Advanced Machining Processes
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Module - 3
Advanced Machining Processes
Lecture - 11
Electro Chemical Discharge Machining (ECDM)

Welcome to this session on electro chemical assisted electric discharge machining, in short ECDM. In the previous few sessions, we have discussed the basic electric discharge, machining process. Some of their variants, their working principles, their setup's, their applications, limitations, etcetera. In this session we will discuss about another hybrid process that is ECDM, electro chemical discharge machining process.

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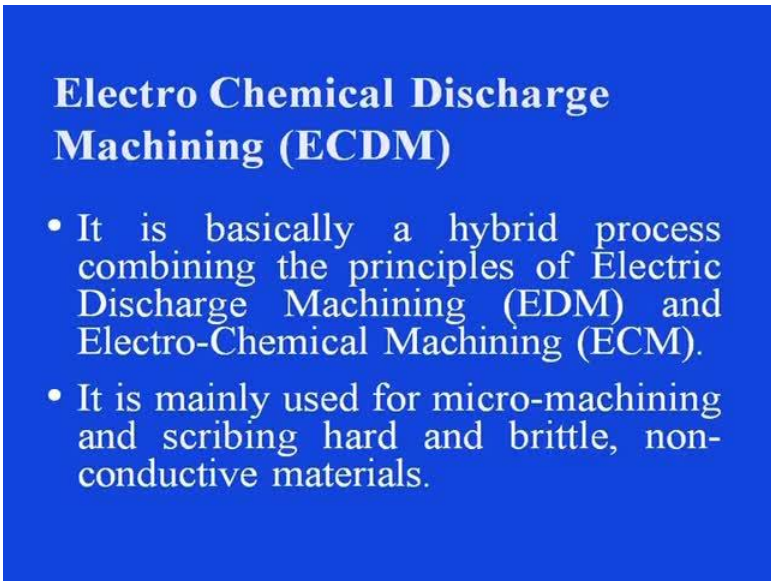

It is basically a hybrid machining process, combining the principles of electric discharge machining that is basic EDM and electro chemical machining. It is mainly used for micro machining and scribing hard and brittle, non conductive materials. The process is basically for very small material removal, and therefore not for bulk material removing applications. So, this is a combination of two processes as the name suggest, in which one action will be by electro chemical action, which is very familiar to almost all of us in which a chemical action takes place, and that causes the dissolution of material into a electrolyte called a working fluid. And therefore, the material removal from the parent body takes place.

In addition to that combining another phenomenon that is electrical discharge phenomena, in which we have discussed already the material removal takes place in the form of erosion due to the cavitation. And then melting and evaporation of material because of the temperatures that develops as the sparks takes place. Therefore, these two things are combined together, in this particular hybridization where basically the material removal will be done by the basic spark erosion process, which is known for rough machining or the stock removal or material removal process. The smoothening effect will be given by the electro chemical effect, which is known for producing smooth surfaces.

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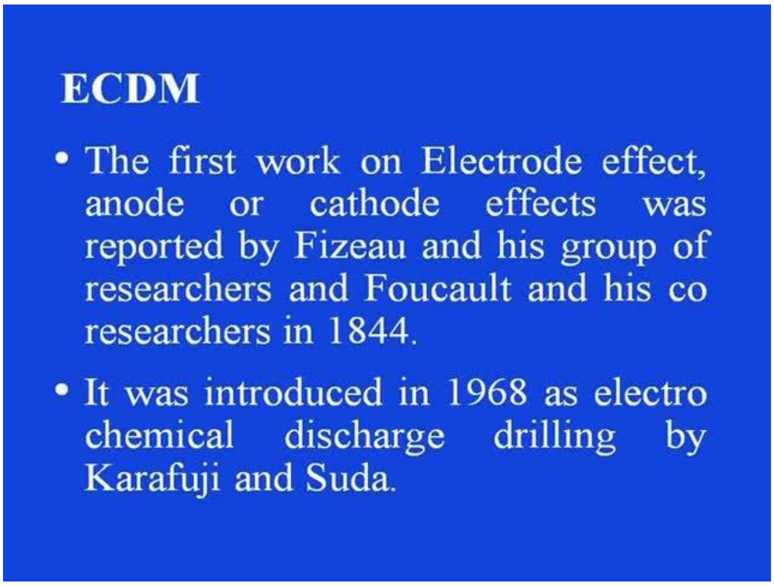

The first work on electrode effect, anode or cathode was first reported by Fizeau and his group of researchers and Foucault and his co researchers in the year 1844, thus as a principal. So, this principles are very old that is of nineteenth century. It was introduced in the year 1968 as electro chemical discharge drilling by Karafuji and Suda.

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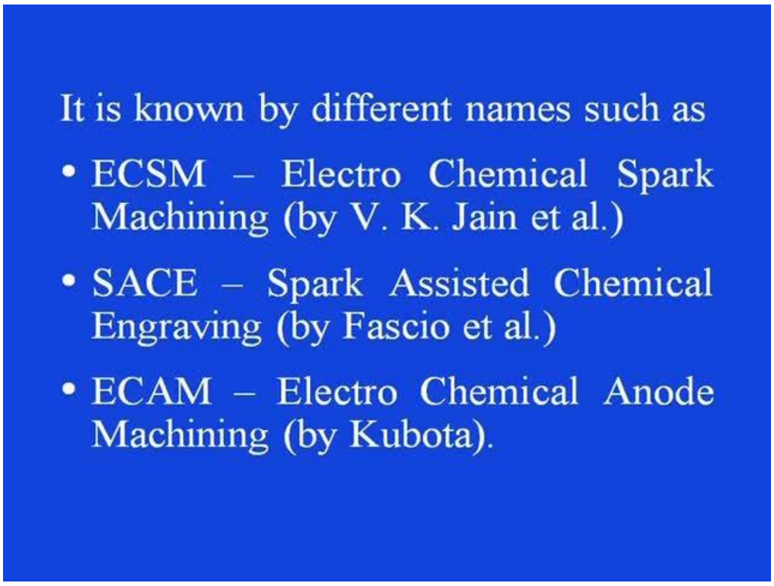

It is known by different names such as ECSM electro chemical spark machining, this was named by VK Jain and his co researchers. SACE spark assisted chemical engraving this was called by Fascio and his co researchers, then ECAM electro chemical anode machining by Kubota.

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Then DMNC discharge machining of non conductors by Cook et al. SAE spark assisted etching this was investigated by Daridon and his co researchers. Now, let us look at the setup of this ECDM process, this process setup consists of the power unit which is a basic requirement, which is mainly a D C supply or an A C to D C convertor. A suitable electrolyte depending on the tool and the work material is required. This electrolyte can be different for a pair of tool, and a work combination, and there will be an optimum use of the electrolyte, electrolyte concentration and different parameters of the electrolyte.

