Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology-Part-2

Module-34
Tool Electrodes and Dielectric fluids & Electron Beam Machining

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Hello and welcome to this manufacturing process technology part 2 module 34. We were talking about the tool electrode material selection and also the dialectic material in a EDM process.

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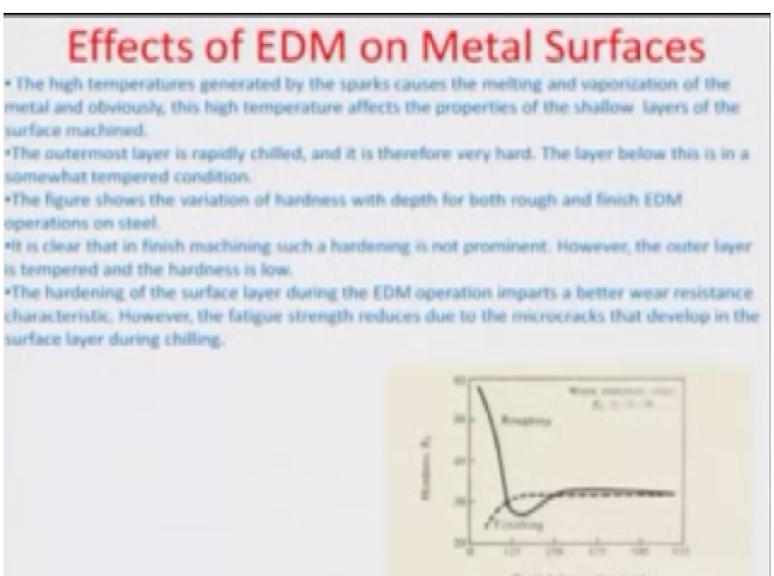

So the first thing which needs to be certain is that.

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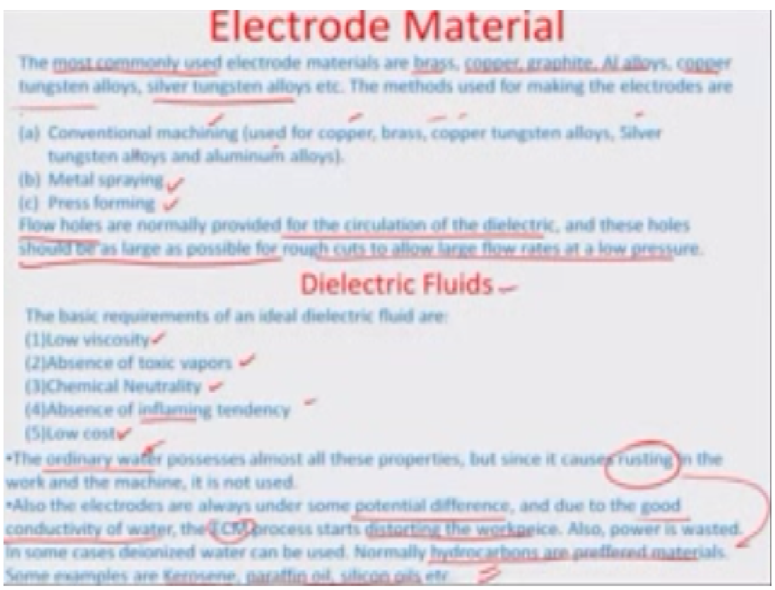

What kind of electrode materials are to be chosen for a successful EDM metal machine to happen and most commonly used electrode materials are brass, copper, graphite, aluminum alloys, copper tungsten alloys, silver tungsten alloys etc,. The method for making the electrodes are either conventional machining that is something that one can think of directly, and, you know this is particularly used for copper brass, copper tungsten alloys, easing to machine materials, you know with silver, maybe tungsten alloys, aluminum alloys etc.

Graphite is not that easy to machine and so therefore, there is some other method that can be deployed for depositing graphite on the surface of any other, you know material which would give enough strength for sustaining the vibrations etc, that are being imposed by the spark generation process alone. There is a metal sprain and press forming which are some of the other processes which are utilized for making tool materials or electrode materials.

