Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology – Part – 2

Module – 14
Effect of Process parameters of USM

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Hello and welcome to this manufacturing process technology part 2 module 14.

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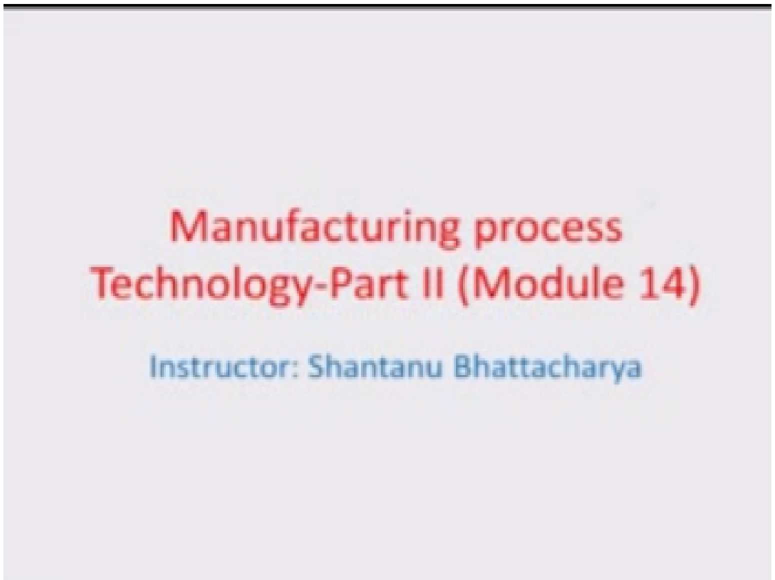

Manufacturing process Technology-Part II (Module 14)

Instructor: Shantanu Bhattacharya

We were talking about why it is important to have parity between the experimental and theoretical the derivations of the MRR in case of USM and we found out that although the theoretical expression that we arrived at has q or MRR proportional to the one-fourth of the average grain diameter in reality in experimental reality the MRR is actually proportional to the diameter to the power of 1.

And we were further discussing how MC Shaw wanted to explain in his theory why this you know proportionality to single power of D comes because of certain assumptions. So what MC Shaw assumes is that.

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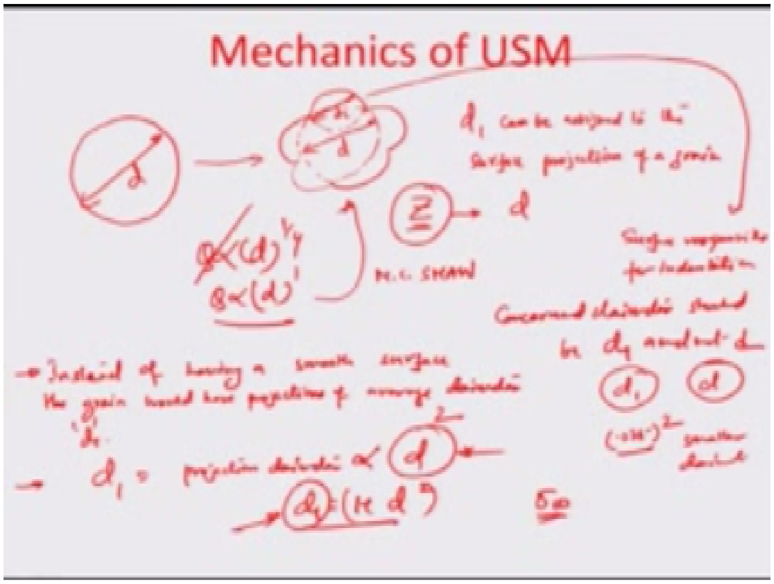

Mechanics of USM

The grain actually is not really a spherical shape at grain but if we look at the grain very closely the grain is comprised of many big and small surfaces and basically that is what the results in and altogether different projection of the surface of the grain and although the grain has an average diameter of small d as had been discussed earlier the surface of the grain may have an altogether different diameter.

So if I project the surface and try to see what is the diameter of the surface it may have an altogether different diameter and this diameter d1 can be assign to the surface projection of a grain. So although when we calculate the number of grains making impact you know all at once between the tool and the work piece and in calculation of Z we may consider the average grain diameter D.

