Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations
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Lecture-10
Surface Properties for Wear and Friction Resistance III

Hello, I welcome you all in this presentation related with the subject fundamentals of surface engineering and we are talking about the surface properties which are important from the friction and wear point of view under this heading we have talked about the 2 important properties these were the surface energy and the chemical composition or surface composition after that we had started the surface micro structure under which we have talked about the phase structure related aspects.

In this presentation initially I will talk about the grain structure related aspect of the micro surface micro structure. And there after I will take up the role of the surface hardness and the surface roughness on friction and wear. So, as we have seen that the micro structure of a any material comprises the 2 aspects. So, 1 is the phase structure which indicates the type of phases, the relative amount of the various phases which are present.

And their distribution where they are present like whether they are within the grain or at the grain boundary or to the kind of whether they are at the surface or in the core or there is a continuous variation. So, it is about the distribution another aspect is the grain structure which indicates the size of the grain, shape of the grains and the distribution. Distribution means where which type and the size of the grains are present with at the surface which type of grain are there.

And at the in core region which type of the grains are present. So, because the both phase as well as grain structure are important from the mechanical properties point of view which in turn affect the tribological behaviour of the surfaces determining the life of the component. So, it is important to look into the micro structure related aspects of the surfaces, so as for as the grain structure is concern.

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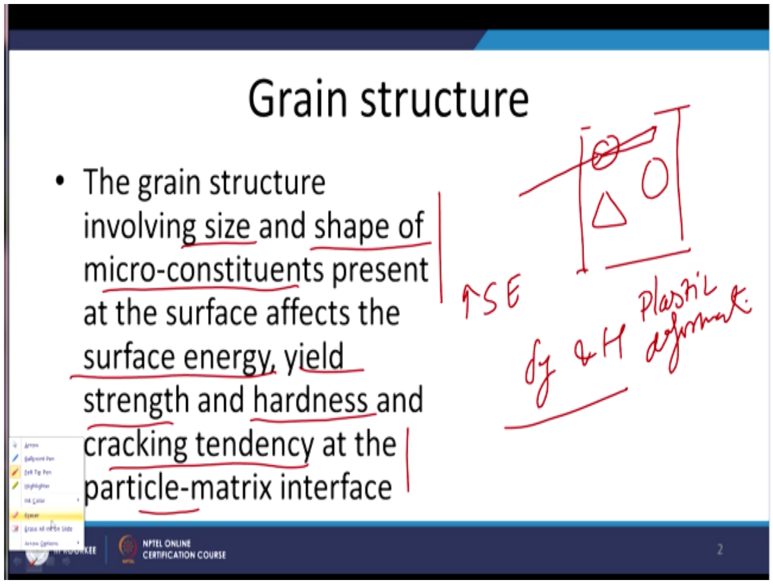

As I have said it involves the average size of the grain, shape of the those grains or the micro-constituents present at the surface and these 2 aspects actually affect the surface energy, yield strength and hardness of the material and cracking tendency at the particle matrix interface we have seen that the higher the surface energy of the material greater will be the wear and the friction while on the other hand the yield strength of the material and the hardness both these are the mechanical properties.

And affect the surface deformation tendency under the wear conditions. So, these will be resisting the plastic deformation of the material under the tribological conditions on the other hand there is 1 more aspect which is influenced by the grain structure is the cracking tendency of the particle matrix interface, what is that like this is the matrix and in which various second phase particles are present, like few needle shape and few polyhedral shape.

So, there is always stress concentration at the particle matrix interface as per the geometry of these constituents. So, those which are the particles or the second phases which are of the high aspect ratio, higher aspect ratio means the needle shape structures they will be offering the greater stress concentration at the particle matrix interface especially near the tip where in the cracking tendency will be high.

Because of the higher stress concentration as compare to the other cases where the particles are of the spherical shape. So, greater is the cracking tendency easier will be the possibility for formation of the debris wear debris and removal of the material from the functional surfaces. So, as per as the quantification of these aspects are concerned.

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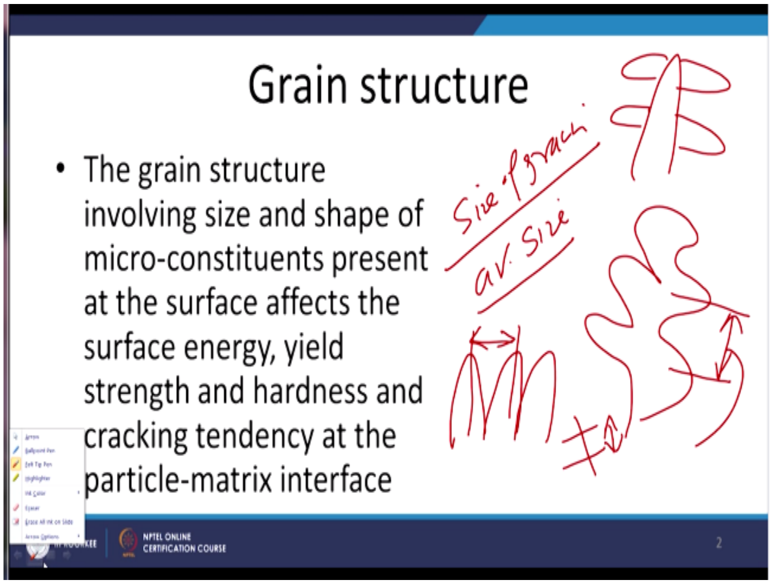

Like the size of grains, size of grain for this purpose basically we determine the average size of the grain because different grains will have the different sizes and rather there will be size range. So, it will be appropriate to determine the average size, now as per the shape of the grains there are different ways to characterise the size of grain, say for example in case of the cellular structure it is the intercellular space which is use to characterise the size of grain while in case of the dendritic structures like this.