You also need to produce flow holes, so they are provided normally for better circulation of the dielectric and these volt should be as large as possible for rough cuts to allow large flow rates at a low pressure. Regarding dielectric fluids the basic requirement of an ideal dielectric fluids are really, there should be low viscosity, there should not be any, you know surface forces of drag which would come out, which may change their addition of the tools particular in thin tools.

There should be absence of toxic vapors, by enlarge dielectric fluid should be chosen in the manner, so that their chemical need, chemical neutral, they are not able to react to any other part of the supports or the tool holders and etc. And there should be generally a low or almost like eligible inflaming tendency, so that is one important point, because there are sparks which are generated and although they are very momentary.

If the initial point is very low there is a tendency of the whole thing to get inflamed and that should not happen okay. And then obviously low cost again is an important criteria. So there are many dielectrics which are normally used like kerosene, paraffin oil, silicon oil, etc, these are all hydrocarbon based materials which are preferable for this purpose. And, you know the basic directory can also start from an ordinary water which poses almost all these properties.

Only this is that in case of water particularly when we are machining steel, there is additional problem of frosting which may come out and it may not be a very good choice. So that is why one shifts to hydrocarbon oils rather than water. So there is another issue about water that there is always a potential difference between the tool in the work piece, you know in EDM. And so, obviously it is all about how much what is the conductivity level of the water if you are using plain water samples.

If the conductivity of water is higher, then there is always a tendency that there would be a electro-chemical machine process which would start happening. And this may lead to some kind of a tool distortion of the work piece distortion which is highly undesirable as far as the EDM process goes actually. So therefore, dis-preferable always to get this hydrocarbon based EDM material as the dielectric fluid.

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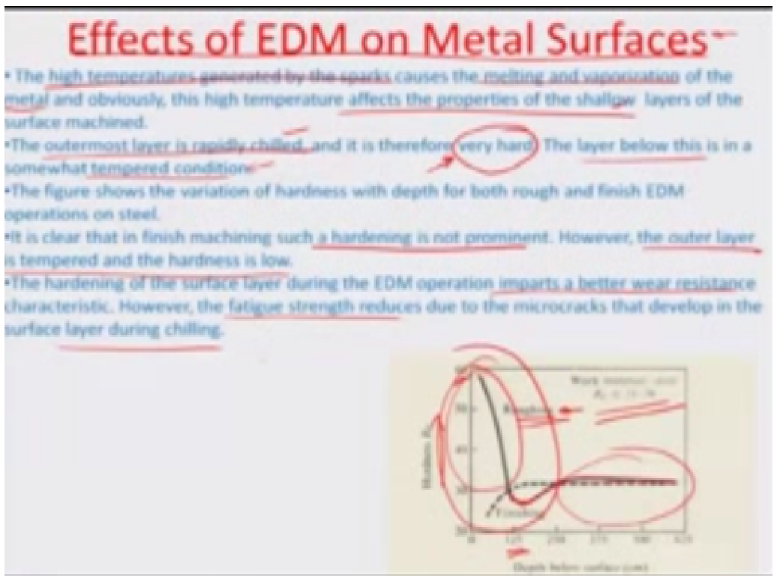

Let us look at another aspect before we close the EDM topic and that is about the effects of EDM on metal surfaces, particularly the hardness and how that gets affected, because the machining process, so whether it is mechanical machining or any other kind of machining, there is always a tendency to have super hardened region, you know which is because of liquid sustain hardening on the surface of the material.

Because it is appealing process and conventional machining that we are looking at. EDM also, because there is a tendency of the material to being melted and re-deposited, there is always a hardness issue which would come up and we need to look at it in more details is to how the hardness changes, because of such spark machining and high temperatures.

So the high temperatures generated by the sparks cause melting and vaporization as you know meting and vaporization of the metal and also resolidification would definitely effect the properties of the materials which are close to the surface may be call them the shallow layers okay of the machine surface so outer most rapid layer is obviously rapidly chilled and so it would be definitely very hard because of the quickly inhaling and because of this quick chilling action there is always a tendency of this material to be very hard if you may remember the time temperature transformation TTT curves as illustrated in part one of the scores.

