**Indian Institute of Technology Kanpur**

**National Programme on Technology Enhanced Learning (NPTEL)**

**Course Title**
**Manufacturing Process Technology-Part-2**

# Module-33
# Effect of various parameters on EDM Process

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Hello and welcome to this manufacturing process technology part 2 module 33. In the last module we had talked about various circuit scripture which are associated with the EDM process in general and is able to supply the voltage signal. So that there is machining, metal machining that takes place. So in context, so with that we had discussed the resistance capacitance relaxation circuit in brief details.

We had also looked into some other circuits like the control pulse circuit and the routine pulse generated circuit. And each of these circuits had advantage over the other in terms of, you know the advancement in the technology. So today we are going to look into little different aspect which is related to the surface finish of an EDM process and how that can be correlated to the various machining parameters which are into picture.

So obviously as you may all recall that the EDM process, because it is a spark machining or pressure and there is always a formation of a melt zone and a crater, therefore, there is going to be in general high surface roughness as initiated to this process. So the challenge is about how to control that by optimizing these spark parameters or the parameters of the machining, and be able to produce relatively smoother surfaces. So let us look at some of the details related to that.

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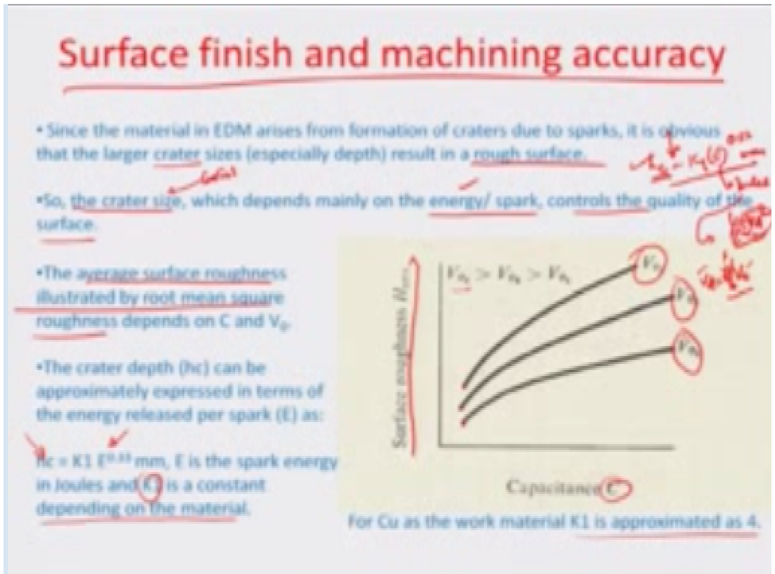


So we talk about surface finishing and machining accuracy. So as we all know that, because the material removal process is really the cratering action all this results in a rough surface. So the important point here is to control the crater size, you know, so control the crater size. And the crater size would depend mainly on the energy per spark as I think, I had illustrated earlier how you may recall how the depth of the crater $h_c$ was related to the spark energy by some constant times of this energy $e^{0.33mm}$.

And e was the energy applied in joules and this would be actually the half $cvd^2$ where that would relate to the discharge energy of the capacitor through the discharge circuit of a resistance capacitance relaxation circuit of an EDM process. So this energy really controls the quality of the surface, makes the surface high finish. And the average surface let us illustrate it by the root mean square, illustrated by the root mean square roughness which typically depends on the capacitance C.

So as the capacitance increases the energy is increasing as you can see here from this relationship, and if the capacitance is more than obviously the crate depth $h_c$ is going to be more and the surface roughness is going to increase. So this is the root square average roughness HRMS. So it depends on what is the discharge voltage okay, and the discharge voltage as we know is again dependent on the source voltage.

So discharge voltage typically is 72% of the source voltage if you may recall what we had done for optimizing the power transfer from the source to the electrode gap okay, in the earlier modules. So obviously the $V_d$ depends on $V_0$ and so if the $V_0$ is higher than overall the surface roughness is higher, you can see here the correlation $V_{03}$ is one of the source voltages greater than $V_{02}$ is greater than $V_{01}$. And so you can see that with an increase in capacitance again.

