Advanced Manufacturing Process
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Module - 3
Advanced Machining Processes
Lecture - 10
Variant Processes in EDM

Welcome, to this session on hybrid electric discharge machining processes under the course advanced manufacturing processes. In the previous session, we have discussed about the wire EDM process, its advantages, limitations, the principals of operations and other details including applications. In this session we will study about the variant and hybrid processes in the EDM category, their unique advantages, process, parameters, applications, advantages and limitations will be discussed.

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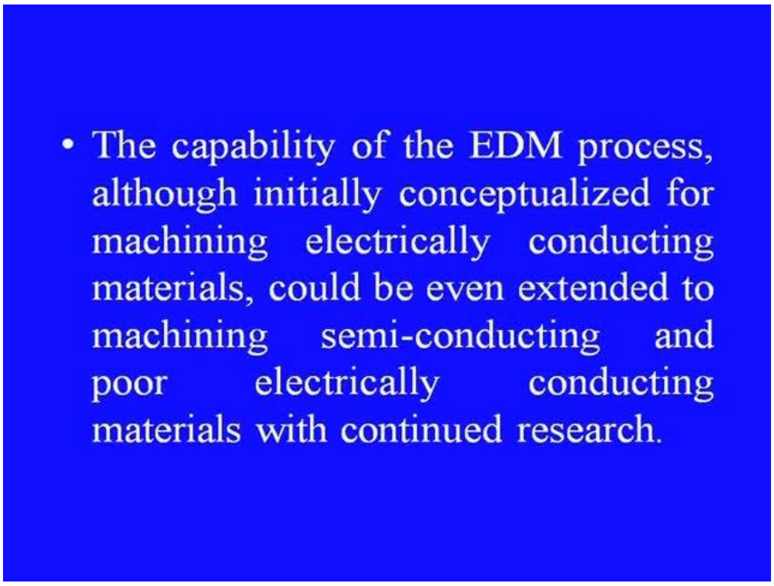

In fact the capability of the EDM process, although initially conceptualized for machining electrically conducting materials could be even extended to machining semi-conducting and poor electrically conducting materials with continued research. As we know EDM process is basically meant for electrically conducting materials, where the work piece itself will be considered as one of the electrodes. Generally, it will be connected to the positive terminal of the power supply system and the tool will be connected to the the other electrode or the other terminal of the power supply.

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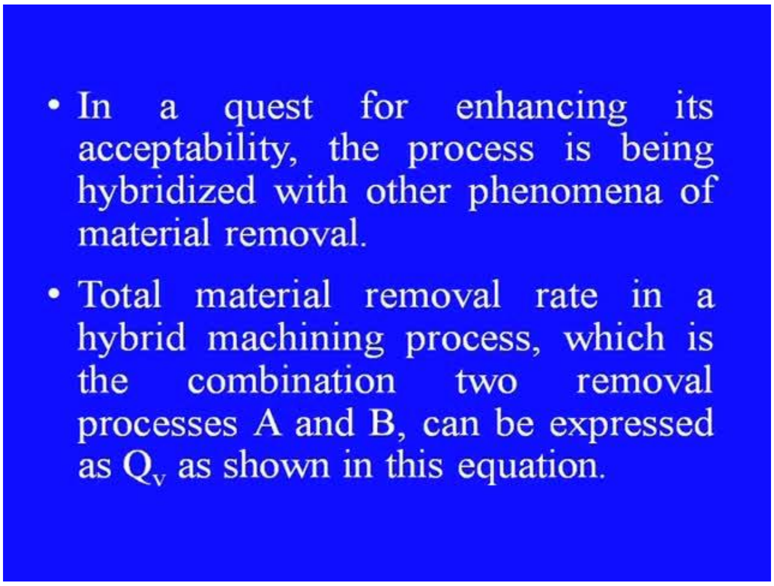

Hence, the work piece is considered to be one of the conducting materials or one of the electrodes. However, the main difficulty with this process is; if the if the work material is non-conducting or semi conducting then the process efficiency either goes very below or it cannot be worked out. Therefore, different theories or different researches have been conducted, how to enhance this capability with the help of some other technique? In a quest for enhancing its acceptability the process is being hybridized with other phenomena of material removal. The total material removal rate in a hybrid machining process, which is the combination of two or more removal processes, say for example, two processes A and B can be expressed as Q v.

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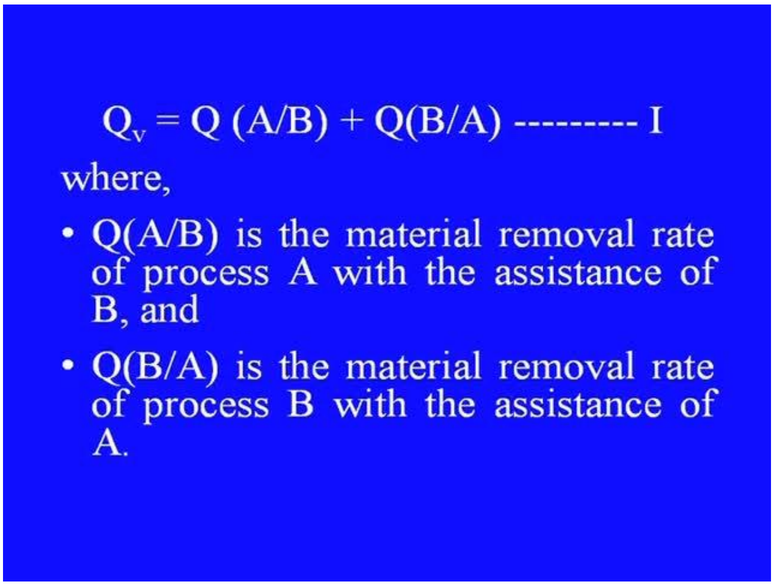

As in this equation, this Q v equal to Q of A/B plus Q of B/A, where Q A/B is the material removal rate of process A with assistance of B and Q B/A is the material removal rate of process B with the assistance of A.

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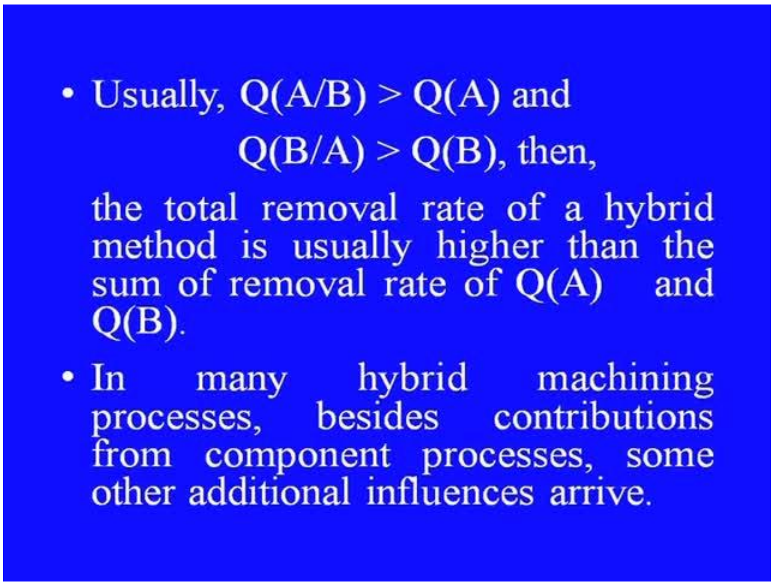

Usually, Q of A/B is greater than Q of A, that means material removal rate of process A with the assistance of B, is higher than the material removal of only A. Similarly, the material removal of the process B with the assistance of A, is higher than the material removal of B independently. Then the total removal rate of hybrid method is usually higher than the sum removal rate of either A or B independently.

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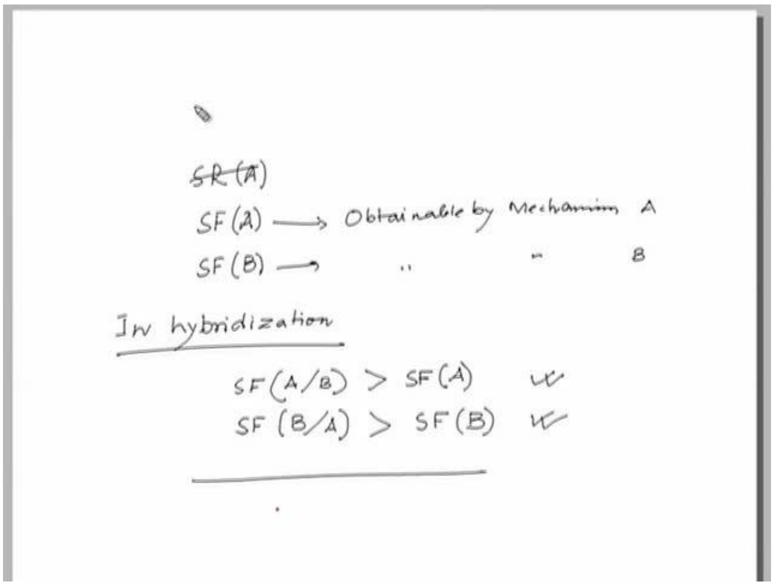

The same can be explained for other properties as well particularly say for example; this can be applicable to surface finish as well. Say surface finish of A and surface sorry, this is, let us write in terms of surface finish, not in terms of surface roughness. So, surface finish obtained alone by the mechanism A and this is SF B represents surface finish by obtainable by, this is obtainable by mechanism mechanism A, then this is surface finish obtainable by mechanism B.

