Non-traditional abrasive machining process: Ultrasonic, Abrasive jet and abrasive water jet machining

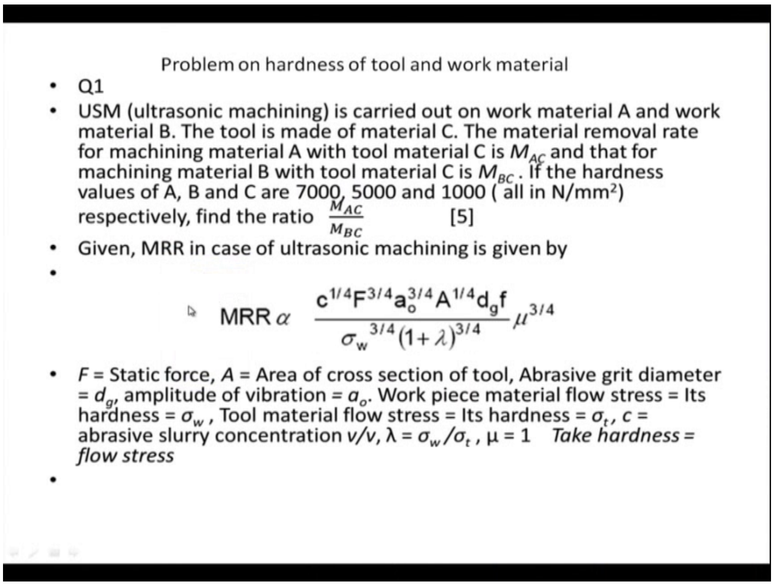
Prof. Asimava Roy Choudhury
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 04
Ultrasonic Machining- Free Impacts and Problem Solving

Welcome to the forth lecture of the series on Non-traditional Abrasive Machining Processes. And today we are going to continue with the subject of Ultrasonic Machining.

We had we had stopped with a particular numerical problem, we will have a solution to that and after that we are going to proceed with new problems, new discussions etcetera. So, to start with this was the problem that we had start at.

(Refer Slide Time: 01:00)



So, this reads that ultrasonic machining is carried out on work material A and work material B. So, there are 2 work materials which we are going to machine by USM the tool is made of material C the material removal rate for machining material A with tool material C is M AC and that for machining material B with the tool machine C is M BC.

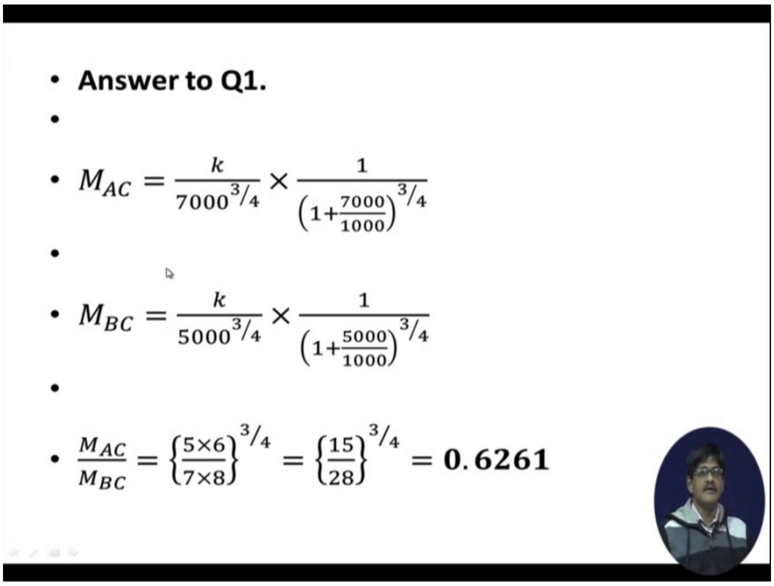
So, these are basically 2 rates of removal rates for a and B material and the tool material is the same for them, if the hardness values of A, B and C are 7000, 5000 and 1000 neutrons per millimeter square. Then we have to find out the ratio of M AC by M BC.

So, first of all we need to think of the differences in the removal rates that will occur for these 2 material combinations; the differences that in the expression of material removal rate that we see written below.

We have sigma w occurring which can be replaced by hardness of the work material. So, here first of all the hardness of the work material is coming into the expression. Second the term lambda is also having contribution from work piece material and tool material. Therefore, there are 2 terms in the material removal rate expression that are going to be affected if we machine material with a different hardness value.

So, with this in mind let us proceed, M AC must be you know if we express the material removal rate as a constant.