First of all even if the capacitance were same there is going to be a difference in the roughness, because of the discharge voltages high value and the capacitance is increased obviously the energy E would further increase by a multiplicative factor here and which would result in an increase in the creator depth and overall all HRMS.

So obviously when we had talked about this empirical formulation here about created depth we are assumed this K1 to be constant depending on a material and copper we had started the copper is a work material K1 is approximately to be treated as 4 so that is how you know the surface finish part happens let us just try to introduce this C and V values here in this equation with the value of K1 for cop so if we put the value of the various you know capacitance and voltage as you can see here for the energy equation here.

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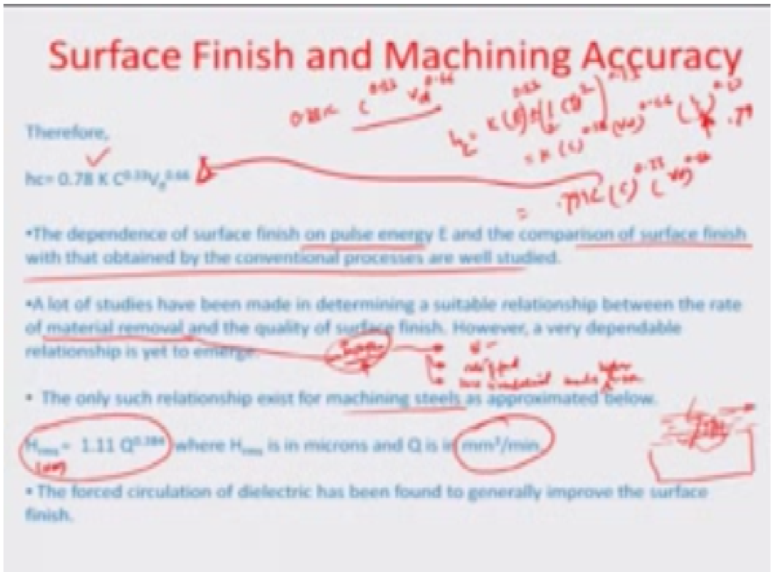


It results in another equation where hc can be represented as this 0.078 k $c^{0.33}$ $v_d^{0.66}$ obviously because E as you know is ½ $cv_d^2$ and if we are raising this to 0 .33 as normally the case for the equation on the greater depth so this we can call it a general K because K1 is typically 4 for the purpose of copper material so not going into only copper so can so this becomes equal to K times of ½ $cv_d^2$ or k times $c^{0.33}v_d^{0.66}$ ½ $^{0.33}$ which is actually 0.79 or 78 you know so this becomes 0.79 k $c^{0.33}$ $v_d^{0.66}$ which is actually.

What is being represented here the dependence of the surface finish on pulse energy En comparison of the surface finish with that obtained by convectional process of very well studied and there is also a lot of empirical study done on this has to you know if I had some material removal rate would there be a relationship between that rate and DHRMS a lot of studies have been made because obviously a critical parameter for all the process or processing related to any other machining process this MRR and the MRR actually would be determinant of what is this spark energy.

For example or what or the other you know associated mechanisms for or parameters for the MRR to have a certain value already there is a good mapping of the NRR into the various other parameter these parameters could include for example the spark energy E okay and also may be the rate at which the fed is given to the system okay so and many other parameters which are related to the EDM process as we have done earlier in the earlier modules.

So an empirical relationship exists between the MRR and the HRMS which makes life simpler because the critical parameter really which depends on all these are parameters really make the MRR happen at a certain rate they would necessary to change if you wanted to change the MRR and such an relationship an empirical relationship between roughness and MRR exist for steels particular steels you know if key q is the MRR in $mm^3$ / min and the HRM is that we are taking is in micrometers.