But actually while calculating the flow stress it is not that average diameter D which participates but the projection diameter d1 which actually participates okay, so in a way it is the surface which is responsible for the indentation and the concern diameter that we should take should be d1 and not d okay as far as the flow stress calculation happens. So in fact the discrepancy of why q is not proportional to D^4 but is proportional to the single power of D was explained through this theory as proposed by MC Shah and he proposed that instead of having a smooth surface.

The grain would have projections of average diameter d1, further it is observed that you know if you look at a number of values d1 and number of values D the D1 which is the projection diameter is much smaller in comparison to D okay, you have to remember what we are talking about D is actually in the microns rain so it could be something like let us say in 25 microns for example you know, so it is 0.0 to 5mm and squaring that would result in a much smaller diameter.

So typically this projection diameter D is proportional to square of the average grain diameter or the diameter d1 much smaller value would be equal to µ times of d^2 but is the average diameter of the grain. So that is how we had to plug in whenever we want to calculate the flow stress σ W which was calculated earlier in case of USM. So let us now go back to the material removal rate equation.

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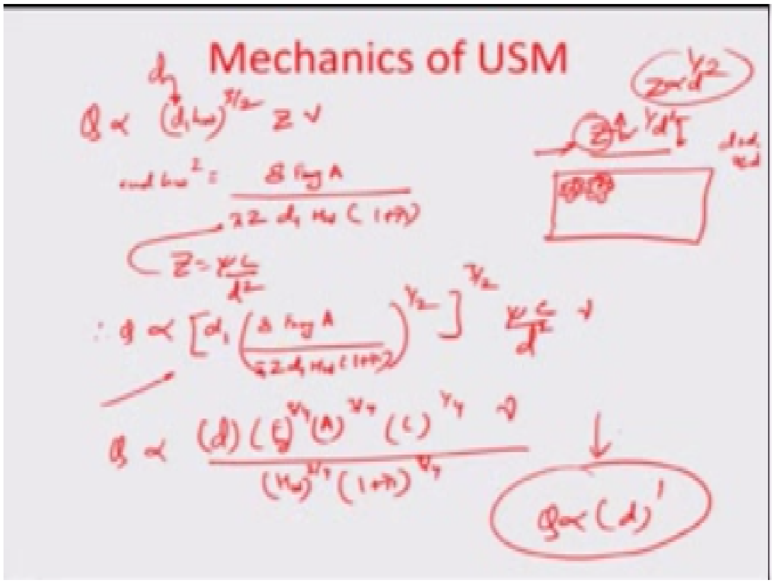

Mechanics of USM

$Q \propto (d_1 h_w)^{3/2} Z \nu$

$h_w^2 = \frac{8 F g A}{\pi Z d_1 H_w (1+q)}$

$Z = \frac{\psi C}{d^2}$

$\therefore Q \propto \left[d_1 \left(\frac{8 F g A}{\pi Z d_1 H_w (1+q)} \right)^{1/2} \right]^{3/2} \frac{\psi C}{d^2} \nu$

$Q \propto \frac{(d)(F)^{3/4}(A)^{3/4}(C)^{1/4} \nu}{(H_w)^{3/4}(1+q)^{3/4}}$

$Q \propto (d)^1$

Which talks about Q to be proportional to in this case it has to be d1 HW to the power of 3 by 2 obviously because the D gets replaced by d 1 here which is actually the projection which you know participates or interferes with the surface in order to produce the material removal times of Z times of new frequency of the tool hand and HW^2e comes out to be equal to eight times of the average force times amplitude a / π Z d1 HW times1 + λ.

Z still remains equal to $\rho C / d^2$ because you have to think of it that even if the projection diameter of the grain is different the number of grains making impact would still be related to the average grain diameter D. So if this diameter is lower these that would increase and vice versa in other words instead of the fact that there is a projection diameter much smaller with respect to the D and so d + d 1 can be approximated with d the value of Z or the number of grains making impact per cycle always is inversely proportional to the square of the diameter okay as before.

So we put all these values plug all these values and try to find out what is effectively the result of all this so Q therefore becomes equal to again you know if I just wanted to substitute HW back into this equation we have D 1 times of 8 force average a / π Z D 1 HW $1+ \lambda^{1/2}$ whole to the power of 3 / 2 times of $\varphi C / d^2$ x of new or in other words q if I solve this algebraically becomes directly proportional to power of D the power 1 F average to the power 3 / 4amplitude the power 3 by 4 concentration the grains to the power of 1 by 4 times of frequency of the tool $\mu / HW^{3/4}$ $1+ \lambda^{3/4}$.