(Refer Slide Time: 03:09)

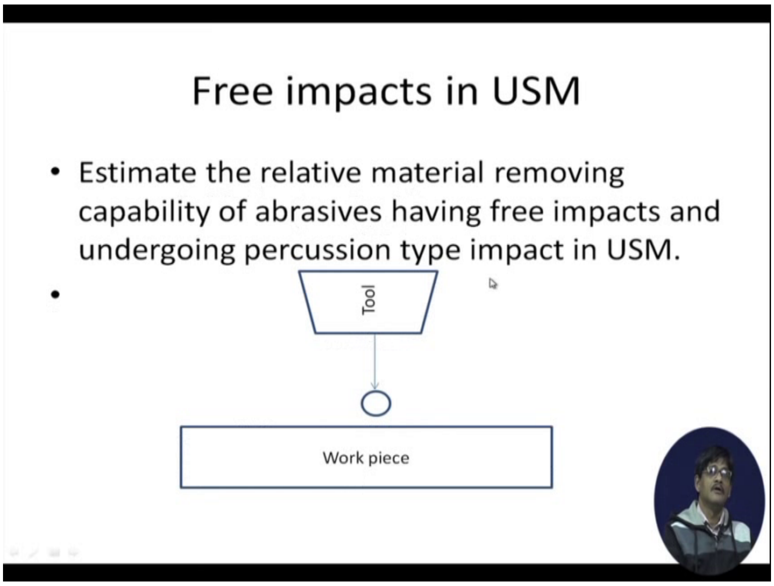


That means that it is it is proportional to all the terms there and therefore, we say that it is constant we only take those terms which are relevant to this particular discussion. So, it is k multiplied by work piece hardness to the power of three-fourth into 1 plus 1 by lambda to the power three-fourth well lambda is equal to work piece hardness divided by tool hardness.

So therefore, in the first case we have k divided by 7000 to the power three-fourth etcetera etcetera. And in the second case now it becomes extremely simple. So, we simply replace the hardness of the work piece by the hardness of B and that is 5000 and we get a fresh expression. So, that their ratio comes out to be 5 by 6 to the power sorry, 5 by 7. M AC by M BC since it is in the denominator. So, 5 raises up 7 goes down, 6 raises up and 6 is coming from here 1 plus 6. 6 raises up by the side of and 8 goes down to the power three-fourth and therefore, this is the particular expression 0.6261 ok

So, this was a problem that we solved on material hardness, material hardness combinations in USM.

(Refer Slide Time: 04:46)

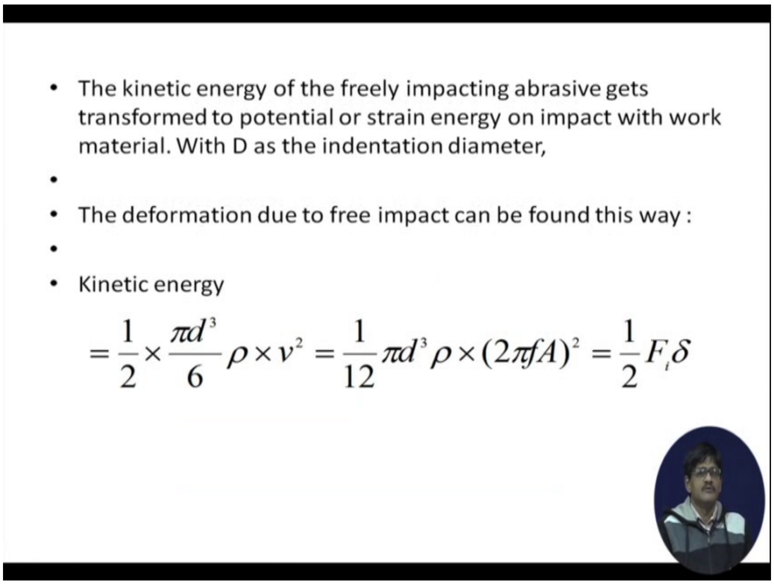


Now, when we are discussing about ultrasonic machining, we need to remember one thing that we are essentially considering, only or rather we are essentially consider up till now only percussion, percussion means hammering. Now there might be yet another aspect of material removal there are different other aspects also among these. We may also consider the free impact of abrasives against the work piece, now how is that possible.