So we can empirical relate the HRSM to Q / $1.113^{0.384}$ now if you wanted to have the dielectric fluid force circulated obviously going to create higher material removal rate, because as if as you are already aware in case of VCM also the same thing happen that is the electric electrodes are circulated at a higher velocity the material rate removal rate would improve in this case also similar kind of thing happens because.

Obviously whatever material has been created an melted inside the surface because of the discharge of the spark still remains there and diffusible moves into the, the electro light which is a rate and if showing this electro light or dielectric, over rate and flowing this higher velocity would mean faster diffuse in the process, so which leads to quick the pretty removal and also you know they can increase this spark frequency because the iron column which has been created would actually disappear.

More quickly on force circulation cases I think we had discussed about these relationships quite a bit, so let us look at some trends related to the HRMS and some process.

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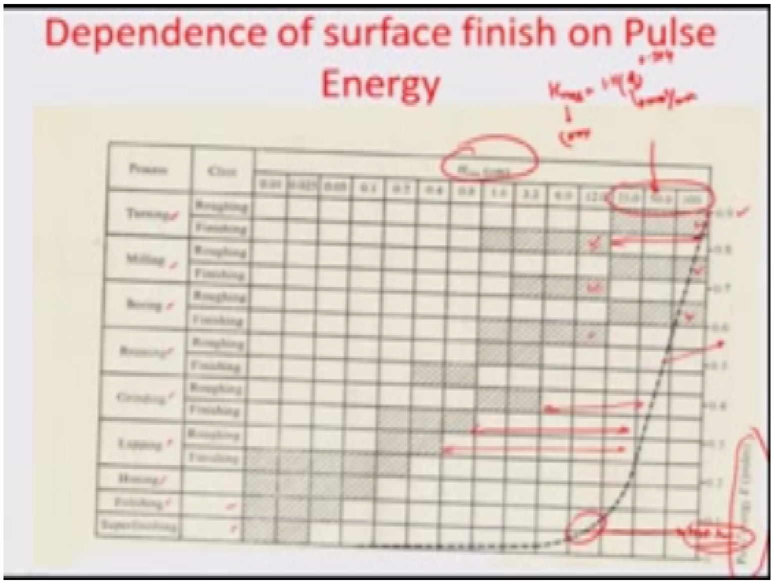


The HRMS for particularly you know different pulse energy is are illustrated here in this example so this is the pulse energy in joules on the right side y axis and the HRMS is actually represented here in a tabular manner, and there are different process which are related to the electro discharge processing so you have EDR EDI boring it is remaining, grinding ,lapping, honing polishing, super finishing these are different process and then you have a roughing process and a finishing process.

And you can look at a comparison of these pulse energy is which would be needed for creating such you know finishes on the surface so for example a rough training produces about 100 micron HRMS, and the pulse energy which is needed for producing the medium 100 microns of roughness is drifty about 0.9j okay, and similarly for a finished turning operation it mean 0.8j for a billing for roughness equal to you know a rough milling process or a rough cut for the milling process you need typically 0.7 to 0.8j.

So you could actually heat upon all these process outputs in conventional systems by using difference spark energy is or pulse energies in EDM surface system what is more interesting is that if you have the pulse energy, very, very small you could always get you know in the domain between let is a0 and 0.1 you get into the domain of as far as you know 0.2 microns surface finish all though, the MRR here or the material removal rate is quite insignificant but you can actually heat upon.

The super finishing domain by using something like a very, very low pulse energy system and so typically electrode discharge micro machining when we talked about really more like a surface finishing issue rather than material removal issue, we can use such low pulse energies to create the lot surfaces equivalent to almost super finishing process so that is how the so the HRMS in microns for all these different process which into drought turning or finish turning or rough milling boring, riming, binding, lapping, honing, polishing super finishing.

