gets stick to this tool surface also as well that we will see in the later part of this session. So therefore, a small or very thin layer will be deposited on this surface because of this molten material getting deposited on this.

And since the dielectric will be continuously flowing and this electrical voltage will be applied in some sort of pulses not continuously therefore, momentarily this sparking will stop which is called as pulse off time, then at that time the new dielectric will fill this gap, this zone and there will not be any sparking for that gap period or pulse off period. Then as the next pulse comes, next pulse on time comes the similar cycle repeats here and the material gets evaporated from this zone. Also there are some other phenomena that are taking place here. This this can be explained like this.

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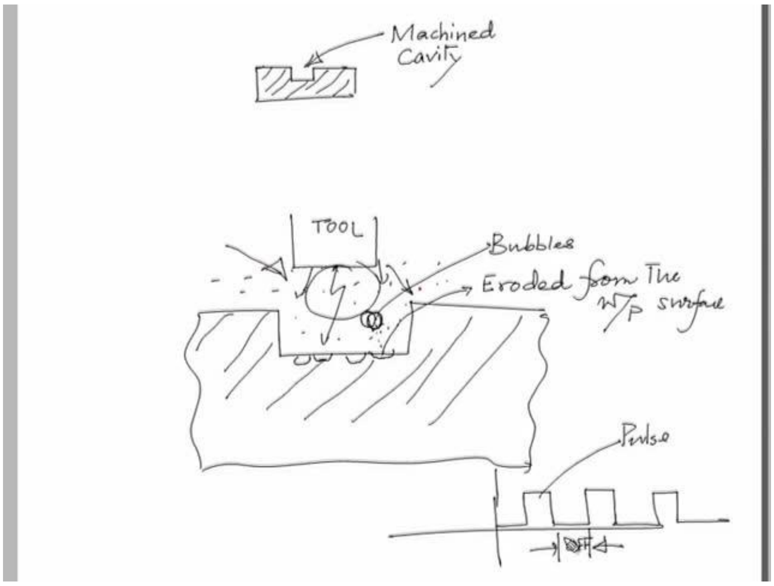

As we have seen so this is the tool and this is the work piece. So, this is the tool and the sparking is taking place here in this zone. Now, because of the sparking this the dielectric fluid present here as I have already indicated they also gets evaporated and small bubbles are formed, some small bubbles are formed. Now, because of the flowing fluid this bubbles will get collapsed momentarily and this collapsing of this bubble will create some shock wave to be created or the cavitations to be produced here, and because of this cavitation some materials from this work piece will be eroded.

So, this material will be eroded from the work piece surface. So, this is another phenomenon that is taking place in during this sparking and it continues as long as the sparking continues. As the tool advances then again the sparing will take place generally through the nearest nearest zones where the tool and the work piece distance is minimum and the process continues. Also, since this process is a, you can say a discreet process because here we are using the pulses of current something like this. So, these are the pulses of current that we are using.

So, here this is the pulse we are using, but this is the time. So, this is when the there is no voltage applied and this we can call that this is the off period or there is no pulse applied between this tool and the work piece during which in fact as I was talking about the new dielectric or the fresh dielectric gets filled this zone. The sparks occur at spots where the tool and the work piece surfaces are the closest, as the spark change after each spark because of the material removal after each spark the spark travels over, all over the surface.

This results in uniform removal of material hence exact shape of the tool gets reproduced on the work piece surface. Any profile can be generated by EDM provided a replica tool can be fabricated. This is the, this is another big advantage of this process. As long as we can produce the shape of a tool which is in the form of an electrode we can machine that particular shape on the work piece.

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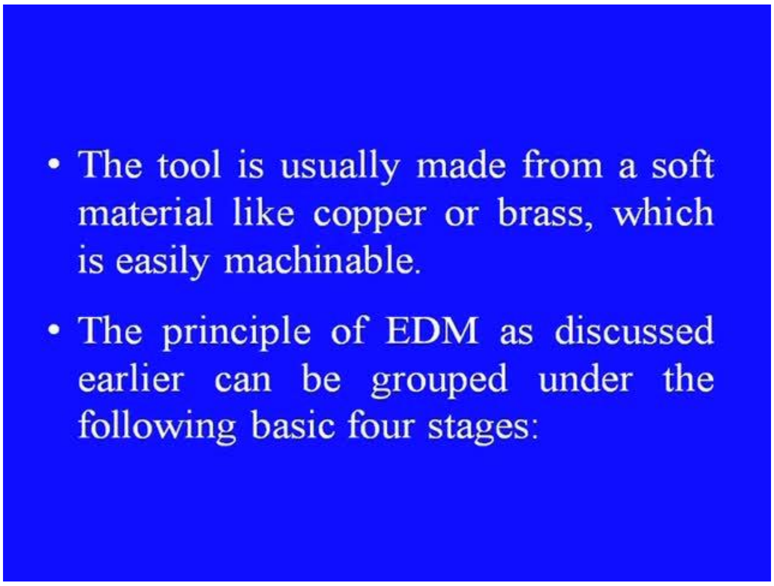

The tool is usually made from a soft material like copper or brass which is easily machinable. The principle of EDM as discussed already can be grouped under the following four basic phases.