This is the primary dendrite and the when we see the branches like this on the primary dendrite these are the secondary dendrites. So, spacing between the secondary dendrites arms is characterised as a grain size in case of the dendrite structures. And same is the criteria which is used for equates structure where the spacing between the arms is use to characterise the size of the grains. Apart from these matrix material structures there can be various other structures like the needles.

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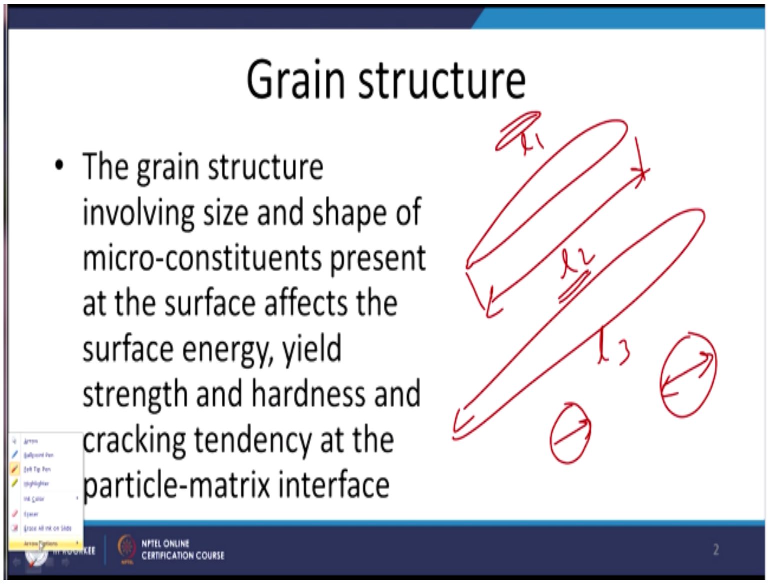

So, in case of the needle, it we can measure the length of the needle is primarily use, so if there are needles of the various sizes like this then average length l1, l2 and l3 average of these 3 will be use to characterise the average length of the needle. Similarly for spherical shape particles it will be the average diameter of the spherical or circular shape particles that will be use to characterise the size of the grains.

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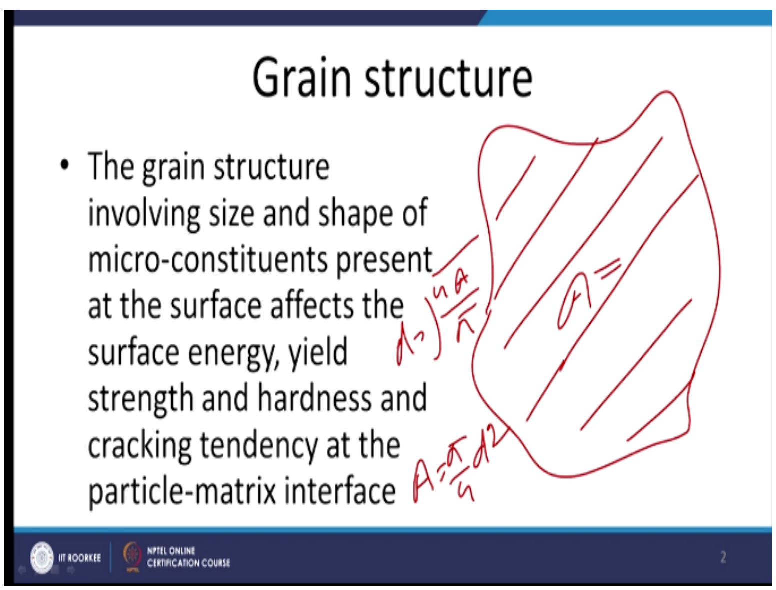

Now if the shape of the grain is very regular like this, in that case to quantify will using the image analysis we can determine the area of the grain like say this and then we determine the equivalent diameter of this grain and for that purpose we use A=pie/4 d square. So, here the d is calculated like 4A/pie square root, so this is how will be determining the average equivalent diameter or this is the average area of particular grain.

So, area will be used to calculate the equivalent diameter of the grain when the grain shape is very regular. So, this is how the grain size is determined.

