

Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title

Manufacturing Process Technology – Part- 2

Module- 13

Mechanics of Ultrasonic Machining (USM)

by

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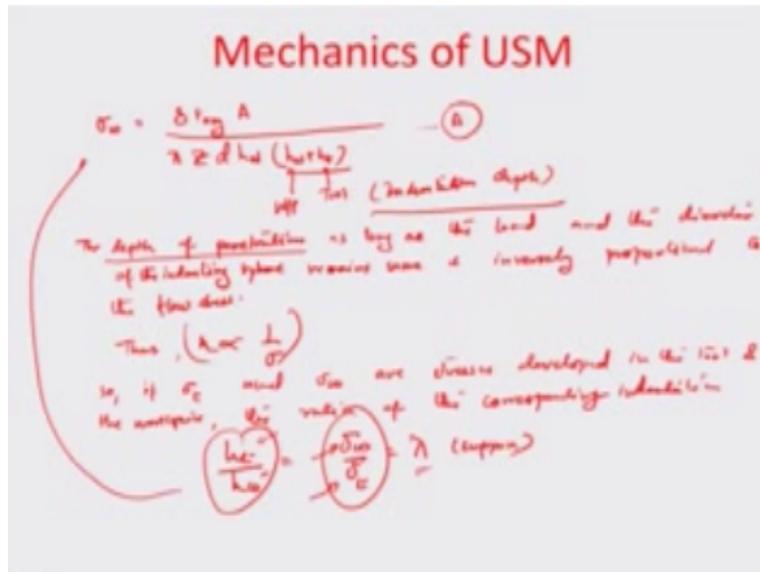
Hello and welcome to this manufacturing process technology part 2 module 13.

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We were discussing about the ultrasonic machining process and in context of that we had actually talked about finding out what is going to be the.

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Flow stress σ_w and we found that it is related to eight times of the average force f average times of the amplitude of motion, of the tool / 5 times of number of grains impacting per cycle times I will tire meter the impressive grain small d times of hw where H_w is basically the indentation depth of the work piece times of $hw + ht$, ht being the indentation depth on the tool side so this is the tool this is the work piece indentation depth so having said that now the question is that you know can we really put everything together in terms of material properties.

And for doing this by a large we are aware that you know the depth of penetration as long as the load and the diameter of the indenting fear remains same, so this is depth of penetration is inversely proportional to the flow stress thus the depth of penetration can be represented as 1 by σ so if σ_t and σ_w are stresses developed in the tool and the work piece the ratio of the corresponding indentation, $ht / hw = \sigma_w / \sigma_t$ that is λ let us say so obviously the flow stresses of the work piece and tool if we do not assume any work hardening to happen.

But remain more or less material properties or constants and so therefore the ratio between that can also be assumed to be a constant λ , so the ht / H_w that is the indentation depth on the tool side by that of the work piece is related to the inverse ratio now the flow stresses, and assuming that to happen if I were to use this logic back in this particular equation here let us call it equation a then.

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Mechanics of USM

$$\sigma_w = \frac{8 F_{avg} A}{2 Z d h^2 (1 + \frac{h}{hw})} = \frac{8 F_{avg} A}{2 Z d h^2 (1 + \lambda)}$$

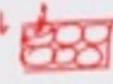
Again it may be assumed that the number of grains acting is inversely proportional to the square of the diameter of each grain for a given area of the tool face

$$Z \propto \frac{1}{d^2} \Rightarrow Z = \frac{c}{d^2}$$

where 'c' is the concentration of the abrasive grains in the slurry and ρ is a constant.

Substituting 'Z' from the earlier eq. (A)

$$h w^2 = \frac{8 F_{avg} A d}{2 \rho c h^2 (1 + \lambda)}$$

$$\sigma_w = \frac{4 F_{avg} A d}{\rho c h^2 (1 + \lambda)}$$


The σ_w becomes equal to a times of the average force times of amplitude divided by five times dhw^2 times of $1 + ht / hw$, in other words we can write this further as $h / 5$ five times of zd^2 of hw times of $1 + \lambda$ because, we already know that this is actually the inverse ratio of the flow stresses of the work piece in the tool and this can be treated as a constant for a certain tool material in a work piece material assuming that there is no strain hardening effect which happens because of this ultrasonic machining.