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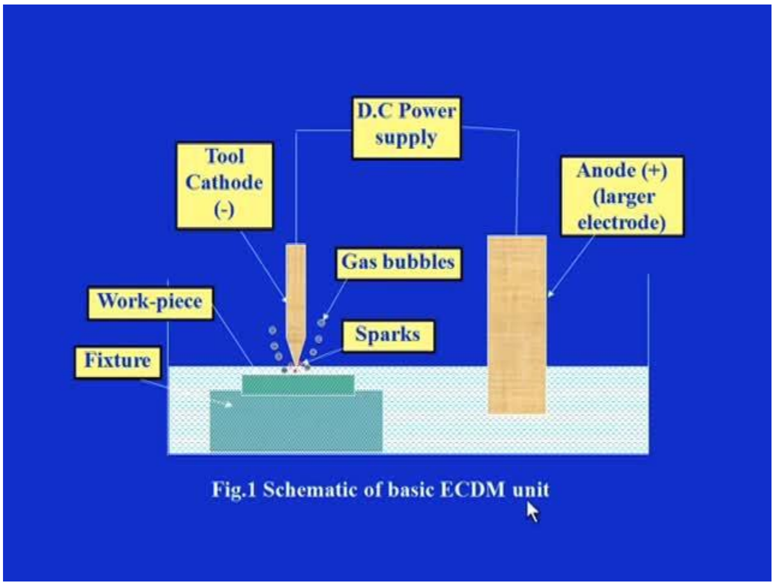

The setup is like this something like this, which is shown schematically this is in the screen. So, in which the the two electrodes are the tool which is normally made cathode as seen here. And the other one is the anode which is kept partially dipped in this electrolyte, and the this is completed through the work-piece. Since, the electrolyte conducts electricity. Therefore, this anode is in contact with the work-piece and the circuit is competed like this through the electrolyte.

There will be a small machining gap maintained in this zone, as we can see and this tool can have different configuration depending on the requirement of our job specification or the application. This maintaining this gap is very critical, if it touches this work material the behavior of the material removal will get changed, and if the gap is increased beyond a certain limit, then also the performance of material removal will get changed. The spark will take place in this zone where the distance between the tool, which is a cathode and the work-piece which is nothing but in contact with the anode will be minimum.

Then because of the electrolyte the chemical action basically, some gas bubbles will be produced. Basically some gases will be produced and they will form a layer here in this small gap, which will further get collapsed and there will be a continuous film of gases in this zone. This will be between the work-piece and the tool, this will be connected through some wires appropriate wires to a D C power supply, and the appropriate or rating or rated voltage will be applied on to it. Basically, what happens in this we can think of like this.

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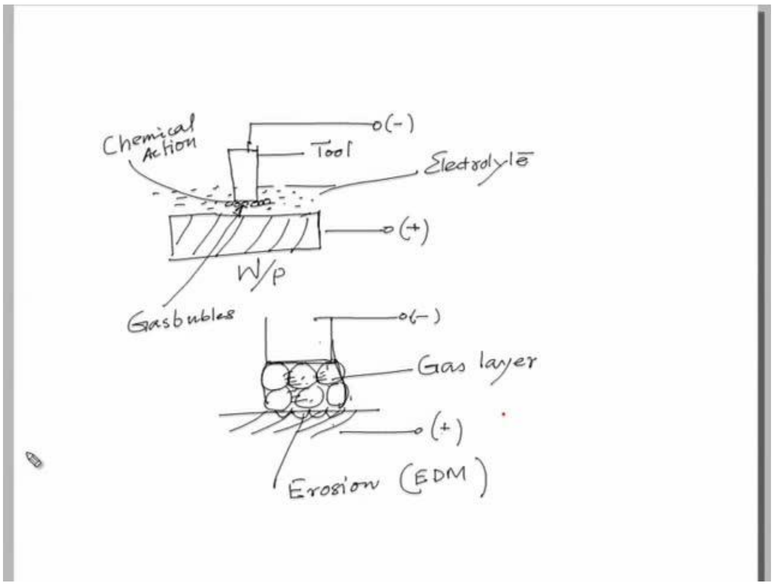

Say for example this is the tool and this is the say work-piece. This is the work-piece and this is the tool, this is connected to negative and this connected to positive end of the power supply. Then these gas bubbles will be produced here because of the electrolyte and the corresponding. So, this is the electrolyte, electrolyte and the corresponding chemical reactions that is taking place. So, this is what is called the chemical action.

And these are the gas bubbles in fact this layer of these gas bubbles will be responsible for producing the EDM effect, which in turn the small, small gas bubbles. So, we can consider them to be a layer between these two pairs. So, this is negative and this is connected to positive and this is like this so this produces a gas layer, which we can think of at times this is nothing but a layer of gases and they collapse in between and forms a complete gaseous zone.

Now, at this moment these two electrodes are separated by this gas layer, you can say this is gas layer in between them and they are. Now, this layer acting as the barrier in between these two electrodes this facilitates, the ionization of this layer and there will be sparking produced between these two electrodes. And this sparking will help in turn in removing material from these work-pieces in the form of erosion, as we have studied in case of EDM principle like as in as it happens in case of EDM.

However, as soon as the sparking takes place and since this is not continuous process, the gas layer will disappear momentarily and again the chemical action will take place and again the gas layer will be formed, and this will continue for further action. The tool is made of a conducting material and its cross section is smaller depending on the type of profile required. The other tool or the anode is usually larger in cross section, and is dipped into electrolyte both the tools are connected to the complete circuit, as we have already seen this is the larger electrode.

This is generally anode and this one is the smaller electrode, which will be a cathode and both will be connected to this power supply, and this competes the circuit. An electrolyte tank is used which contains, the suitable electrolyte a flushing and recirculation system can keep the electrolyte flowing and keeps the, keeps helps in taking the debris out from the machining zone. Suitable fixtures are used for holding the work-piece at place. Once the parameters of current and voltage are set, and a suitable gap is established between the tool and the work-piece sparking begins. Due to electrolysis effect, bubbles are released which help in initiation of the sparking.

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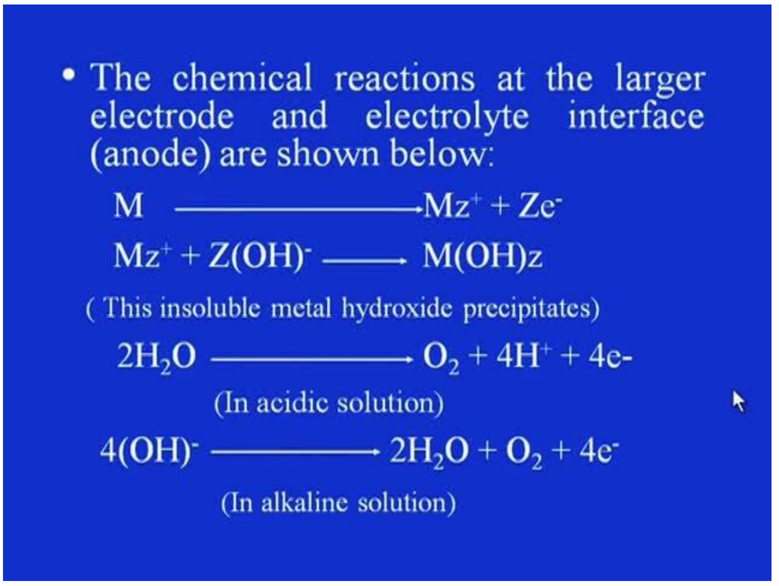

The chemical reactions at the larger electrode and the electrolyte interface that is at anode, can be shown like this in the electrolyte invariably water will be present and this water will get dissociate like this H 2 O will be broken down to oxygen and nascent hydrogen, with the release of electrons like this. If there are two molecules of water then 4 electrons will be released then OH ions that is present in alkaline solutions, which is a characteristic of any alkaline solutions. So, OH ions will be there, these OH ions will form continuously water, oxygen and it can release again electrons.