This different process and we mention in the in table here through the hatched areas for example a right turning would typically result in about 2500 micron surface finish these are the range in which they finish the operation happen and on the right here on the right Y axis you know it looks at some of the EDM related to assess parameters particularly is a function of the pulse energy.

So you can look at you know the various intersections so this line here dotted line represent what is going to be the surface roughness like for a certain amount of pulse energy, now pulse energy 0.9 would result in a surface roughness which is almost same as turning rough turning you know about 100 microns HRMS on the surface, is if we look at the intersection of the hatched areas with the pulse energy we could get the different you know pulse energies for which you have similar roughness to the process is mentioned here for example.

You could have with the DM surface roughness as good as you know rough milling or rough turning or even let us say rough boring you know something like that and the finishing processes are little far away you can see always there is a distance between the trend the curve and the hatched area for the different finishing processes so EDM really in order to fall into the finishing domain may need a little more you know to do in terms of pulse energy.

For example we can actually have good amount of let us say finish turning or which is this 12 microns or finish milling which is about 12 microns associated with the EDM process at extremely low pulse energy of the rate about 0 to 0.1 joules so this is typically more like a it is not really a material removal operation but more like a surface finish operation okay. So typically that low pulse energy of this grade about 0 to 0.1.

Is only done in very specific cases particularly in micro machining etc using electrode charge machining okay so that is how we can correlate the conventional processes and their outputs in terms of roughness with respect to what these spark machine does and as one can interpret from this curve that these low pulse energy processes which are almost used as material finishing processes can to some extent arrival rhythm with the finish turning or finish milling or finish boring.

But you know the kind of finishing that is needed for polishing or super finishing processes can never be obtained through the pulse system in a EDM process or a electrode discharge machining process, so let us look at some numerical the problem designs and try to estimate through the empirical relation that had been made earlier about HRMS with respect to the MRR which was 1.11 $q^{0.384}$ where q was an millimeters cube per minute.

And HRMS was an micro meter so that is how you know we where empirically relating the HRMS to the q.

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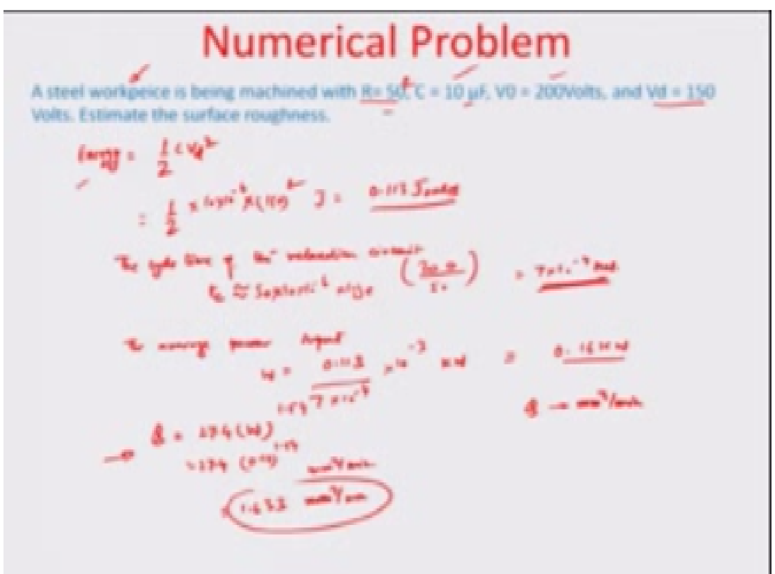

We give a problem design where let us say there is steel work piece being machined so the formulation that has been mentioned earlier would follow very well and the resistance capacitance circuit for the EDM system which is actually machining on this steel work pieces at a resistance of 50 ohms and capacitance of about 10 micro farads input power supply of 200volts discharge power supply about 150 volts.

So we have to estimate what is going to be the surface roughness in this particular case so let us talk about the pulse energy okay so the energy actually in this cases given by ½ $cvd^2$ where vd is basically the discharge voltage and c is the capacitance so if we look at the energy here it is ½ times ( $10^{-6}$ times of $150^2$ and that much joules which is actually 0.113 joules is what is needed as energy.