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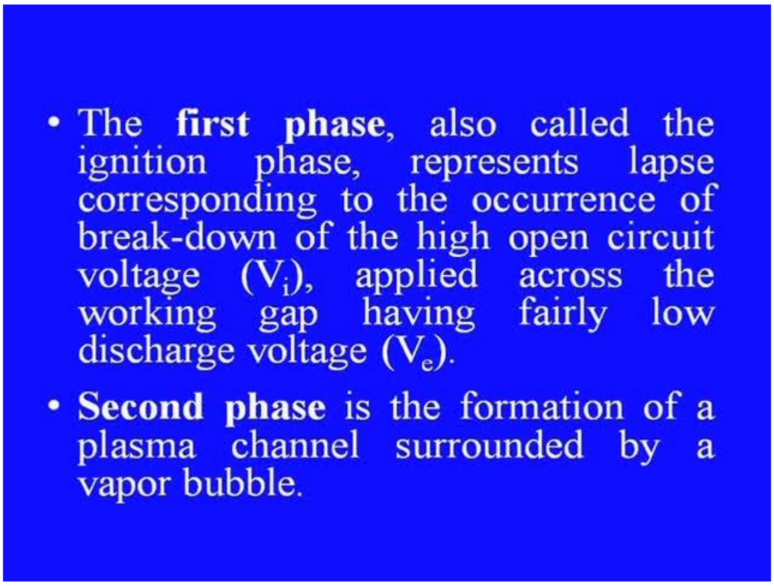

The first phase also called the ignition phase represents lapse corresponding to the occurrence of breakdown of the high open circuit voltage V i applied across the working gap having fairly low discharge voltage also called V e. In the second phase the formation of plasma channel thus takes place and this is surrounded by the vapor bubble. Just I have indicated how the vapor bubbles are produced in that working zone or in the dielectric in that sparking zone.

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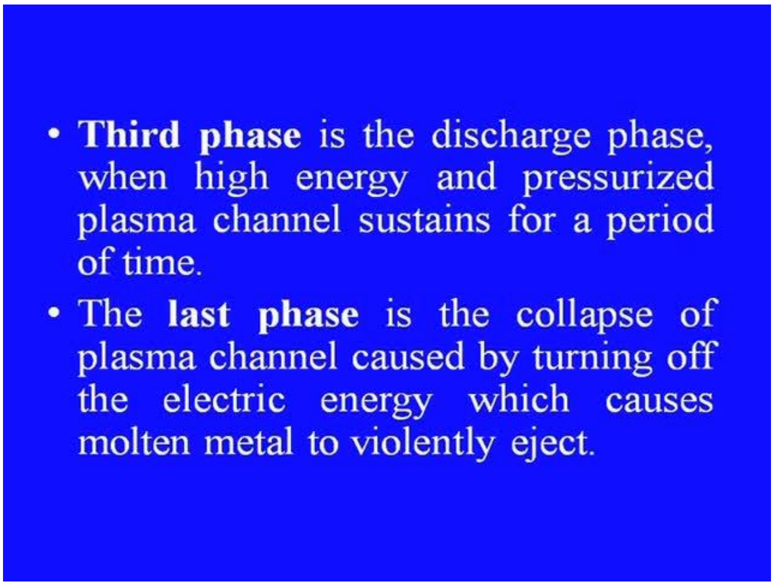

The third phase is the discharge phase when high energy and pressurized plasma channel sustains for a period of time. The last phase is the collapse of the plasma channel caused by turning off the electric energy which causes molten metal to violently eject. Now, let us see another phenomenon that takes place invariably in electric discharge machining. This is called has heat affected zone also in short it is called HAZ.

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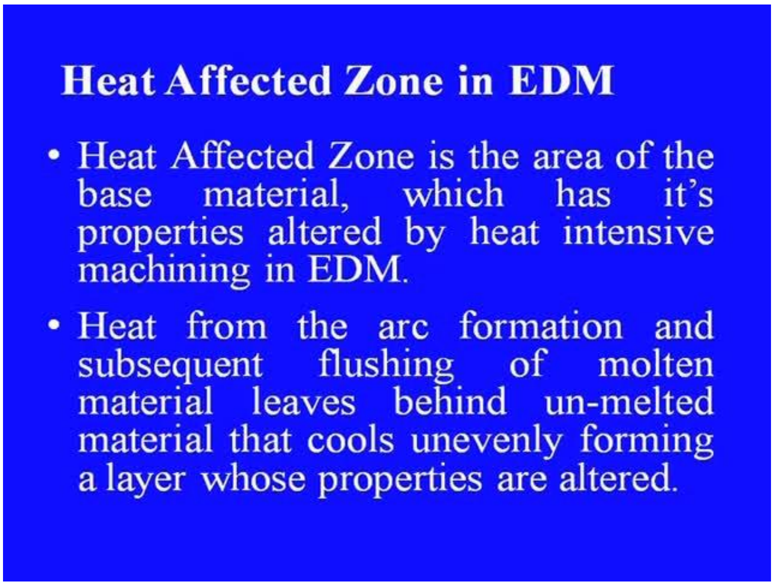

Head affected zone is the area of the base material which has its properties altered by heat intensive machining during electric discharge. Heat from the arc formation and subsequent flushing of molten material leaves behind un melted material that cools unevenly forming a layer which properties are altered. This layer is known as white layer which has poor machinability. Generally the hardness will be much more in this white layer than that of the parent material. Thermal properties like fatigue strength, corrosion to resistance and service life gets greatly reduced due to the formation of heat affected zone.