We had mentioned there the quick formation of the metal side state which results in hardening so we are also machining steels here so obviously this rapid chilling or you know rapid cooling would result in this kind of hardness. Obviously there is going to be layer below this hard layer which is somewhat tempered in it is condition and if I look at the profile of a you know in case for roughing EDM operation and by roughing we mean a very high spark energy we can see that the hardness suddenly you know if we look at it as a function of depth so on the surface the hardness is pretty good pretty high it is in the range of about 60 rock well.

So hardness 60HRC and it goes down all the way to about 100 and you know at a depth of below about 125 micros on the surface with the hardness really is an all time low which is probably about 25 HRC so from 60 to 25 HRC and this could be a actually as a result of the fact that you know just adjoins to rapid chilled layer is a layer which is also supplying the amount of carbon which could really lead to metal side for machine on the top layer.

So this is a lot of buffer layer you could say you know where there is a it is a carbon provider for metal side to get generated on the top layer and then obviously as you increase further these layers are more less in a tempered condition the roughness just gradually changes you know up till it goes to almost stability of near about 30 to 32 rock well hardness so the work material normally would have hardness of what 31 to 36 and so the remaining area is really not very important to be considered but the sudden down grading of the hardness of a layer which as a complete metal side state and a layer which is like supply layer for the excess carbon to the metal side to happen okay.

These are the two important states which need some discussion for a finishing process because this spark energy already is very low you know the it is clear that such hardening is not promoting prominent feature because we are not really super heating or anything the material it is only just a few atomic layers that we are trying to move out by such process and so therefore the outer layer in this case tempered and the hardness low okay.

And in this case the beyond a few layers of the top the shallow layer is below the top surface are really tempered and the hardness is low so the hardening of the surface layer during the EDM operation obviously would import a better where resistance for a roughing process course and because the hardness changes however the overall fat strength would reduce due to micro cracks and that develops doing rapid chilling process almost all always weather it is a casting process or it is you know some kind of a heat treatemmat of the cast or a far part etc…

That we had discussed about earlier in the material property section so with this I would like to close on the EDM topic and start a new machining topic which is about EBM machining EBM machining is again deploying electrons or fast moving electrons but the process of the spark machining as been election sudden reduce because of a change in potential and also the dielectric break down in this particular case EBM process the continuous source emanates electrons at high velocity.

And this electrons make a momentum transfer at the surface where they are heating which would result in a bound vibration or a change in the overall temperature of the surface where the electrons hit so let us talk about this process in some details E beam machining.

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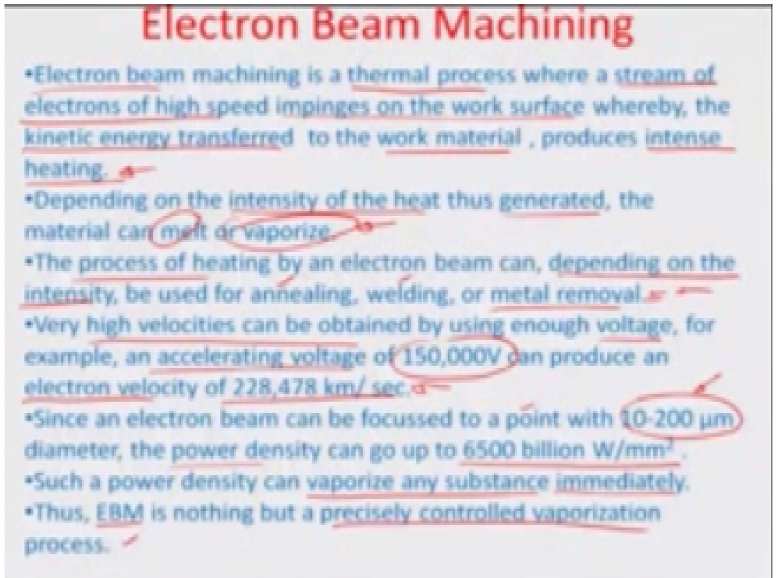

So it is obviously another thermal process where the agent which is doing the heat transfer here is electron beam there is a stream of electrons in fact of high speed which in pinch on the work surface, and transfer all their kinetic energy to the work material and this produces intense heating and sometimes melting or sometimes even the vaporization so obviously, depending on the intensity of the heat generated the material either can melt or vaporize.