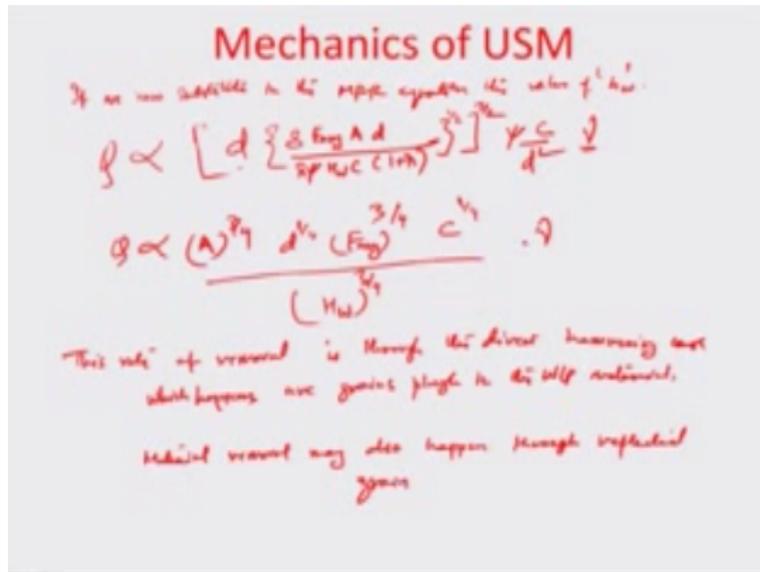
Again it may be assumed that the number of grains acting is inversely proportional to the square of the diameter of each grain, for a given area of the tool phase so basically z becomes proportional to the concentration of the grains in the slurry and inversely proportional to the square of the diameter this is obvious, because of let us say for example if we look at the tool cross-section and if we look at number of grains all of size or diameter small d obviously the higher is the diameter lower.

Would be the number of grains which come between one impact of the tool phase with respect to the work piece surface and, so obviously also if this concentration is more or less which also depends on the slurry loading with respect to the abrasive grain that we are putting in so you know the number of grains would be proportional to the concentration, so we can always write that the number of grains making impact per unit cycle of tool is equal to constant ζc by d^2 where c is the concentration.

Of the abrasive grains and the slurry and ψ is a constant, so if we substitute the z value from the earlier equation we have square of hw equals the average force eight times the average force times a and we can actually substitute $z = z_c / d^2$ times of d divided by ψ times i times of hw which is actually the flow stress of the material times of c times of $1 + \lambda$, so we are assuming that this σ_w here is actually equal to the flow stress of the work material okay the total amount of stress becomes equal to the ultimate real strength of the material or the hardness of the material, as and when the point of fracture arises where the material is actually getting yielded and come into flow state.

So it is safe to assume that the hole machining process will start happening and mrr is obviously concerned with the start of the machining process, only when the π_w approaches the hardness of the material hw flow stress of the material hw , so that is how you lay out the total amount of indentation which happens of the grain on the work piece surface and you and we can write further $hw = \sqrt{\text{of this whole term } 8 f \text{ average amplitude } a \text{ times of } d / \psi i \text{ will } w c 1 + \psi \text{ to the power of } \frac{1}{2}}$.

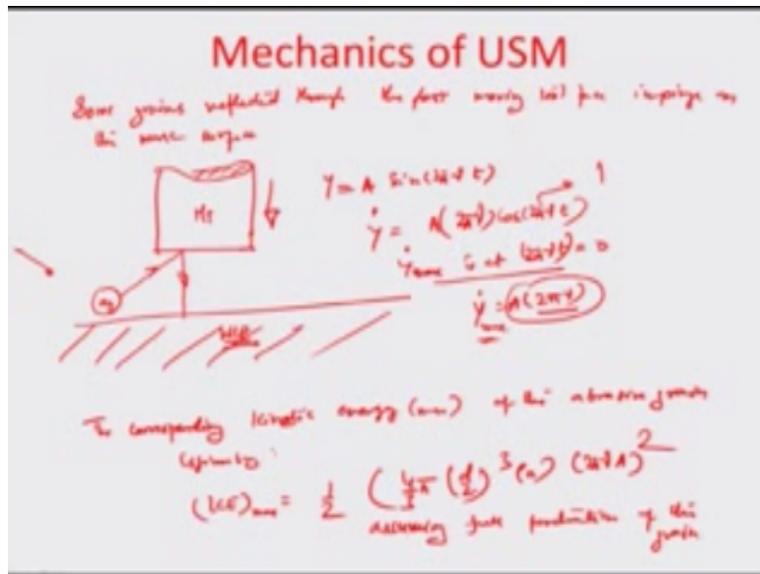
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So if we now substitute in the mrr equation the value of hw we can have Q equals d times of this whole value that, we just found out in the last step about a times of f average times of amplitude $ad / \psi \zeta hwc 1 + \lambda$ whole to the power of half to the power of 3 by 2, so that is $dhw^{3/2}$ times of z which it is proportional to so it becomes $\psi C / d^2$ times of new when you is the number of cycles per second so obviously then Q comes out be equal to $A^{3/4} d^{1/4} F^{3/4}$ and this is the average force concentration to the power of 1 / 4.