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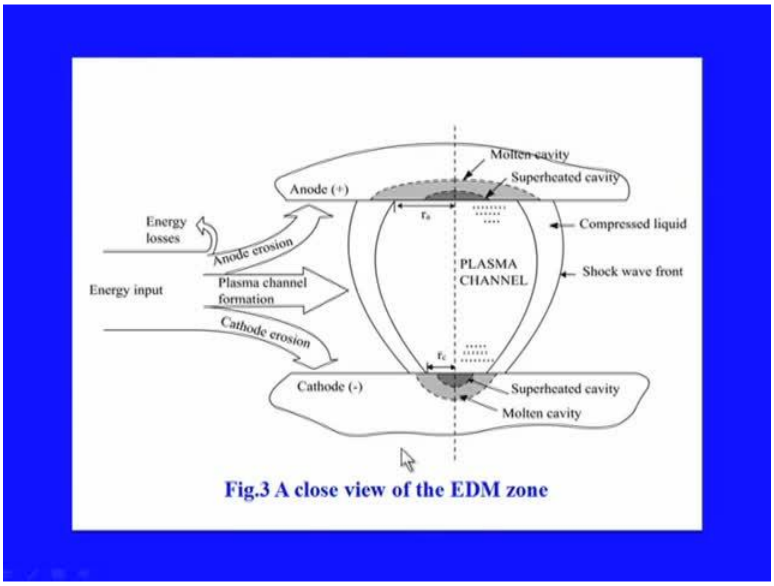

This is a close view of the EDM zone where you can see this is the energy output and that causes anode erosion as well as cathode erosion and plasma is created in this zone as as can be seen in the screen. And the liquid gets compressed in this zone and because of the evaporation or the bubble formation the shock wave gets created and it propagates which is actually responsible for causing the erosion on the work piece surface, but at the same time we should remember that similar phenomena or the tool also can experience to some extent this erosion phenomena and it does.

However, because of the polarity, nature of the different polarity of the tool and the work piece the erosion experienced by the tool is much, much less than what happens in the positive electrode or at the work piece zone. Microscopic study of the machined component reveals three kinds of layers.

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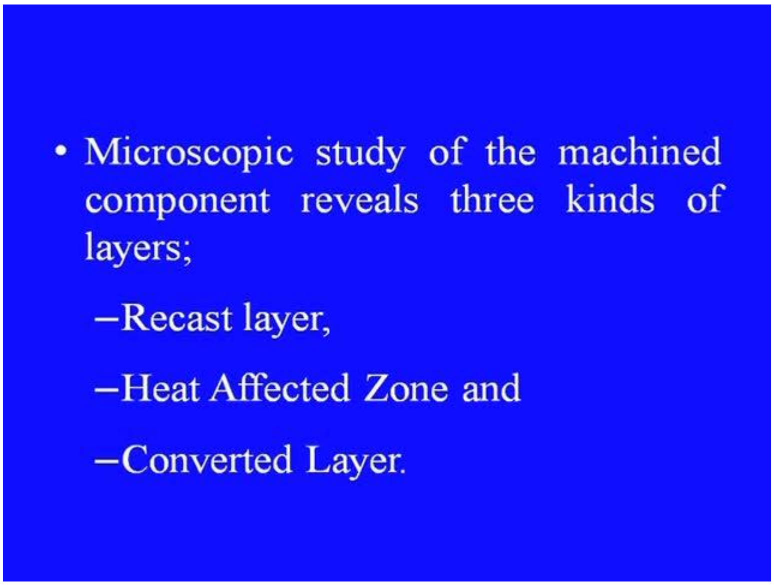

One is recast layer, another is heat affected zone and the third one is converted layer. If the molten layer from the work piece is not flushed out quickly it will re solidify and get hardened due to cooling effect of the dielectric and it gets adhered to the machined surface. This thin layer say about 2.5 to 50 micron or so is known as the recast layer and subsequently we may have to adopt or use some other secondary processing technique to remove this recast layer, if the nature of the job or application demands so.

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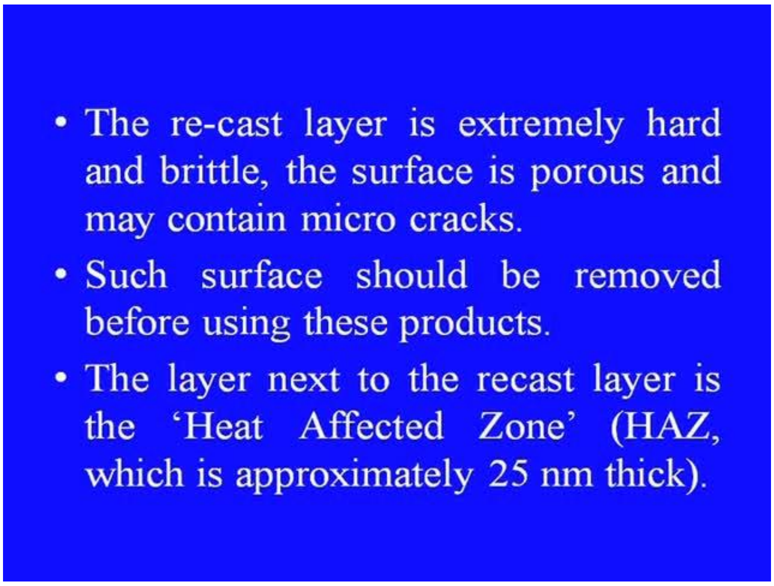