Then if we apply in case of hybrid hybridization, surface finish obtainable by A with the assistance of B should be greater than surface finish that can be obtainable by only A. Similarly, the same is true for surface finish that is obtainable by B, with the assistance of mechanism A, should be greater than the surface finish that is obtainable by mechanism B alone. In these cases only if this is true then the hybridization is hybridization is said to be fruitful.

This is in line with the affect of hybridization as far as the material removal is concerned and the as far as the surface finish obtainable is concerned. So, this hybrid idiom also aims to attain either of these objectives fulfilled, like higher MRR or enhanced MRR or the enhanced surface quality in the form of low surface roughness and high MRR through hybridization of two or more than two mechanisms. In many hybrid machining processes besides contributions from component processes, some other additional influences also arrive.

This is another significant point, this is not only that individual mechanisms A and B, they are complementing each other to get an enhanced output in terms of maybe material removal or in terms of surface finish. But it could help indirectly in achieving some other parameters getting right, because of the hybridization or the combination of the mechanisms or combinations of the phenomena.

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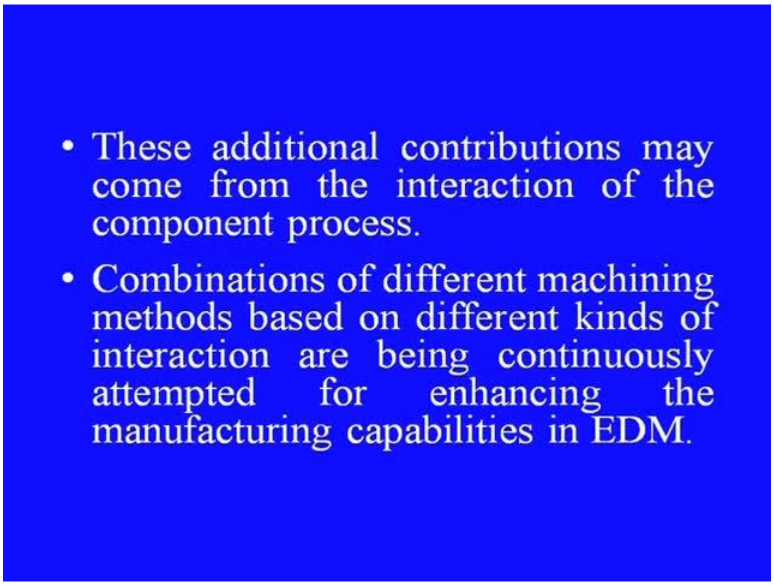

These additional contributions may come from the interaction of the component processes. Combinations of different machining methods based on different kinds of interaction are being continuously attempted for enhancing the manufacturing capabilities in electric discharge machining process as well.

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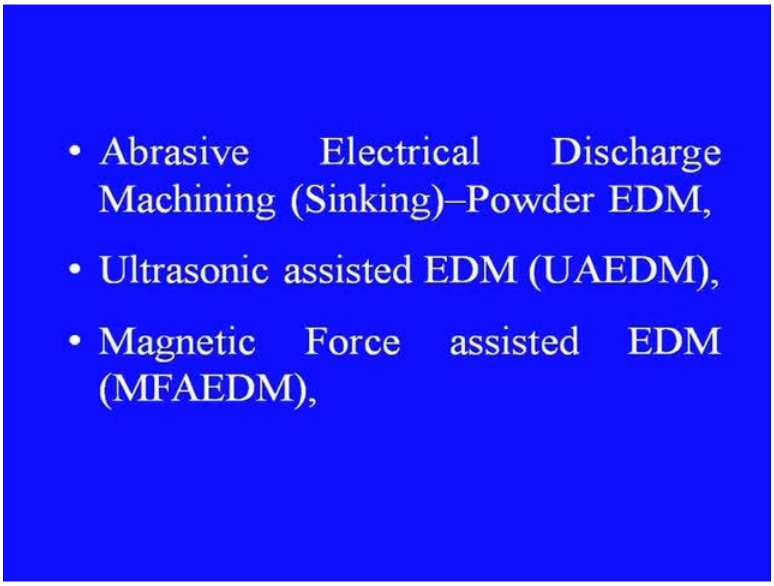

Let us see some of the major cross or hybrid machining processes that are still under development at present. Some of these include, abrasive electrical discharge machining that is also called sinking or powder EDM, then ultrasonic assisted EDM in short it is called UAEDM, then magnetic force assisted EDM in short it is known as MFAEDM. Then electro chemical discharge machining, this we will discuss in details, then abrasive electrical discharge grinding AEDG etcetera.

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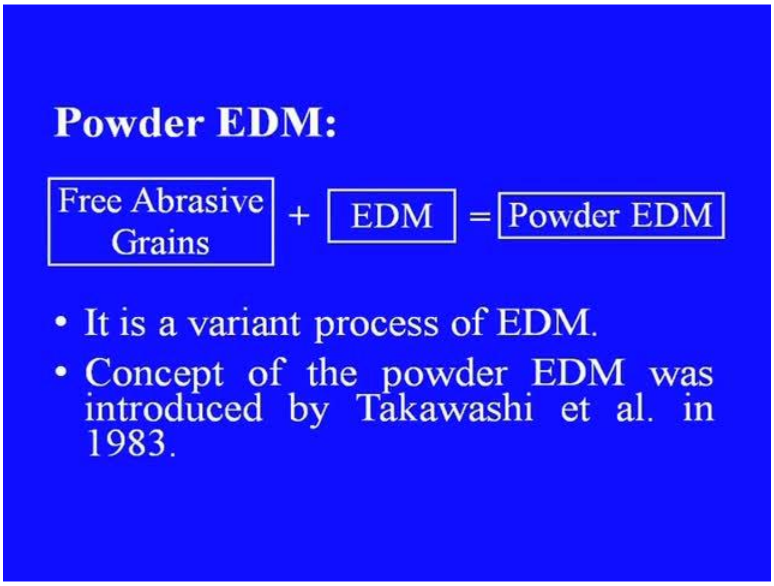

Let us discuss little details about the powder EDM; this is also a hybrid method, in which free abrasive particles are added to the basic EDM process, which gives us powder EDM, as we have shown in the screen. Both the mechanisms where abrasive action will also take place and the EDM action will also take place and that gives enhanced result of the process. So, it is a variant process of EDM. As we know in EDM the material removal mostly takes place in the form of erosion of the materials, due to the cavitations effect as well as thermal melting and evaporation of the material, what material? Due to the high frequency sparking.

The concept of this powder EDM was first introduced by Takawashi and his group of researchers in the year 1983, thus it is relatively a new process. In this process when free abrasive grains such as Silicon carbide powders are added to the dielectric, it reduces the electrical capacitance across the discharge gap by increasing the gap size. This results in higher spark dispersions and improvement in discharge characteristics.

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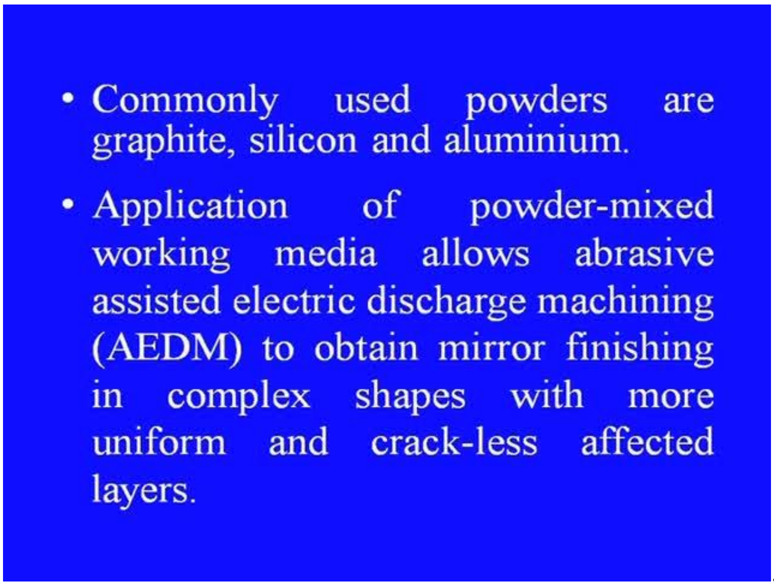

Commonly used powders in this process are graphite, silicon and aluminum. Application of powder-mixed working media allows abrasive assisted electric discharge machining, AEDM to obtain mirror finishing in complex shapes with more uniform and crack-less affected layers. The AEDM process produces dies without the need for removing the affected layer and can be effectively used for finishing applications, such as in plastic molding and die casting.