That means in either in acidic or in alkaline solution, the basic principal is the availability of electrons for doing some work. Now, let us see in the anode, let us consider this as metal M, metal M we can think of the metal ion and electrons plus electrons. If both of them get neutralized then we can get a stable metal ion, metal metal molecule. In ionic form that metal ion which is positively charged will combine with OH ions, if it is an alkaline solution that is the dielectric is composed of alkaline solution then they will give rise to because of the chemical reaction between this metallic ion which, we can call as M z plus and OH ions, which we call as OH minus can give rise to a metallic hydroxide.

Which is nothing but symbolically can be represented as M OH z. This metallic hydroxide is insoluble to the electrolyte and therefore, it goes into the solution in to the electrolyte system. As a precipitate and this is nothing but this metallic hydroxide is the material removed from the parent material. The chemical reactions at the smaller electrode and the electrolyte interface can be represented like this, as we have already said.

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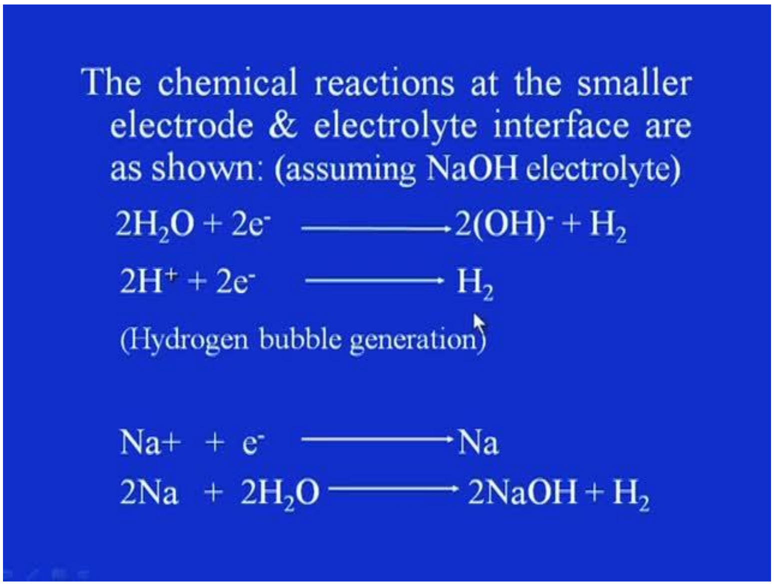

In the electrolyte solution the hydrogen will be there and the electrons released from the electrolyte will combine with or will act on these water molecules, which will form the nascent hydrogen as well as the OH ions as we have just now seen. These OH ions are responsible for forming the metallic hydroxides, this is the fall out of the reaction of or the action of the electrons available, in the electrolyte and with water they form these OH ions and hydrogen bubbles. And continuously this hydrogen ion and electron they will continue to react together like this.

This hydrogen bubble generation is basically responsible for the gas layer, or the bubble layer. What we have discussed few minutes back on the other hand, the metal say for example, sodium ion and electron present in the electrolyte, they will combine and form the metal. Say sodium and sodium with water, that they will form sodium hydroxide which is metallic hydroxide plus hydrogen, which is this sodium hydroxide is insoluble in this electrolyte and gets precipitated thus, the entire dynamics of this electrochemical reaction continue.

Now, let us see the materials for machining in this process. The common materials that are machined through process include glass that can be a pirex glass, flexi glass, boro silicate glass, optical glass etcetera. Then ceramics can be of pure alumina then the refractory bricks, then quartz and could be composite materials like FRP or GFRP or Kevlar fiber, reinforced composites etcetera.

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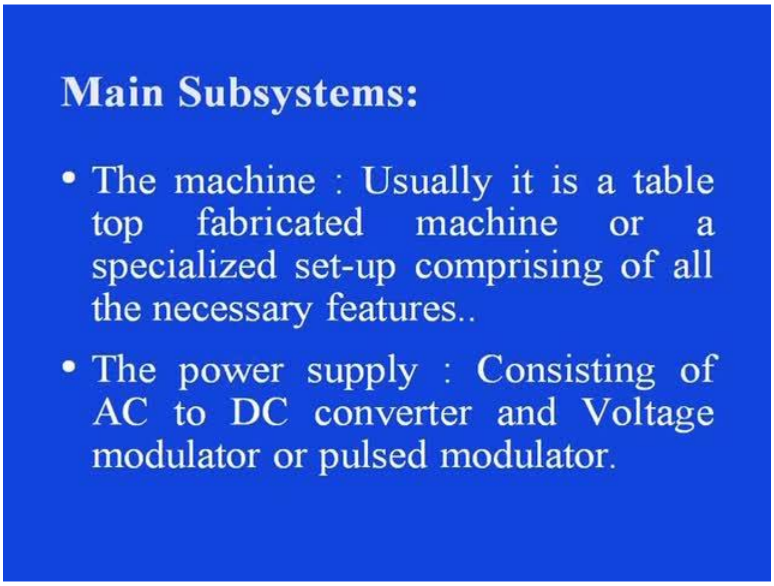

Now, let us look at the main subsystems of this process. The machine itself is a component so it is usually a table top fabricated machine or a specialized set up comprising of all the necessary features. There should be a power supply, as we have indicated earlier it consists of A C to D C convertor or direct D C supply and a voltage modulator or a pulse modulator.

The electrolyte circulation system and the flushing arrangement should be there so that the electrolyte can be continuously kept on flowing and the debris produced can be removed. Next, subsystem is the control system this control system consists of micro controller or servo operated subsystem with which, we can have the flexibility to program the motions of the tool or the work-piece very precisely

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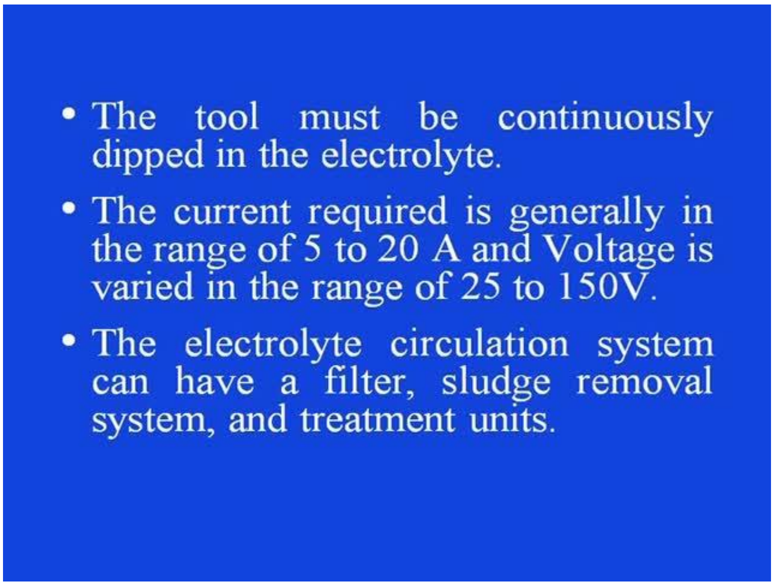

The tool must be continuously dipped in the electrolyte so as to complete the circuit. the current required is generally, in the range of 5 to 20 ampere and voltage is varied in the range of 25 to 150 volts. The electrolyte circulation system can have a filter sludge removal system and treatment units.