The recast layer is extremely hard and brittle; the surface is porous and may contain micro cracks which is not a good characteristic of a machined surface. Such surface should be removed before using these products. The layer next to the recast layer is the heat affected zone which is approximately 25 millimeter thick. Of course, it can vary depending on the parameters we use, depending on the material we use and depending on basically the pressure at which we are using the dielectric to flow or the flow rate of the dielectric.

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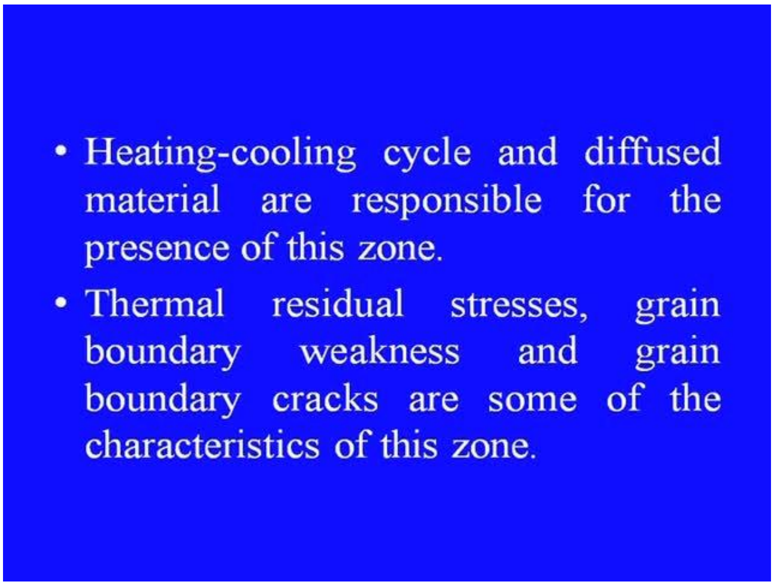

The heating cooling cycle and diffused material are responsible for presence of this zone. Thermal residual stresses, grain boundary weakness and grain boundary cracks are some of the characteristics of this zone. Thus, what we have seen is almost all the effects because in present in this heat affected zone are not good for a good work surface or job surface.

Therefore, it is to be seen how this heat affected zone can be minimized during this process. This is possible by sweet ably adjusting different parameters as I have already indicated. It can be identified which parameter affects this heat affected zone the most and accordingly the actions can be taken. The conversion zone is identified below the heat affected zone. It is characterized by a change in the grains structure from the original structure.

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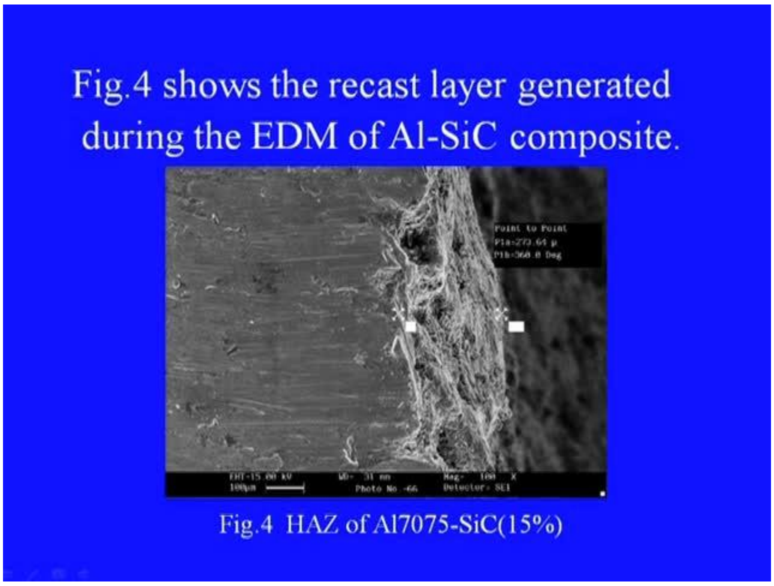

So, here is the, here is a typical figure of the machined work piece and the white layer we can see. This is white layer and this material and this material we can see a vast difference between them. And therefore, the property of this layer will be different from that of the property of this layer. The hardness, the strength of this zone will be different, then the conductivity of this zone will be different, thermal as well as electrical conductivity of this zone will be different and there are certain certain flaws, voracities or in some cases some cracks like micro cracks we can see here on the screen itself, some micro cracks those are also present in this.

Therefore, once this machined work piece is put into service there is a possibility that the part may fail trough this zone which is not acceptable. Therefore, in general if the part is going for a critical use then this white layer needs to be machined out or removed by using some secondary processes. Now, let us have look at the advantages of this electric discharge machining process.