As we have already mentioned AEDM process is capable of producing very good surface finish, therefore it is particularly suitable for die making processes etcetera. Adding powder of materials, such as silicon in the dielectric improves the material removal rate and surface finish considerably.

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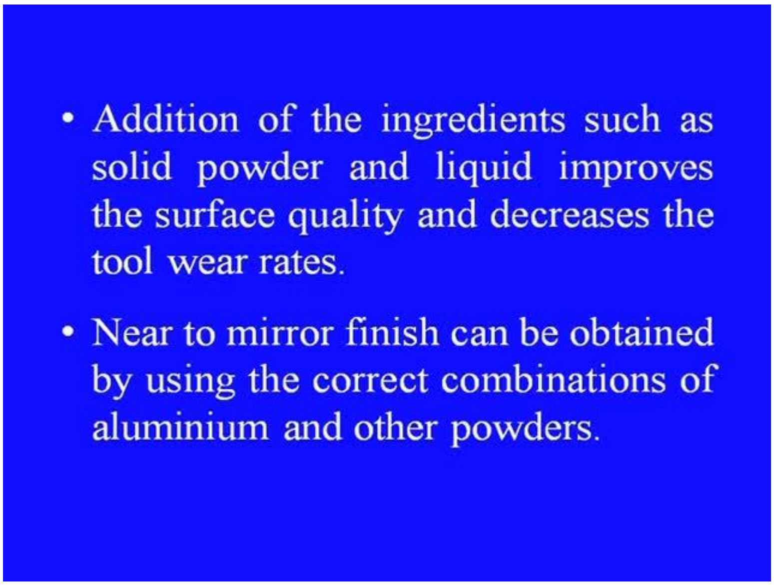

Addition of the ingredients such as solid powder and liquid improves the surface quality and decreases the tool wear rates. As we have already discussed in case of in case of normal EDM along with the work piece the tool also gets eroded, like if this is the tool and this is the work piece, as we have seen in another session, so this is work piece and this is the tool, so sparking takes place here. Now, because of this sparking not only the work material will get eroded from this portion. So, this will go as debris in this process, but this part at the same time will cause some erosion on this tool face as well. So, this will also go as small debris into the flowing dielectric. So, this is the dielectric flowing here, dielectric.

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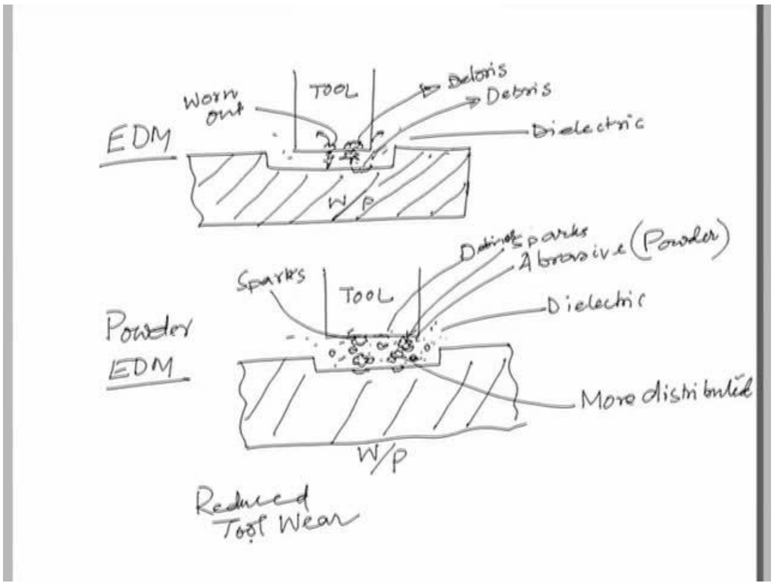

Therefore, because of this small removal of material from this tool surface, tool surface the tool also gets worn out with continuation of this sparking process. However, if we use some powder particles here then what happens, principally it works like this, this is the work piece, this is the tool. Now, if small, small particles are there, abrasives are there these are suspended on this dielectric, this is the dielectric flowing through this which is an essential component in EDM. So, this is dielectric and these are the abrasives. So, what we call as powder and is the component additional component in case of powder EDM, this is called powder EDM, whereas this is the conventional EDM case.

Now, here because of this presence of these particles the spark intensity will be smaller or we can say in other words we can say, these sparks will be more distributed, so these are say sparks and these are sparks. Now, in comparison to the previous cases where more concentrated sparks were produced, but here in the powder EDM cases the sparks are more distributed, we can say more distributed. Therefore, the erosion corresponding erosion that is taking place will be in the smaller quantity. So, this is the debris debris produced because of this powder EDM, which is as far as the quantity is concerned, which is less in comparison to the previous cases.

So, this ultimate affect or these results in the reduced tool wear. Because of this near to mirror finish can be obtained by using the correct combination of aluminum and other powders. This also gives relatively higher machining rates through the use of negative polarity for the electrodes. Silicon carbide powder has also been tried with pure water and it results in increased fluid electric conductivity, increase in the material removal rate and it also helps in extruding the debris away quickly. This is another important factor as we have discussed while discussing the basic EDM process. The debris that gets produced during sparks or the erosion should be taken away from the machining zone as early as possible.

Otherwise, this accumulation of this debris can clog the gap in-between the tool and the work piece that is what is we know, we call popularly as inter electrode gap. And if this gap gets clogged, there will be short circuiting conditions and no longer sparking will take place rather the circuit will be completed and the current flow takes place. Therefore, the basic phenomena, which is responsible for producing the material removal or erosion of the material removal will not take place any further.

Therefore, in EDM related processes, it is very important to take away the debris as early as possible, as quickly as possible from the machining zone. In powder EDM with the help of suspended particles powder particles, this may be silicon carbide as we have seen just now, it can be aluminum powders or it can be graphite powders this is possible in a more efficient way.

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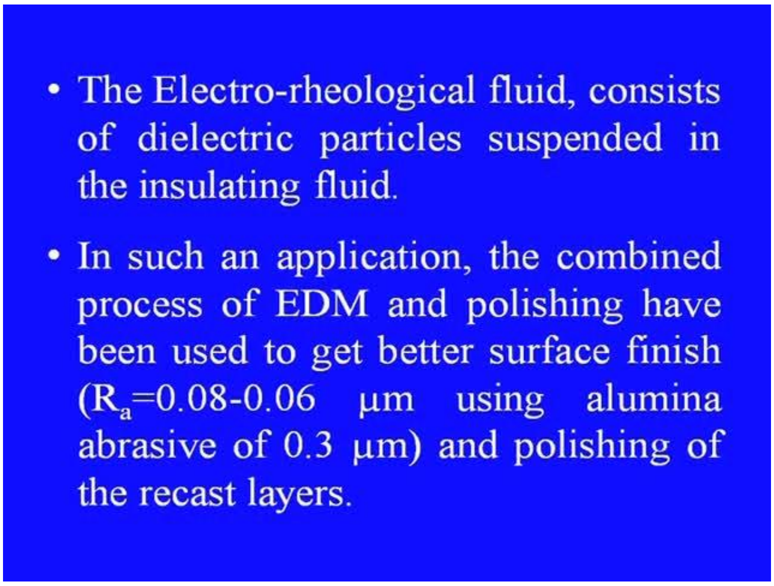

The Electro-rheological fluid, consists of dielectric particles suspended in the insulating fluid. In such an application, the combined process of EDM and polishing have been used to get better surface finish, in which average roughness is obtainable to the tune of 0.08 to 0.06 micro meter, using alumina abrasives of 0.3 micro meter size and polishing of the recast layer could be obtained. Using titanium powder green compact electrodes a new process for coating on the work piece, which is known as electric discharge coating has also been reported. This is another variant of this electric discharge machining process itself, the basic mechanism is EDM.

Then the coating which is additional to this EDM process is being done in the same process. This process is capable of producing a ceramic layer on the work piece, thereby increasing its surface hardness and can be taken as a coating process. As we know ceramic ceramics are known for their enhanced hardness or higher hardness. So, therefore in this process simultaneously if we can coat a material like this, say alumina or silicon carbide, which has got much higher hardness on to the machine surface, then the machining surface will acquire better hardness as a result of this combined process. Therefore, it can be termed as a hybrid process, in which we are getting better results than it could have been with single phenomena.

