Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations

Prof. Dr. D. K. Dwivedi
Department for Mechanical and Industrial Engineering
Indian Institute of Technology-Roorkee

Lecture-17
Surface Damage: Abrasive Wear II

Hello I welcome you all in this presentation related with the subject fundamentals of surface engineering and we are talking about the average to wear. We have talked about the mechanisms which are responsible for the material lost by the abrasive wear and we have also talked about the summary of different parameters that affect the abrasive wear behaviour of a material.

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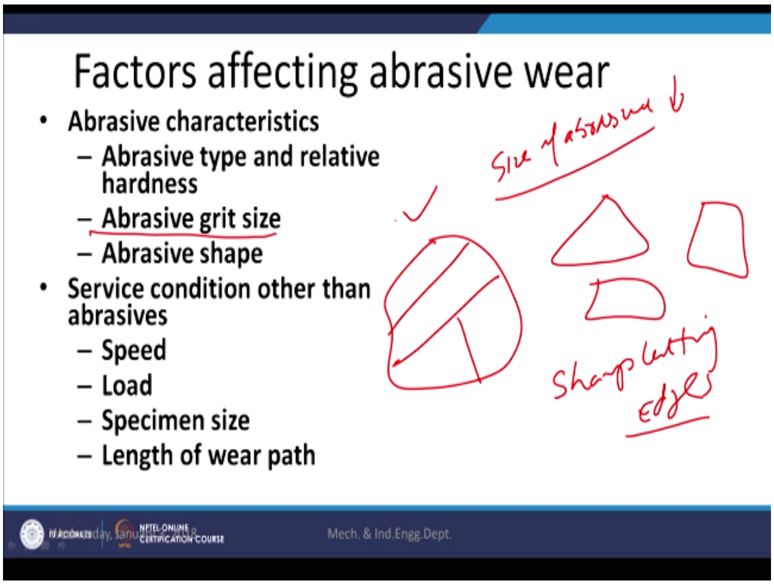

So among the different parameters that affect the abrasive wear behaviour we have talked about the abrasive wear particles, so just a quick look of the different factors that affect the abrasive wear behaviour of the material includes like the abrasive wear characteristic means which type of the abrasive will be causing the wear of the materials due to the abrasion. So it is abrasive type and it is a relative hardness.

Relative hardness it is with respect to the workpiece. So as we have seen that since the different abrasives like alumina, silicon carbide and different particles will have the different hardness according to the hardness of the abrasive particles with respect to the workpiece. The wear behaviour is influenced in different ways as per the hardness of the abrasive.

It has also been said that if the hardness of the abrasive is too high as compared to that of the hardness of the workpiece, then hardness of the average does not affect the things much, but if the hardness of the abrasive is almost close to that of the hardness of the workpiece and definitely it affects abrasive wear behaviour significantly. Now will be talking just taking of the other factors related with their effect on the abrasive wear behaviour.

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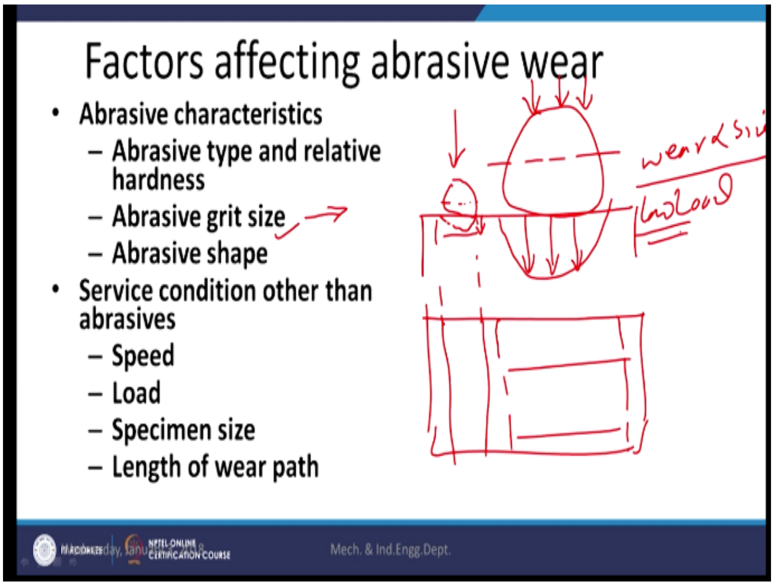

So that the other factor is like abrasive grid size abrasive grid size, so among the abrasive grid size we know that this is the surface of the workpiece which is under the influence of abrasive and particle size is small then under a given load conditions it will be causing a limited maximum up to the half of the diameter of the particle. So maximum intention usually caused by the abrasive particle will be smaller one.