Divided by flow stress of the work material to the power of 3 / 4 times of new the frequency so the rate indicated, so this rate of removal is through the direct hammering case which happens as grains plow in the work piece material, so this is not the only case which leads to the material removal there are some instances where the material removal may also happen through reflected grains and by reflected grains what I mean is that.

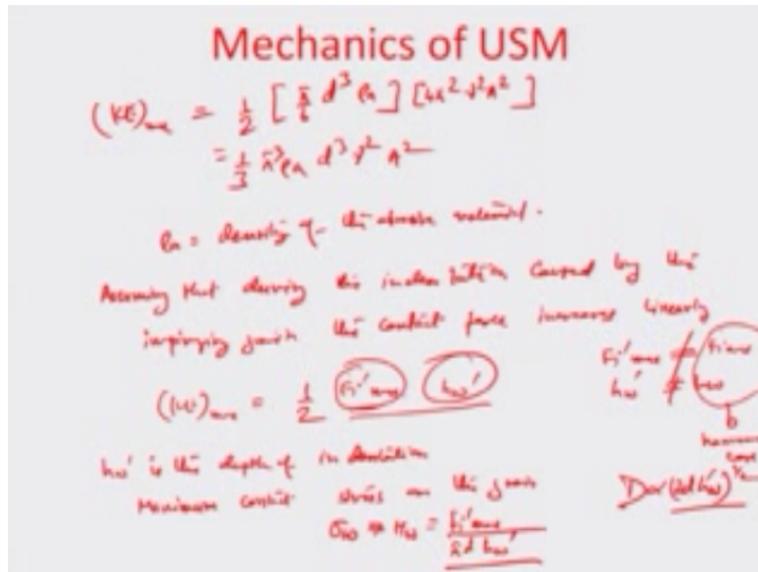
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Some of the grains would get reflected through the fast-moving tool phase impinge on the work surface and, it can cause indentation so let us assume this to happen here let us say this is the vibrating tool head and supposing it is moving in a certain direction at certain velocity and here there is a work piece and there is a grain which is pumped in by a slurry and it gets bounced off the surface and goes and hits the tool surface and obviously the tool imparts momentum to the grain.

And this grain is insignificant anything you can be small in comparison to the tool, so basically it assumes a almost a vertical motion or change of quick change of direction perpendicular to the tool face towards the work surface, so this is the work piece so if we assume this tool to move sinusoidally with the equation of motion amplitude $a \sin$ of $2\psi \mu t$, so obviously $y = a \sin 2\psi \mu t$ times of $\cos 2\psi \mu t$ and y_{max} is at $2\psi \mu t = 0$, actually it is a times of twice $\psi \mu$ $\cos 0$ is 1, so therefore we can have this as the maximum velocity of the tool.

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Head at a certain instance of time and if we assume this to be the maximum velocity, so obviously the corresponding kinetic energy again maximized kinetic energy of the abrasive grain is given by 1/2 times of $(4/3\pi d/2)^3 \rho_a$ two times $(2\pi)^2$ assuming full penetration of the grain so in this particular case the KE_{max} maximum kinetic energy imparted to the grain would come out to be halftimes of $(\pi/6)^3$ of $d \rho_a$ times of $4\pi^2 \mu^2 a^2$ and in other words one-third cube of $\pi \rho_a d^3$ square of μ square of a so a again is the density of the abrasive material.

So assuming that during the indentation caused by such an impinging grain caused by the impending grain the contact force increases linearly which is actually a true assumption because we would like to you know in the same manner as I had discussed earlier in the hammered grain case the it was as if the, the contact point between the tool and the grain would result in the start of the force which will go all the way up to a maximum force corresponding to the yield stress of the material.