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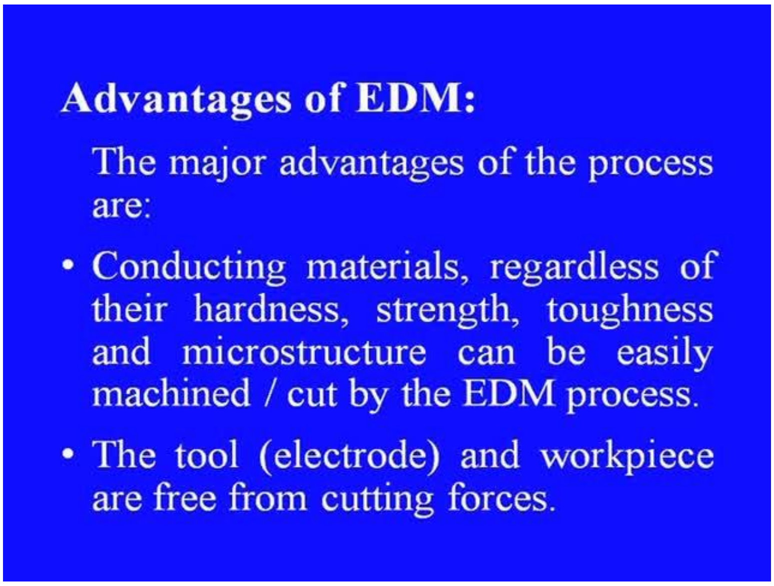

The major advantages are this is useful for conducting materials, regardless of their hardness, strength, toughness and microstructure. This is what I have indicated at the very beginning. In the conventional machining processes we are constrained by that hardness rule what we call as that the tool should be harder than the work piece, but here in the case of EDM this is not so. Even these processes more suitable for machining the materials are having higher hardness than the tool hardness.

Usually the tool will be copper or brass or something like that which are usually softer and the material, work material will be something like inconel or some super alloys, other super alloys which has got very high hardness as well as very high toughness. As there are, there is no physical contact between the tool and the work piece they are free from cutting forces.

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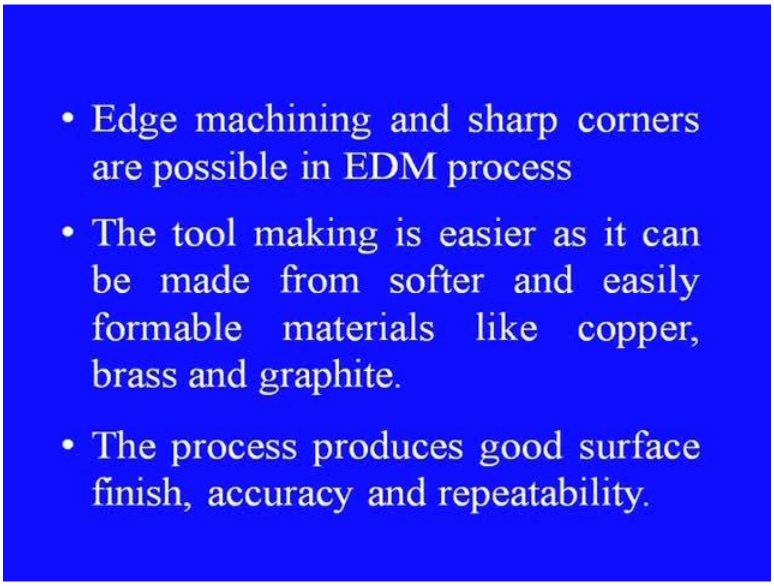

Edge machining and sharp corners are possible in EDM process. The tool making is easier as it can be made from softer and easily formable materials like copper, brass, graphite etcetera. The process produces relatively good surface finish, accuracy and repeatability. However, EDM is not recommended for fine surface finishes. It generally produces core, coarse surface finish as far as other finishing processes like honing, grinding or ECM are concerned. Hardened work pieces can also be machined using this EDM process since the deformation caused by it does not affect the final dimensions.

The EDM is a bar free process. This is another advantage. In most of the conventional machining processes as we have seen like drilling, even in milling or turning some bars are produced and which necessitates another secondary processing for removal of the bars, but here no bars will be produced. Therefore, secondary machining for bar removal is not necessary. No physical contact between the tool and the work piece. And therefore, the associated forces etcetera are not there.

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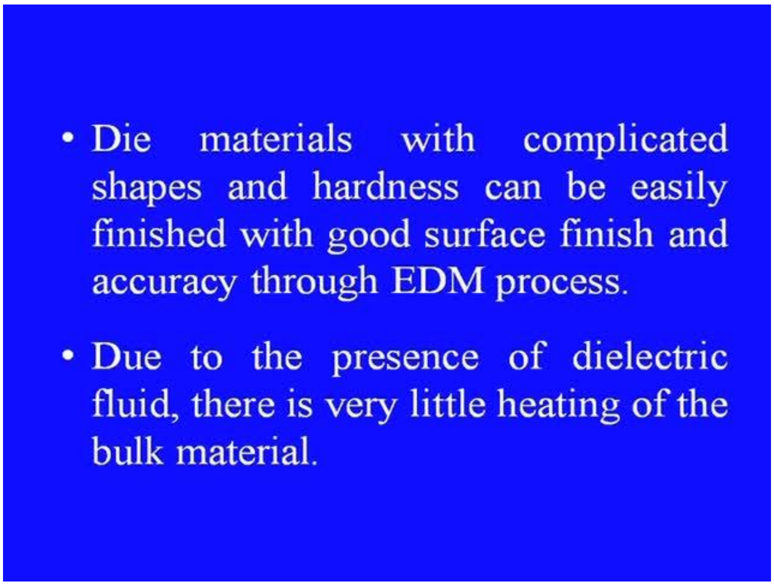