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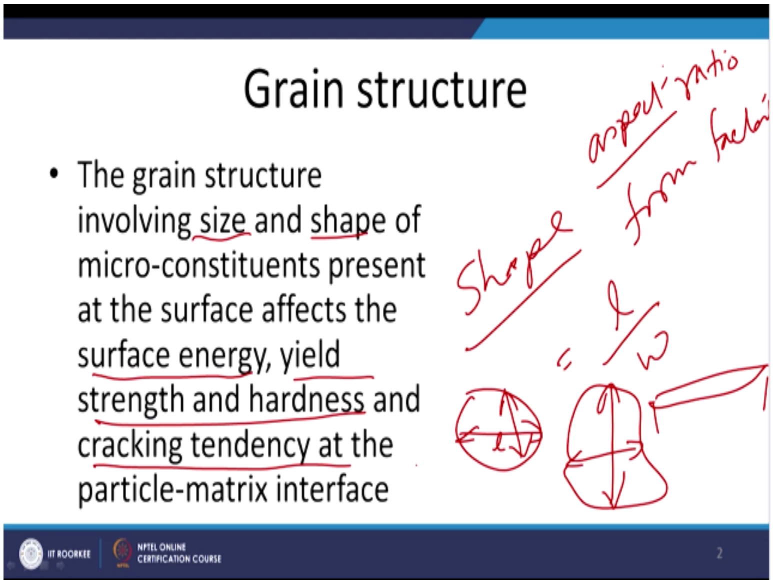

Similarly as I have said earlier the shape of grain is characterised using the 2 parameters these are called aspect ratio or form factor**.** So, both for both we use the length to width ratio of particular constituent whether it is the particle regular shape or the needle shape. So, in that case the length to the width ratio is used what is the maximum length and width of the constituent that is use to characterise the aspect ratio.

So, greater is the aspect ratio or the form factor greater will be the nodularity or needle shape structure as compare to the spherical or circular shape micro constituents. So, these over the about the size and the shape related aspects. And both these have significant effect on the since the grain size and shape have significant effect on the surface energy and the yield strength hardness of the material and cracking tendency which in turn determines the friction and wear behaviour of the material.

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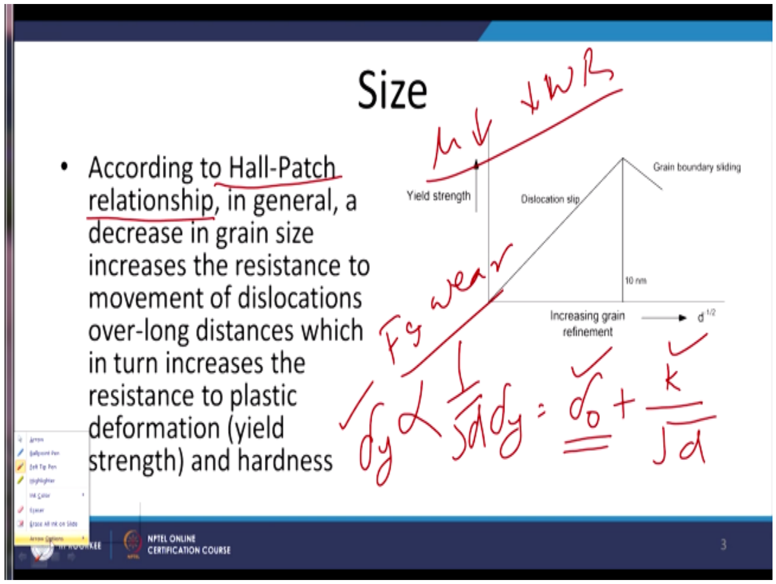

Now in order to see that how the average grain size or grain size is related with the mechanical properties, so there is 1 very commonly known relationship that is called Hall-Patch relationship which indicates that sigma y=sigma 0 means this is the yield strength of the material of the single crystal +k/square root of the d. So, indirectly if we see these and these 2 are the constant.

So, yield strength of the material found proportional to be square root of the diameter, so decrease in the diameter of the decrease in the diameter of the grains or reduction in grains size will be increasing the yield strength. So, this is the simple relationship since under the external load conditions surface layers especially will have tendency to get deform and if the material is having the higher yield strength.

Because of the finer grains then it will be showing the greater resistance to the deformation, greater resistance to the metallic intimacy. So, this in turn will be reducing the friction as well as the wear rate, so both will be improved especially under the adhesive wear condition.

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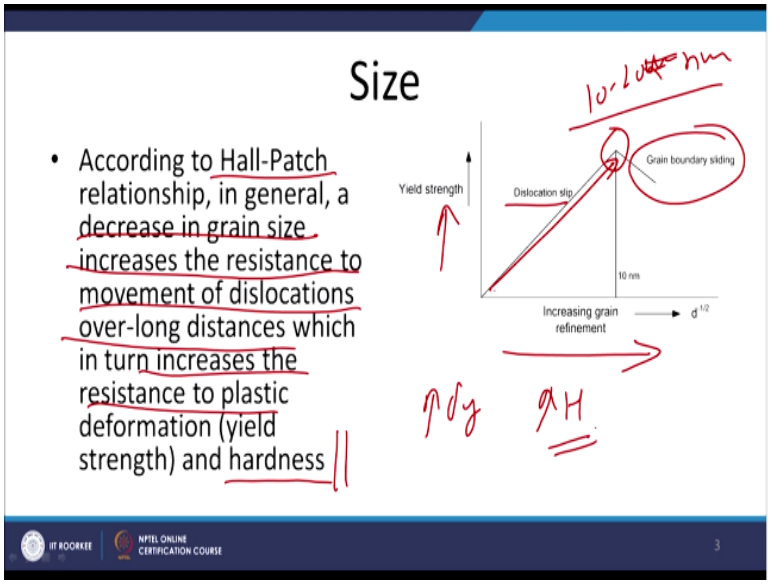