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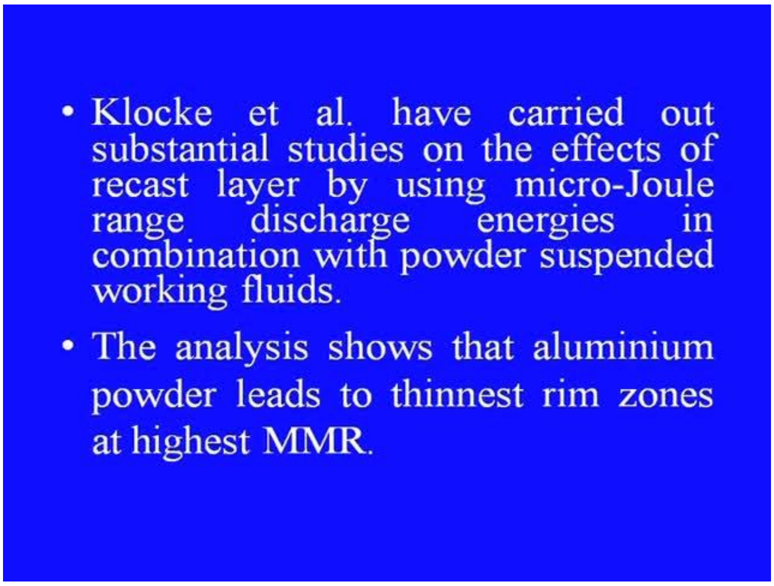

Klocke and his co researchers have carried out substantial studies on the effects of recast layer by using micro-Joule range discharge energies, in combination with powder suspended working fluids.

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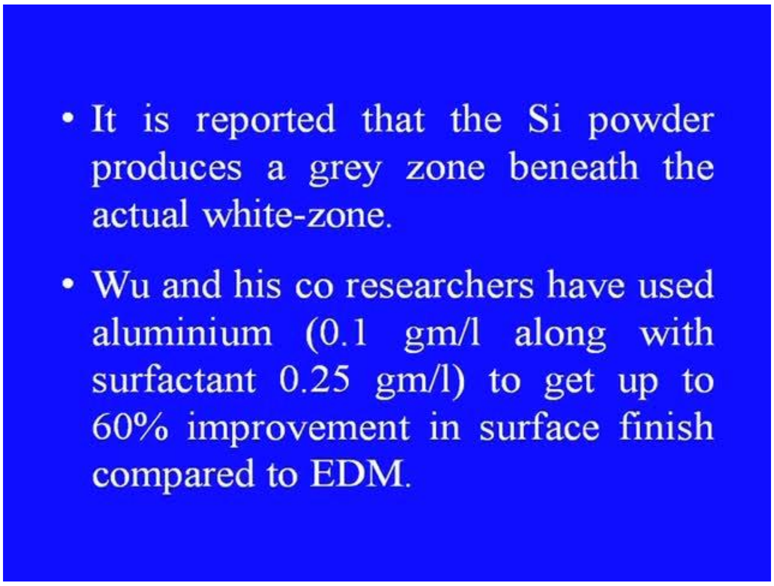

The analysis shows that aluminum powder leads to thinnest rim zones at higher material removal rate. It is also reported that the silicon powder produces a grey zone beneath the actual white zone. Wu and his co researchers have used aluminum suspended 0.1 gram per liter, along with a surfactant 0.25 gram per liter, to get up to 60 percent improvement in surface finish compared to normal EDM. So, this is this result suggest that the hybrid process is giving us substantially better result, in which 60 percent improvement in the surface finish can be obtained. So, this process can be useful where high surface finish is required.

As well as where intricate shapes are to be machined, which is usually very difficult in using the normal processes or conventional machining processes? But if we go alone with the electric discharge machining process, the surface finish results are not very good, as we have already discussed in several other sessions. But the same surface finish with the addition of some other technique, we can enhance to say 60 percent or 70 percent, which is quite substantial or beneficial as far as the productivity or the cost of machining or production is concerned. In this process the surfactant molecules act as static barrier to the separate, the agglomerated aluminium powder and disperse them within dielectric thus, improving the surface finish.

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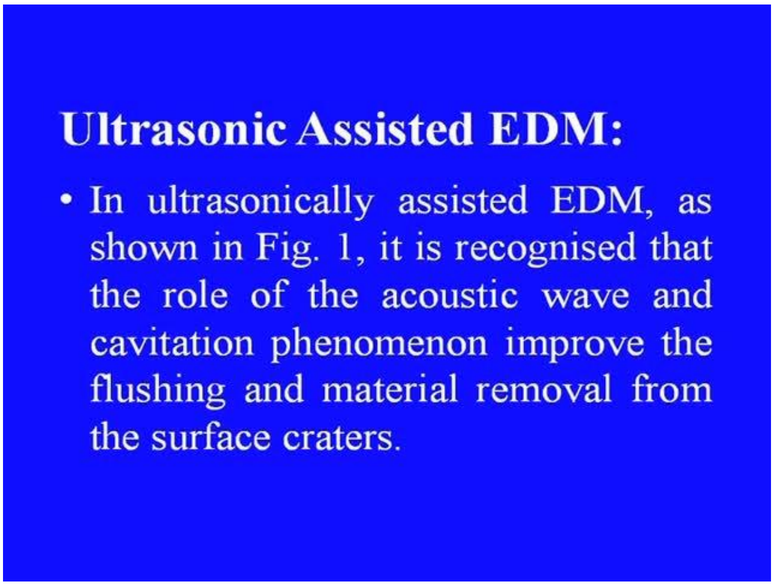

Now, let us move on to another process that is called ultrasonic assisted EDM, also called UAEDM, this is another hybrid process of EDM. In this process as we can see in the figure later, it is recognized that the role of acoustic wave and cavitation phenomenon improve the flushing and material removal from the surface craters. These process conditions are significant for a micro drilling and production of slots and groves. In such a case the vibrations can be given either to the tool or to the work piece with a suitable attachment. As we have already discussed while discussing ultrasonic machining in ultrasonic machining, ultrasonic vibrations can be given either to the tool or to the work piece.

But in most of the convenient ultrasonic machining processes, giving ultrasonic vibration to the tool is considered to be more convenient. While in case of micro ultrasonic machining giving ultrasonic vibration to the work piece has been considered as more convenient process. Similarly, in this process ultrasonic assisted EDM process, either tool or the work piece can be given this ultrasonic assistance, which will help in removing the debris more efficiently. Here is the principal explained the figure is on the screen:

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This is the tool which is responsible for the ultrasonic vibration. So, as usual as in the case of a normal ultrasonic machining, this tool head will be connected to the horn, as well as the ultrasonic generating equipment. This is the abrasive slurry, which will be introduced into the gap between the tool as well as the work piece. Now, in this particular configuration, we are trying to show that the ultrasonic vibration is given to the tool itself and the work piece will remain stationary.

Now, here both the actions will take place, the normal EDM because of the dielectric being flown here, which is nothing but the form of the slurry, in which some abrasive particles are also suspended. These abrasive particles in turn will take part in this ultrasonic mechanism, which we have already discussed in several sessions. Therefore, here both the actions will take place, ultrasonic machining because of the tool, vibrating tool hitting the abrasives, which are suspended on this slurry. Then the discharge that is taking place in this tool and the work piece gap tool electrode inter electrode gap.

Therefore, the combination of these two processes will give enhanced machining performance, it can be either as we have already discussed in the form of material removal or in the form of enhanced surface finish. The vibrating movement of the tool electrode or the work piece improves the slurry circulation and the pumping action by the pushing debris away and sucking new fresh dielectric. It provides ideal condition for discharges and gives higher removal rate.

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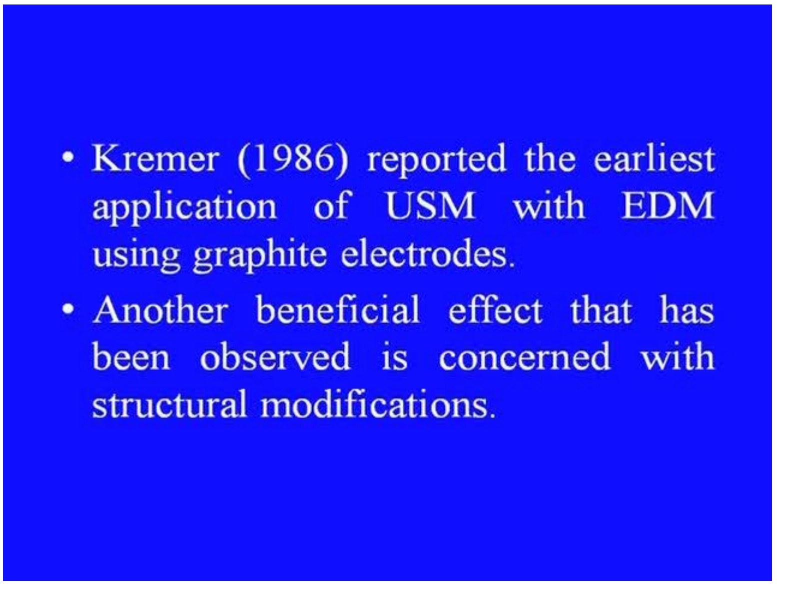

Kremer in the year 1986 reported the earliest application of ultrasonic machining with electric discharge machining using graphite electrodes. Another beneficial effect that has been observed is concerned with the structural modifications, because of this hybridization.