Die materials with complicated shapes and hardness can can be easily machined with good surface finish at a reasonable surface finish and accuracy through this process. Due to the presence of dielectric fluid there is very little heating of the bulk material. Then let us look at the limitations of this process as well. Material removal rates are basically low making the process economically only for few hard and difficult to machine materials, not for all materials as we have discussed already. Recast layers and micro cracks are inherent features of this process and this makes the surface quality of the machined surface poor.

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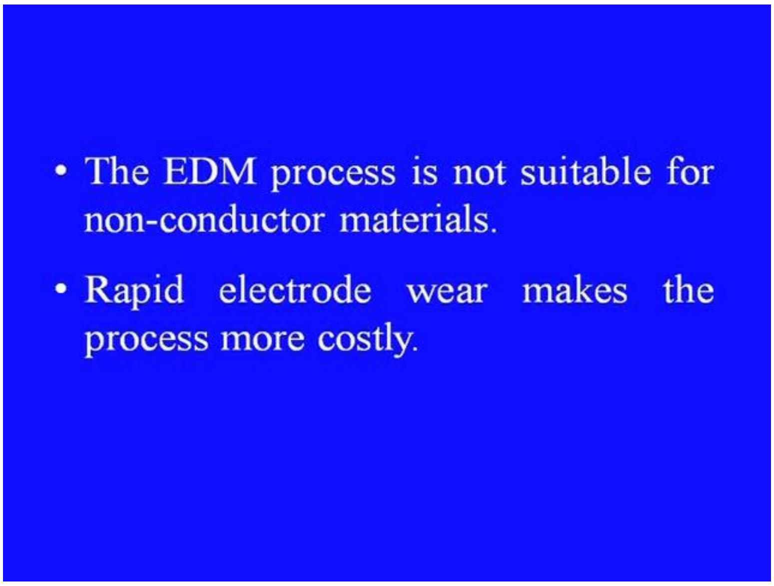

The EDM process is not suitable for non conducting materials. Rapid electrode wear makes the process more costly. This also we have already discussed, the erosion takes place not only on the work surface, but also on the tool end or the tool head also. However, that quantum of erosion at the tool head is much less in compared to the erosion at the work, work place or the work piece. However, there is disintegration in the tool as well and the tool needs to be replaced periodically and this can vary that wear can vary depending on the parameters, different conditions used for machining this material.

The surface is produced by EDM generally have a mac type of appearance, that is not very good surface finish and not very shining appearance as there will be the thermal distortion of the surface and there will be the heat affected or recast layer deposited on the machined surface. It requires further polishing to attain a glossy surface. Now, let us look at the material removal mechanism involved in EDM process.

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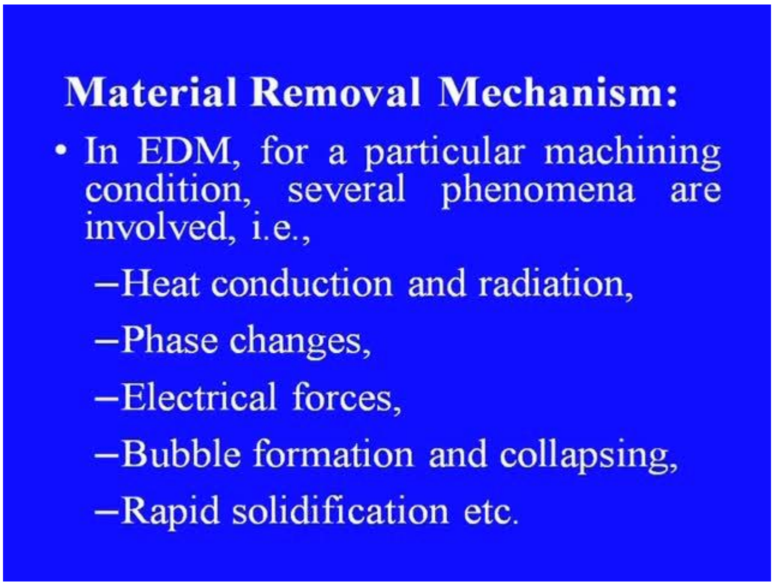

In EDM for a particular machining condition several phenomena are involved. This includes heat conduction and radiation, phase changes, electrical forces, bubble formation and collapsing, rapid solidification, etcetera. The thermo electric phenomenon is the most appropriate theory for the explanation of the electrical discharge machining process. The removal of material in EDM is associated with the erosive effects produced when discreet and special discharge occurs between the tool and the work piece electrode.

