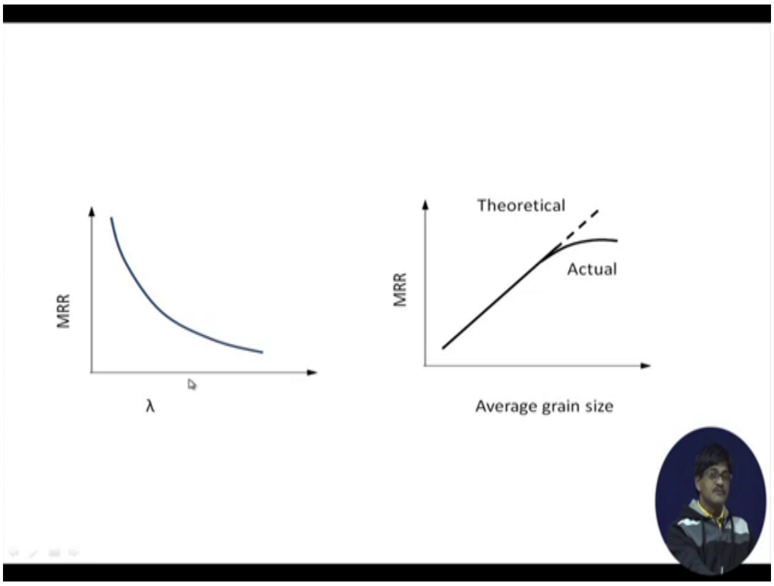
Non-traditional abrasive machining process: Ultrasonic, Abrasive jet and abrasive water jet machining
Prof. Asimava Roy Choudhury
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 09
Ultrasonic machining - Effects of various inputs on the output

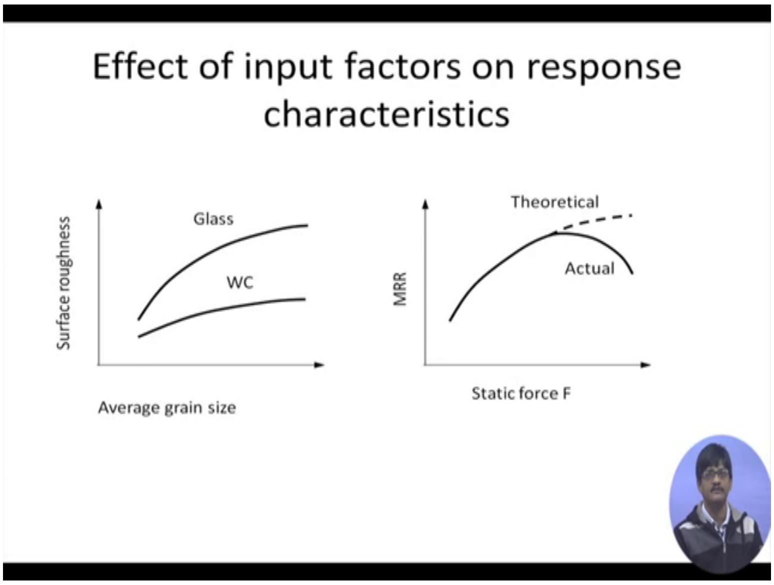
Welcome to the 9th lecture of the course on Non-traditional Abrasive Machining Processes.

(Refer Slide Time: 00:29)



Today we are going to deal with ultrasonic machining effects of various inputs on the outputs etcetera and other subjects also which in order you know complete everything there are some other things that I have included.

(Refer Slide Time: 00:46)

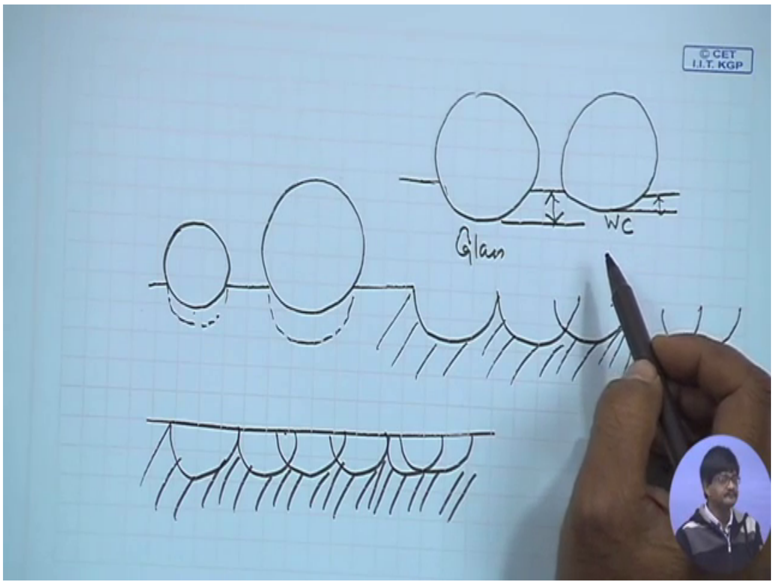


So, starting with starting with the effects of the different inputs we had already started this thing in the last lecture, but we had to stop in between. So, I will just recapitulate the first 2 graphs and move on with the rest of the graphs.