So as you can see here the Q actually becomes equal to the first power or directly proportional to the first power of D which is what we started with which was a disparity between the earlier theoretical model and the experimental observations.

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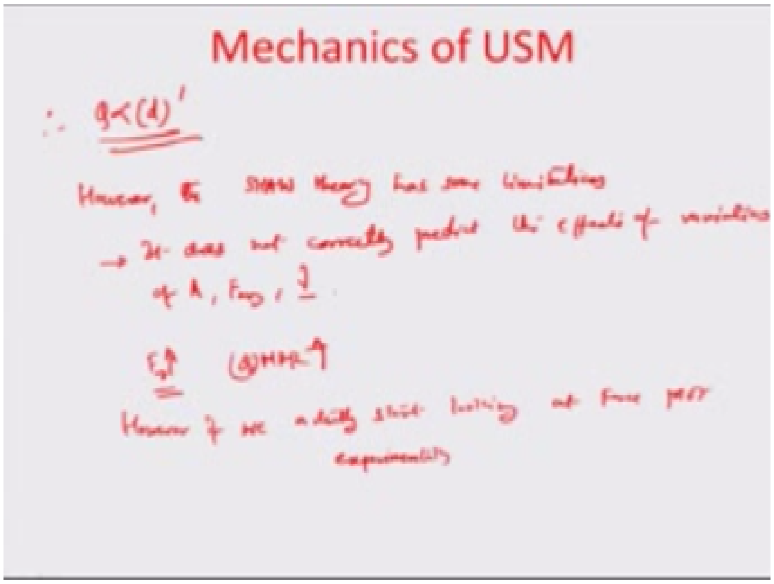

Mechanics of USM

∴ $q \propto (d)^1$

However, the SHAW theory has some limitations

→ It does not correctly predict the effects of variations of A, F_{avg}, f

$F\uparrow$ (Q) MRR ↑

However if we actually start looking at force plot experimentally

So Q therefore becomes proportional to D^1 however the show Theory has some limitations let me just point that out step by step it does not correctly predict the effects of variations of amplitude average force or frequency. So obviously if F would increase the MRR should also increase because as I earlier illustrated in the last relationship q is proportional to the force $R^{3/4}$. However if we actually start looking experimentally force plot experimentally it is illustrated here.

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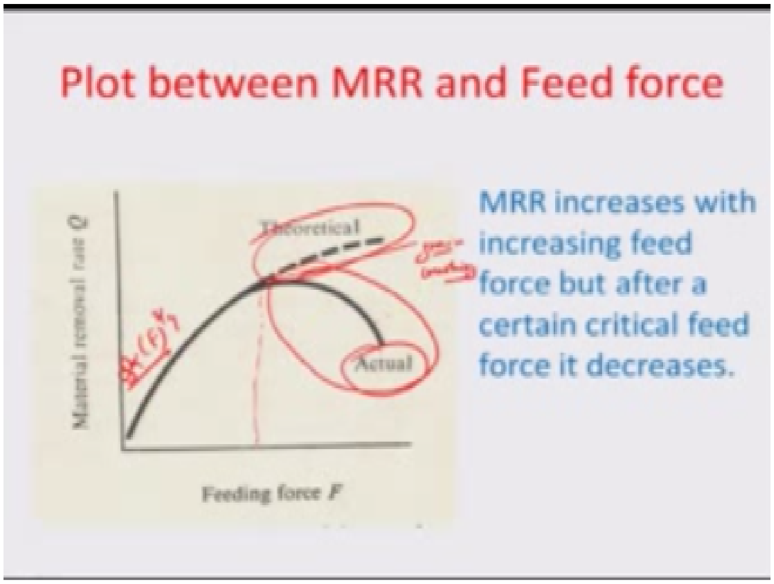

Plot between MRR and Feed force

MRR increases with increasing feed force but after a certain critical feed force it decreases.

That corresponding to some particular feed force there is still a proportionality maintained between Q and f ¾. Beyond which there is a complete deviation in this region from the theoretical and this effect is more because there is something called grain crushing which you cannot avoid supposing there is a certain stress value certain average force value of this tool and obviously force per unit area which does all this brittle fracture on the work piece. So there may be a critical force a kind of force beyond which the stress applied to the grain would result in the grain getting crushed or getting fragmented into pieces.