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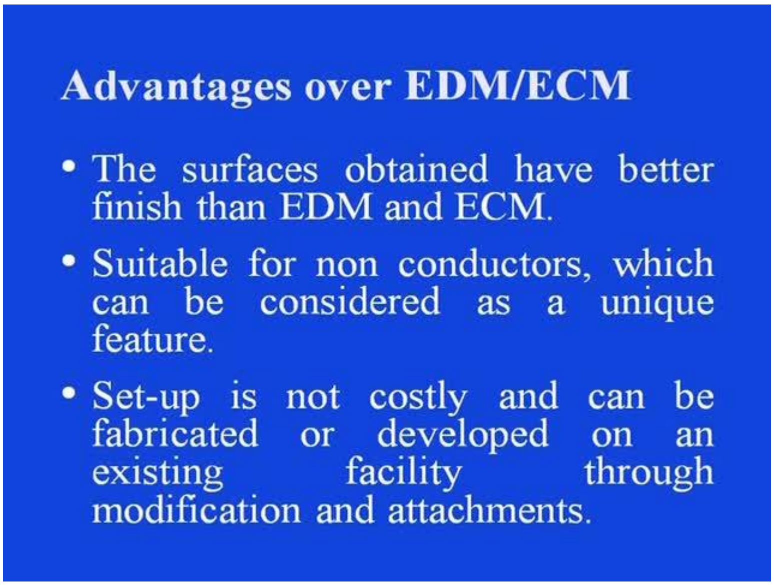

Now, let us see the advantages over EDM or the ECM process alone, which are the basic individual processes and ECDM is the combination of these two processes. The surfaces obtained in the ECDM processes have better finish, than EDM or ECM can produce alone. This process is suitable for non conductors, which can be considered as a unique feature of this particular process. As we have seen EDM process is not efficient for non conductors or cannot be done machining cannot be done as well, as in case of ECM without a conductor, conducting material the processes cannot take place. The setup is not costly and can be fabricated or developed on an existing facility through modification and simple attachments.

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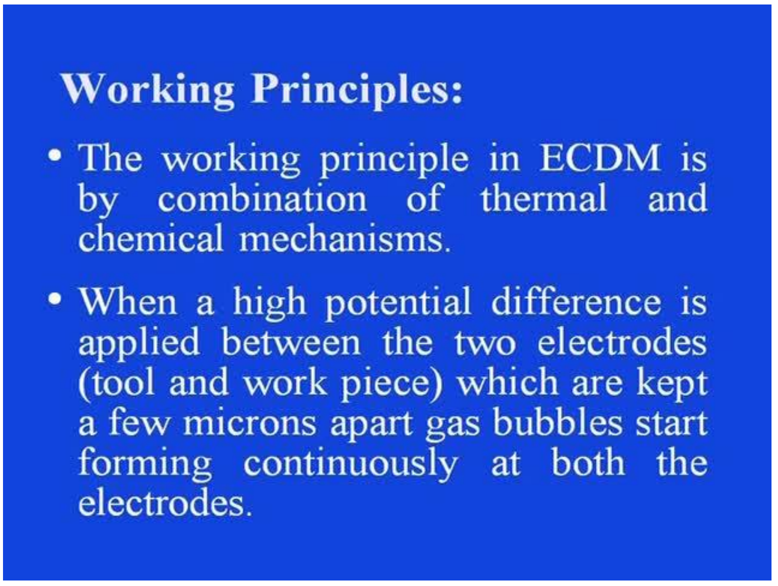

Let us see the working principles of this process. The working principle in ECDM is by combination of thermal and chemical mechanisms, we have already discussed few things about this let us see the mechanism how it happens. When a high potential difference is applied between two electrodes, here the tool and the work-piece which are kept at a few microns apart, gas bubbles start forming continuously at both the electrodes, this is because of the chemical action. These bubbles on the smaller electrode which is nothing but the cathode collides to form a thin gaseous film on the tool, this we have already seen how it forms and how it collides to form the film.

Now at a critical point, sparking occurs between the tool and the electrolyte. The material removal takes place, when the work-piece is in the close vicinity of the sparks this is due to the basic EDM phenomena, which is nothing but the sparking or the cavitation erosion and thermal removal of the material because of the EDM action. Thus we have seen both the actions chemical action, as well as the action due to the EDM are present in this mechanism.

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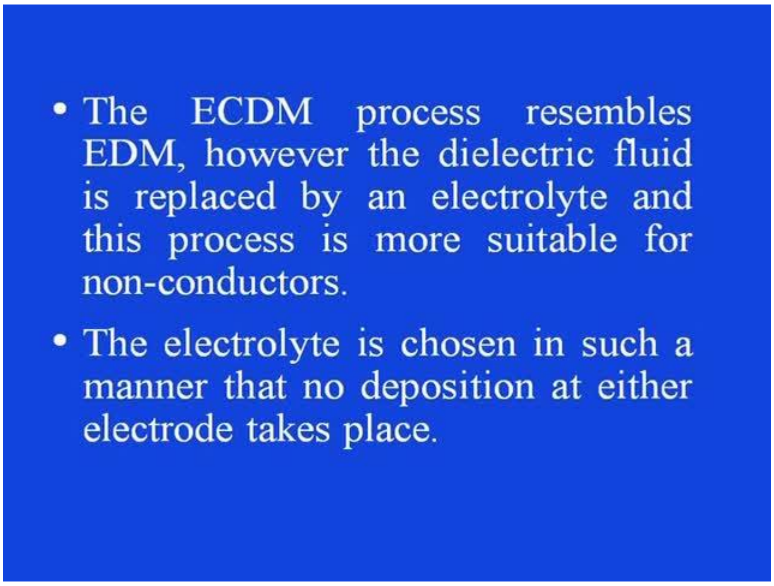

The ECDM process resembles EDM, however the dielectric fluid is replaced by an electrolyte and this process is more suitable for non conductors, contrary to the normal EDM process, which is rather to say not suitable for non conductors. The electrolyte is chosen in such a manner that, no deposition at either of the electrode takes place. The commonly used electrolytes are sodium hydroxide, sodium chloride, sodium nitrate, potassium hydroxide, hydrochloric acid, sulphuric acid, sodium fluoride etcetera.