We had first come across a diagram in which we have seen the effect of average grain size on the surface roughness created on tungsten carbide and glass. So, glass and tungsten carbide here they are the work piece materials. And average grain size basically means the average abrasive grit size. So, it basically means that I am increasing grit size and I am checking up the effect of the grit size increase in grit size on the surface roughness which is produced on tungsten carbide around glass. The first and foremost thing that we notice is that the with increase in grain size the surface roughness is increasing; that means, it is becoming more and more rough; however, the effect is more pronounced on glass. So, let us first let us let us check up these 2 things separately.

First of all why should surface roughness increase with average grain size.

(Refer Slide Time: 02:14)



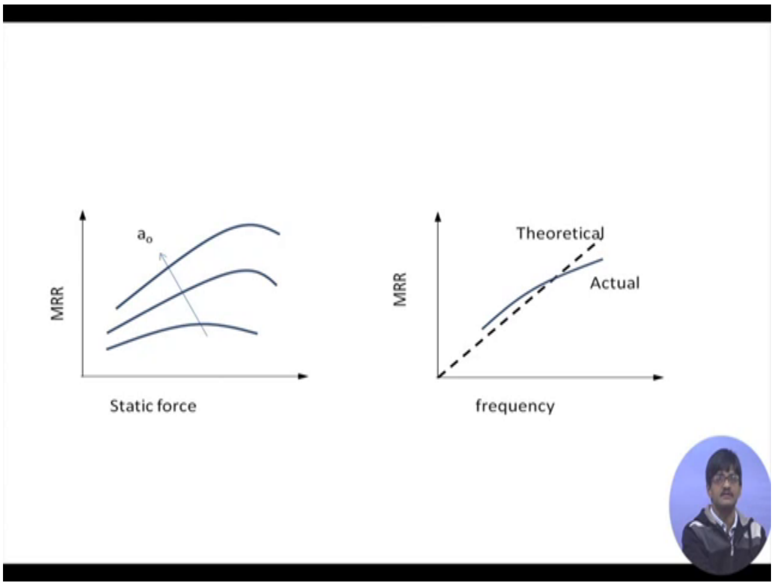
For that Let us have a quick look at this particular diagram. This is one grain, this is another grain and the roughness corresponding roughness that it will produce will be corresponding to the crater size. So, this one will be producing this particular crater. This will be producing this particular crater of course, on you know brittle materials. So, glass is brittle tungsten carbide is brittle and therefore, larger the grain size larger will be the crater diameter so that for larger grain sizes we will have something of this time this type; that means, overlapped large craters. So, that ultimately the surface will come out like this. So naturally, we can say that the ultimate surface roughness produced has a possibility of having higher roughness than this particular case. What will this produce? This will produce something of this type. So, we will say that the probability of this one being more rough is higher, that is what ok.

Next is that that coming back to the graph we see that glass is having you know a higher surface roughness compared to tungsten carbide, why is this So? This is because of this particular figure let us have a look that si the same grit will be going into glass by this, while the same grit would be going in to a much lower depth in tungsten carbide. So that means, these 2 distance is doing different this will produce larger craters and that will possibly I mean the probability of producing higher surface roughness with larger craters is more. This will produce smaller crater. So, the probability of producing lower surface roughness with smaller sized craters is more. So, that is why this is the behaviour of I mean this is the graph of surface roughness with respect to average abrasive grit size.

Coming to this one second one is static force. If the static force is increased you will expect the m a MRR to be you know increased by f to the power 3 4, because MRR is proportional to static force to the power of three-fourth. So, the theoretical graph will be continuously increasing while the actual; that means, experimental graph we find that the MRR starts falling down after a particular period. I mean after a particular increase in or a after a particular value has been attained by static force, beyond that if some increase is there in static force the MRR comes down.