And wonder the average where conditions accordingly to forming the scratch of the same size along the length of the workpiece as per the abrasion until it is stopped or scratch, scratching is stop by the presence of the hard particles. On the other hand if you consider that abrasive is of the largest size and in that case under the service conditions when the load is transferred through such kind of the particles.

Then it will be causing the larger size of the indentation which will be much deeper and accordingly it will be developing the much larger size of the scratch and since the volume of the materials removed by the abrasion will be equal to the volume of the scratch which is being formed. So the abrasive grid size directly affects the volume of the material being removed due to the scratching action.

And if we see this closely then this area of the material which is being is removed from a particular section is being a directly influenced by the depth up to which is taking place by the depth of which is being caused by the abrasive particles. So when the depth is small for the fine particle while it is some in case of the coarse particles in the depth of penetration is more and that is why what we see for the initial in the initial stages the wear directly increases with the abrasive grid size especially under the low load conditions.

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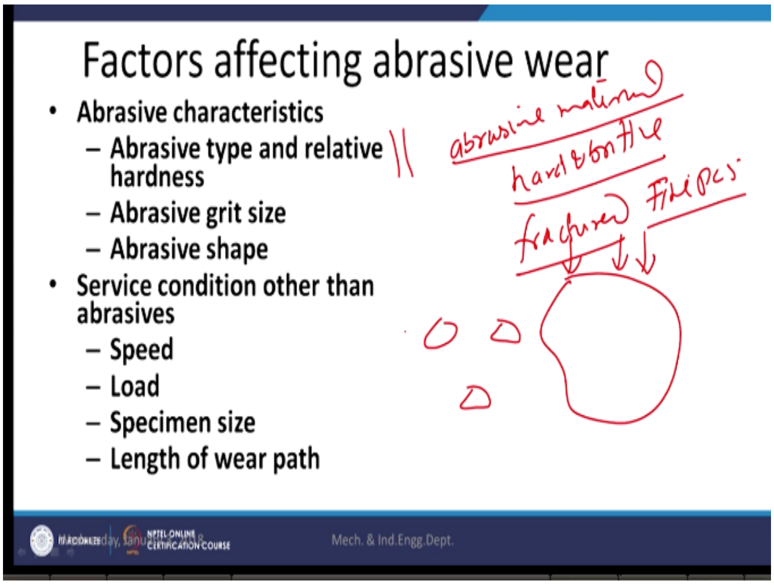

Why it is about the low load the about that I will talk now and then effect of the load on the wear rate with regard to the grid size we can see with respect to the abrasive material, abrasive material itself like few abrasive materials are very hard and brittle. So this hard and brittle materials when they are subjected to the external loading they have tendency to get have fractured.

They tend to get fractured into the fine pieces, so even if the particle size is big under the service conditions if the hard brittle particle comes under the influence of external load it will have tendency to get fractured. So such kind of the fragmentation will be leading to the reduction in the size of the abrasive. So if the load is limited then the abrasive will be able to withstand and if the load is high then hard and brittle abrasive will get fractured.