In this case intensity also goes to an extent where saw in the material can actually get vaporized, so sublimates directly process of heating by an electron beam can generally depended on the intensity of the beam okay and can be used for various operations for example annealing of the work surface, welding of two different parts together or even metal removal operations and in fact now a day E beam with the softer energies is also used for doing the lot of for resist processing at a nano micro nano scale.

In fact if you remember during the first section of this particular and fraction process technology may took your cross process of, you know even lithography which is also known as a nano in lithography and also nano impend lithography which engaged in fact the E beam based photo resist processing, so very high velocity is can be obtained if you use higher voltages for example and accelerating voltage for the electron beam of about 150kv would produce electron velocity is which are almost.

Is near the speed of light about 228, 1478km per second and since a electron bean can be focused to a point by pneumatic fields, almost has narrow send to 200n micro meters and inside this limit has gone down further in the easiest the power density of that particular point can go up almost to the level of what 6500 billion watts per mm^2, so such a power density obviously can vaporize in substance which comes in contact with immediately in fact what happens in E beam is that when the high velocity electrons are.

Being moved to a surface there as few surface layers we do not even register that there is a fast moving electrons coming and in fact the machining process starts at beyond certain surface layers it starts from the certain depth where the momentum is being felt and the impact is being registered as a born vibration or a increase in kinetic energy, so e beam is therefore nothing but the precisely control vaporization process in wish to material can evaporate real quick.

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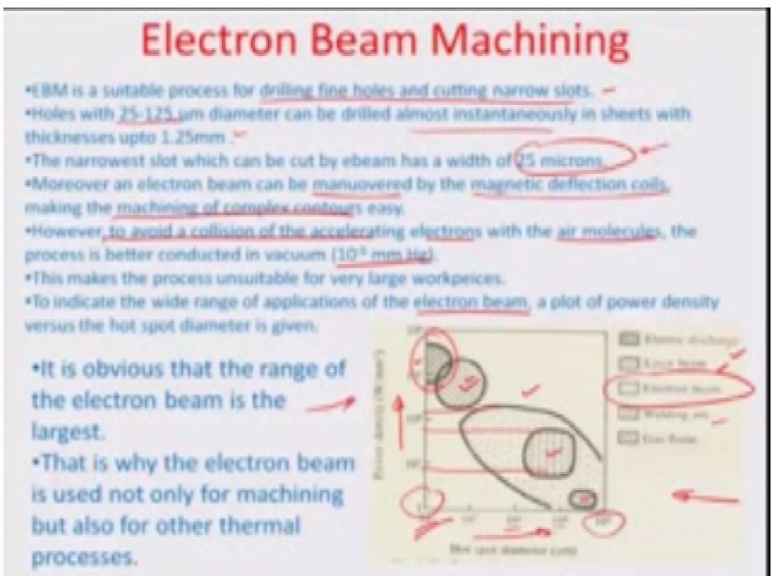

Let us look at some of these different process around the hotspot diameter that they may generate in the power density that we are talking about so we can think of electron electric discharge in the very left corner of this particular plot here and hotspot diameters are typically in the range over about 10 microns, and the power density goes has high as about 10^7 water mm2 the lasers again would give a hotspot of between 10 and 100 micro meters high hotspot high side is more and power density is slightly lower is probably the range if some around at 10^5 to 10^7.

And watt/ mm^2 there is also another process of let say welding are you know gas flame to generates really a high hotspot size it would go 10^5 almost close to 10^5 in a micro meters about

0.1m and you take have very less power density in the range of about 1 to probably 10 or 15 watt/mm^2 similarly in case of welding the hotspot is slightly lower may be 10^3 to 10^4 microns but the power density is slightly higher which is in the range of about close to you know about 90 to about 10 almost 10^4 watt/mm^2 .

What is interesting here is the EBM processes you can see which has which can offer a variety of different power and densities as well as hot spot sizes so that is the reason why EBM is preferred process for even things which welding cannot do or at a you know even like joining processes or cutting process so EBM obviously is that way much suitable process for drilling fine holes cutting narrow slots.