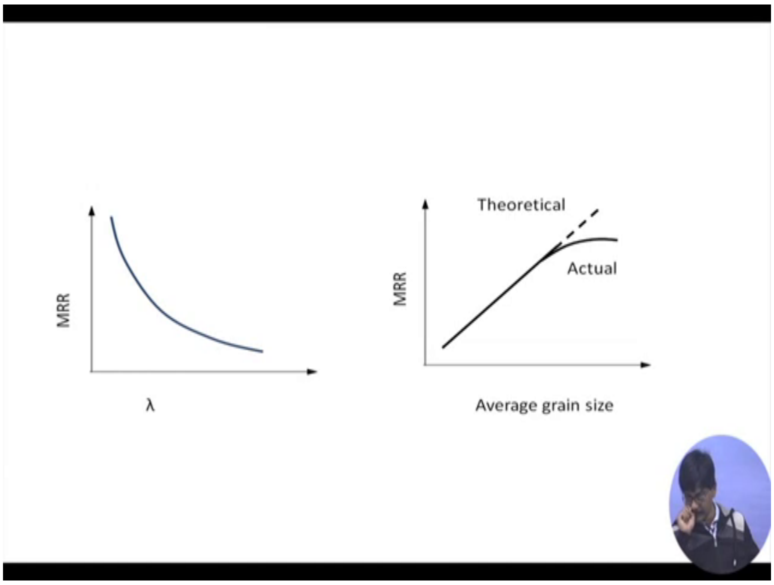
This is because at higher static loads the average size get crushed. And MRR comes down as a consequence, because they become smaller grits and they have less ability to remove material.

(Refer Slide Time: 06:33)



So now comes static force versus MRR we have discussed this just now just the effect of amplitude increase is being shown superposed on this graph. Frequency, with frequency MRR should be having you know proportional increase; however, when we actually do the experiment we find that in the long run that is as frequency is increased, MRR starts falling down. This is because the average speed which has been considered due to vibration, this is not fully accurate a gross sort of averaging has been done by dividing 4 amplitudes by the time period, that is where an error peeps in this we had discussed last day.

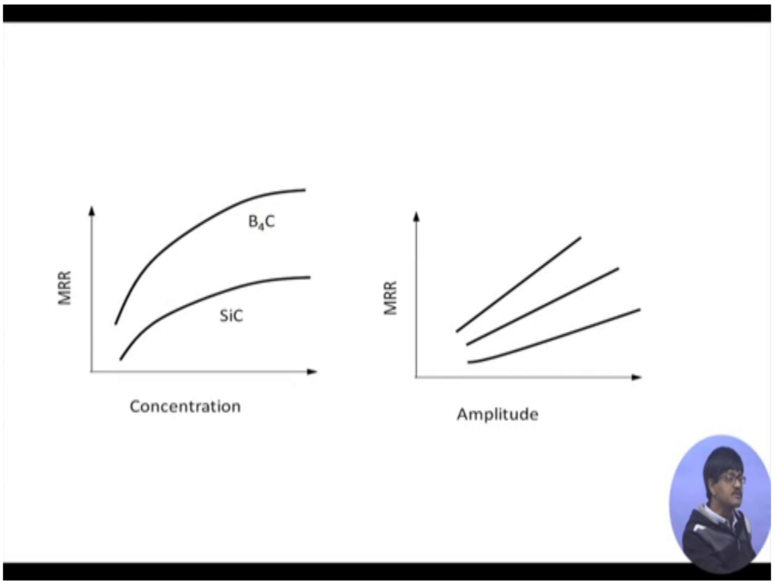
(Refer Slide Time: 07:29)



MRR change of MRR with respect to lambda; that means, work piece hardness divided by tool hardness. So, if the work piece hardness by tool hardness increases; that means, work piece becomes more and more hard relative to the tool therefore, the tool will take up most of the damage and therefore, MRR will be coming down. So, that is what is reflect tool will be taking up more of the damage delta t will be much higher than delta w and therefore, MRR will come down MRR essentially refers to the metal removal rate of the work piece.

Next average grain size goes on increasing as suggested by the MRR equation and a theoretical value should be you know always proportional, but after a particular stage it is found that average grain size starts reaches a maximum and then falls. So, in the average case it is found that the there is again the crashing tendency coming in average the grains become very large in size, they have a tendency to get crushed and they a difficulty to enter the machining zone because they are. So, large in size compared to the amplitude.

(Refer Slide Time: 09:06)



Boron carbide silicon carbide with concentration we find that MRR is increasing, but after a certain stage it stops increasing.