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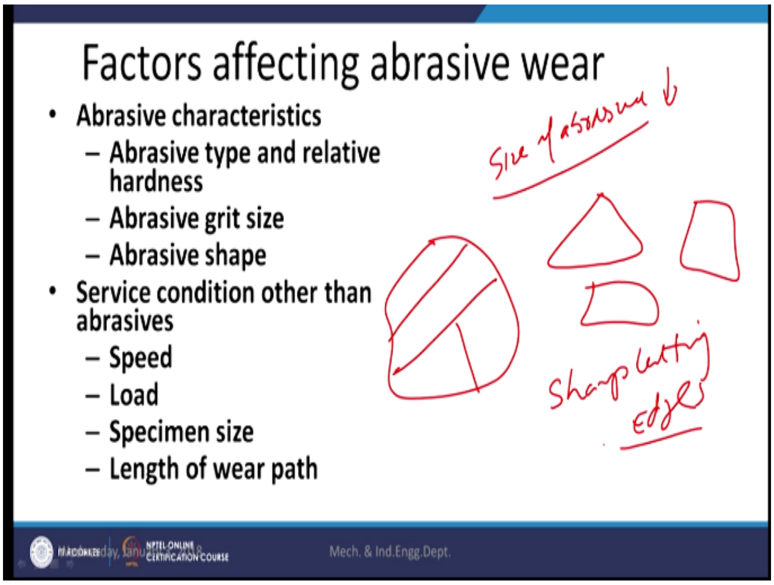

Now this fracture can affect the abrasive wear in 2 ways, 1 is a directly that the size of the abrasive is reduced, abrasive part is reduced, another side is that 1 brittle fracture of the abrasive particle takes place it happens to the development of the sharp edges and corners. So this is sharp edged pieces of which are produced due to the fracture of the large size of abrasive particle this you have the sharp cutting edges.

And these sharp cutting edges promote the removal of the material by the abrasion as well as the metal cutting. So basically if the hard and brittle particles are there and after the fracture it will produces the fine particles although reduction in size should reduce the abrasive wear but sometimes this is neutralized by the development of so many particles which are having the sharp cutting edges which promotes the abrasive to the sharper cutting edges and removal of the material by cutting.

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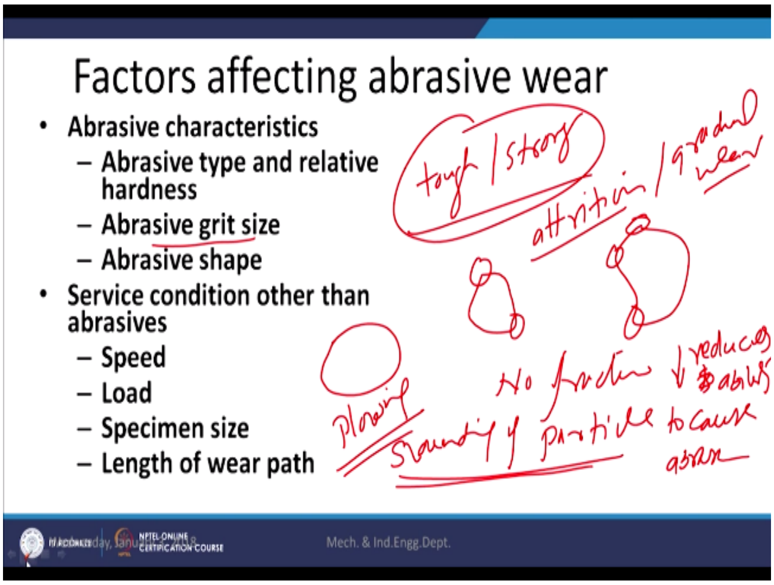

So the abrasive grid size has a different kind of effects in light of if we see as per the kind of material which is abrading. On the other hand if the abrasive is tough and strong in that case the abrasive particle whether it is fine or the big one it will not tend to break, so no fracture in these cases or no easy fracture is observed, but the sharp edges corners of such kind of the particles are subjected to attrition which we can say gradual wear of the particles itself.

And such kind of attrition leads to the rounding of particles which are hard and which are a visit of and strong and such rounding of the abrasive particles reduces their cuttability reduces their ability to cause abrasion. So in case of the tough and strong abrasives continuous attrition during the abrasion leads to the rounding of the abrasive particles which in turn reduces their abradability cuttability due to the reduction in the number of sharp corners cutting edges.

And so the cutting ability reduces, so even if the particle is very large in size but if it does not have sharp corners then it will have tendency to cause more ploughing action rather than cutting or microcracking. So cutting will be more effective when there are sharp corners and edges are present in the material. So what we can see here the size of abrasives in the beginning and size of the abrasive which is actually acting on to the surface of the workpiece.