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Now, let us see the ECDM applications. ECDM is a novel hybrid machining technology, for production of through and blind micro holes, micro grooves, micro slots, micro channels, and complex shaped micro contours in electrically non conductive materials.

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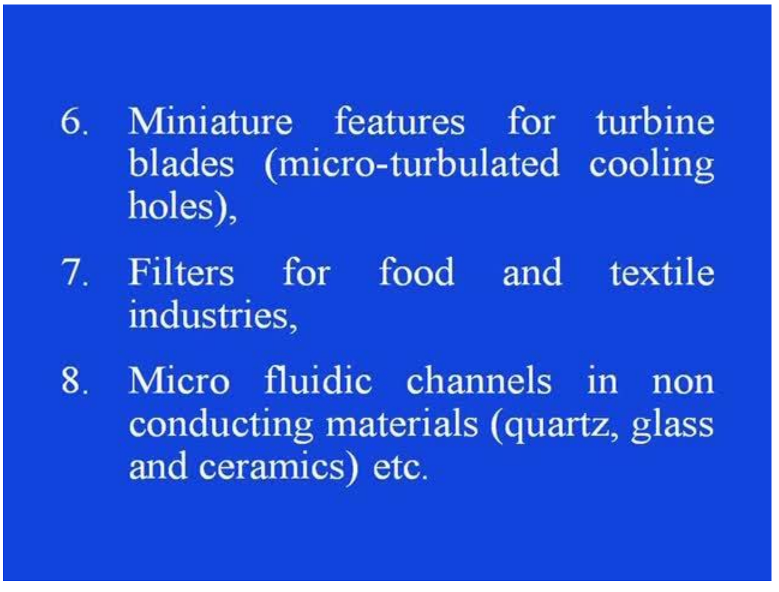

Miniature features for turbine blades, that is micro turbulated cooling holes then it is also useful for making filters for food and textile industries, where very minute holes are to be produced. Then this process also useful for micro fluidic channels in non conducting materials like glass, quartz, and ceramics. One such application will be shown we will discuss little later. Other applications of ECDM include turning and bracing of metal, mounded, grinding tools this was reported by several researchers. Then the process is very simple yet they are very useful also, and this is efficient than the other conventional methods.

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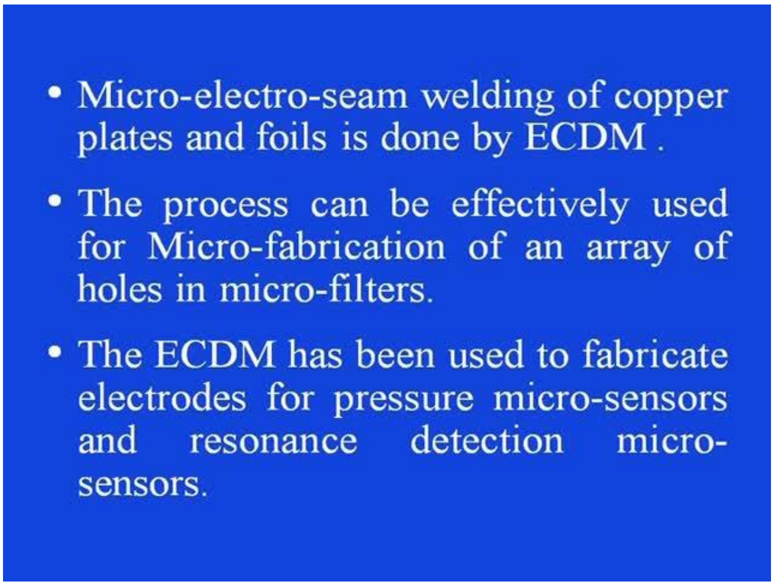

Micro electro seam welding of copper plates and foils can be done by this ECDM process. The process can be effectively used for micro fabrication of an array of holes, in micro filters as we have already discussed. In micro filters that is used in food applications, micro holes are required to be produced in a very close spacing's and this can be used useful, this process can be useful for manufacturing that.

This ECDM process has been used to fabricate electrodes for pressure micro sensors, and resonance detection micro sensors. The ECDM process has been used to machine micro fluidic channels and three dimensional fissures, in glass substrates. The other applications are in micro pumps, micro accelerometers, and drug delivery devices.

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Material removal mechanism in this process let us see how it takes place. Material removal mechanism in ECDM are explained by different researchers in different way, some of these are being discussed here. The first and the most acceptable mechanism of this material removal, in this ECDM process is due to the thermal mode primarily by melting and vaporization due to discharge sparking. As we have already discussed about this mechanism, which is similar to what happens in normal EDM process.

The other modes include chemical mode, in this chemical mode material removal is mainly through the itching process, which is seen predominantly at the green boundaries. As we know green boundaries are the locations where the densities of, densities of the atoms are much less. Therefore, for any chemical itch chance it is easier to attack these locations for any chemical reactions to take place. And in this case also these green boundaries are attacked first, in which the atomic densities are much less and therefore, the etching process starts. Some mechanical wear and spalling has also been reported in ECDM by some researchers.

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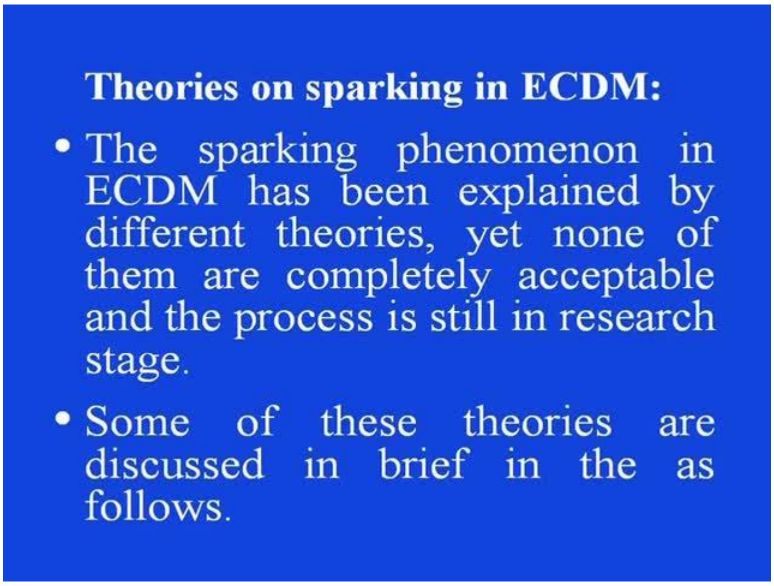

Now, let us see the theories on sparking in ECDM. The sparking phenomenon in ECDM has been explained by different theories, yet none of them are completely acceptable at this moment and the process is still in the research stage. Some of these theories are discussed as follows.