If we see this relations between the grain size means the grain refinement in increasing the d rise to the power -1/2. So, means this is in the order of decreasing grain size, so this reduction in grain size increases the yield strength up to a limit which maybe like say the 10 to 20 nano meter and thereafter further reduction in grain size has the adverse effect on the yield strength, this is what we can see in the initially stage of the reduction of the grain size the deformation is facilitated through the dislocation slip.

And with by this when the deformation takes place by this mechanism reduction in grain size increases the yield strength well the further reduction in grain size reduces starts decreasing the yield strength because of the grain because the grain boundary sliding is facilitated. According to the Hall-Patch relationship in general decrease in grain size, increases the resistance to the movement of dislocations over a longer distance which in turn increases the resistance to the plastic deformation.

And since in hardness stress also there is sidewise flow of the material and if the flow of the material is resisted then this in turn will be leading to the reduction in size of the indentation and which in turn will be showing the greater hardness. So, in general increasing yield strength shows the increasing hardness of the material since the hardness is closely related with the abrasive and adhesive wear. Therefore it is important that grain size is properly control, so that required yield strength and the hardness can be realised.

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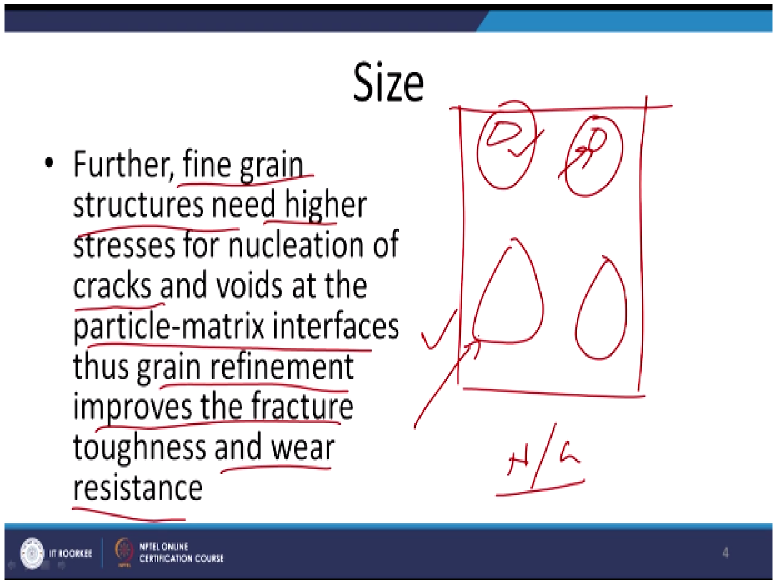

There is 1 other aspect like in a material which is having the matrix and in the matrix we are having the few fine and very few very course particles. So, in case of the course particles the nucleation of the crack at the particle matrix interface becomes easier as compare to the case when the particle size is fine, so the stresses required for nucleation.

And growth of crack at the particle matrix interface that increases in case of the fine size or a small size of the micro constituents as compare to the case when the constituent size is very course, when we have the fine grain size it will increase the resistance to the crack nucleation and growth and which in turn will be increasing the removal of the material from the functional surfaces and so the wear resistance is improved which in turn increases the life of the tribological life of the component.

So, refinement of the grain structure is needed you see whenever the grain structure is refined it requires higher stresses for nucleation and growth whites at the particle matrix interface thus the grain refinement improves the fracture toughness and the wear resistance. This is what I have explained with the help of this diagram, if the particle size is large it requires lower stresses, lesser stresses for nucleation of whites and their growth as compare to the case when the grain size is fine.

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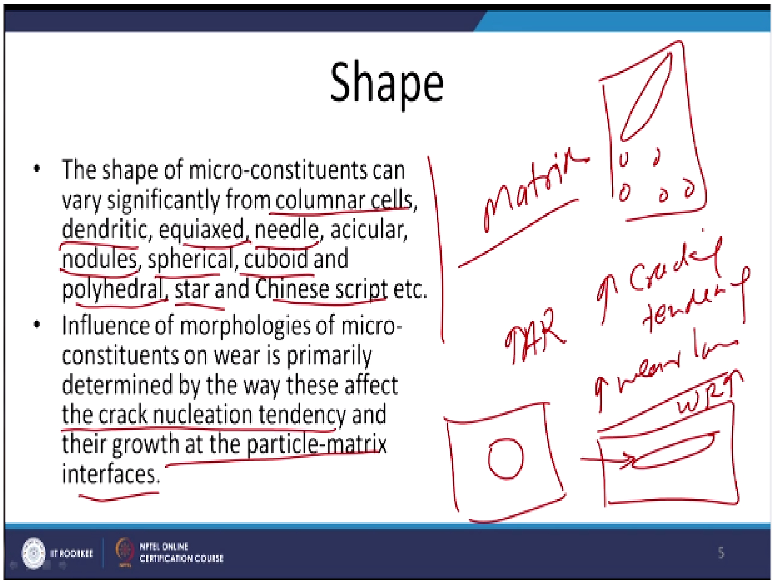