Short duration sparks are generated between these two electrodes. The generator releases electrical energy which is responsible for melting a small quantity of material from both the electrodes as I have already indicated, both tool as well as work piece gets eroded and the end of the pulse duration a pause time begins.

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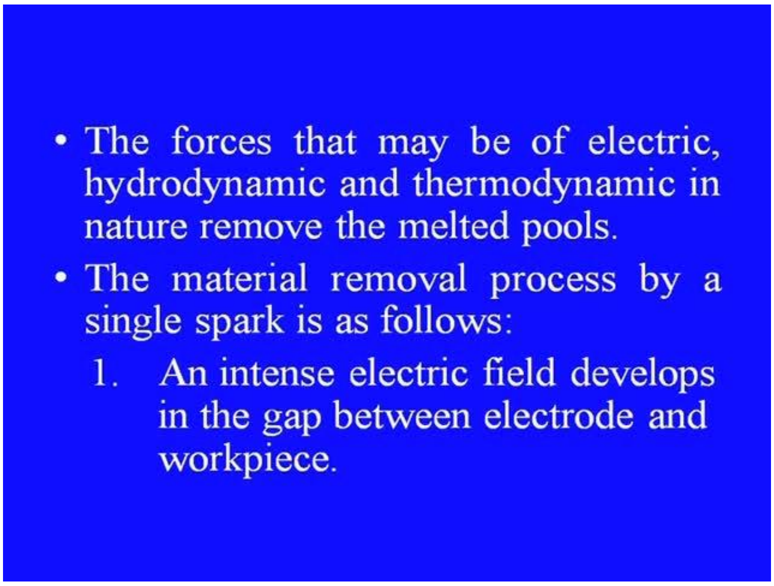

The forces that may be of electric hydrodynamic and thermodynamic in nature remove the melted pools. The material removal process by a single spark consists of the following sequence of events. Number one, an intense electric field develops in the gap between electrode and the work piece.

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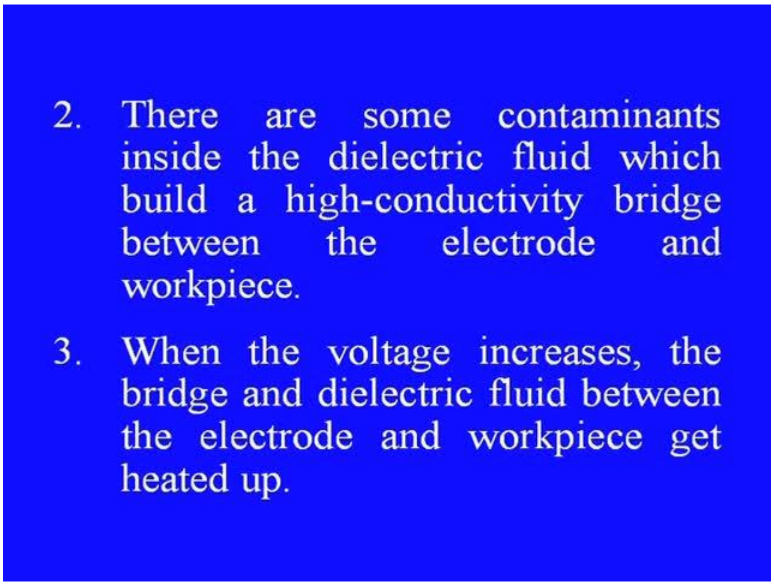

Number two; there are some contaminants inside the dielectric fluid which build a high-conductivity bridge between the electrode and the work piece. Number three; when the voltage increases the bridge and the dielectric fluid between the electrode and the work piece gets heated up. Number four; the dielectric is ionized to form a spark channel what is called a plasma channel also. The temperature and pressure rapidly increase and a spark is generated. A small amount of material is evaporated on the electrode and the work piece at the spark contact point.

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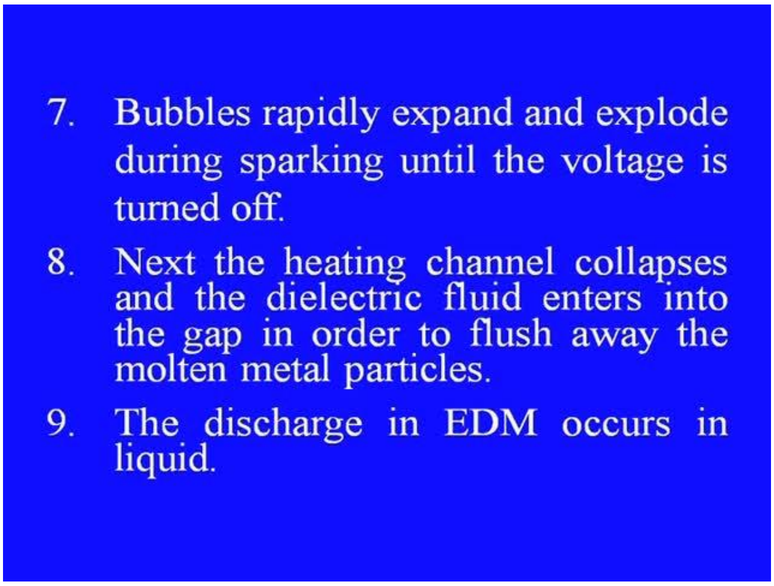

The bubble so created rapidly expand and explode during sparking until the voltage is turned off. Next the heating channel collapses and the dielectric fluid enters into the gap in order to flush away the molten metal particles which are also called debris. The discharge in EDM occurs in the liquid. The single spark theory is inadequate to explain the discharge. More recently researches have used electro thermal, electro mechanical and numerical methods to explain the dynamics and nature of EDM discharge process. Maybe some more new dimensions will be given to this understanding of this EDM working principle.