When we are essentially going for certain percussion is predominating. It is possible this way that if there is a there is a abrasive particle, if it if it you know contacts the tool surface when it is at say a very high velocity say in it is mean position it will be having the highest velocity 2 pi f a. So, it will take up this particular velocity, and it will move towards the work piece. So, the (Refer Time: 06:03) is at that time going to slow down as it moves more and more towards it is extreme position, but the, but the abrasive part it will after getting a hit from the tool. It is going to travel at quite a higher velocity may be about 10 meters per second, and it is going to hit the work piece and since it is a very hard and rigid body it might be able to remove some material by this type of free impact.

So, let us quickly have a look mathematically whether we can make an estimate of that particular indentation of depth.

(Refer Slide Time: 06:49)



So, what happens actually is that when this particular body is you know impacted by the rapidly vibrating horn, and it is moves towards the work piece with a reasonably high velocity, it has acquired a definite amount of kinetic energy and it gives up this kinetic energy to the work piece surface by plastically elastically of course, and by also hopefully plastically deforming it So that some sort of indentation is made and from a basic assumption that whenever there is an indentation there is brittle fracture of the material leaving leading to the removal of hemispherical chunk of brittle material that we can apply.

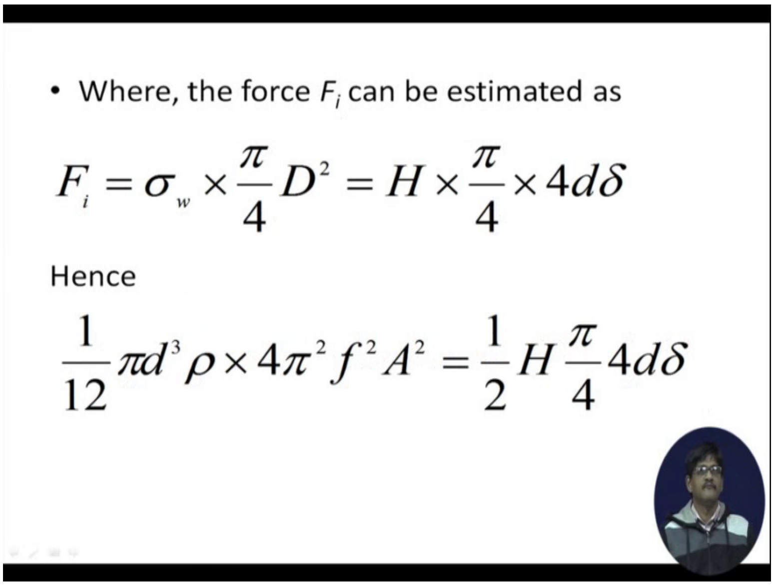
So, let us first have a look at the indentation that is what we are interested in. So, first of all the kinetic energy which is acquired is half m into v square. So, if you look at this particular expression half and this is you know the volume of a spherical abrasive grit we are we are assuming here that the volume of the abrasive grit is perfectly spherical. And it is diameter is D so that fo 2 by 3 pi r cube becomes pi by 6 into D cube. Where D is the diameter of this sphere, multiplied by rho, rho is the density of the abrasive material (Refer Time: 08:26) silicon carbide aluminum oxide all these have density in the range of

2 to 3 maximum 4 grams per cc multiplied B y the velocity. And this velocity will be coming out as you know a omega at the mean position you can it can transfer. Maximum velocity of a omega and omega being equal to twice pi f we have twice pi f into a as the maximum velocity imparted to the grit.

So, we have 1 by 12 in to pi D cube into rho rho into 2 pi f a there is v square, 2 pi f a whole square. Now this will be equal to the plastic deformation energy which is gained by the work piece. How can we express it? We can express it as f being impulse force it will leads to the deformation of the work piece surface, and we will say that this particular strain which is undergone by the work piece that is equal to delta indentation is delta. And since you know the forces do not always equal to the maximum f impulse of course, it gradually builds up. So, we take the mean value to work force occurring through the event and we have half into f into delta.

So, delta is the indentation f value we do not know, but we can we can make an estimate of it and therefore, plasti kinetic energy is being converted to plastic deformation energy or strain energy of the work piece.