And so because of that you know you may not have a grain available anymore for doing the material removal because all the grains seem to be crushed at that particular I frequency, so in that even obviously the MRR has to come down so the actual MRR comes down because of such an effect where these effects may not be able to get really predicted by the Shaw theory okay. So there are many other associated factors which as to be clubbed to the material removal model which has been suggested earlier by Shaw theory.

So that it can really fit well the practical situation the other thing that would like to say is about how you know there is a change of the MRR with respect to the various parameters like frequency.

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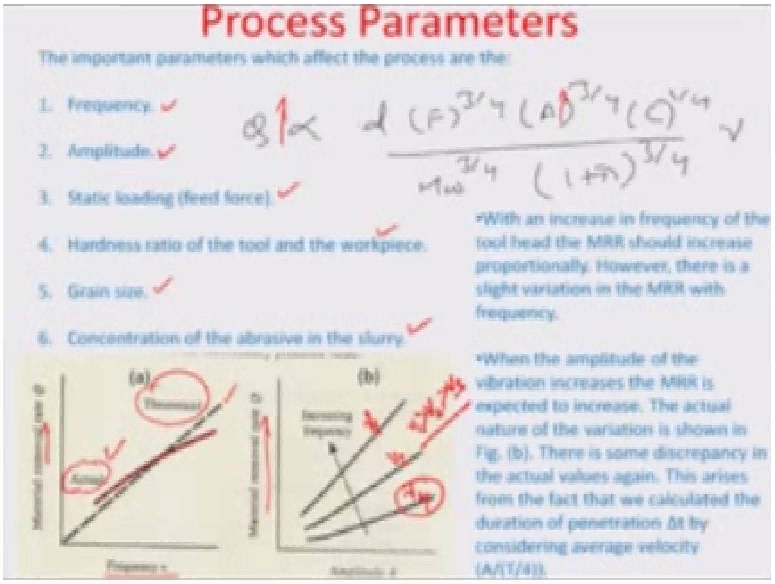

Process Parameters

The important parameters which affect the process are the:

1. Frequency. ✓
2. Amplitude. ✓
3. Static loading (feed force). ✓
4. Hardness ratio of the tool and the workpiece. ✓
5. Grain size. ✓
6. Concentration of the abrasive in the slurry. ✓

$$Q \uparrow \propto \frac{d\,(F)^{3/4}\,(A)^{3/4}\,(C)^{1/4}}{H_w^{3/4}\,(1+\lambda)^{3/4}} \checkmark$$

- With an increase in frequency of the tool head the MRR should increase proportionally. However, there is a slight variation in the MRR with frequency.

- When the amplitude of the vibration increases the MRR is expected to increase. The actual nature of the variation is shown in Fig. (b). There is some discrepancy in the actual values again. This arises from the fact that we calculated the duration of penetration Δt by considering average velocity (A/(T/4)).

Amplitude feed force harness ratio of the tool and the work piece that is λ the grain size concentration of the abrasive in the slurry so on so forth. So let us for example look at frequency, so obviously the material removal rate varies linearly with respect to frequency and so theoretically it should be a straight line plot as seen by the dotted line here. But in the actual case if you remember the way we predicted the frequency was on the basis of velocity of the tool was on the basis of an average made between them, you know amplitude and exactly one fourth of the time period.

So that is actually not a very good estimate of the velocity of the tool which would lead to obviously errors in the frequency. So actually the frequency and material removal rate are related to each other in not so linear manner you can see this is how the actual material removal rate varies with frequency. Similarly for you know variation with respect to amplitude obviously there will be a increase in the MRR if the amplitude also increases but as you vary the frequency you know and the combination of amplitude and frequency will see MRR to be more and more as the amplitude varies along with the frequency. So this is for example are higher frequency and U_3 is the lower frequency and you can see that with respect to the amplitude on a certain frequency you have more or less direct proportionality between as estimated by the Shaw theory. Similarly we can look into.