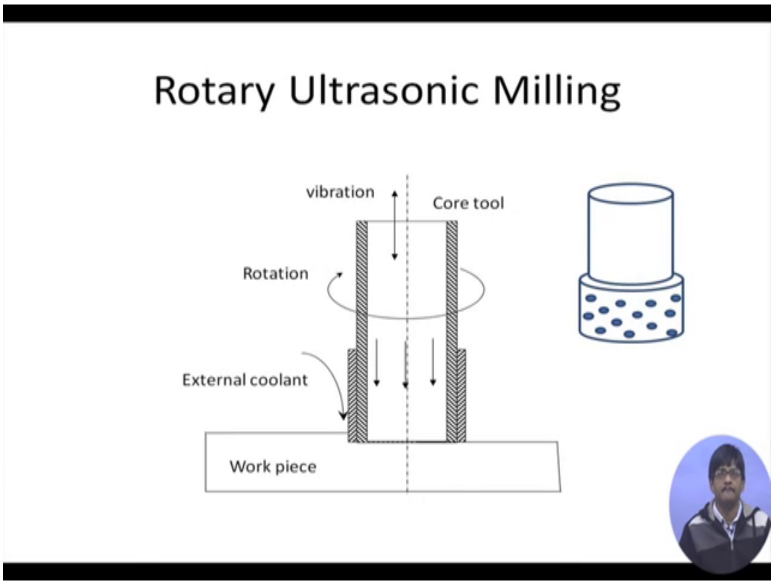
This is because concentration to the power one-fourth, I mean MRR is proportional to concentration to the power one-fourth and therefore, after a particular stage the increase in MRR with respect to concentration is not very significant. C to the power one-fourth that is why both these curves are showing a tendency to flatten after say 30 percent concentration has been attained.

We also notice that for the same concentration boron carbide is giving higher MRR compared to silicon carbide. What can be the difference? How is this particular difference you know explained by the model? The model however, that we have studied does not take into account any of the abrasive properties. These are the 2 abrasives which are used. So, if these are the abrasives used why then should they give different MRR? Because there are no properties of abrasives in the final expression of MRR; you know f to the power three-fourth divided by sigma w to the power three-fourth plus 1 plus lambda to the power three-fourth into amplitude to the power three-fourth into grit diameter into frequency and all those terms, there is no term of abrasive a hardness or what you call it strength nothing of the abrasives except abrasive size.

So, material properties are not included. So, why should there be a difference, this may be due to the fact first of all that abrasive is also undergo some kind of compression when they are pressed between the tool and the work piece So that the compression being equal to delta t plus delta w is not fully correct. And also it could be that many of the grids get crushed in the process of impacts or they undergo fatigue failure because there are so many impacts per second, and that maybe effecting silicon carbide in a more drastic manner than the effect on boron carbide that is a possible solution.

Amplitude MRR has a relation with the amplitude like amplitude to the power three-fourth, I mean MRR is proportional to the amplitude to the power three-fourth and that is what is reflected here. If the results are taken you know more towards the higher values of amplitude, surely they will show a tendency to have less gradient.

(Refer Slide Time: 12:37)

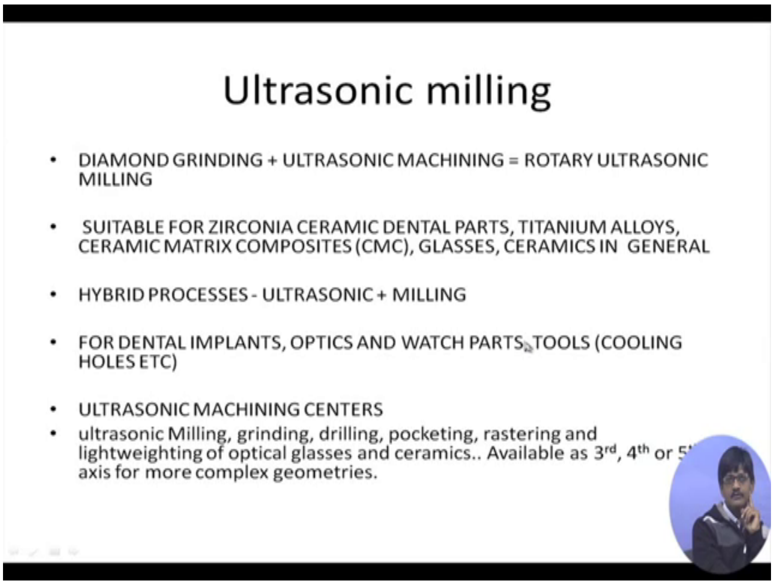


Now, we will quickly have a look at some of the other ultrasonic methods which are taking not exactly you know not exactly of the same type as our ultrasonic machine, ultrasonic typical die sinking type machine that we are seeing it is not exactly of that type. So, let us have a quick look.

This is the isometric view. So, there is a core you know, tool which is rotating and it is vibrating and there are abrasives here or the (Refer Time: 13:26) cooling coolant is given from inside. And external cooling is also applied like this. And therefore, in addition to this sort of vibration we are having rotational motion as well high, high speed of rotation some people refer to rotary ultrasonic milling as simply ultrasonic machining plus grinding convention grinding. How is grinding taking place, due to by virtue of these abrasive. What can be the you know advantages of this method, the advantage of this method is that over and above ordinary you know grinding action we can have better material removal by vibrations.