(Refer Slide Time: 10:16)

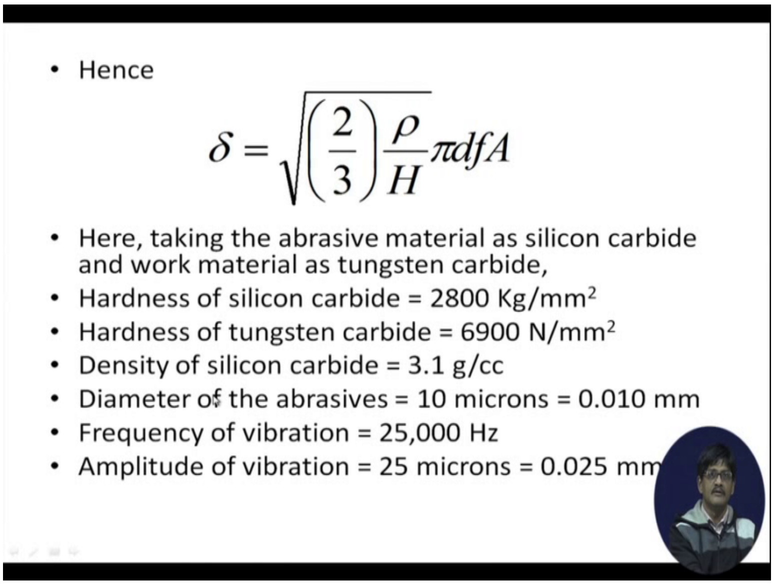


So, after that how do we estimate this impulse? Where f I impulse force, this is equal to sigma w; that means, the flow stress of the work piece multiplied by the projected area. So, if it is making you know creator of diameter D in that case the area of the creator is equal to pi by 4 d square and therefore, sigma w into pi by 4 into d square is going to give it give us the value of the force. That is we are assuming that the it is just at the boundary of plastic deformation when the deformation starts. Just ahead of it the force was high enough to cause plastic deformation.

So, we can replace you know this since we have already discussed it and accepted, it we can interchangeably use hardness value of the work piece and it is plastic flow stress. And pi by 4 into 4 D delta where D is the diameter of the abrasive grit and delta is the indentation depth. So, if we replace the value of the force the force is being made equal to the flow stress into the projected area, and flow stress is mainly replaced by a hardness value. And projected area diameter is being replaced by abrasive grit and the indentation.

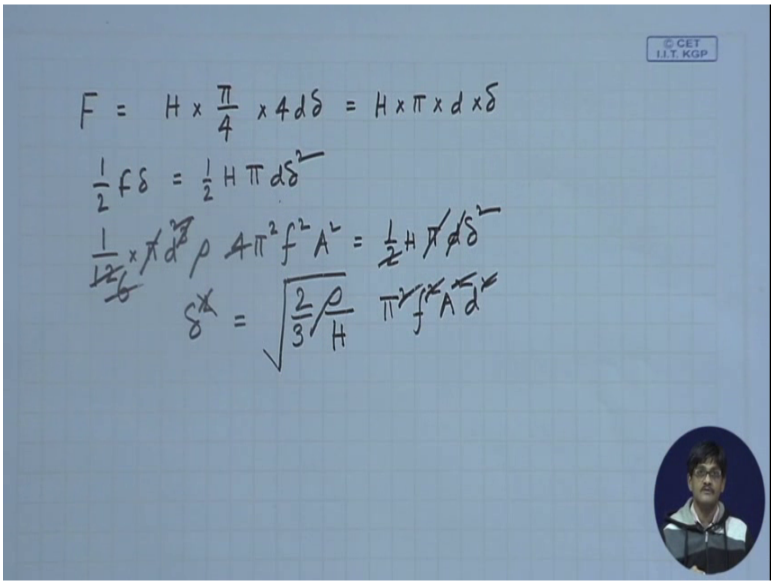
So, we have ultimately this particular expression. Just one moment I think I have missed one particular delta value here. Let me have let quickly have a look the next expression ok.

(Refer Slide Time: 12:20)



I think this gives us a good opportunity to work it out.

(Refer Slide Time: 12:31)



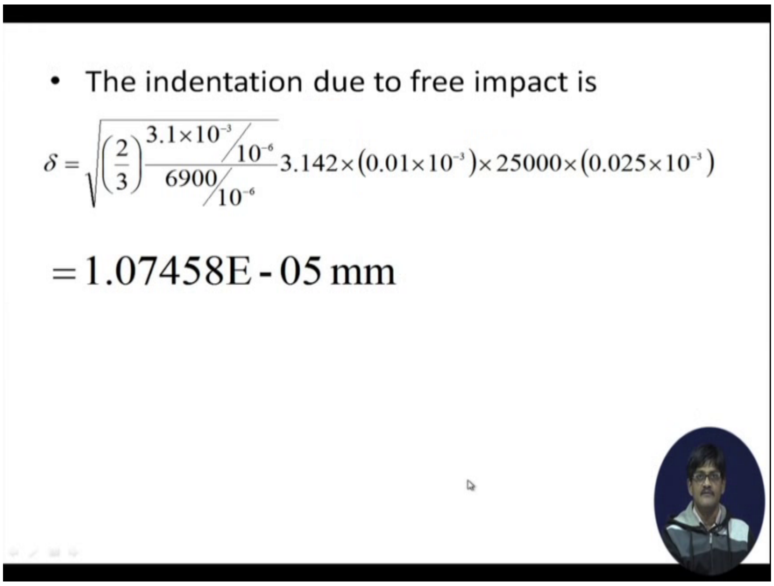
So, we have first of all f equal to we have worked out as h into pi by 4 into 4 D delta this is equal to h into pi into D into delta. Now therefore, half f into what you call it delta will naturally give us, h half into h into pi into D into delta square. So, a delta square value is occurring here.