You know whatever can be done with welding arc or a gas flame can almost always be done with EB machining, so holes with diameter of about 25 to 125 microns can be drilled almost in continuously in sheets of thickness up to 1.25 mm this is the power of a beam and narrow slot which I have hitter by the radium as a beam as a width of about 25 microns we are talking about an EBM which would be very effective.

I am not talking about software processing here but about metal processing mostly so here as where it can go upto 25 microns more overran electron beam can be many overfed and maneuvering can mostly take place because electrons which are moving fast moving they face Lawrence forces through ampere magnetic fields so if you have magnetic deflection coils they are able to deflect and raster the beam typically over the surface.

And so you can actually go for machining very complex shapes and contours when we talk about such magnetically assisted electron beam movement, however to avoid the collision of accelerating electrons with air molecules you need typically apply vacuum columns in which this electron beam processing can be done, so you know the work piece therefore is quite limited it size which is limited by the vacuum column.

This is very expensive to evacuate the column in fact and the vacuum levels we are talking about is about 10^{-5} mm of mercury so to indicate the wide range of applications of a beam you know you can probably look at this power plot and decide for yourself that compare to the process like electric discharge laser beam machining, where we are wanting to place electron beam really. In comparison to other for you know thermal processes. It really has a very wide range power density and hot spot diameters.

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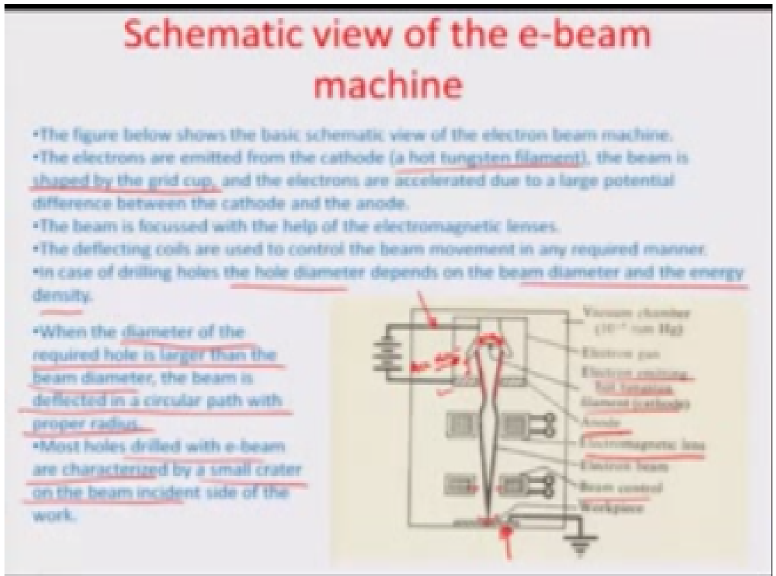

So let us look at how EBM is produced and what is the basic principle of generating a fast moving electron beam so it is basically the thermionic effect and it starts with the hot tungsten filament so you have a automatic you know electron emitting hot tungsten gun or filament which is the basis of starting the electrons and then there are series of either series or you know series or perforated anodes you can say where there is an acceleration key to the electrons and also there is some absorption.

Which is generated so this is the perforated anode here and then further there are electromagnetic lenses and this controls the shape and size of the beam and also there are beam control lenses once the size has been optimized and a sudden diameter has been tacked or a focuses been hitter you could actually raster this beam in a small zone okay around by changing by deflecting the magnetic forces which are being applied in these concerns of both directions since why you could do beam rastering and this is really the work piece which we are talking about. So the beam is shaped by a grid cup which makes assure that the beam actually you know is like more like a self focusing beam as you can see here.

So these are the cathodes really so you can have sort of deflection cathodes so that you can actually have the beam shape up in to small RFS so in case of drilling holes the whole diameter depends on the beam diameter and the energy density that you are plugging in and this accelerating voltage here which really depends on the cathode, anode difference of potential okay, so this is the beam accelerating voltage this is a very critical component which determines what is the level of machining or what is the extend of machining that can happen the electron beam that has been produced.