Let us also estimate what is the cycle time which can be approximated by looking at all these parametric here this is resistance capacitance we know at the cycle time TC of the relaxation circuit, can be approximated as the resistance RC times the capacitance which is $10 \times 10^{-6}$ farads times of $\log_e$ ( v0/v0 – vd) which is 200/50.
So this comes out to be about close to $7 \times 10^{-4}$ sec, so this is the cycle for really one discharge to happen which includes the charging time in most of the case you know which includes in most of the portion as the charging time and very less portion has really the discharging time, discharging is almost treated as momentary or spontaneous. So the average power input will then be calculated as w=0.113 divided by the cycle time $7 \times 10^{-4}$ sec so this many watts or if I wanted to convert this into kilo watts we just multiply at by $10^{-3}$ so many kilo watts.

So this comes out to be equal to 0.16kw and so we use for steals the empirical relationship we just formulated earlier for the material removal rate Q, where Q is actually related to 27 .4 times of this value $w^{-1.54}$ where Q is in $m^3$/min okay, and here we can have this as 27.4 times of $0.16^{-1.54}$ $m^3$/min that is how we can correlate Q this is about 1.633$m^3$/min and with this as the new value of Q I could be able to calculate surface finish through the HRMS formulation.

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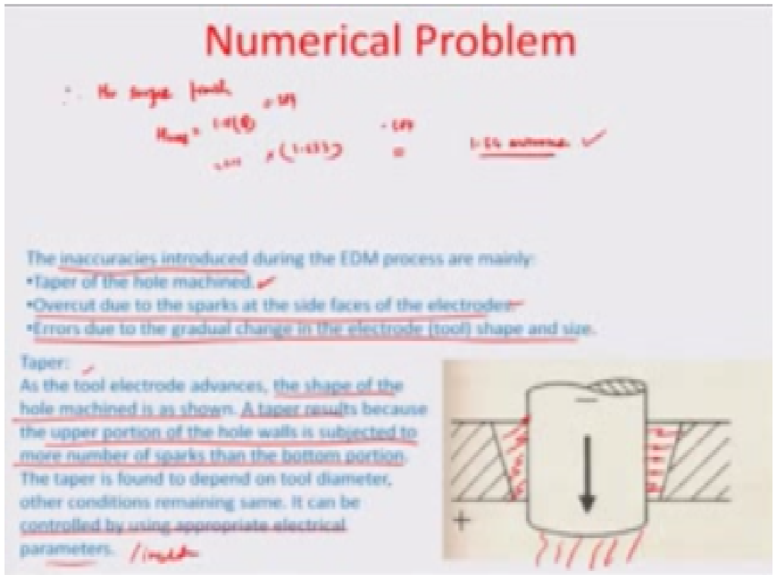


For the steels, so the surface finish in this particular case is represented by HRMS equals $1.11Q^{0.384}$ which is $1.11 \times 1.633^{0.384}$, 1.43 microns so the surface finish for this small spark is roughly similar to what you get for you know around finish turning or even to some extend finish boring or probably to some extend remaining processes so that is how you can define surface roughness particularly for steels while cutting it in EDM process. The other huge which are important for me to mention here about EDM are the different in accuracies which are introduced because of the way that the EDM process happens.

There are mainly three different in accuracies or kind of you know in accurate machining which is introduced because of the way that that EDM is done one of them is whole tapering, so basically whenever you are doing a tool drilling using an EDM using ED trill system there is always a possibility of formation of a tapered hole. One of the reasons why that is so is very obvious that the sides of the tool here for example in this zone are always exposed to creating a break down field and creating sparks to happen.

So not only the sparks are actually created by the phase of the tool but also the sides of the tool which results in same kind of a tapering action, so obviously this portion of the work piece would be exposed to more number of sparks in comparison to this portion of the work piece, because the tool has been inserted for a longer time there. So obviously the erosion at this place would be much more in comparison to the erosion at this place.