And from the other side we have got half a sorry, 12 into pi into D cube into rho into 4 pi square f square a square equal to half h pi, just one moment pi into D into delta square. So, here from here what we find is that one delta cube will cancel with this delta. So, d square will be obtained, and since this pi is here and this pi will be cancelled out and therefore, delta square will be tried to express and rho is here. So, we write rho here h here and this h will go down 2 will come up sorry, 2 will already cancelled with this one produce the 6, this 6 will canceled with this. So, 2 will remain here and 3 will come here and therefore, we are going to get pi square here f square here a square here and that means, when you take the root over we will get something of this type right; so 2 third rho by h into pi f a.

So, 2 third rho by h into pi D f a, oh my god I missed the d, d square was here right; so d square that will also to be included. So, this expression though there was you know in one of the intermediate step mistake. So, kindly bear with me finally, the expression is however correct. So, if we take you know some typical values, let us have a quick look we are taking silicon carbide as the abrasive material. And the work material is being taken as tungsten carbide and we have listed some values of these 2 materials, and we will be utilizing them in order get an estimate of the typical indentation value that be able to obtain for this material combination. That is silicon carbide as a abrasive particle material and tungsten provide as work piece material.

How are they going to affect these? For example, rho is going to be affected by silicon carbide density h is that of tungsten, D is the diameter of the abrasive particles which is 10 microns. And f is the frequency given to be 25000 and a is the amplitude of vibration which is 25 microns.

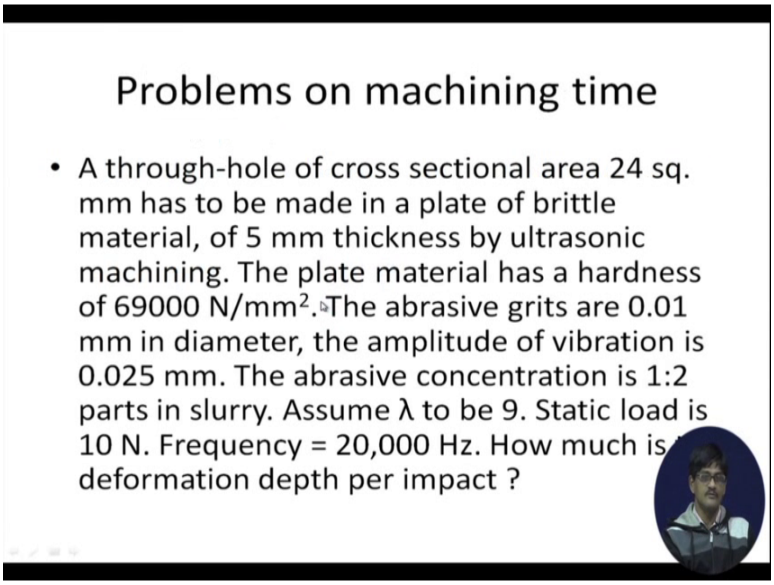
(Refer Slide Time: 16:13)



So, with that you can make a calculations and it comes out to be 1.074 into 10 to the power minus 5. You can checkup this calculation that we have I have done.

By chance there might be a one or 2 mistakes. So, I will be really I really appreciate if you do it yourself. And try to match this answer with yourself. So, let us have a quick look if it is one into 10 to the power 5 millimeters, let us see how many microns that comes up to. So, for converting this into microns 3 of these you know 10 to the power minus 5, 3 of them will be gone it will be 1 into 10 to the power minus 2 microns 1 into 10 to the power minus 2 microns. So, not even one micron, but 1 by sort of 100 microns 1 by 100 microns. So, not even a some micron deformation, very less.