Let us have a quick look to the area of application of these with this particular method. So, in addition to vibration we are having rotational motion. So, ultrasonic milling we can have a quick look diamond grinding plus ultrasonic machining is equal to rotary ultrasonic milling.

(Refer Slide Time: 14:52)



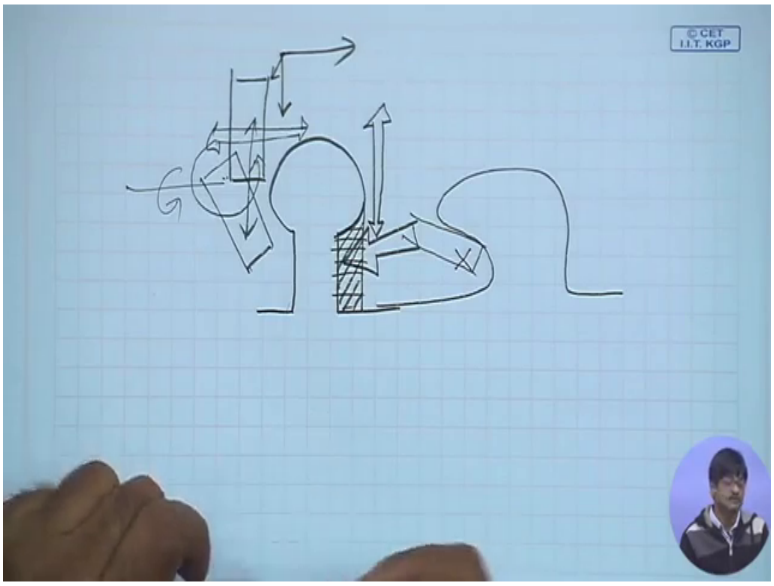
So, those grids that we had seen they are essentially diamond grits diamond grinding plus ultrasonic machining.

What are they good for that is the areas of application, one big area of application is the grinding of the ultrasonic grinding of zirconia ceramic dental parts; that means, these are dental part replacements zirconia ceramic; that means, zirconium oxide titanium alloys; that means, difficult machine materials ceramics matrix composites or CMC glasses and ceramics in general. So, these are the areas in which ultrasonic sorry, rotary ultrasonic milling is resorted to. Next we can also have hybrid processes like ultrasonic machining plus ordinary milling. What is it good for where is it used it is once again used for dental implants optics in watch parts and tools like for example, cooling holes in tapping tools for making external internal threads. So, in those tapping tools if you want to make cooling holes t (Refer Time: 16:38) this particular process can be used you know to our advantage.

There can be ultrasonic machining centers also. So, just like we have ordinary machining centers in which milling, grinding, drilling and all these operations can be carried out conventional, we can have ultrasonic machining centers in which ultrasonic milling, grinding, drilling, pocketing, raftering, lightweighting of optical glasses and ceramics these are possible. And these can be available as you know 3 axis, 4 axis, 5 axis for complex geometries.

What do we mean by 3 axis, 4 axis, 5 axis? It means in 3 axis there will be 3 of the axis moving it is axis motion that is (Refer Time: 17:22) the work piece with respect to the tool can be given motion in 3 axis x y and z. In 4 axis additionally you might be having a rotary axis about a particular you know linear axis, and in 5 axis there will be 2 such axis. Why is this so? Let us have a quick look for this 4 5 6.

(Refer Slide Time: 17:46)

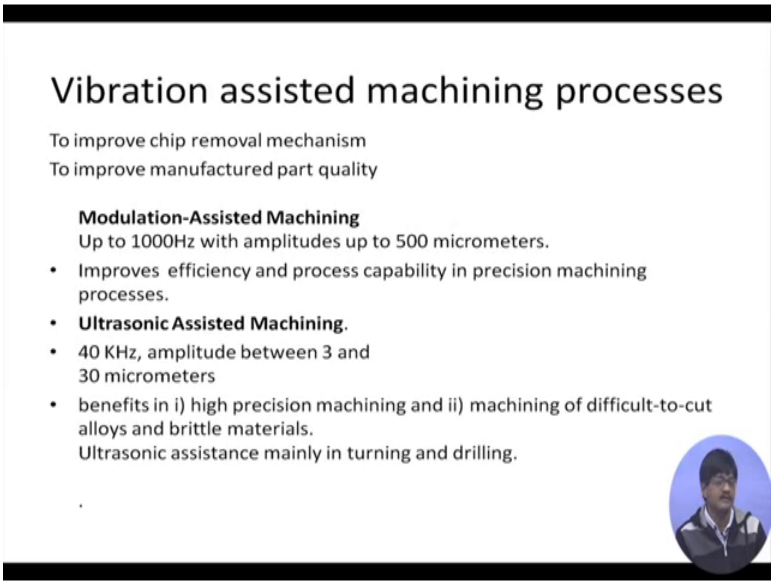


If you have a body of this type this side of the body is called reentrant side, why?