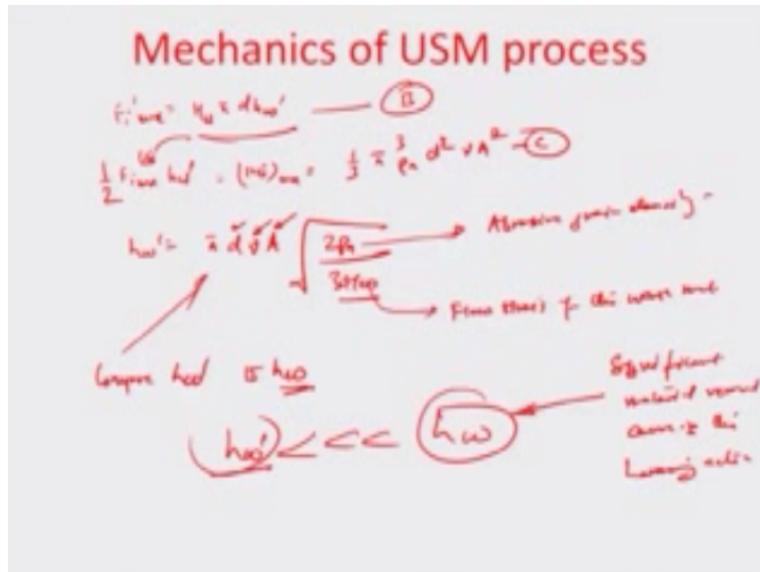
And then the force would fall back so in a similar manner here although there is no active pushing of the of the grain we can assume that because of its velocity there is a force because of the change of momentum imparted onto the work piece but obviously the momentum is so big that there are few layers which get broken or fractured reaching to the ultimate yield point and then the slurry actually takes that broken fragment of A so the experience of the force of the grain should be in a similar manner as in the hammering case that the force starts from some value goes all the way to the maximum which corresponds to the flow stress of the work material.

And then once the dislodgement has happened then there is no use and the you know the force comes down because the material is now having a cavity at that particular place so the KE-max in this case would be equal to half $f_i \cdot \max \cdot h_w$ just would like to recall at the step that this $f_i \cdot \max$ is not equal to the $F_i \cdot \max$ and so as the h_w not equal to the h_w which were discussed in the hammered case obviously the magnitude of these are much different in comparison to the hammering case.

So H_w is the depth of indentation on the maximum contact stress on the grain can be given as σ_w equals to $F_i \cdot \max$ divided by $\pi d H_w$ so as you may recall the diameter D as zoomed earlier was proportional to DH to the power of half twice dh to the power of choiced h_w to the power of half in this case obviously the grain because I you know the total indentation depth on the work piece.

Because of the throne grain is H_w as has been illustrated earlier here and so therefore the σ_w comes out to be equal to the total force times of $\pi d^2 / 4$ which is actually the area of impingement of the grain on the work surface and therefore σ_w comes out to be $F_i \cdot \max$ divided by $\pi d H_w$ has been illustrated here.

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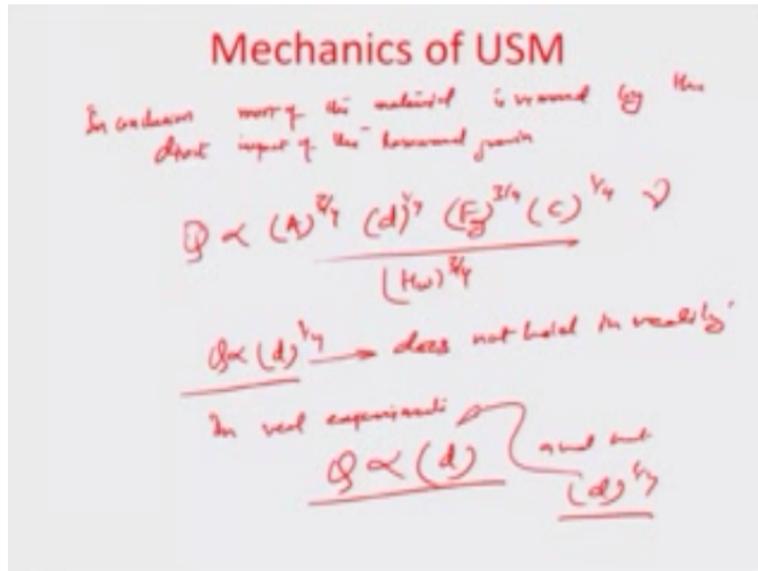
So if we assume this kinetic energy to be equal to the kinetic energy of the grain for so we can now correlate the F_{max} the maximum force that the grain comes across in the impingement case the free-throw case that can be represented as HW times of πd small is h_w' and if I wanted to equate the kinetic energy to the force distance product.

If I have F_{max} times of HW assuming a triangular characteristics or end of the curve which is equal to the maximum kinetic energy should be that of that of the grain which is $\frac{1}{3} \pi^3 \rho_a d^2$ as derived in the last step so from this equation B and equation C the HW' if I substituted the value of F_{max} in this equation from B and C that W' comes out to be equal to $\pi d \mu_a$ root over twice ρ_a my HW this HW corresponds to the flow stress of the work material.