The shape of the grain is the another aspect of the micro-constituents that significantly affect the stresses required for nucleation of the crack and their growth especially under the adhesive wear conditions as I have said there can be normally the matrix metallic matrix shows certain types of the grain shapes like columnar cells dendrites, equated while the second phase particles show the shape like needles, cuboids, spherical, nodules, polyhedral shape, star shape, Chinese script shape.

So, and each type depending upon the shape which is characterised so the form factor or aspect ratio depending upon the aspect ratio of these shapes they will have the different effect on the tendency for nucleation and the growth of crack. In general higher is the aspect ratio, higher will be the cracking tendency at the particle matrix interface, so, which in turn will be increasing the wear loss from the functional surfaces.

So, influence of the morphologies of micro constituent on the wear is primarily determined by the way these morphologies affect the nucleation tendency crack nucleation tendency and their growth at the particle matrix interfaces. So, spherical particles will have the minimum stress concentration at the particle and matrix interface, so it will resist the crack nucleation and it is growth effectively as compare to the case when there is needular shape particles at the particle matrix.

So, in that case the crack nucleation and growth will be easier, so such cases the wear rate will be high as compare to the another case when this fine and it is spherical shape particles are there. So, it is always preferred to have the fine and spherical shapes second phase particles as compare to the large and needle shape particles. So, we need to actually alter the surface morphologies in such a way that they are fine well distributed and largely of the circular family.

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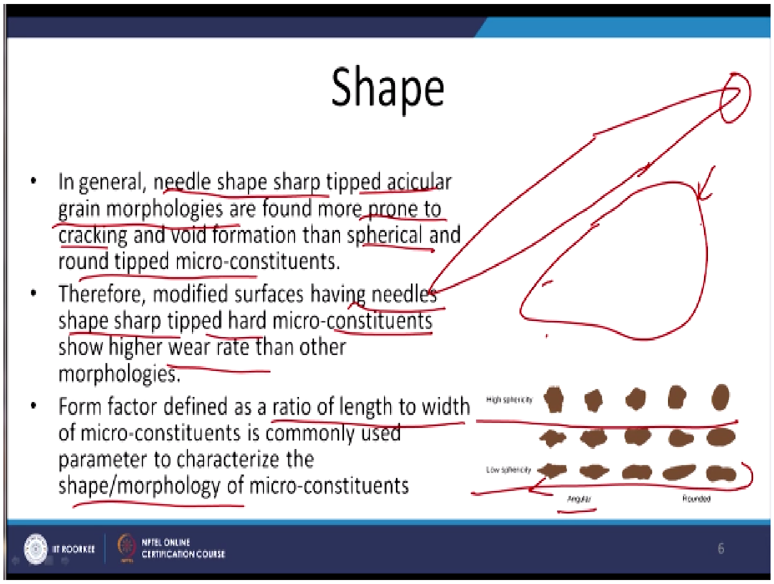

In general needle shape, sharp tipped acicular grain morphologies are found more prone to the cracking and white formation than the spherical and round tipped shape micro-constituents. Therefore modified surfaces if they are having the needles shape sharp tipped micro constituents then the wear rate will be high as compare to the other morphologies, form factor is use to define as I have already said.

Form factor is use to define the ratio of the length at 2 ratio of length 2, width of the micro-constituent to characterise the shape and morphology of the micro-constituent. We can see they are certain morphologies these are the high asphericity morphologies and these are lowest asphericity morphologies. And if we see the here this one is very angular while this side the tip is rounded.

So, aspect ratio of the lowest asphericity and angular particles will be greater as compare to the highest ferocity and rounded shape particles. So, these are the 2 different aspects like we may have the needle like this having the angularity is more roundness is less but there can be another possibility where we have the spherical particles like this with the reduced angularity increased the roundness.

So, increased ferocity and roundness will be reducing the stress concentration at the particle matrix interface and which will be leading to the more favourable situation with regard to the resistance to the crack nucleation and their growth under the means tribological conditions.