So very simple reason why there would be a self tapering of the hole and in fact one of the ways to control is to sort of may be introduce some insulating materials in the tool around this particular zone so that only the phase is the one which creates the break down and the sparking process but again that something that needs to be addressed by the tool designer because not all tools are having the request amount of size and shape for supporting such process of insulation.

So the second problem that exists is the over cut due to the sparks at the side phases of the electrodes particularly the problem comes when there is a tendency of a derby material to be or between the side wall of the tool and the hole that is being created on the ED surface ED machine surface. So there is always a change in the spark length because of it which would adversely affect the roughness surface, roughness at the side phases also there are errors due to the gradual change in electrode tool shape and size.

Let us look at some of these error one by one tapper for example so as you can see here there has to little electrode at one as and the shape of the whole machined is like a taper okay. And taper is because the upper portion of the whole walls is always subjected to more number of sparks than the bottom portion obviously because the tool sides are also generating sparks in comparison to the tool faces.

So you could control this by using appropriate electrical parameters and also insulation at times if you want to avoid the taper.

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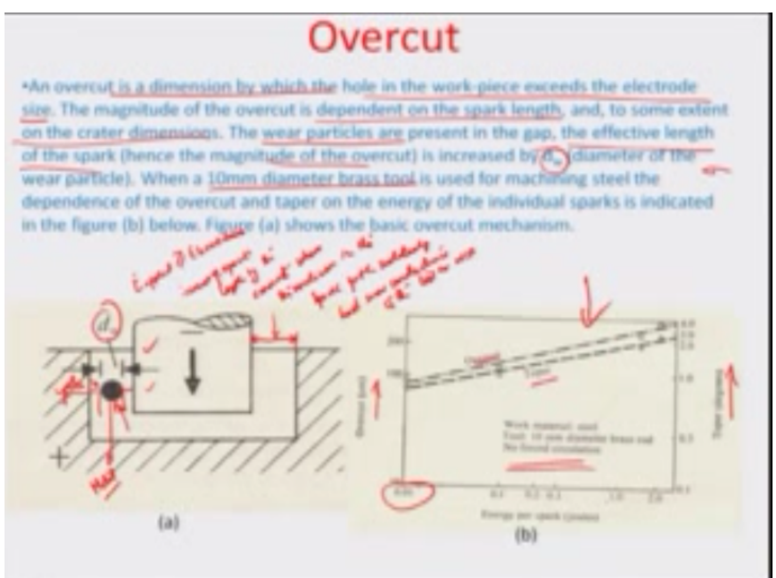

The overcut basically is a dimension by which the whole in the work piece would exceed the electrode size so magnitude of the overcut would be dependent obviously on the spark length and to some extent on the created dimensions this dw here for example okay. So you can see here the overcut actually represent by this arrow okay, so you see that the tool diameter is always lesser in comparison to the whole diameter obviously because there are go be spark from the side phases as well the tool.

So the wear particles which are present sometimes from the debris in the gap they create a lot more problem in terms of enhancement of the overcut size and this phenomena is represented here that let suppose there is particle from the debrey this black circle that is being represented here of diameter dw present in the gap between the tool and the work piece okay, the effective length of this spark now and hence the magnitude of the over curt would be increased by the diameter dw.

So because obviously when we talk about the break down fields or break down electrical field the particle because of being mostly of metal you know mostly because of decree is treated as you know of the same dielectric capacity as the tool or the work piece and so therefore the effective spark length that would allowed this break down it to happen okay. So where the condition e if you may recall e applied greater than or equal to e brick down would necessitate at least dw increase this is break down would necessitate the increase of spark length by the amount where the medium suddenly where the medium in this spark path suddenly had same conductions to the tool or work piece okay.