Because if you have an ultrasonic tool here and if you have 3 axis machine which can make the you know movements in these 3 directions. So, it can move down the tool can move sideways; so sideways up down and out of the paper into the paper. So, in way can it (Refer Time: 18:31) reach it has no way of reaching this particular space, but in addition if it can you know rotate this way; that means, if it has an axis of rotation, about this particular axis in that case it can rotate an axis these portions. And it can also have that ability to rotate about this axis. So, that it can rotate this way also if it has a problem in that direction this also it can take care of.

So, 5 axis machines can machine surfaces which fold over themselves surfaces which fold over themselves. So, that they have apparently (Refer Time: 19:25) inaccessible portions, these can be reached by 4 axis and 5 axis machines. So, such machines just for ultrasonic machining they are also available and they are called ultrasonic machining centers.

(Refer Slide Time: 19:40)

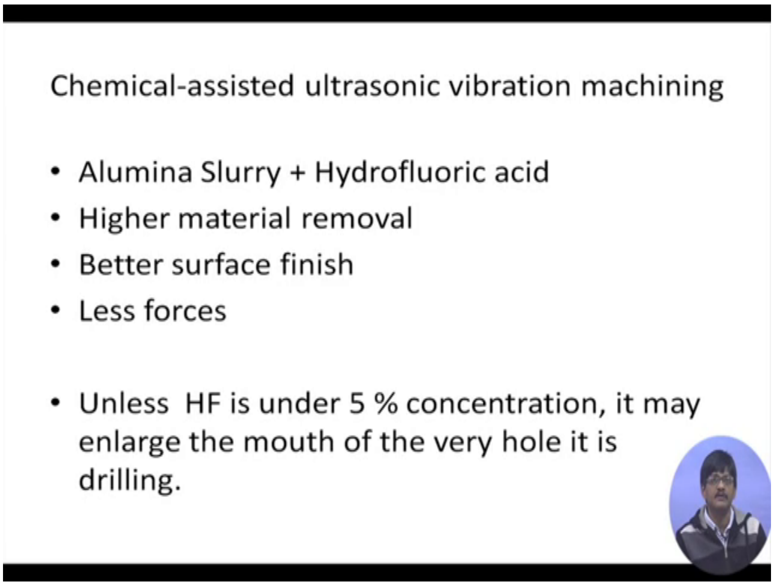


So, let us quickly go through some of the other processes which are existing as you know either hybrid processes or vibration or ultrasonic assistant machining processes or associated processes.

So, in order to make chip removal easier, and in order to improve the quality of manufactured parts we have basically 2 methods in which you know use of vibration as an assistance is used. One is called module modulation assisted machining in which the range of you know frequency is generally up to 1000 hertz; that means, one kilo hertz and the amplitudes are up to 500 microns that is quite a large value indeed and this (Refer Time: 20:37) includes the efficiency and process capability in precision machining processes.

However, this is not exactly the machining. In ultrasonic assisted machining the frequency can go up to 40 kilo hertz. 40 kilo hertz and amplitudes are generally between they are much lower generally between 3 to 30 micros. And it helps in high precision machining and machining of difficult to cut alloys, and brittle materials. Difficult to cut alloys and brittle materials, and generally ultrasonic assistance is in turning and drilling.

(Refer Slide Time: 21:30)



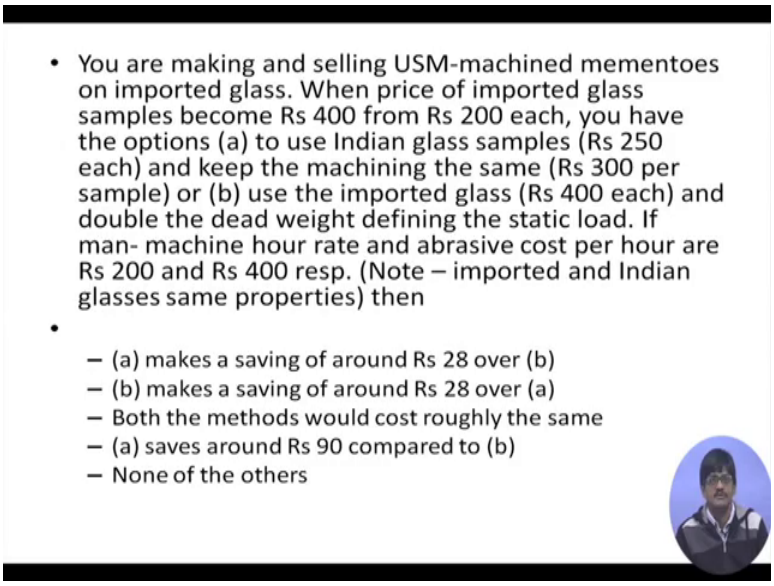
Chemically assisted ultrasonic vibration machining: chemically assisted, how can we assist? First of all why do we need this assistance in ultrasonic machining? Ultrasonic machining is associated with 2 distinct problems. One is that the material removal rate is not very high. Material removal rate is not very high, and the surface roughness is also not very high because it directly corresponds to the average grit size. So, what is the way in which this can be solved? One way of solving this is to use some acidic medium which will be you know chemically removing parts of the work surface which is not touched by the abrasive grids; that means, those places where abrasive grit action is not taken place.