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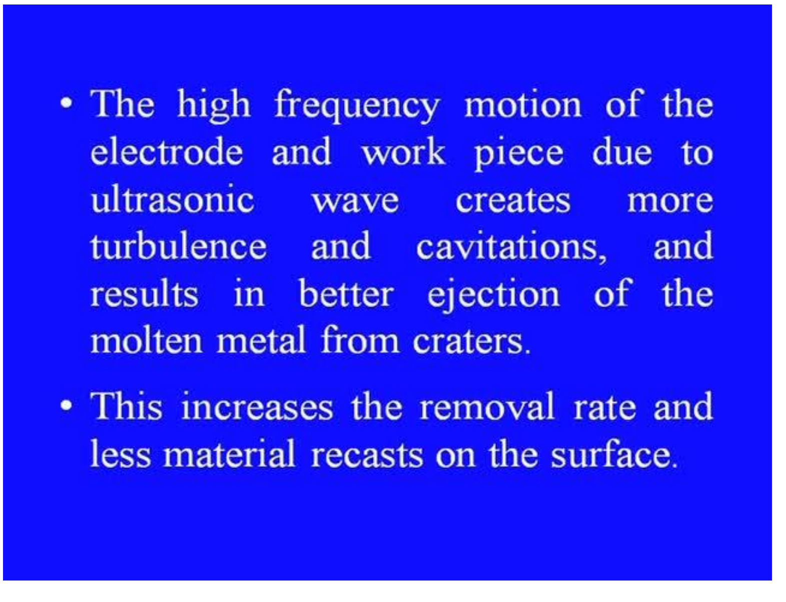

The high frequency motion of the electrode and the work piece due to ultrasonic wave creates more turbulence and cavitations and this results in better ejection of the molten metal from the craters. As we have earlier discussed the molten materials, because of the disurge action or melting and evaporation action. If they are not removed from the gap quickly, then there is a possibility that these molten or semi molten material will get adhered either to the tool or to the work piece, that forms ultimately a white layer or additional spattered layer on the tool or the work piece.

This can reduce the further sparking rate resulting in reduced performance of the process, but here because of the continued ultrasonic machining processes or the ultrasonic vibrations, there will be cavitations continuously taking place. And that will cause the ejection of the molten material from the zone machining zone and will be subsequently flown away by the flowing dielectric fluid. Therefore, the consequent formation of spattered layer or the white layer phenomena will be reduced. This increases the removal rate and less material recasts on the surface. Thus, structural modifications are minimized, less micro cracks are observed and the fatigue life is increased. Associating EDM and UASM can lead to considerable improvements in the production of complex shape work pieces.

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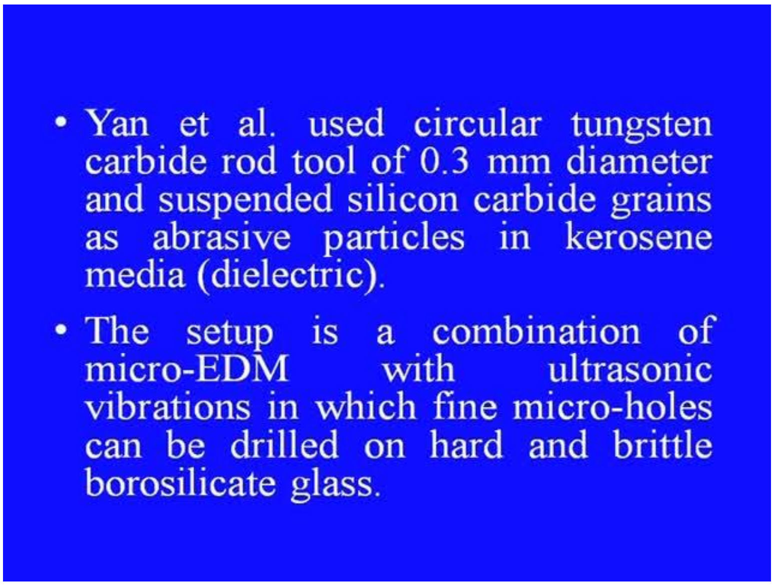

Yan and his co researchers used circular tungsten carbide rod of 0.3 Millimeter diameter and suspended silicon carbide grains as abrasive particles in kerosene media, which works as dielectric in another attempt for hybridization of this process. The setup is a combination of micro-EDM with ultrasonic vibrations in which, fine micro holes could be drilled on hard and brittle borosilicate glass.

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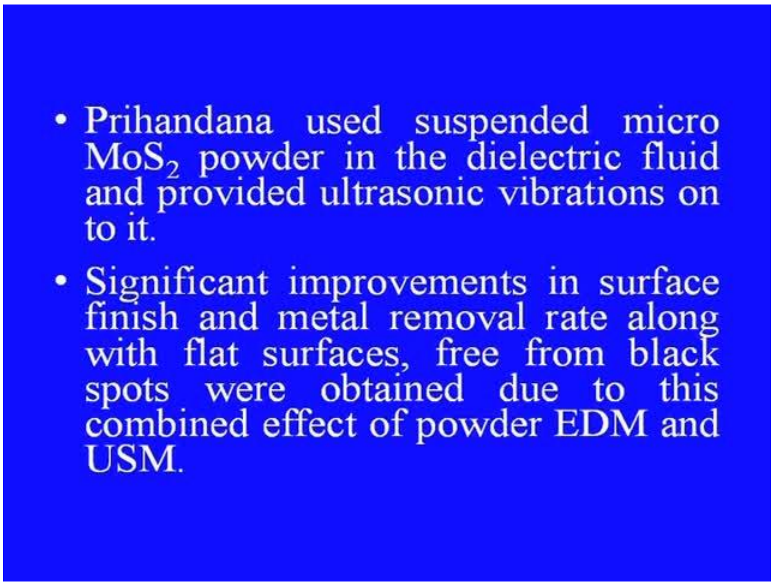

Prihandana used suspended micro molybdenum sulphide powder, in the dielectric fluid and provided ultrasonic vibrations on to it. So, these are different attempts by different researchers to make the ultrasonic machining and the electrical discharge machining processes work together, in order to enhance their performance. Significant improvements in surface finish and material removal rate along with flat surfaces free from black spots were obtained, due to this combined effect of powder EDM as well as ultrasonic machining.

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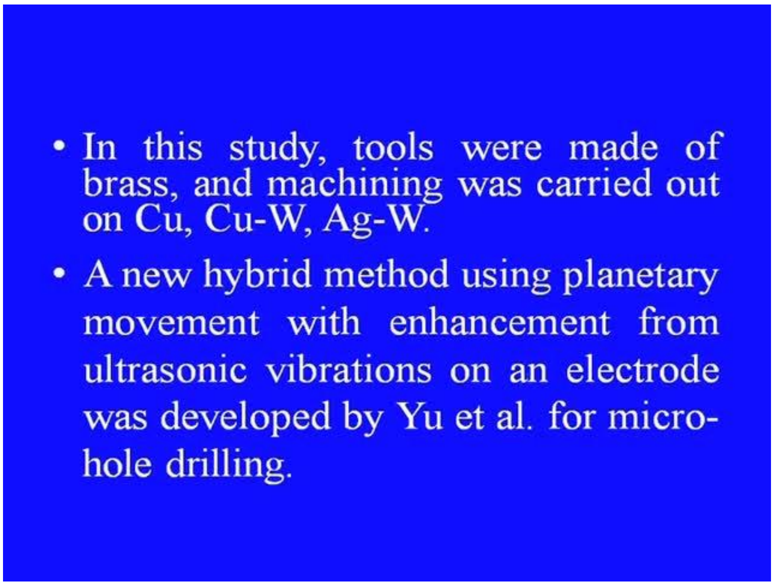

In this study, tools were made of brass, and machining was carried out on copper, copper tungsten and silver tungsten material. A new hybrid method using planetary movement with enhancement from ultrasonic vibrations on an electrode was developed by Yu and his co researchers for micro-hole drilling. It was found that the use of these hybrid methods can give unevenly distributed gap for bubbles and gases to escape. Surn and Swang designed a vibrating worktable and employed it in mass producing of micro holes using EDM; this also can be considered as a kind of modifications in EDM in order to have better effect of the process.

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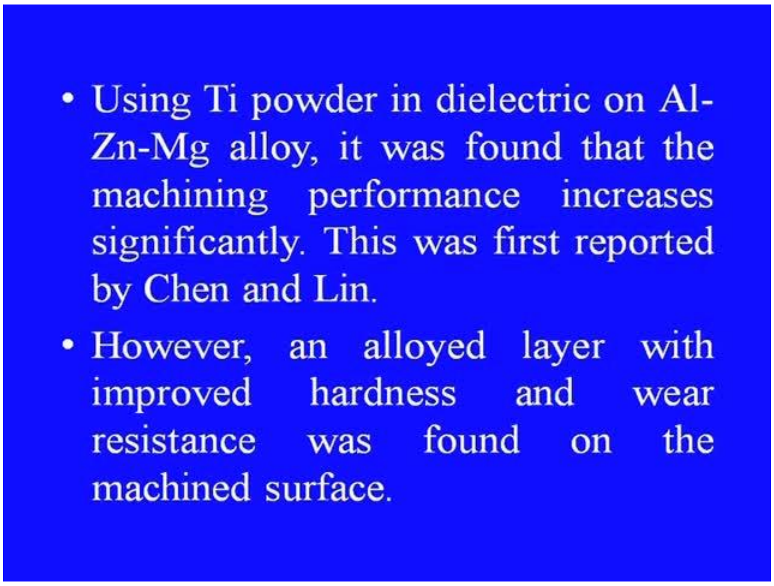

Using titanium powder in dielectric on aluminum zinc magnesium alloy, it was found that the machining performance increases significantly. This was first reported by Chen and Lin. However, an alloyed layer with improved hardness and wear resistance was found on the machined surface.