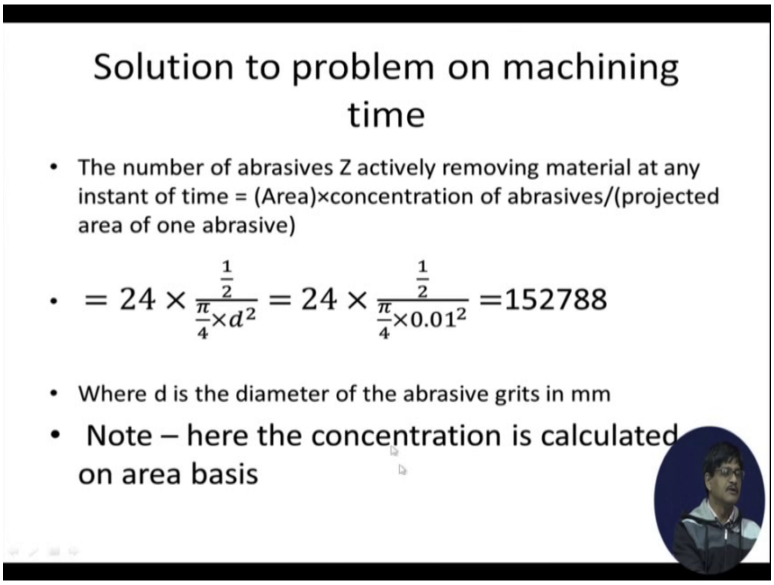
(Refer Slide Time: 17:18)



But in that case in order to compare we need to find out what is the deformation caused by hammering. So, let us take a typical example. So, here there are particular values provided let us see what are the differences with the previous case. We have taken a much harder material. Let us see what happens much harder even if you take a much harder material the plastic material the plate material has the hardness of 69000 neutrons per millimeter square n times harder, but still you will find it will be much higher deformation indentation, abrasive grits are 0.01 what is happening here?

A through hole of cross sectional area 24 square millimeters has to be made in a plate brittle material of 5 millimeter thickness by ultrasonic machining. A through hold cross sectional area of the tool is given to be 24 millimeter square. And 5 millimeters thickness, the plate material is 69000 the abrasive grits are 0.01 in diameter. Amplitude is 0.025 millimeters; that means, 25 microns the abrasive concentration is 1 is to 2, parts in slurry. Lambda is to be assumed to be 9. Static load is 10 newtons and frequency is 20 1000. How much is the deformation depth per impact?

(Refer Slide Time: 18:54)

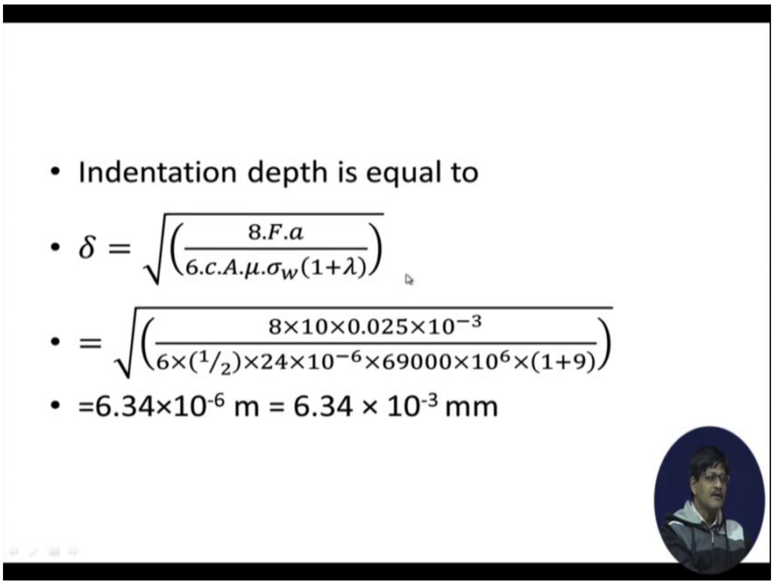


First of all we have tried to estimate how many abrasives are actually acting. This is not a part of this particular problem, but we have done this with a particular purpose. All that text books which are circulating in the market, among them some text books are working out the expression of concentration by volume consideration. And there are other text books in which concentration has been given in area concentration consideration, what do I mean by that? I mean that if the area of the say surface of the tool is 10 millimeter square, and the concentration is half, in that case it will be assumed that 5 millimeter square of that particular area is occupied by abrasives. And then this particular perceptional area will be divided by the perceptional area of one, abrasive particle and it will result in the number of abrasives that we have to deal with. That calculation only I have done here.