So obviously when the diameter of the hole is larger than the beam diameter so the beam has to be deflected in a circular path so that the hole radius can be machined you know on the work piece surface, so most holes drilled with EBM capacitor by a small creator on the beam incident side okay, although a piece and when such you know holes are continuously being drilled you have a throw hole and you can have a EBM drilling process.

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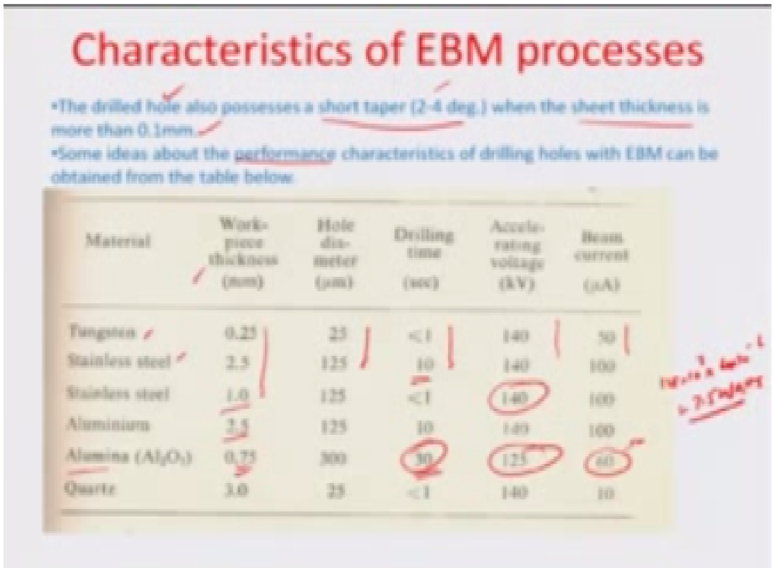

Material	Work-piece thickness (mm)	Hole dia-meter (μm)	Drilling time (sec)	Accele-rating voltage (kV)	Beam current (μA)
Tungsten	0.25	25	<1	140	50
Stainless steel	2.5	125	10	140	100
Stainless steel	1.0	125	<1	140	100
Aluminium	2.5	125	10	140	100
Alumina (Al_2O_3)	0.75	300	30	125	60
Quartz	3.0	25	<1	140	10

So the drilled hole will also possesses a short taper in this particular case particularly because of the fact that the beam also narrows down and there is something like a focus beam focus you know which is set up on and that is somewhere at the depth where up to which the cutting has to happen really and so for doing this you always have this tendency of about 2 to 4° taper whenever you are using a sheet thickness is more than about 100 microns, okay.

So anywhere about 100 microns you will definitely get a taper in the hole that you are trying to drill, so these are some performance parameters about the drilling of holes with different work pieces like for example if you are drilling in tungsten stainless steels, aluminum, alumina, coats you have different work piece thicknesses, hole diameters drilling times accelerating voltages and beam current which are being given in this particular illustration this table.

So you can see the very, very high accelerating voltages which have to be hit up on for drilling not very high thicknesses the range of 2.5mm to 1mm okay, and you have excessively high drilling time which is in particularly the stainless steel is about 10 seconds for drilling about 2.5mm work piece thickness. So if you compare it with the conventional drilling you can find out how much more energy you will be assumed in drilling this.

But obviously because such processes are meant for extremely complex contours or shapes or even to extend to the loyalties which are otherwise hard to machine therefore you can still consider EBM process although it is energy of tungsten in comparison to conversional processes. So material like alumina for example which is very, very hard can be cut with a higher drilling time okay, so 0.75mm work piece thickness is cut in about 30 seconds and there you apply almost a beam current of 60 and accelerating voltage of 125kv which make set about how many watts we can just check this, so $125x10^{3}x60x10^{-6}$.

So this makes about 7.5 watts of power this is only good power that you using for cutting a small 0.75 MM to 750m thick Elmina work piece. So that is how you can characterize the various performance you know related parameters with respect to the beam process.