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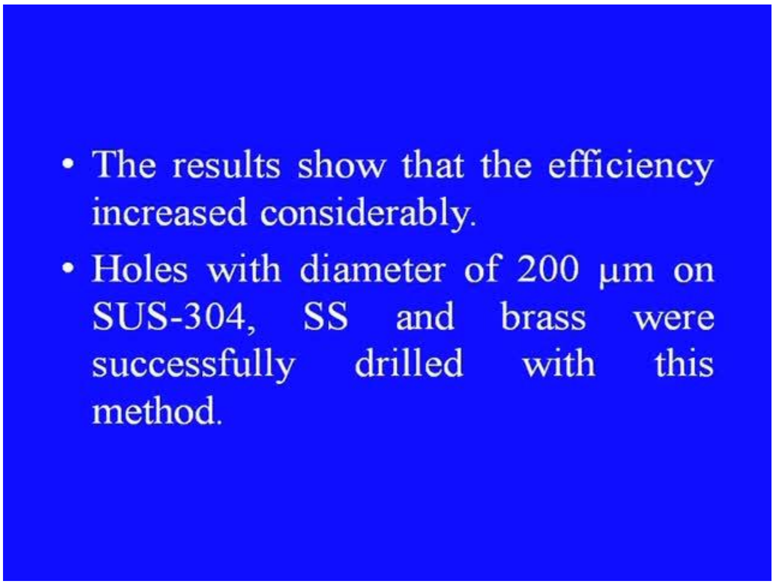

The results show that the efficiency increased considerably. Holes with diameter of 200 micro meter on SUS-304, stainless steel and brass were successfully drilled with this method.

Now, let us move on to another hybrid process that is magnetic force assisted EDM. In this process magnetic field has also been used effectively with the normal EDM machining process the typical setup consist of magnetic field consisting of a rotating disk motor and magnets. The magnetic field is created in-between the electrode and the work piece, this helps in driving the removed material away from the zone, thereby increasing the efficiency of the process.

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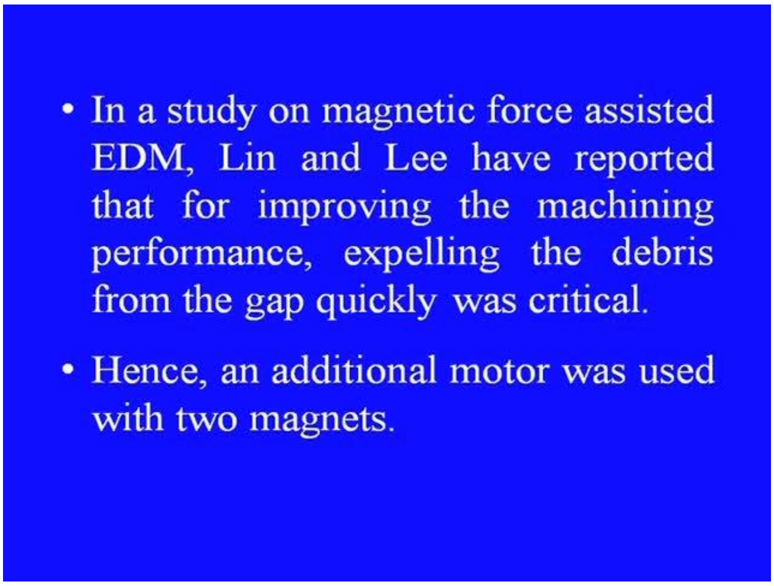

In a study on magnetic force assisted EDM, Lin and Lee have reported that for improving the machining performance, expelling the debris from the gap quickly was critical. As we have already discussed, debris removal from the inter electrode gap is very very critical as far as the enhancement of the performance of the EDM, normal EDM process is concerned. Hence, an additional motor was used by these scientists with two magnets, which enhance the performance of the system.

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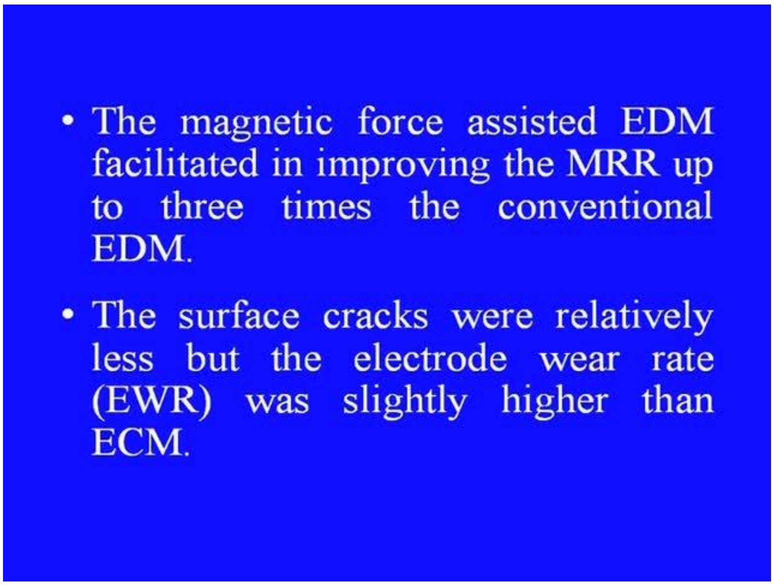

The magnetic force assisted EDM facilitated in improving the material removal rate up to three times the conventional EDM, which is quite substantial. The surface cracks were relatively less, but the electrode wear rate was slightly higher than what is observed with electro chemical machining.

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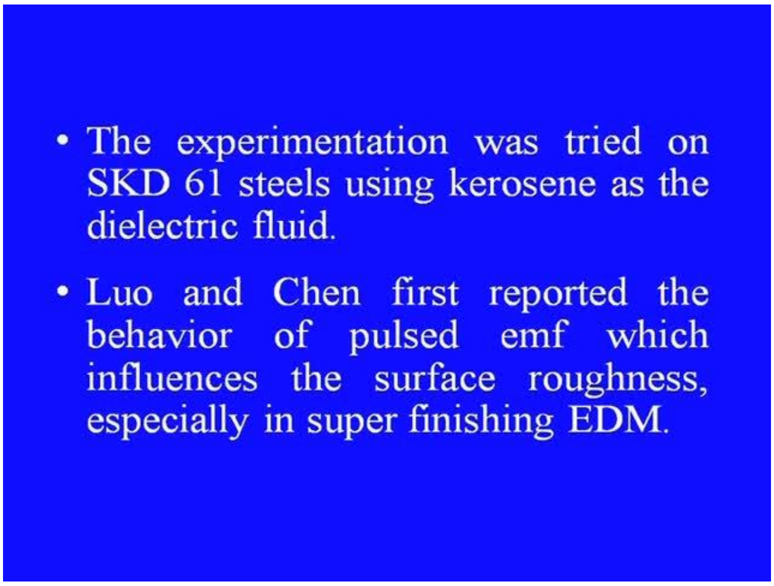

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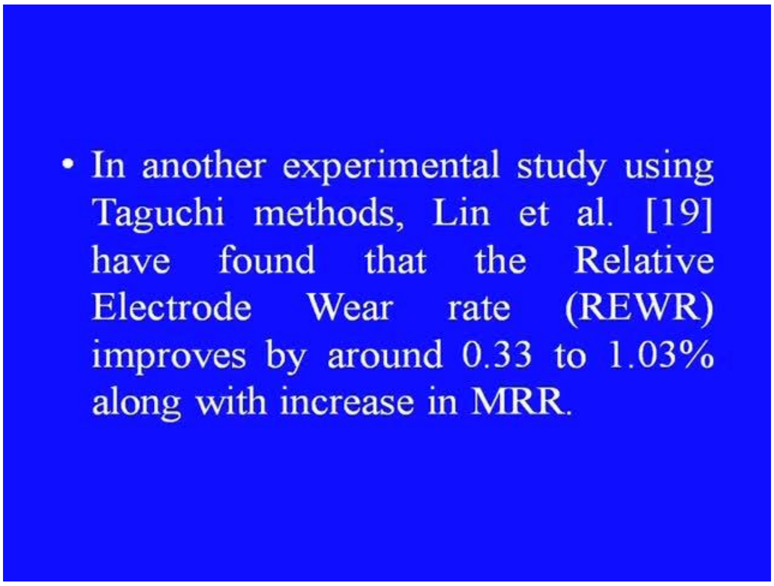

The experimentation was tried on SKD 61 steels using kerosene as the dielectric fluid. Luo and Chen first reported the behavior of pulsed emf which influences the surface roughness, especially in super finishing EDM. The use of magnetic force in EDM is primarily to remove the debris from the discharge zone by applying short discharge pulses, very smooth surfaces up to 0.04 micro meter of average roughness could be achieved. In another experimental study using Taguchi methods, Lin and his co researchers have found that the relative electrode wear rate improves by around 0.33 to 1.03 percent, along with the increase in material removal rate.