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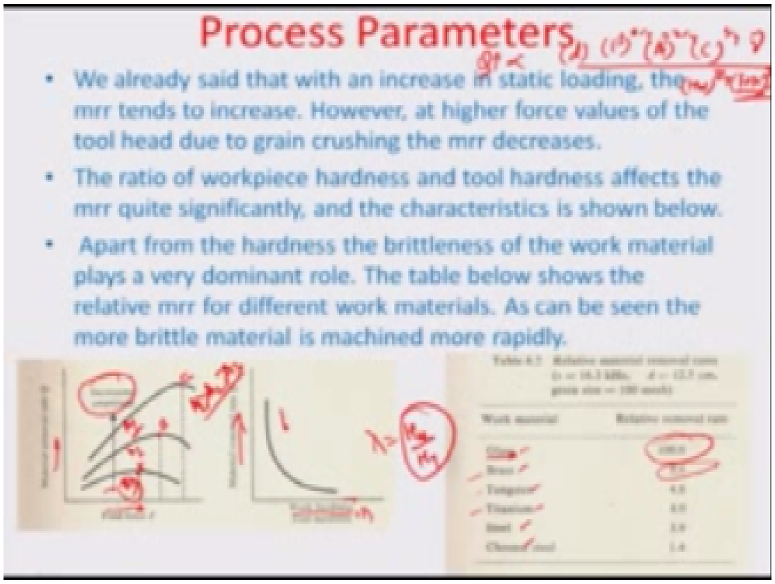

Process Parameters

- We already said that with an increase in static loading, the mrr tends to increase. However, at higher force values of the tool head due to grain crushing the mrr decreases.
- The ratio of workpiece hardness and tool hardness affects the mrr quite significantly, and the characteristics is shown below.
- Apart from the hardness the brittleness of the work material plays a very dominant role. The table below shows the relative mrr for different work materials. As can be seen the more brittle material is machined more rapidly.

How the material removal varies with respect to the feed force, so obviously as the amplitude increases the material removal rate should also increase because you will have to again remember the same formulation Q proportional to d^1 $f^{3/4}$ A^3/4 concentration 1 /4 times of new the frequency / $hw^{3/4}$ 1 + $\lambda^{3/4}$ so here as you can see that with increasing amplitude and with the you know increasing feed force, there is a tendency of this material removal rate Q to go up, so as the amplitude increases let us say this is a_1 a_2 a_3 different amplitudes where a_1 is more than a_2 is more than a_3.

So obviously at lower amplitude the material removal rate would be lower with respect to speed force in comparison to what would happen at higher amplitude. So it is also notable that the grain crushing effect leading to a reduction in the material removal is probably corresponding to lower amplitude you know the grains can withstand lower force in order to get crushed comparison to higher amplitude. You can think of relaxation effect here that the amplitude is more than the drains would have more time between two impacts of the hammer and therefore they can last longer, so therefore if the amplitude is more it has that time relaxation effect because of which the average force at which the grain crushing would happen would shift between these three points a, b and c.

So you can see at the highest amplitude the grain crushing force is shifted towards that is the maximum the grains can take. Similarly if I had to compare or if I were to compare the λ which is actually the hardness ratio between the work and the tool, you know with increasing λ material removal would obviously decrease because as Q is proportional to inversely proportional to 1 plus $\lambda^{3/4}$. So that is how we can have an estimate of what would happen to metal removal with respect to λ okay. So for certain materials like glass brass tungsten titanium steel and chrome.

You can see that the more brittle the material is the better the removal rate is, for example in all these materials glasses the most brittle material and you can see almost 100% material removal rate in comparison to some of the more ductile ones like brass tungsten, titanium steel, where you know the percentage of material removal is much less in comparison to that at the brittle material, so you have 6.6 as opposed to hundred which is quite an increase. So all the process when it was designed to begin with really for the brittle materials but later on because of the utilization that it had it is a passive process people used it for a variety of even metal removal applications as well.

But at the stop getting a very low material removal rate, so let us look at how the same you know Q would vary your material removal rate would vary with respect to the diameters again.