So that is the reason why this spark length here would actually be this plus this much where this extra width here is equal to the dw, so this results in even bigger overcuts and bigger problem, so if the debrey is not flushed out properly obviously the overcut size is going to be much more. This figure right here shows a case when at ten diameters 10mm diameter pass tool is used for machining steels.

And this shows really the taper that could be formulated by the values on the right side x axes and the overcut that could be formulated by the values on the left side x axes as function of the spark energy. So you can see if this spark energy is low the overcut also generated is low and similarly so is the taper is okay but as is spark energy is increase both the overcut and tapers are

Increased, so this is only the case where there is no forces circulation mechanism and only passive medium operation without any dielectric ring circulated going on.

So this is the major, major issue were we talked about EDM so electrodes really play a very, very important role in EDM operation and therefore we also need to look at some of the wear related characteristics of the tool electrodes because that may determine the ultimate shape and size that you are wanting to die sink on the surface to which machining is been carried out.

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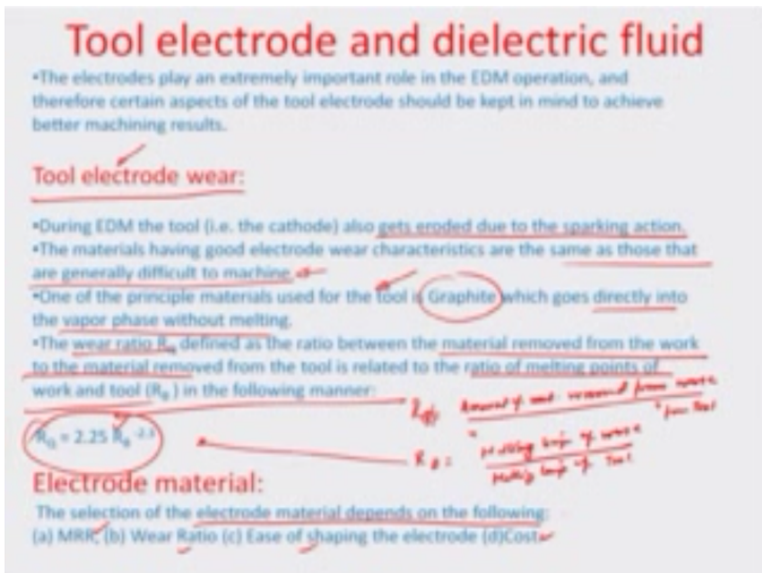


So of we look at that aspect the tool electrode were in the EDM is really because the tool gets eroded due to sparking action itself and the materials having good electrode were characteristics are same as those that are generally difficult to machine one of the principle materials used for the tooling in EDM graphite because of its highly conducting nature it goes directly into the vapor phase without melting and creating any problem etc which may result in the increased in sparking over cut etc.

So we look at the various tool electrodes through parameter called wear ratio Rq which is defined as the ratio between the material removals from the work to the material removal from the tool so Rq is really equal to the amount of material removed from work the same removed from tool so obviously if Rq is low the amount of material remove from work is lower income terminate to the tools.

So you have to have a hierarchy for electrode to be propagate okay so this you can also directly relate to the ratio that melting point so the work and the tool and the way that the relationship goes is that Rq really depends on the ratio of meting point of the work and the tool in this manner so Rq equal to 2.25 Rq $\zeta^{-2.3}$ R$\zeta$ is melting point or melting temperature let us say of work by melting temperature of tool.

So that is how the Rq and R$\zeta$ forced here regarding electrode material the selection of the electrode materials are really dependent on lots of this parameters like MRR wear ratio E's or shaping of the electrodes the cost at which the electrodes are bought etc and in fact there is a detail analysis about what work piece would necessitate what electrode material and also the work dialectic material.

So the interest of time I will close this particular module today at may be the next module we will talk a little bit about electrode materials and dialectic fluids and then also look t some of the different effects of EDM on surface roughness and hardness which is very important critical parameter behind any machining process which happens because of this ablations because of thermal means and with this I would like to finish this particular module thank you and bye.


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