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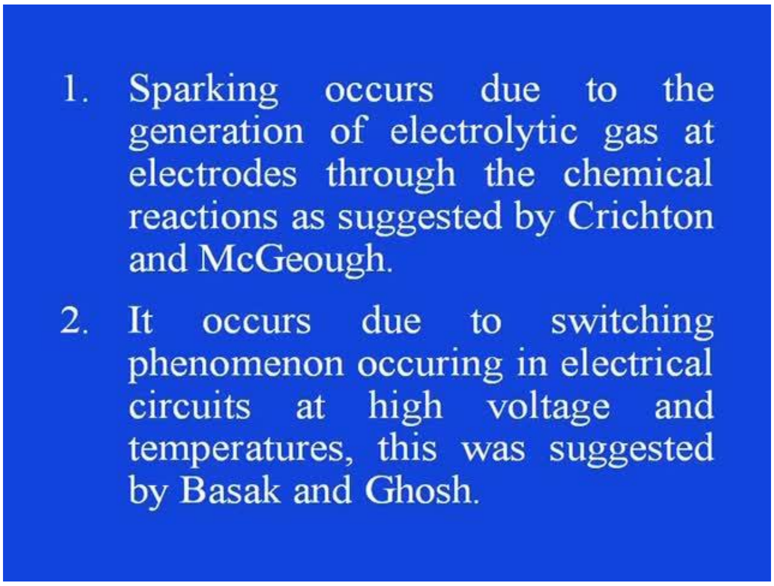

Number one sparking in ECDM occurs due to the generation of electrolytic gas at electrodes, through the chemical reactions as suggested by Crichton and McGeough. This was also discussed earlier part of this particular session. It occurs due to switching phenomenon, occurring in electrical circuits at high voltage and temperature. This is another theory regarding the sparking this was suggested by Basak and Ghosh.

The third theory talks about the sparking occurs due to the discharge of bubbles, acting as a valve operating at high electric field as postulated by Zen and his co researchers. According to Kulkarni and his group of researchers, the sparking occurs due to ark discharges, when small hydrogen bubbles quells to form large bubbles.

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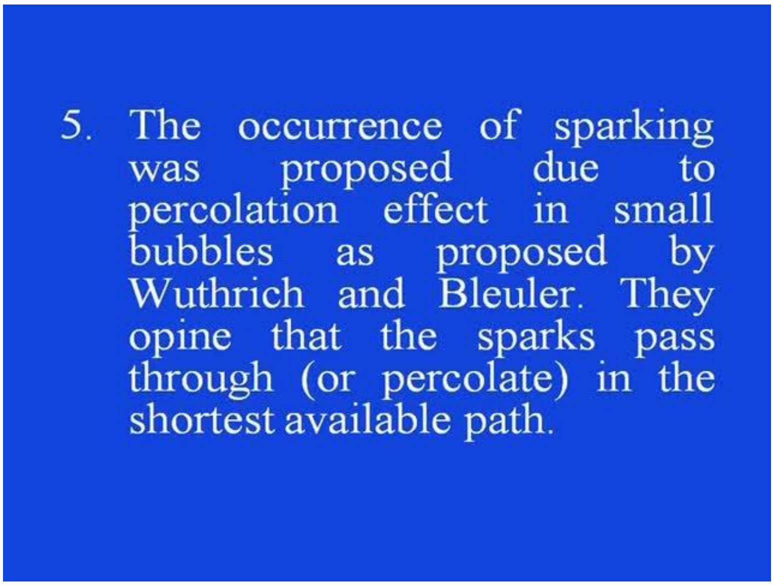

In another theory, the occurrence of sparking is postulated to have occurred due to the percolation effect in small bubbles, this was proposed by Wuthrich and Bleuler. They opine that the sparks pass through or percolate in the shortest available path, as reported by Wuthrich and his co researcher’s main challenge is in the controlling of the gas film its stability and its dynamics. It is also reported that material removal rate increases with applied D C voltage and electrolyte temperature.

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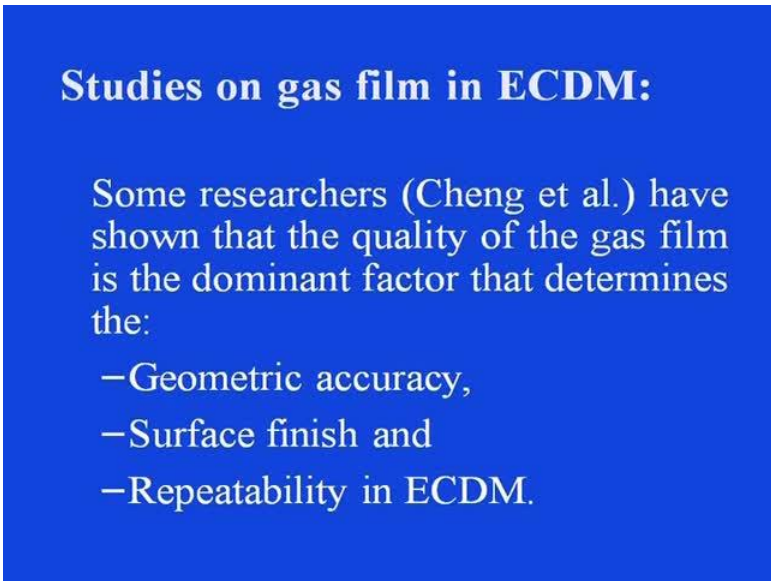

Here are some studies on gas film in ECDM. Some researchers Cheng and his group and all have shown that, the quality of the gas film is the dominant factor that determines the geometric accuracy, in ECDM surface finish and repeatability in this ECDM process. Whereas, Bhattacharya and his co researchers have reported that the critical voltage depends on the concentration of the electrolyte, the conductivity of the electrolyte and the tool geometry.

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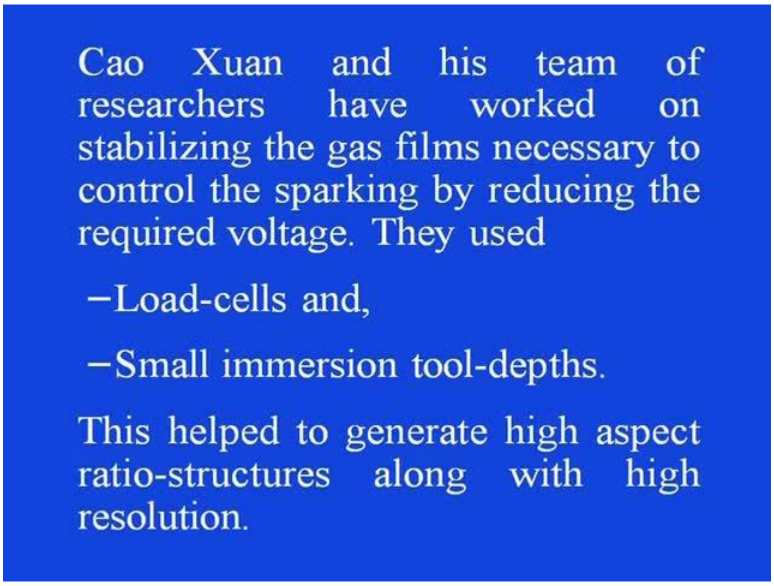

Cao Xuan and his team of researchers have worked on stabilizing these gas films, necessary to control the sparking by reducing the required voltage. They used load cells and small immersion tool depths, this helped to generate high aspect ratio structures along with high resolution. Now, there are one or two variant processes also in ECDM one is wire ECDM also called WECDM. This is a combination of wire EDM and ECDM. So, you can say this is the hybridization of one hybridized process already and the basic EDM. Wherein a continuous moving wire is controlled by a spool feeder, which moves over a non conducting work-piece, dipped in an electrolyte the sparking causes the material removal.