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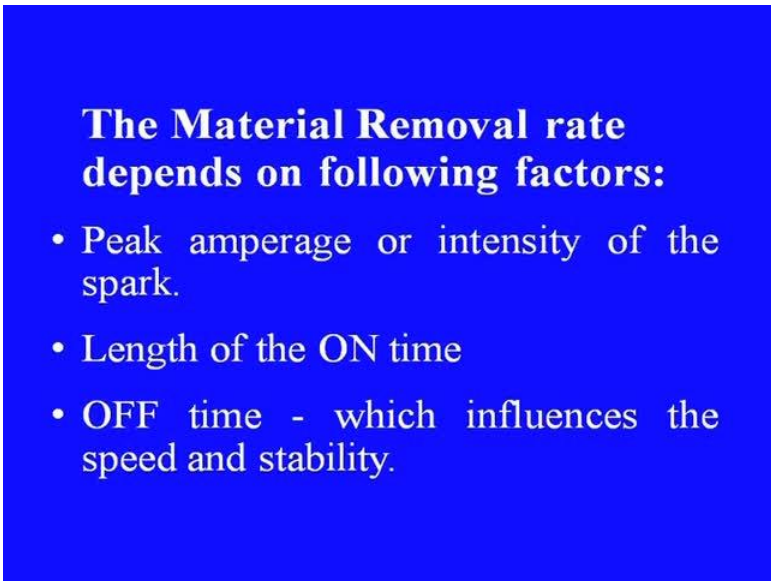

The material removal rate depends on the following factors. Number one, peak amperage or intensity of the spark, the length of the on time, the length of the off time as I have already indicated which influences the speed and stability of the sparking, then the duty cycle. Duty cycle is the percentage of on time relative to the total cycle time during which actually the material will be removed, then the gap distance as we have already discussed. This is a very important parameter in this EDM process, smaller the gap better is the accuracy and slower is the material removal rate.

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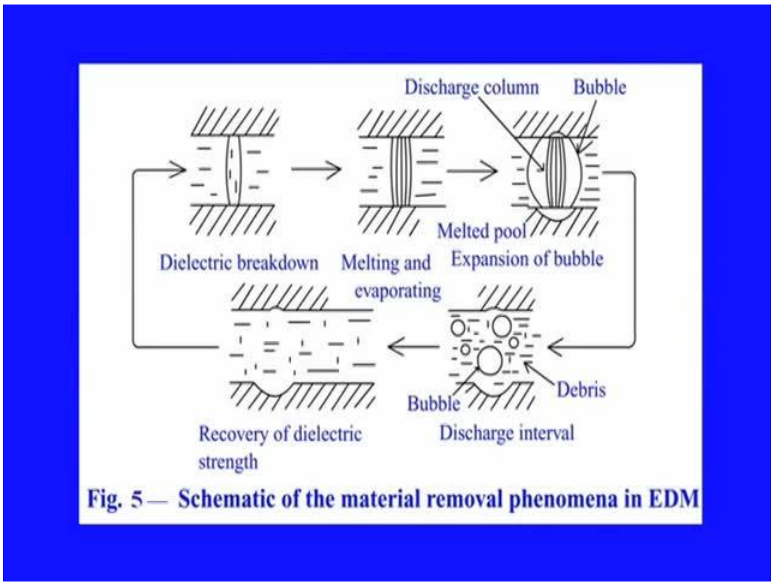

The material removal phenomenon in EDM are shown in this figure where applying the voltage, then the dielectric breakdown of the column in the nearest zone or the closest points between the tool and the work piece. Then that column increases the discharge starts, bubble formation takes place, the pressure difference takes place and the bubbles collapse, because of the pressure difference and it erodes the work material creating the debris in the dielectric.

And these debris will be flown away by this flowing electrical dielectric fluid, if these debris get accumulated here once at one time, this debris will create a conducting bridge between this tool and the work piece and no more sparking will be possible in future. Therefore, it is important to efficiently remove this debris from this working zone. This is done by the flushing fluid and now the new fluid will enter in this zone and the process will get repeated. Since, this this process, this material is eroded here.

Now, this distance between this and this gets increased. Therefore, the next sparking will take place through the nearest points like through this or through this and thereby an uniform removal of material will take place throughout this zone of the tool and work piece interaction. Now, let us summarize what we have discussed in this particular session. In this session we have studied the basics of electric discharge machining process, its working principles, the process features and the heat affected zone produced during this process or during the machining, the advantages and limitations of this process have also been discussed. In the next session we will discuss about the die sinker and wear EDM process along with other variant processes, hybrid processes and new developments in EDM. We hope this session was informative and enjoyable.

Thank you.