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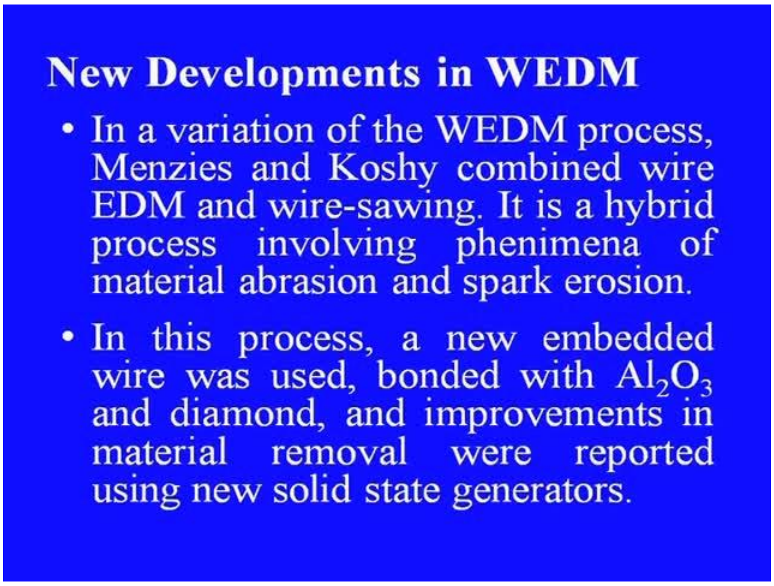

Now, let us move on to some new developments in wire EDM process.

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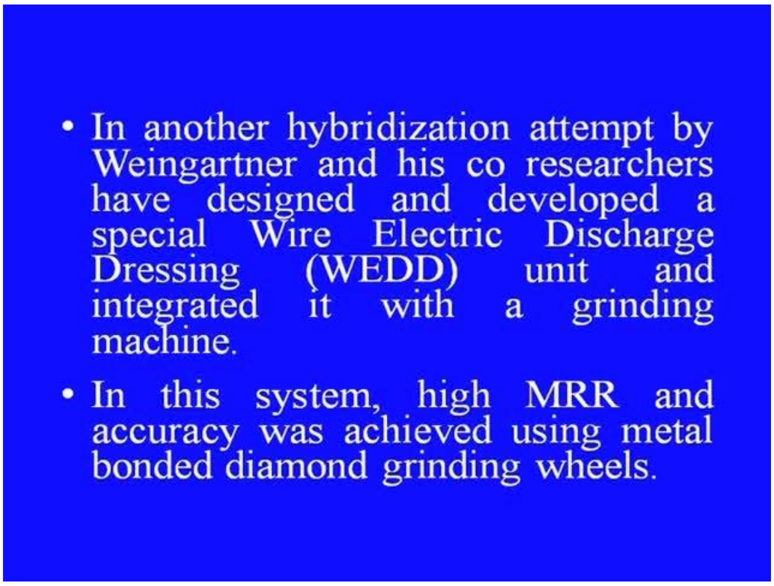

In a variation of the WEDM process, Menzies and Koshy combined wire EDM and wire-sawing. It is a hybrid process involving phenomena of material abrasion and spark erosion. In this process, a new embedded wire was used, bonded with alumina and diamond. The improvements in material removal were reported using new solid state generators. Some studies also suggest that in WEDM, low conductivity of the dielectric should be incorporated, for discharge sparks to take place.

It was found that an AC pulse generator and low conducting dielectric provide better surfaces with reduced surface cracks and residual stresses by Weingartner and his co researchers have designed and developed a special wire electric discharge dressing WEDD unit and integrated it with a grinding machine. In this system, which is also a hybrid system, high material removal rate, higher accuracy was achieved using metal bonded diamond grinding wheels.

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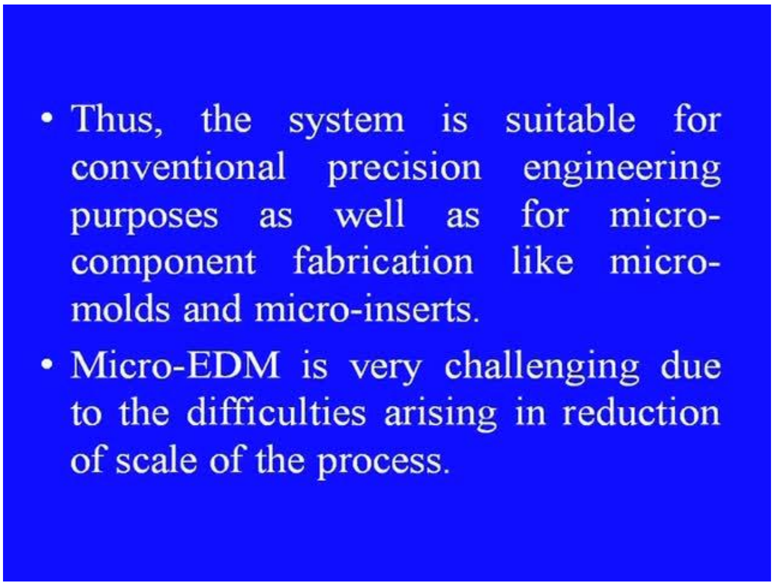

Now, let us move on to another process that is called micro electric discharge machining process. In micro EDM, the principal is almost same with that of the normal electric discharge machining process. This process has also a servo system with high sensitivity and positional accuracy, which is something near plus minus 0.5 micrometer. This permits the setting of minimized discharge gap of one micron. Thus, the system is suitable for conventional precision engineering purposes, as well as for micro-component fabrication, like micro-molds and micro-inserts. Micro EDM is very challenging due to the difficulties arising in reduction of scale of the process. Fabrication of small electrodes having small inter electrode gap achieving accuracy removal of debris, keeping HAZ or heat affected zone to a minimum are very, very challenging issues in micro EDM.

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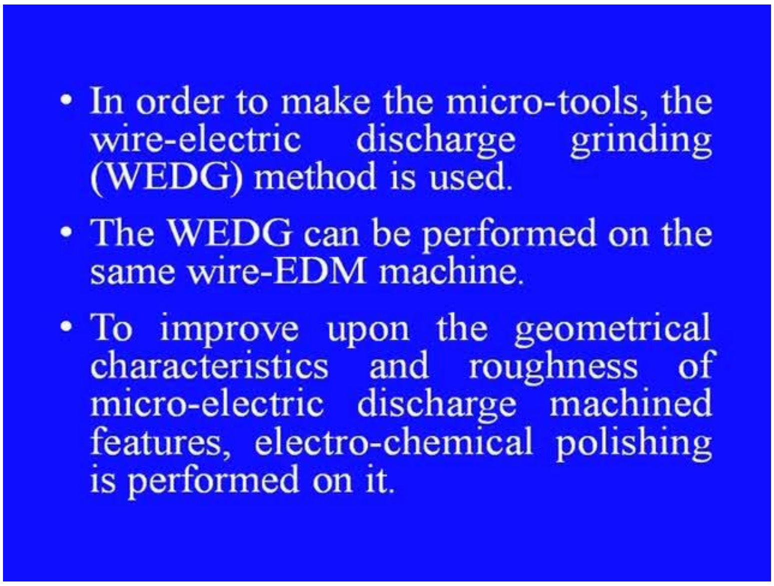

In order to make the micro-tools, the wire-electric discharge grinding WEDG method is used. The WEDG method can be performed on the same wire-EDM machine. In order to improve upon the electrical geometrical characteristics and roughness of micro-electric discharge machined features, electro chemical polishing is performed on it.