So, that if I ask such a question in the final exam or give an assignment of that type you have no problem in solving it, but I will definitely I mean explicitly state that use such and such method So that unnecessarily no controversy gets created. So, here what we are doing is the 24 is the cross sectional area and multiplying it with the concentrations; so getting the area of the area covered by the abrasive particles to be 12. And this, I am dividing by cross sectional area of the abrasive, single abrasive and this is giving me 152788 abrasive grits not money, but abrasive. So, 152788 in grits are present under the tool of this particular case. And we have considered area here. What if we considered volume? In that case we would have considered a volume equal to surface area of the tool multiplied by the you know multiplied by the height equal to the diameter of one abrasive ok.

So, the cross section area of the tool multiplied by the diameter as the height of that cylinder or whatever type of body results; that will be the volume half of that volume is concentration is half half of that volume would have been considered to be belonging to the abrasives. And then this would have been divided by the volume of the one single spherical abrasive, and we would have obtained the number of abrasives in this manner.

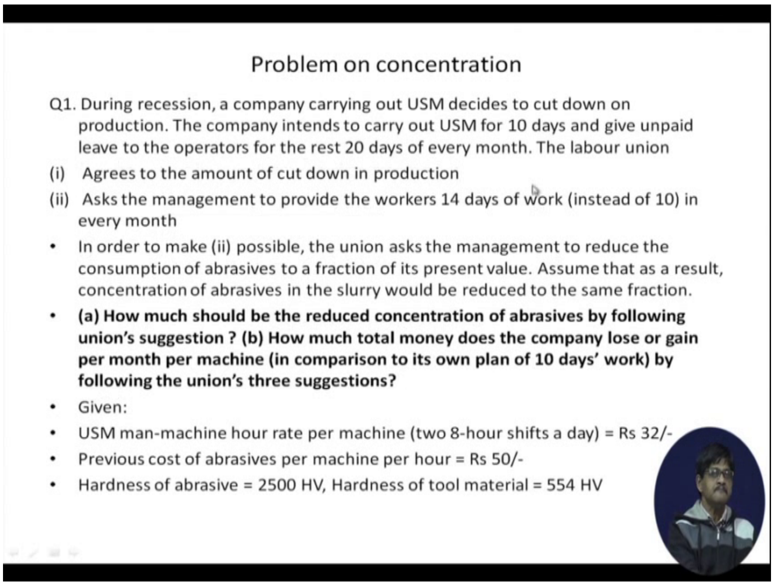
(Refer Slide Time: 22:25)



So, if we consider the indentation depth from this point of view. We have straight cut you know imported expression of delta from our derivation just few lectures back. Most probably in the third lecture we derived the expression of delta to be this volume. What does it contain? It contains the static force, contains the amplitude and in the denominator it contains concentration, cross sectional area of the tool and what else? And what you call flow stress of the work piece and of course, lambda. So, we have put all these values for example, lambda has been put as 9. So, 1 plus 9 and the flow stress of the work piece has been put as 69000 it is 10 to the power 6 newtons per millimeter squares. So, 10 to the power 6 comes to convert millimeters to meters 24 square millimeters once again.

So, another 20 (Refer Time: 23:35) power minus 6 comes. So, this way an concentration is equal to half. So, this way we get a value of 10 to the power sorry, 6.34 in to 10 to the power minus 6, you will get converted to 6.34 into 10 to the power minus 3 millimeters. And that will get converted to 6.34 microns. So, just imagine, 6.34 microns and the other one is I think one into 10 to the power minus 2 microns. So, it is a considerable difference between indentation depth of you know percussion USM and free impact USM.

(Refer Slide Time: 24:24)



So, let us proceed with one or 2 problems, after that we will again take up the rest part of the theory and the description of the setup, as and when it becomes relevant. So, we had done problem on hardness of work piece problem on what you call it what is have been done problem on work piece hardness was 1 and may be problem on indentation depth was 1. So, we have also probably done another problem, whatever we are now going to deal with a few questions on concentration. Concentration means what? There is how much abrasive you are using. So, this question reads during recession a company carrying out USM decides to cut down on production. You know, in the last recession this actually happened. That is the company is you know either shutdown or they say that we are going to cut down on production because there are no takers for our product.

So, what is the point making you know, say car after car after car where the cars are not selling. So, unnecessarily we will not go for producing these cars, but instead we will cut down on production. So, the workers said what are we going to do? So, the company said you work whatever in number of days it is required for us and then you go for holidays, and the workers asked are you going to pay us for that holidays and company says no you are not working why should we pay.