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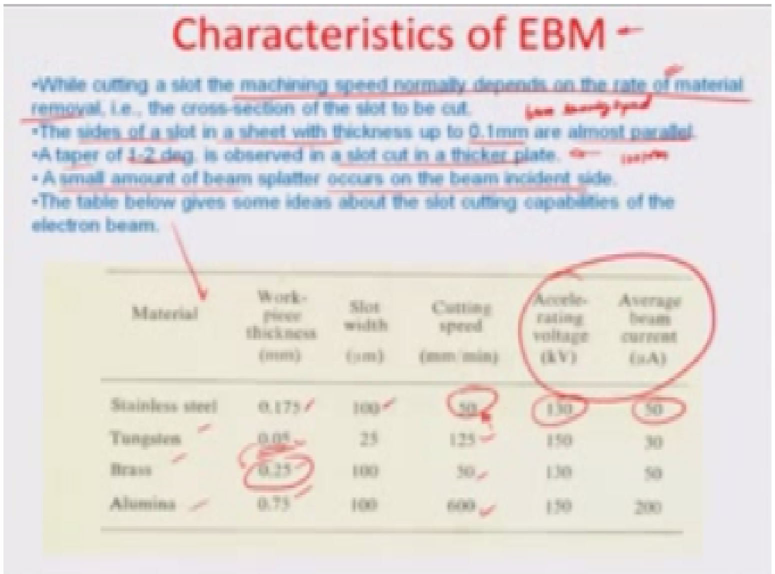

While cutting a slot the machines speed normally depend on the rate of material removal so obviously we have to have some parity between what is the rate of material removal so that we can fix up what is a beam scanning speed okay. So this is more so important whenever we are doing or processing or diameter which have much larger than the bema diameter where it necessitate the beam to scan over the surface to remove the whole material from the surface.

So this sides of the slot in a sheet with thickness up to 0. 1mm are almost parallel and a 1 to 2^0 taper is absorbed in a sort thicker plate anything about 100 microns is add earlier told you had a almost always have taper of 1 to 2 degrees. There is also a small amount of beam splatter which would occur particularly on the beam incident sight and this may result in some kind of a re solidification sometimes of the vaporized or molt in material.

Another tables here give some idea about the slot cutting capabilities of e beam for example if I have a work piece thickness of 0.175mm in the slot width of about 100 mm, you know I would typically have at an accelerating voltage 130or 50 beam current 50m amperes beam current 130 KV is accelerating voltage would have a cutting speed of about 50mm per minute okay, so it is not really a very big speed of cutting as for as the sum of other process on the conventional side go.

Similarly for tungsten, bras, alumina you can have various cutting speeds ranging from 125 mm per minute to about 50 mm per minute for bras, and alumina it could be has size about 600mm per minute obviously these are corresponding to different thicknesses as you can see here the tungsten plate that we are removing at higher speed is about 0.05 mm about 50microns. Similarly or 5 microns s I am sorry.

Similarly about 50 microns similarly bras you know this is about 250 micron about 5 times thick than tungsten, so what we are referring here is basically the range of cutting speed that could be obtain for various thickness and various slot width as can be seen with EV machining. So the other small issue is about you know if there is some relationship that would happen between this beam power which I just calculated sometime back you know as about probably 7 or 8 watts power with respect to may be the material removal rate. And so in such co relation does exist empirically.

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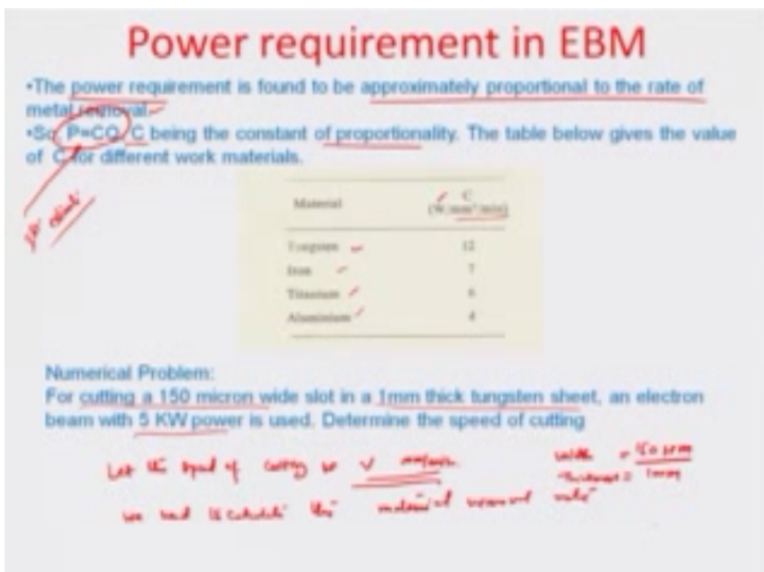