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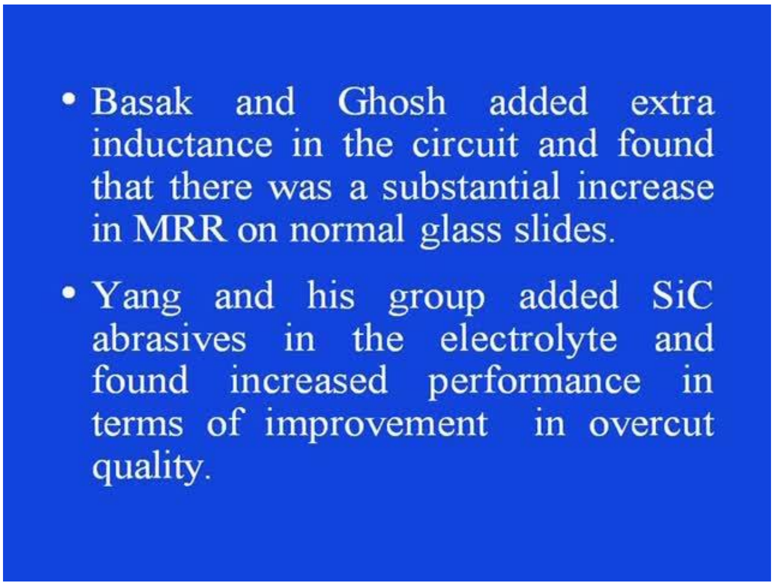

Basak and Ghosh added extra inductance in the circuit and found that, there was a substantial increase in material removal rate on normal glass slides. Yang and his group added silicon carbide abrasives in the electrolyte, and found increased performance in terms of improvement in the overcut quality. In traveling wire ECDM it was also found that stronger pulse current has better machining affects, while slicing glass and quartz.

Few researchers suggest that, the tool positioning control system is a key factor and discussed its control, stability and robustness. Thus we have seen in most of the aspects, in this process are at the research stage only, and the things are to be yet to be concretized and different groups and different countries are working in this process.

Some experiments on ceramics using gas filled process reported saving, an amount of electrochemical energy and increase in material removal rate.

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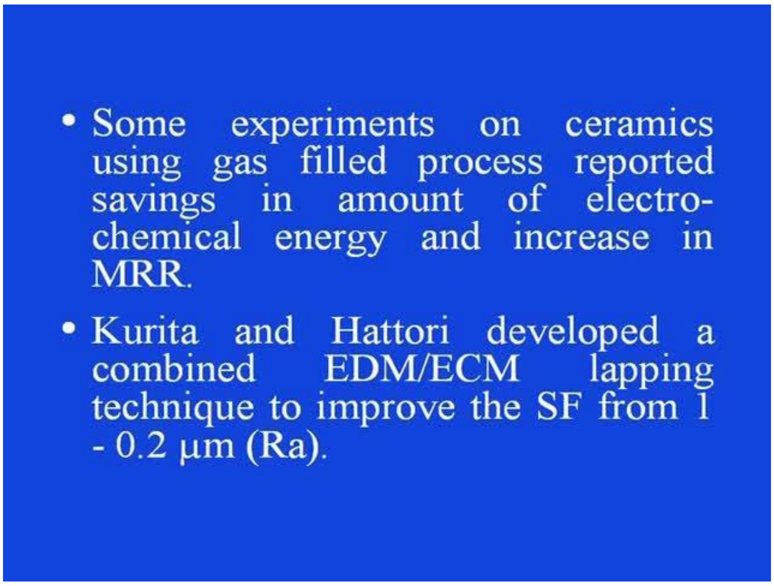

Kurita and Hattori they have developed a combined EDM, ECM lapping technique to improve the surface finish, in which they have achieved surface finish of 0.2 micrometer of average roughness, which was improved from 1 micrometer to 0.2 micrometer. Zain and his group have used alumina glass composite ceramic material, and found that the machining rate is greatly affected by porosity of the samples. The results also show that the material removal occurs by attacking, the green boundaries most probably due to the etching process.

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Liu has reported that the craters formed in the ECDM process, are almost same as those formed in the EDM process along with some recast effects, which is mainly due to the sparking action. Spalling is the major material removal mechanism, as per his research findings. Now, let us move to a case study which describes the machining of glass using this particular process ECDM. These experiments were carried out in IIT, Roorkee, the material used was soda lime glass and the tool material was copper and stainless steel.

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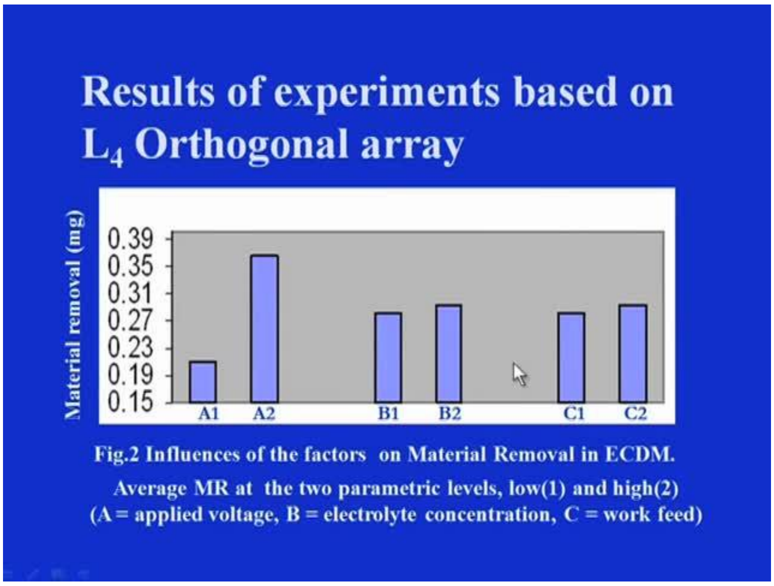

So, this a figure in the screen shows the results of the experiments conducted using this ECDM process, in which the effect of different parameters like applied voltage, electrolyte concentration and work feed are shown on the material removal. And here as we can see this is the effect of applied voltage and this is the effect of the electrolyte concentration, not much variations as far as the electrolyte variation is concerned, not much variation in the corresponding material removal. And so is the case with work feed rate with the variation in the work feed there is not much changes in the material removal.

However little changes are there, but as far as the applied voltage is concerned, there is a huge difference between two levels of voltages applied on the material removed. These results were produced in IIT, Roorkee. Here we have seen the material removal occurs more at higher level of voltage due to the increased thermal effect. At higher level of electrolyte concentration, marginally higher material removal takes place. Higher feed plays a smaller role in material removal rate this we have seen, this may be attributed to the fact that it gives more space for gases to escape freely, thereby allowing more stable film and sparks.