Normally when abrasives are impacting there will be some upraised portions where the abrasive is not hit and they will be defining the surface roughness. So, simply we put some acidic medium which eats away those portions we may have a much you know smoother surface. So, hydrofluoric acid is known to attack glasses etcetera. So, a common practice is in chemically assisted vibration ultrasonic vibration machining to add some hydrofluoric acid into the alumina slurry. And in that case material removal also gets enhanced because chemical action associated with ultrasonic vibration you know greatly enhances the material removal rate.

In some case even 200 percent increase in material removal rate has been noted. So, when hydrofluoric acid is added higher material removal is obtained better surface finish is obtained, and forces in between the work piece and the you know and the and the vibrating (Refer Time: 24:10) they also come down drastically. However, if the concentration of h f is more than 5 percent, it may result in enlargement of the you know entry point of the hole which is being drilled. And therefore, concentration has to be kept within limits.

So, before we and formally enter the tenth lecture, I will just take one or 2 problems that we had left unsolved from the previous you know questions and quickly have a go at it.

(Refer Slide Time: 24:49)

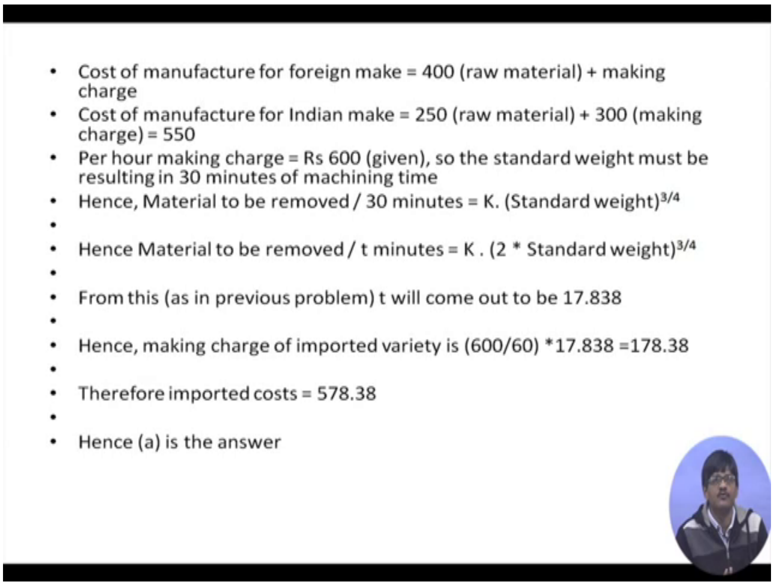


So, suppose you are making and selling USM machined mementos. This was one problem which I had set for you for solving, and since we are getting some time I will quickly have a look at it for solution. You are making and selling USM mementos on imported glass when the price of imported glass samples become rupees 400 to rupees 200 you have the options to use Indian glass samples which are rupees 250. So, you will be saving from the material side 150 rupees.

Now if you use Indian glass and keep the machining the same; that means, you keep the machining the same and you use Indian glass. And machining rate is rupees 300 per sample. So, quickly you can save again rupees 350 plus 300 means makes 550 rupees. Or we can use the imported glass rupees 400 and double the dead weight defining the static load, if man machine hour rate and abrasive cost per hour are 200 and 400 respectively. What is this? Man machine hour rate and abrasive cost per hour is 200 and 400; that means, 600 per hour, 600 rupees per hour.

Find you know, what are we (Refer Time: 26:31) to find. So, we have to choose from these multiple choices. So, if man machine hour rate and abrasive cost together they make 600 rupees per hour, then first one is a makes a saving of rupees 28 over b, a is what a is Indian glass. And b is imported glass. So, 550 rupees must be the cost of you know Indian memento. Let us now calculate; what is the cost of producing an imported glass memento. So, that we can let us quickly see b is a saving of rupees 28 and next option is b makes a saving of rupees 28 over a, and a saves around rupees 90 compared to be none of the others ok.