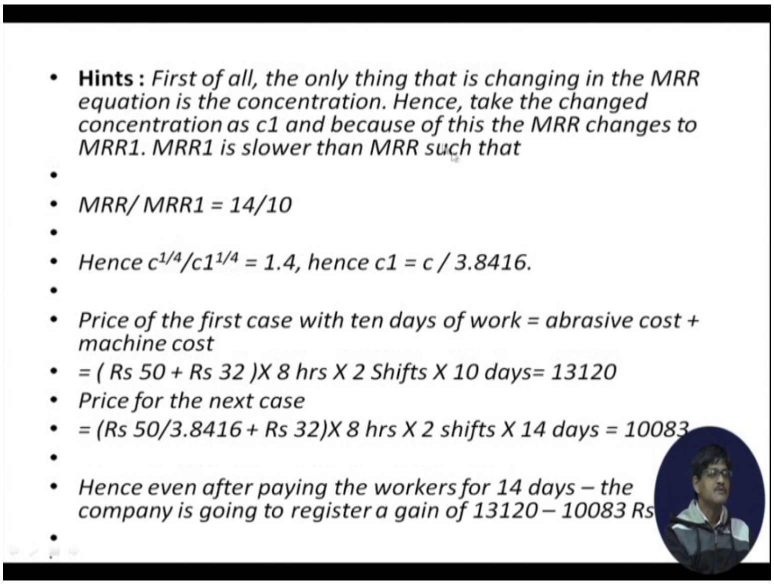
So, this was the problem and there have to be solution. So, the company says you work for 10 days. I will pay you for 10 days, 10 days work for a month and for the rest 20 days you go on holidays, no work no pay. So, naturally labour union says if you want to cut down on the production we understand yes there is a valid reason for it, but give us 14 days of work instead of 10 company says why so? Why do you want 14 days of work? The labour union say because we can get 14 days of pay in that manner, but the labour union itself proposes that in order to you know in order to make 14 days of work possible there is no 14 days of work there is only 10 days of work.

So, they says that you cut down on the consumption of abrasives so that you are only using of fraction of the abrasives as the previous production of fraction of the abrasives will be used So that concentration will come down. And if the concentration comes down you will take more days to finish your work and that will be get more pay, but the company says your payment will be required you I need to pay you. So, the labour union says you are going to pay us from that the money that you save the money that you save from you know diluting the abrasives it is going to be more. So, make a calculation and find out 14 days of work instead of 10 days and abrasives costs I am going to provide you.

Its written ultra sonic machining man machine hour rate. Per machine is rupees 32 to 8 hour shifts a day. Previous cost of abrasives were 50 rupees. Hardness of abrasives is given hardness of tool material is given how much should be the reduced concentration of abrasives by following the union suggestion. And how much money does the company lose or gain per month per machine by following the unions 3 suggestions.

So, let us work it out and we will assume that if the abrasives are cut down to a particular fraction, the concentration also gets cut down to the same fraction.

(Refer Slide Time: 28:34)



So, actually the sum is very simple the sum says that the concentrations are different therefore, the production rate are going to be different. And MRR original by MRR 1 is going to be 14 is to 10. Inverse ratio of the you know days if you take more days your MRR is less if you take less days your MRR is high. So, they are inversely related. So, first relation that we get is MRR by MRR 1; that means, previous MRR by present MRR is equal to 14 by 10, and therefore, if MRR is replaced by k into C to the power one 4th because, we know that the MRR is proportional to concentration to the power one 4^{th}. That is it C to the power three-fourth MRR is proportional to C to the power three-fourth ok.

So, let us quickly go back. So, MRR by MRR 1 essentially means C to the power one 4th by C 1 to the power 1 4th is equal to 1.4, 14 by 10 is 1.4. And from there we can relate C 1 to be equal to C 2 the C by 3.8416. So now, we can easily calculate the price in the first case with 10 days of work rupees 50 plus rupees 32 into 8 hour shift into 2 shifts into 10 days equal to 13120 rupees in the second case we have we have considered if the concentration goes down. So, this the cost of the abrasives go down proportionately; so previous concentration by 3.8416. So, 50 rupees by 3.8416 plus rupees 32 rupees 32 you cannot change 8 hours 2 shifts 14 days. Now 14 days equal to 10083, price is come down. So, the company after even after paying the workers will save lump sum amount of money equal to 13120 minus 10083 rupees.

So now, we come to the end of the 4th lecture. We will again take up different cases of ultrasonic machining in the fifth lecture. And in the fifth lecture I will try to give you as many you know questions numerical questions are MCQ's is possible So that you are well prepared for your first assignment.

Thank you.