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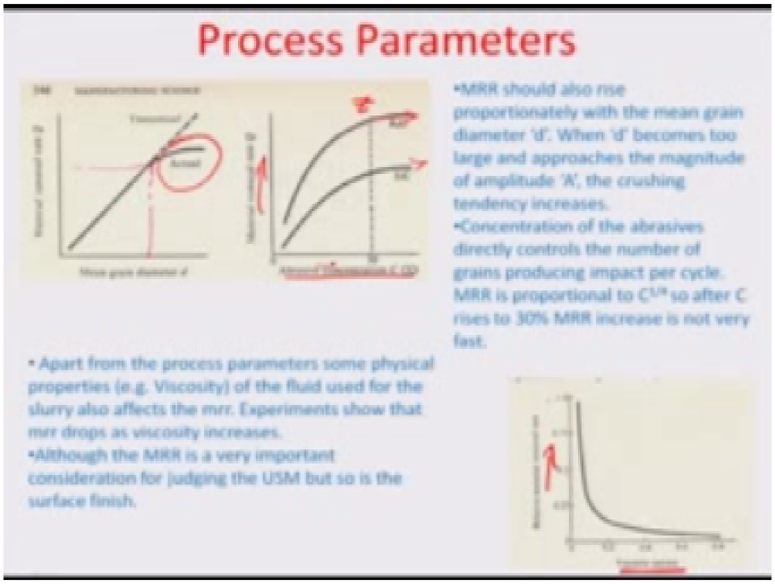

Process Parameters

- MRR should also rise proportionately with the mean grain diameter 'd'. When 'd' becomes too large and approaches the magnitude of amplitude 'A', the crushing tendency increases.
- Concentration of the abrasives directly controls the number of grains producing impact per cycle. MRR is proportional to $C^{1/4}$ so after C rises to 30% MRR increase is not very fast.

- Apart from the process parameters some physical properties (e.g. Viscosity) of the fluid used for the slurry also affects the mrr. Experiments show that mrr drops as viscosity increases.
- Although the MRR is a very important consideration for judging the USM but so is the surface finish.

The same problem here that at a certain critical diameter the grain crushing effect would start to take place if the diameter is higher and so the material removal rate obviously would be lesser in that that instance and so with the concentration. So corresponding to a certain critical concentration the material removal rate peaks beyond which it plateaus because you can think of it that you know even if the concentration is increased then you further the Z value is more or less limited, you know. So it is occupied at a certain loading almost full space between itself and the work piece with abrasive grains.

So even if you vary the loading beyond that what is going to be the effect? There is no extra grain that is going to come in because the area is already occupied, so therefore you have a criticality of concentration beyond which increase in concentration may not result in you know many any increase any further increase in the material removal rate.

Similarly with viscosity if I were to look at how material removal gets changed, so high as the slurry viscosity lower would be the material removal obviously because you know the way that the fragments get carried away is through the process of diffusion and diffusion is more into stream and so if the shear between the layers is higher, then the diffusion effects may be lower and therefore there may not be a tendency of the broken pieces to go as frequently as would happen.

If the diffusion if the viscosity was lowers okay, so those are some of the process parameter details. Let us also look at the dependence of surface finish on the grain size.

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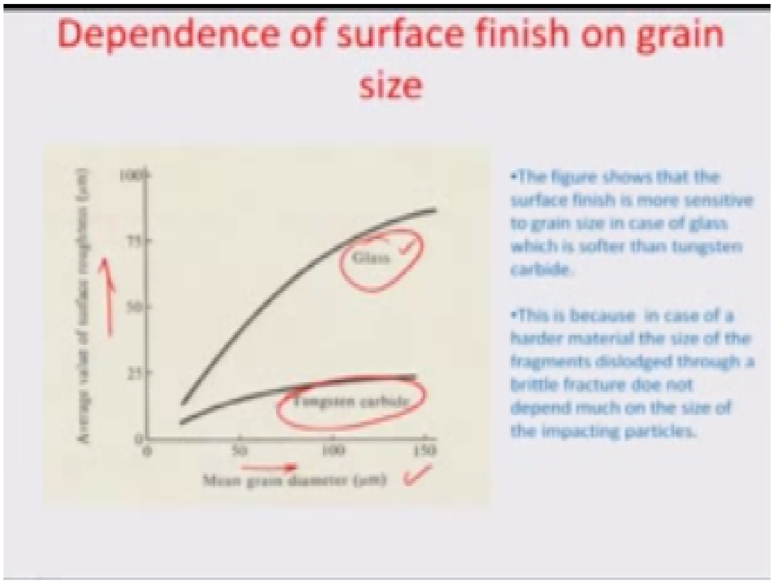

Dependence of surface finish on grain size

- The figure shows that the surface finish is more sensitive to grain size in case of glass which is softer than tungsten carbide.
- This is because in case of a harder material the size of the fragments dislodged through a brittle fracture doe not depend much on the size of the impacting particles.