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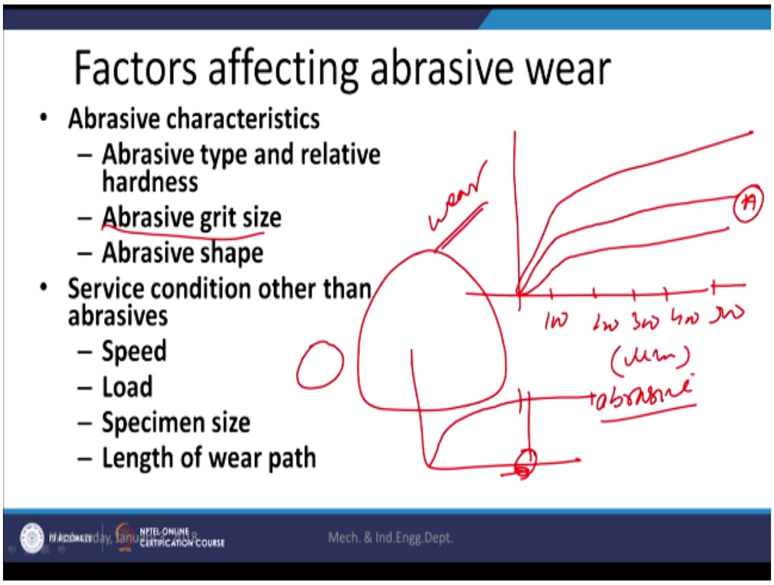

And causing the abrasion, these may be two different things because as per the abrasive material, this size will keep on changing, the shape of the abrasive will also keep on changing. So with regard to the size if we see size effects so on increasing the size of the abrasive say 100, 200, 300, 400, 500 micrometre average diameter of the abrasive, then initially it rapidly increases the wear of the material.

And then rate at which the wear of the material will be increasing with the increase of the abrasive size that will be reducing. However this rate may vary for the different material, this may be for 1 material, material A then for the material B it may change like this for materials C it may change like this. So initially there is a increase in the wear with the increase of the abrasives size and there after the rate of increase in the wear decreases with further increase of the abrasive.

So this what you may see after sometime after initial fast increase there may be flattening where in means for the largest size abrasives may not be able to increase the wear further, but wear will keep on taking place at a particular rate only. So what will say and what is the reason behind this when the abrasive size is small it has less tendency to get fractured as compared to the case when the abrasive particle size is large.

Large abrasive particles will start getting fractures, so after certain stage when it happens then say for this particular plot beyond size means this size of the abrasives the further increased in size of the abrasive will lead to the situation where under the given service conditions abrasive may start getting fractures, So the size will start getting reduced. So the abrasive increase an abrasive size increases the wear up to a certain critical level thereafter.

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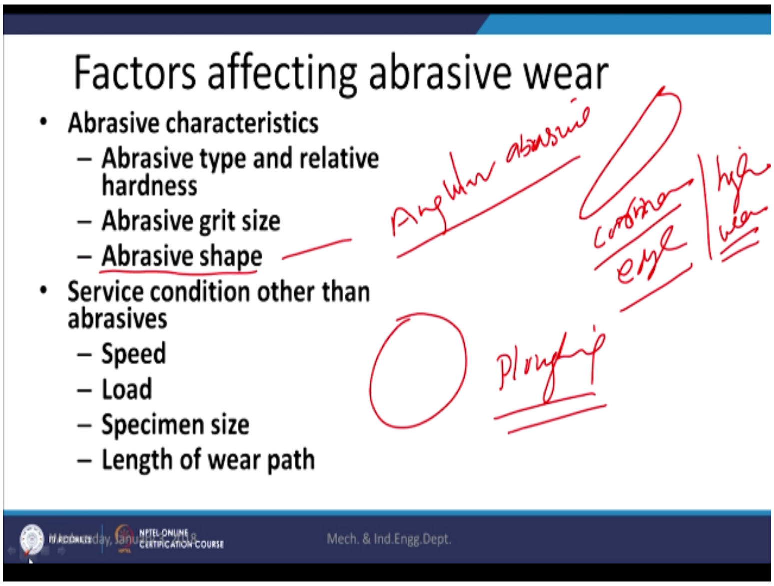

There may not be a significant increase in the wear with the increase of the abrasive size, abrasive shape is the another aspect like the shape is like the angular abrasives which may be like in form of the sharp corners are sharp edges are these will be causing the higher wear rate higher abrasive wear as compared to the round shape particles and round shape particles will be causing the lesser wear due to the absence of the sharp cutting edges.