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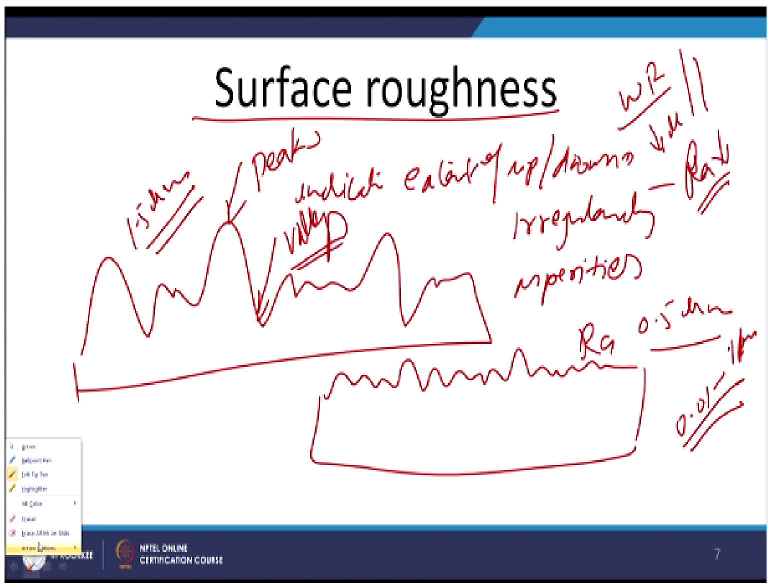

So, this is how we can see even the micro structural even at the micro structural level, size of micro-constituents and the shape of micro-constituents and their distribution affect the their mechanical behaviour and so the friction and wear behaviour another important aspect is the surface roughness. So, surface roughness is what another parameter which is another surface property which is important from the wear and friction point of view is the surface roughness.

So, what surface roughness is, surface roughness indicates the extent of the extent of ups and downs which are present or extent of irregularities which are present at the surface or extent of asperities which are present. So, if we see here ups and downs are very limited all real surfaces will have such kind of the irregularities as compare to the case when ups and downs are of this level.

So, if we quantify these 2 roughness is here we may find Ra of the point 5 micrometer and here it maybe 1.5 micrometer. So, there is a so Ra simply indicates the extent of the ups and downs surface are regularities or asperities or what we can say peaks and valleys are present on the surface. So, greater is the roughness means greater will be the surface regularities or asperities will be present higher will be the peaks and deeper will be the deeper valleys will be present on the surface.

And why it is important for having good control over the wear rate as well as having the low friction co-efficient it is important that surface roughness Ra is as less as possible but not very too high finish is also needed. Because that in turn is starts increasing the friction, so an optimum level of the Ra is important and like say the 0.01 or 0.1 Ra micrometer Ra will be excellent surface roughness for from the tribological performance point of view.

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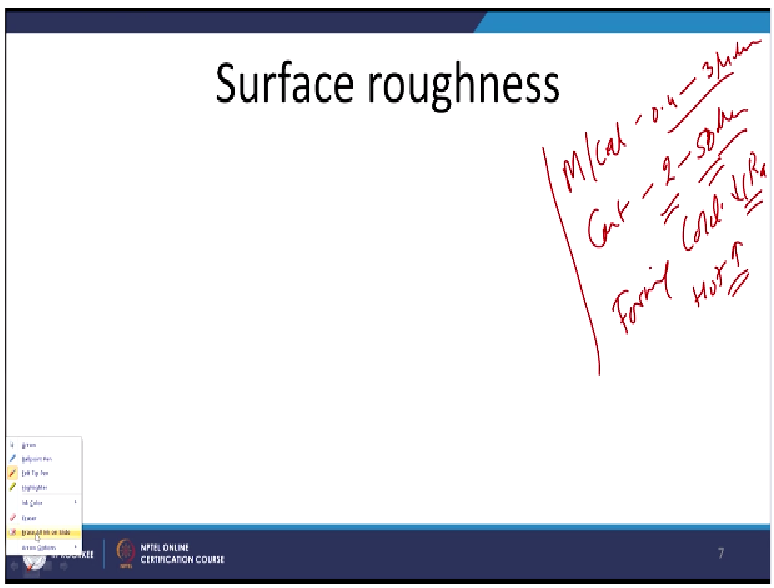

But if considering that most of the manufacturing processes all the depending upon the manufacturing process use to being make a particular component the different kind of the surface roughness can be there like all machine components. So, roughness varying from like say 0.4 to like maybe 3 or 4 micrometer also which is too high well the cost components results in like maybe 2 to 50 micrometer Ra 50 for like send cost or very course send cost and very fine dye cost components.

So, depending upon the kind of manufacturing processes being used the roughness, similarly in case of the forming based methods like whether it is cold, cold will be having cold forming methods will be showing the lower Ra values as compare to the hard forming based method they will showing the higher Ra value. So, what if there is kind of particular kind of the roughness is present and why it is important from the wear and friction point of view.

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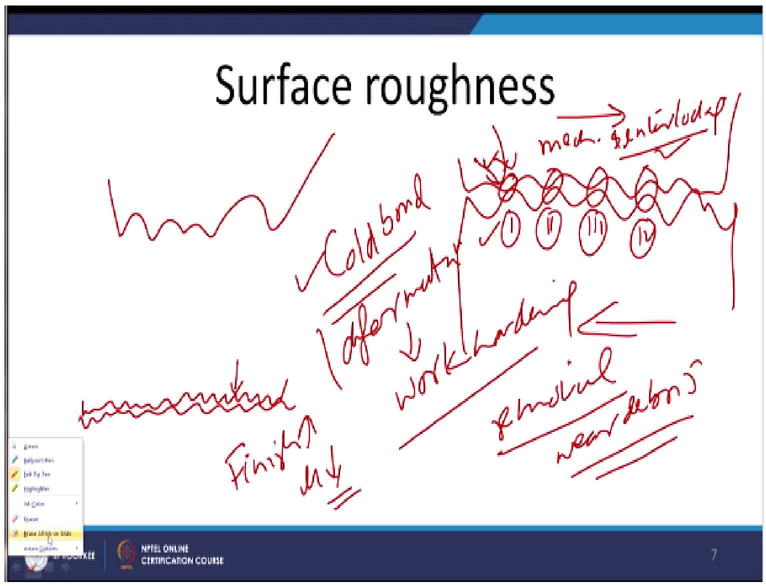