So it is a property of the material which is again known this is the abrasive grain density this is again if the grain does not change is a material property okay and obviously the diameter which is the average diameter the drain the frequency of to the amplitude these are also experimentally measured quantities and so if I were to compare in this manner the HW' to the HW which obtained which was obtained by in the previous case.

When actually the green was hammered on the surface it is found that HW' is much, much, much smaller in comparison to HW so obviously the significant material removal cause is the hammering action and not the free grain case so henceforth will kind of neglect this HW' which is created by the free grain throw because it hardly has any contribution to the overall material removal process.

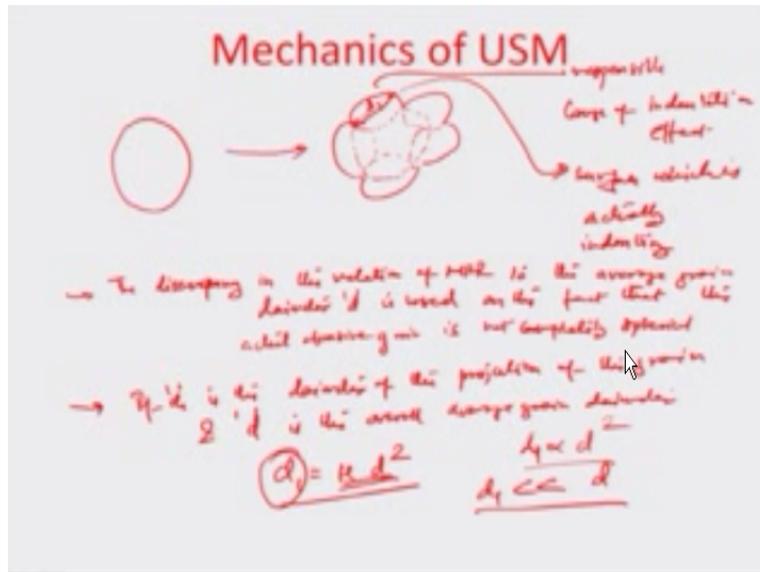
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So it can be concluded so in conclusion most of the material is removed by the direct impact of the ploughing grain or hammered grain and from the earlier relation the material removal rate Q is proportional to amplitude the power of 3/4 diameter to the power 1 by 4 the average force to the power of 3/4 concentration to the power of 1/4 need to the power of 1 divided by the flow stress of the work material the power of 3/4 but if you look at experimental results.

The relationship Q directly proportional to the fourth one fourth power of diameter does not hold in fact in real experiments Q happens to be proportional to D and not $d^{1/4}$ so MC Shah try to do something in this area by studying what is the cause of this change of power you know although dimensionally from the material model from the geometric model it seems as if the material removal rate is proportional to non fourth power of D .

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And so what he obtains is that you know instead of a circular grain almost all the grains that actually come in contact with the work surface are something like this so they are not really circular but they do have an average diameter but each of them can be projected out to be small circles and if we assume that small circular diameter to be D_1 this would be the responsible cause of indentation effect obviously this is the surface which is actually indenting okay.

So this is the surface which is actually indenting so in brief then the discrepancy in the relation of MRR to the average grain diameter D small d is based on the fact that the actual abrasive grain is not completely spherical and what Shaw studied and Shaw found out is that if d_1 is the diameter of the projection of the grain and D is the overall average grain diameter then obviously the d_1 is proportional to square of the averaged in grain diameter or d_1 is actually equal to a constant μ times of square of the average in diameter.

So in an hour's d_1 one actually is much, much smaller in comparison to d okay as a small projected grain diameter on the top of overall diameter D which we are talking about so that is how you can find out d_1 and in fact the impact on the indentation and the area that is created because of the grain is actually because of the projected surface of the grain and not the actual grain and so even though while calculating the concentration.

You would assume the maximum diameter to be the average grain diameter small d but when we are talking about flow stress or determination of what is the force per unit area the actual area impacting is that small D_1 and not small d okay so there it changes the whole you know way that

we define the MRR equations and in fact we in this module is time wise over so I am going to close it now but in the next module I am going to definitely take it up.

That if we substitute this value D_1 for the calculation of the flow stress within the material what is going to be the impact and as we will see that the material removal rate in that case will actually come to almost mimic the reality that the queue would be proportional to the average grain diameter small D so with this I would like to close on this module thank you very much.

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