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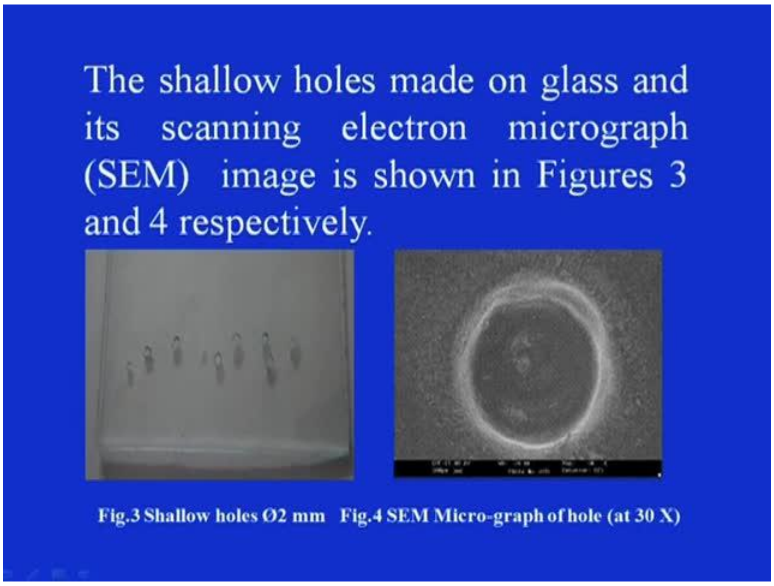

The shallow holes made on glass, and its scanning electron micrograph images are shown here. So, these are some of the holes, shallow holes that is of 2 millimeter approximately 2 millimeter diameter, these were made on the soda lime glass and this is the corresponding enlarged view obtained through scanning electron micrograph, this is the hole this we can see clearly.

How the material removal is taking place and the smoothing effect of the 2 phenomena, that is electrochemical action and the material removal is basically because of the electric discharge machining. And this is the combination of the combined result is like this of course, little bit of stray machining is there which is slightly towards the periphery of this. This can be minimized by using some proper masking etcetera. This figure is at thirty times larger than these original holes.

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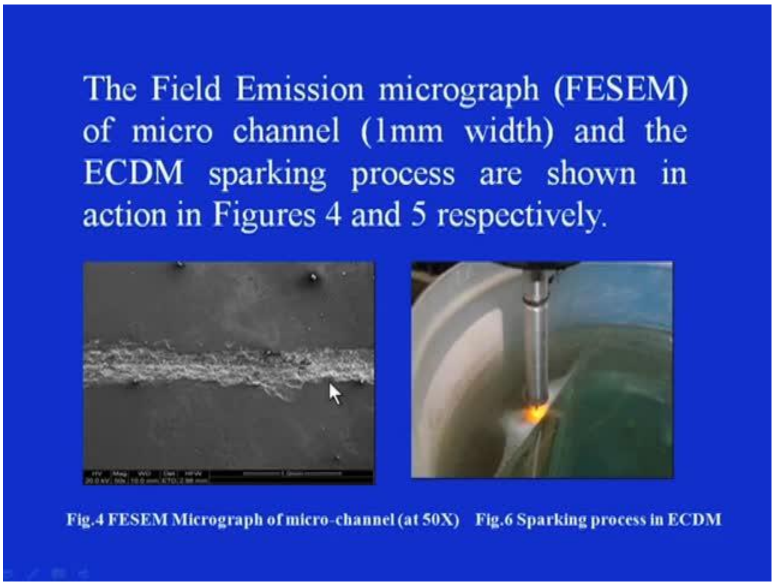

Then this is another another image, this is another image of field emission micrograph. This is, this is a channel which is 1 millimeter width and this was manufactured or fabricated by this ECDM process, in the same laboratory and this is the we can see the sparking taking place in the actual process, and this is the tool is being dipped in this electrolyte. This is the work-piece and this is where the sparking is taking place, this is the sparking zone. And this tool can be moved or this work-piece can be moved by some programming mechanisms, it can be programmed through CNC controlled or other mechanisms. And this is the resulting micro channel that is been cut using this process.

One such micro channels can be like this optical glass specimen in which, we have machined a channel micro channel using this ECDM process. So, this channel you can see in between these two lines, this is the channel and this is being produced by dipping this piece on the electrolyte, and then moving the tool like this from one position to another position. This can be done in the either way also, keeping this tool stationary and then moving the work-piece from this side to this side, or like this from this side to this side.

Another way of producing this could be by using a long tool, which has got one long edge then dipping this in the electrolyte and bringing it near to this, then the sparking will take place as well as the chemical action will take place, which will create the channel micro channel something like this. This will be of course, an open channel and by covering this suitably with another material, this can be used for micro fluidic applications.

We have already tested that there are sufficient clearances for fluid to flow through this once, we cover this with another material of same kind and this could be useful for micro fluidic applications. So, this could be a very good application of the ECDM process as far as the production of micro channels are concerned. The filled emission micro graph of holes and its edges, can be seen in these figures. It is evident from these figures that the thermal effect and the micro cracks are predominant.

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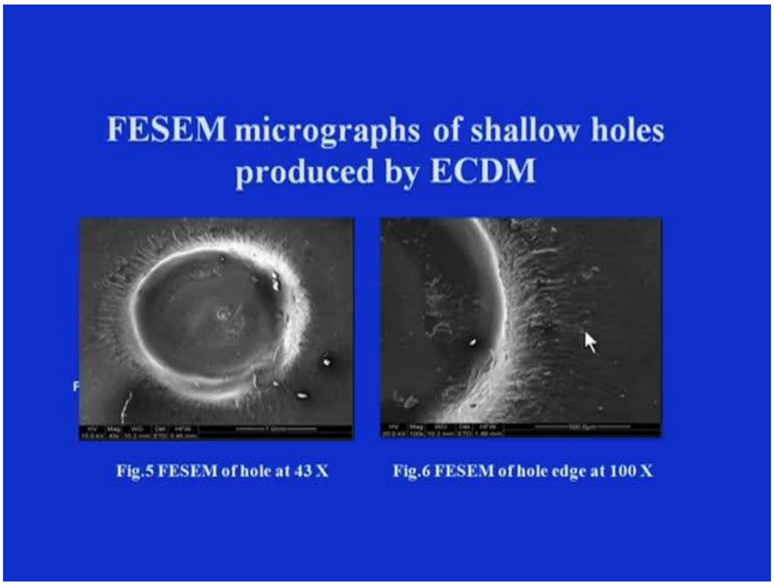

These are some of the other images of further magnification, that is this is at hundred times magnified view of the hole edges, where we can see some micro cracks and some stray cutting as I have already indicated and this is the complete picture of the hole. So, we can see some of the stations that are taking place, which is away from the hole edges and this is because of the chemical action basically, and some stray sparking that is taking place this is 43 times magnified view of the typical holes.

Now, let us summarize what we have discussed in this session. In this session we have studied about an important variant process of EDM and ECM. Namely the ECDM process, this has been discussed in terms of its principles features applications and a case study. We hope this session was informative and interesting.

Thank you.

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