So, the Ra is important why because whenever if the surface roughness is present on the real component and the 2 are brought enclose contact with the each other during the sliding. In that case these peaks and valleys come in contact with each other and try to have the mechanical interlocking and when the 2 come very close means 2 peaks and valleys come very close to each other from both the mating components they form cold bond.

The cold bond is formed and due to the relative motion between the 2 there is always some kind of near surface layer deformation. So, which facilitates the work hardening of the surface layer material, so in that case out of the 2 mating components which are in relative motion with each other whichever is weaker the removal of the material or removal of the debris from that zone takes place say these are like 4, 5 cold bonds have been formed.

So, to maintain the relative motion these bond should be broken, so these bonds can be broken from the interface or from any of the 2 sides. So, whichever is weaker, if the bond is weak then the fracture of the bond will be occurring otherwise removal of the material from 1 side will be occurring whichever is weaker. So, whenever the metals come in direct metal to metal contact, cold bond is formed due to the mechanical interlocking followed by removal of the material from one side.

And that the material whatever has been removed from 1 or other side that finally will be removed in form wear debris as a loss of material from the functional surfaces. So, in this case if the surface is very rough then the area of the bond is great is large and so it requires greater force to maintain the relative movement. So, as compare to the case when the finish is too high means roughness is very low.

Then the cold bonding will be taking place over a smaller area cold bond area will be very small. So, to maintain the relative movement the force required for breaking of such kind of bonds will be less and therefore friction will also be less. That is why whenever finish is increased we find that friction force is reduced because of the reduced possibility for such kind of the cold bond formation or mechanical interlocking tendency.

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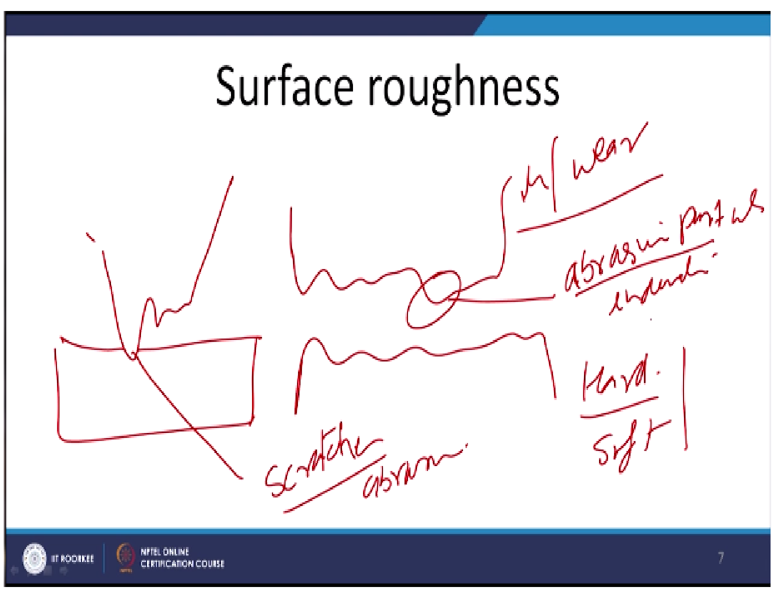

This is 1 aspect of the surface roughness where mechanical interlocking will be affecting the friction as well as wear greater the mechanical interlocking and cold bonding, greater will be the friction, greater will be the wear tendency as compare to the case when the limited size of the cold bonds or bond area is formed. Another aspect is that out of the 2 mating components like this 1 will be hard and another will be soft.

We do not use the mating components of the same type, they will be they will always the design is always made in such a way that the 2 are different for good wear and friction performance. So, out of the 2 one will be harden, 1 will be soft there should not be much gap between the 2 but anyway if 1 is too hard. So, if the hard component having the too high roughness then these peaks will be acting as a abrasive particles or indenter**.**

So, such kind of the peaks which are present on the hard surfaces they will be indenting the soft surface, such kind of indentation will be leading to the formation of scratches and abrasive marks onto the soft surface. So, the peaks present on the rough surfaces will be acting as a abrasive particles are indenters onto the soft surfaces forming the indentation and removal of the material by scratching.

So, this is another aspect that if the hard surfaces are having the greater roughness then they will be increasing the loss of material by abrasion.