So if the grain size is more obviously the average roughness would increase and it would increase more in case of a brittle material then in case of a hard or you know ductile material and so the effect becomes more prominent of the mean grain diameter increase on the average surface roughness if we were talking about, a brittle material rather than a ductile material. So let us now look at some you know instances of numerical problems and try to see how we can find out the material removal rate or how we can determine the percentage in the change in the machining time for a USM operation.

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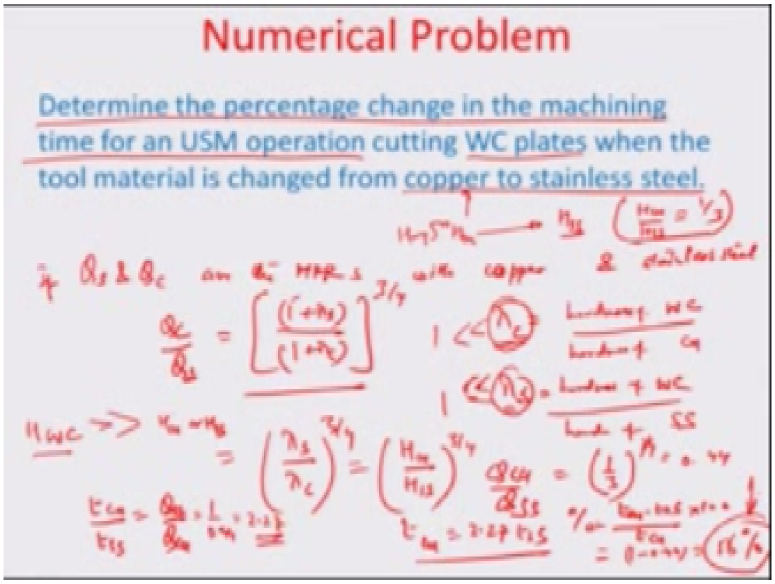

Numerical Problem

Determine the percentage change in the machining time for an USM operation cutting WC plates when the tool material is changed from copper to stainless steel.

So in this particular problem we want to determine the percentage change in the machining time related to a new in process while cutting these tungsten carbide plates when tool material they suddenly change from copper to stainless steel. So obviously the hardness of copper would be different in comparison to that of SS, so the HT is going to change from copper to HSS and that is going to be changing the material removal rate.

So we already know that if let us say Qs and Qc are the MRR with copper and the stainless steel. So Qc / Qs can be represented as 1+ λ s / 1 + λ C $^{3/4}$ this is borrowed from the American as theoretically obtained earlier and λ C happens to be the hardness of the work piece which is tungsten carbide by the hardness of copper.

Similarly λ s happens to be the hardness of the work piece by hardness of SS or a stainless steel, so the you know if we if we look at W_C it is much harder ok so the hardness of WC is much harder in comparison to either copper okay or stainless steel and so this ratio really what is λ C or λ s is much greater in comparison to one okay and I can actually replace this by just the ratio λ C / λ C neglecting λ s by λ C neglecting the one term it is much greater in comparison to $1_{3/4}$.

So this becomes effectively equal to the oddness of copper by hardness of stainless steel $^{3/4}$ and we already know that you know from common literature, that hardness of copper to hardness of stainless steel is actually one third stainless steel is about three times harder than copper.

So we can get the Q_C bike us to be equal to $1/3^{3/4}$ which is 0.44 in other words the timescales if we look at from the copper tool and the SS tool which is actually equal to which is inversely proportional to the material removal rates of the stainless steel comparison to copper becomes = 1/0.4 for that is about 2.27. So the time of a copper tool or is at least 2.27 times more than what is obtained on a stainless steel tool, so in other words if I want to see what is the percentage reduction when the tool is changed from copper to stainless steel it can be represented as T copper - t stainless steel / t copper and 100.

So that becomes =1- 0.44 or about 56%, so there is a change of time of almost the order of 56% and we are changing the tool material from copper to stainless steel talking about, the US in process on a tungsten carbide plate. So similar numerical can be derived when you know even the work piece material gets changed and a ball park figure could be arrived at about what is going to be the difference in the timing of machining based on change of the tool as well as the work piece materials. So we will actually look into a material removal numerical problem but in the interest of time, I will close this particular module.

And in the next module we will start looking at how numerically we can estimate the material removal rate in the situation and that would help us to also estimate, the machining time for a certain geometry that has to be cut within a certain work material. So with this I would like to bring to an end this particular module thank you very much.

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