(Refer Slide Time: 27:26)



So, let us quickly calculate.

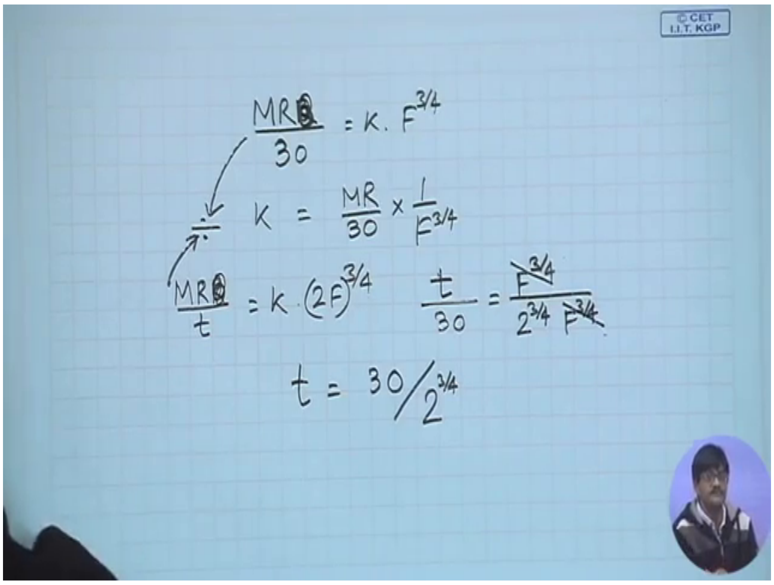
First of all we may notice that cost of manufacture of a foreign make is equal to 400 rupees raw material plus making charge. What will be making charge cost of manufacture for Indian make is 250 rupees? Plus 300 rupees this we had done you know orally just a few minutes back. So, 550 rupees is the Indian. So, per hour making charge is equal to rupees 600. So, the standard weight must be resulting in 30 minutes of machining time.

So, standard way this term is slightly misleading it means that if per hour we are having a making charge of 600 rupees and if the Indian make requires 300 rupees. So, it must be a 30 minutes of machining. So, 30 minutes of machining must be required in case of the Indian make hence the material to be remove in 30 minutes is equal to k into standard weight oh I understand standard weight here means the standard static load that we are using.

So, if the material to be removed in 30 minutes; that means, the material removal rate must be proportional to k into static load to the power three-fourth. This is understood no problem. So, from here we can get an estimate of the imported glass machining time let it be t minutes therefore, in the second case material to be removed in t minutes in t minutes is equal to k into twice the standard weight to the power of three-fourth. Why we are doing this? Because we are saying in the second case we are increasing for imported glass.

For imported glass we double the dead weight. We double the dead weight. So, in that case the equation must be material removal rate, where we are taking basically t minutes for the time of manufacture equal to k into twice the standard weight to the power of three-fourth. After this from this as in the previous problem t will come out to be 17.838; I have foregone the rigorous calculation, but as you can notice here from here we will find out the value of k in terms of standard weight. That is k is equal to MRR devided by 30 into standard weight sorry, divided by standard weight to the power of three-fourth. And we will put the value of k here and easily find out the value of t. I am sure you can I will write down, but you can solve it yourselves.

(Refer Slide Time: 30:34)



So, look at this we have here in the first case MRR by 30 sorry, MR material removed by 30 is equal to k into f to the power three-fourth. Therefore, k must be equal to MR by 30 into 1 by f to the power three-fourth. K is found out in the next relation we have MRR by t, is equal to k into twice f to the power three-fourth. Which means that t is equal to sorry, if we divide this one once again this is MR if we divide this which one should we divide ok.

If we divide this with this let us say what we get we get t cancels out. So, we get t sorry MR cancels out, we are dividing it. So, t by 30 is equal to k cancels out f by three-fourth divided by 2 by three-fourth into f by three-fourth. So, this one cancels with this and t becomes equal to 30 divided by 2 to the power three-fourth. This is the peer number which you can easily calculate and this will come to be roughly 17.838.

Coming back to the question sorry; so if it is 17.838 we can quickly calculate the making charge as 600 divided by 60 into 17.83, which comes to be 170.838, so that the imported costs come out to be 400 plus 178.38 equal to 570.38. And therefore, it is 28 rupees roughly more than 550 rupees. Therefore, a is the answer. Let us see: a, b makes a saving sorry a makes a saving of rupees 28 over b. So, a is the answer.

Thank you very much. Thank you.