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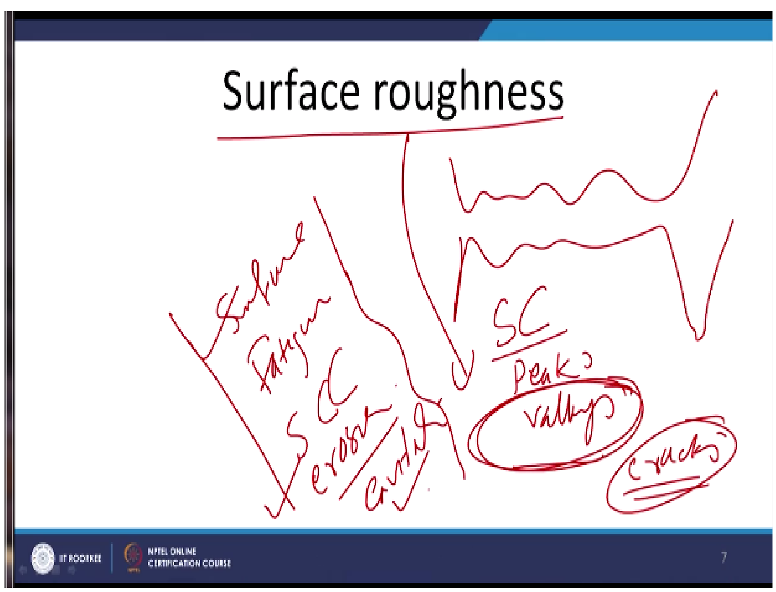

Another aspect is that whenever the surface roughness is too high surface roughness will be like if the roughness is too high then there will be presence of the peaks and valleys. So, these valleys especially act as cracks, fine cracks and so in all those conditions like under the surface fatigue wear, stress corrosion cracking, erosion conditions where impact is involved, cavitation conditions.

So, in all those conditions where impact is involved or the forces onto the surface will be acting at regular interval the high depth valleys will be acting as a crack and these will be facilitating the growth of crack easily for removal of the material. So, surface roughness if the roughness is too high it can act as a stress concentrator and especially at the location of these valleys.

And if the stress concentration is too high because of the high surface roughness then under the surface fatigue wear conditions, erosion conditions cavitation conditions the rate of material removal will be high. So, it is good to control the surface roughness especially the component is subjected to the conditions where the stresses onto the surface will be acting at regular interval.

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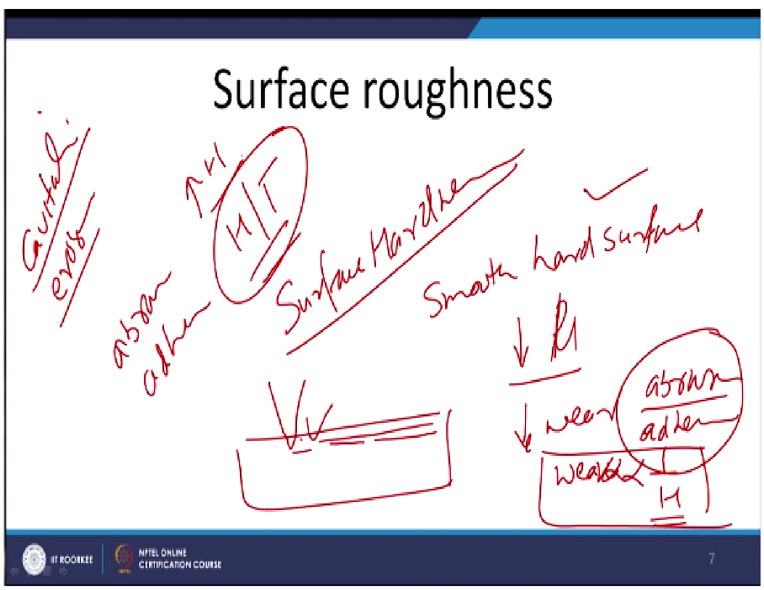

Now another aspect is about the means the next important property is the surface hardness which is very important from the wear and friction point of view very smooth hard surface results in the lower friction and reduced wear both abrasive and adhesive type. There is very famous archers law on the adhesive wear which says that the wear is inversely proportional to the hardness of the material inversely proportional to the hardness of the material.

So, greater is the hardness, greater will lower will be the wear loss from the material similarly the hardness also affects the abrasive wear. Because in case of the abrasive wear abrasive particle or intender should indent the surface and then due to the relative movement 1 sketch will be formed onto the surface for removal of the material. But if the hardness of the material is high then the depth of indentation is reduced.

And accordingly the volume of the material being removed by the scratching or abrasion that will also be reduced. So, an optimum level of the hardness is good for both abrasive and adhesive wear, if it is the only abrasive wear then hardness should be high but if it is the adhesive wear then combination of the hardness and toughness is important while under the conditions of erosive wear and the cavitation erosion conditions it is important that a good combination of the hardness and toughness maintained.

So, that surface can remain coherent and the material from the functional surface is controlled. Now I will summarise this presentation, in this presentation basically I have talked about the role of the grain structure on the wear and friction behaviour of the material, the role of the surface roughness and the surface hardness and how these surface characteristics can be related in the wear and friction properties, thank you for your attention.