It has been found that the power requirement is approximately you know proportional to the rate of the material removal and it basically represented as Pcu CQ this is only a very fast estimate you could say, I would actually show you a little different model in some slides to come where we will be talking about slightly more accurate version of this p = cq model, so this is only fast estimate or estimate you can say of the power.

So c is sort of a proportionally constant which has been calculated for different materials like tungsten iron titanium aluminum and this will respect to what is the power needed per unit material removal rate the power is in watts and you can see some of this values so let us look at a small example problem here let say for we have to cut a 150 microns wide slot in EBM and we are cutting that 1 mm thickness of tungsten sheet okay.

And B power of about 5 kilo watts is used in this particular case we have to determine what is the speed of cutting so let the speed of cutting be V millimeters per minute and we need to calculate the material removal rate with v millimeter per minute speed so we cutting a slot which is about 150 micro meter in width so this is the width of the slot and we are also cutting thickness of the sheet equal to 1 mm okay.

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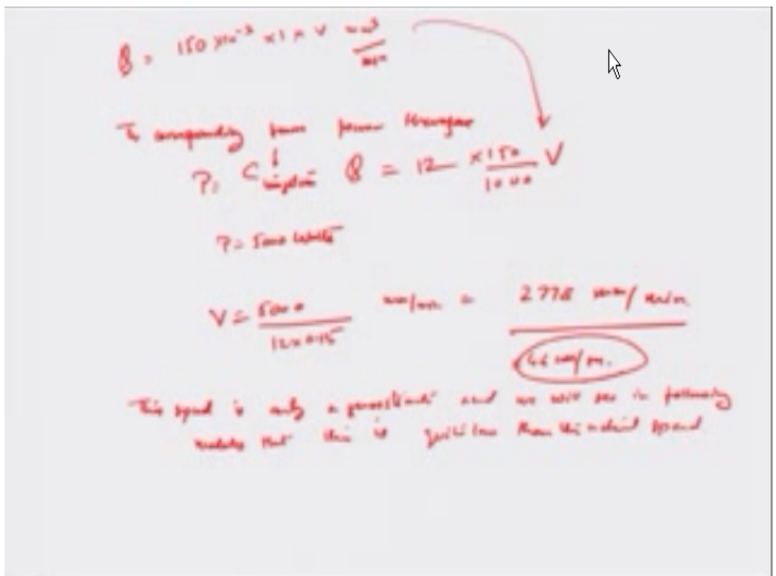

So obviously if we looked at Q the material removal rate it would be the thickness of the slot that we are cutting multiply this with -3 to have a corresponding number of mm okay so 150 microns or $150*10^{-3}$ millimeters into 1mm that is sectional area times V millimeter per minute oaky so this becomes so many mm cube per minute okay.

And the corresponding beam power therefore will be given by P equal to let us say C for tungsten material uses tungsten here this being cut times of cube so the C for tungsten I borrowed as 12 volts per millimeter cube per minute times of the number of millimeter cube terminate actually predicted through the estimation in the earlier step here.

So since the P is given to be about 5000 watts that is how beam power is V become equal to 5000/12 $^{1012*0.15}$ millimeter per minute and so you can see here the scan rate is really about 2778 millimeters per minute of above 4.6 you can say centimeters per second that is how the beam scan rate can be so this speed is only a guess estimate okay and we will see in following modules that this is quite low than the actual speed.

So we will try to do some dimensional analysis and we will try to see if you can get an accurate version of the actual speed with all these parameters like thermal connectivity of the work piece or the beam temperature so on and so forth which comes are the melting point of the material so on and so forth which comes together you know in a more consolidated electrical form so with this I would like to close this particular module and in the next module we will talk little more about EBM process thank you and good bye.

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