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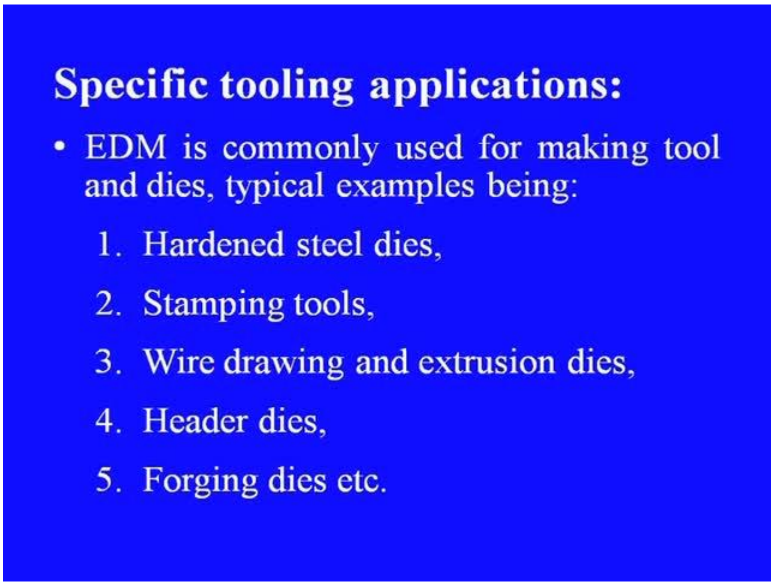

Specific tooling applications of this process, EDM is commonly used for making tool and dies, typical examples being; number one hardened steel dies, stamping tools, wire drawing and extrusion dies, header dies, forging dies etcetera.

Let us see another variation in this EDM process in which machining with electric discharges in de ionized water was attempted. In this process (( )) and his research group have used a new EDM process with polymer carbon electrode material, which could be molded repeatedly into complex geometries and used to perform precision EDM machining in de ionized water. This is a novel process used to perform automated finishing and polishing operations of electrically conductive material parts, which reduces development time and cost of tool steels that are used for mass production of broad variety of commercial products.

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Another variation is ECDM, this ECDM is another hybrid process this was initiated by Karafuji, the process is mainly used for machining non conductors such as glass, ceramics, quartz, granite and composites etcetera, This process we will discuss in little more detail later on in another session. Then let us look at the possibilities of electric discharge machining of metal matrix composites, which are also commonly known as MMC's.

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The EDM process requires electrical conductivity for spark initiation. Hence, trying with MMC's having metal ingredients with some other non conducting materials such as ceramic or composites was a possibility. A summary of machining of MMC's by EDM is shown in the following table, which we will see shortly.

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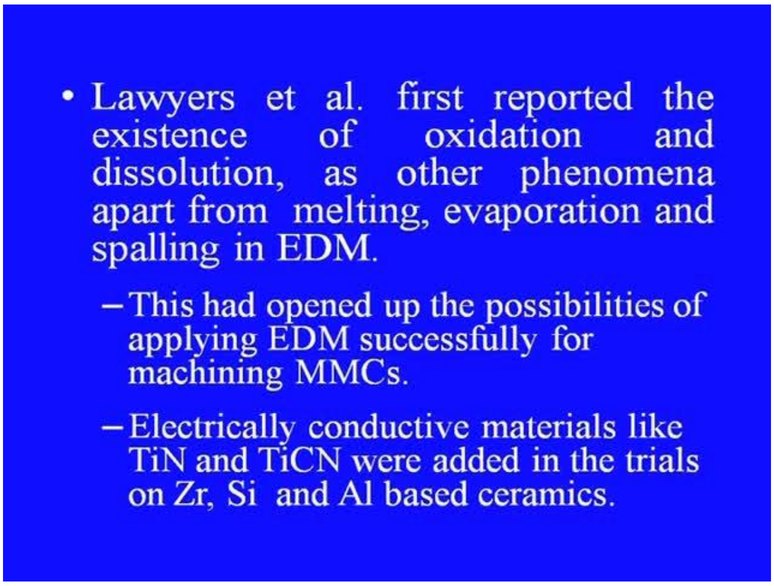

Lawyers et al first reported the existence of oxidation and dissolution as other phenomena apart from melting evaporation and spalling in EDM. This had opened up the possibilities of applying EDM successfully for machining of materials like MMC's. Electrically conductive materials like T i N titanium nitrite and T i CN were added in the trials on zirconium, silicon and aluminum based ceramics. These are some of the attempts on machining of MMC's using EDM.

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Table-1

Material	Research findings	Reported by
Al-SiC MMC's	In rotary tube EDM process study, genetic algorithms were used for getting optimized machining parameters for MRR, EWR and surface finish (SF).	Mohan et al.
Carbon-Carbon composite	Increase in MRR was reported with higher values of pulse current, gap voltage and pulse on-time.	George et al.

Mohan and his co researchers have suggested one process; this is rotary tube EDM process. Then George and his co researchers, they have also used EDM process for carbon carbon composite machining and they have reported increase in the MRR.

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Material	Research findings	Reported by
Al_2O_3 and Al-Si composites.	Surface degradations and inferior surface integrity have been reported in machining.	
SiC with Al alloy MMC	EDM and laser process were studied and reported that EDM gives less thermal damages than Laser Beam Machining.	Muller and Monaghan

Then alumina and aluminum silicon composites were machined in another attempt, where people have observed the surface degradations and inferior surface integrity have been found. Then EDM and laser processes were studied and reported, that EDM gives better or thermal damages less thermal damages, than the laser beam machining. This was done on silicon carbide with aluminum alloy that is also another kind of MMC.

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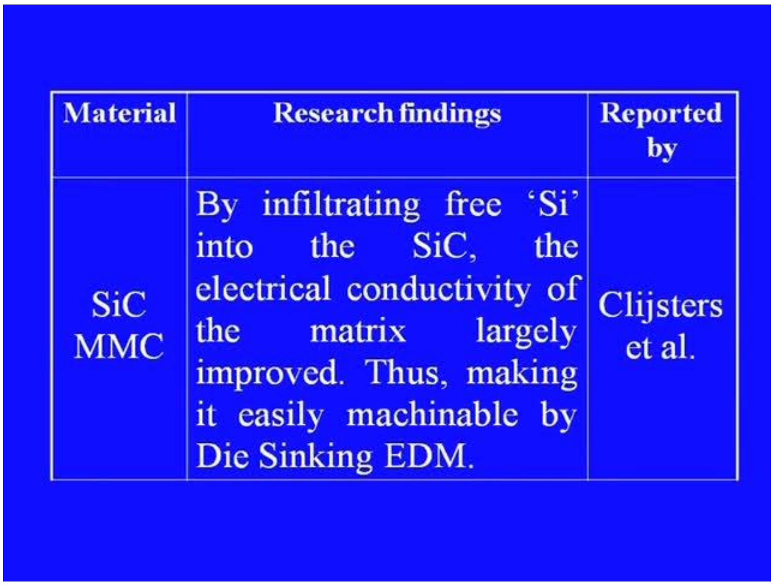

Material	Research findings	Reported by
SiC MMC	By infiltrating free 'Si' into the SiC, the electrical conductivity of the matrix largely improved. Thus, making it easily machinable by Die Sinking EDM.	Clijsters et al.

By infiltrating free silicon into the silicon carbide, the electrical conductivity of the matrix largely improved and therefore, the machining performance became better and this made the material easily machinable by die sinking EDM. Now, let us summarize what we have discussed in this session. The concept of EDM is quite old that we have already seen, yet it is being commonly continuously innovated through new hybrid technologies.

Future generation industrial requirement is to process materials and composites with highest material removal rate, least material wastages, that means the lean manufacturing approaches and to cater to the continuously increasing demands for higher accuracy and higher quality.

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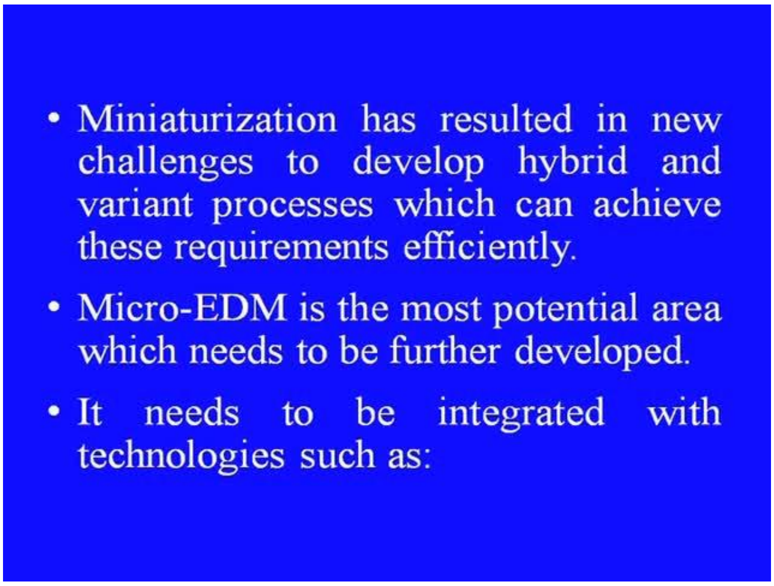

Miniaturization has resulted in new challenges to develop hybrid and variant processes, which can achieve these requirements efficiently. Micro EDM is the most potential area which needs to be further developed. It needs to be integrated with technologies such as magnetic assisted EDM, abrasive assisted EDM and ultrasonically assisted EDM for conducting materials. ECDM and powder EDM for machining of non conducting materials, ceramics and composites are better options. We hope this session was informative and useful.

Thank you. .