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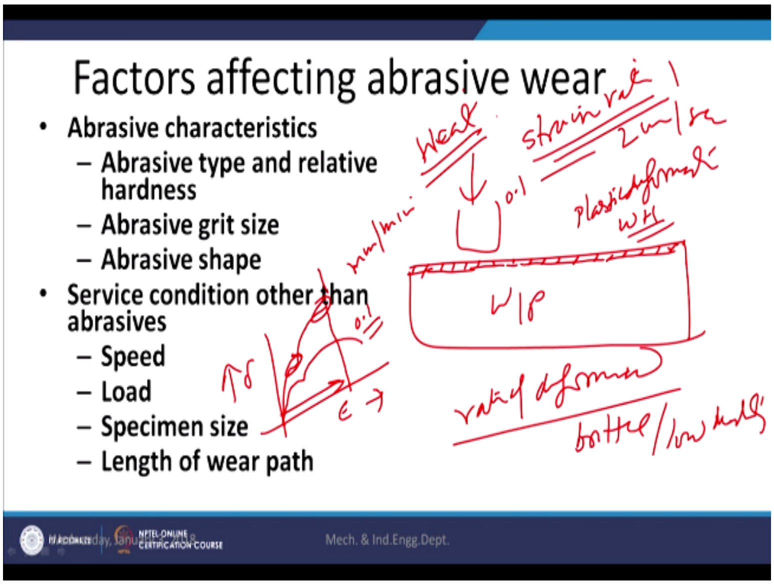

So in this cases mostly the material loss takes place by the ploughing action. The other factors like speed load specimen size and the wear track. So if we see abrasive wear means like say the speed at which the abrasive medium is moving over the surface of the workpiece. So it may move at like say 0.1 meter or it may move 2 metre per second. So when the abrasive is moving at the different speeds with respect to the workpiece.

Accordingly the material present at the surface will be affected by the deformation or by the work hardening because whenever the abrasive load is applied through the abrasive material will be deformed plastically, plastic deformation and which intern will be experiencing the work hardening. So near surface layers will always be experiencing the deformation as well as work hardening.

So work hardening material will have its own effect whenever there is a change in the speed then the rate of the deformation of the material is affected, if it to deform the material at higher rate then it tends to behave more like a brittle material, low ductility. This is what we can see from the one simple diagram also like during the tensile test if you perform the tensile test at lowest strain rate then we find 1 plot like this say at 0.1 which is basically about crosshead speed 0.1 mm per minute.

And if we do it at 1 mm per minute then we may find with the higher yield strength and higher ultimate strength and lower ductility in terms of the percentage elongation. So this side we have a stress and this size we have a strain, so higher strain rate tends to increase the yield strength and hardness and reduces the ductility similar kind of the experience will be similar kind of behaviour will be shown by the material present at the surface when it is subjected to the abrasion by the particles moving at a different speeds.

So at lowest speed so this is 1 aspect that the strain rate experienced by the material at with variation of the abrasive speed that will be different, another aspect is whatever work done during the interaction of the abrasive particles with the workpiece a part of that work is convert into heat. So when we move the abrasive at higher speed so more heat localisation will be taking place which in turn on increasing the temperature of the workpiece surface layer.

So they may not be all the during the abrasive, there may not be very high temperature rise, temperature rise maybe like 2 degree, 3 degree, 5 degree or 10 degree most of the time it is not much, while in case of the adhesive the rise in temperature is significantly like 100, 150 or even 200 degree centigrade rise in temperature can occur in the abrasive wear condition. So these are basically 2 factors which affect the average to wear with the change of the speed.

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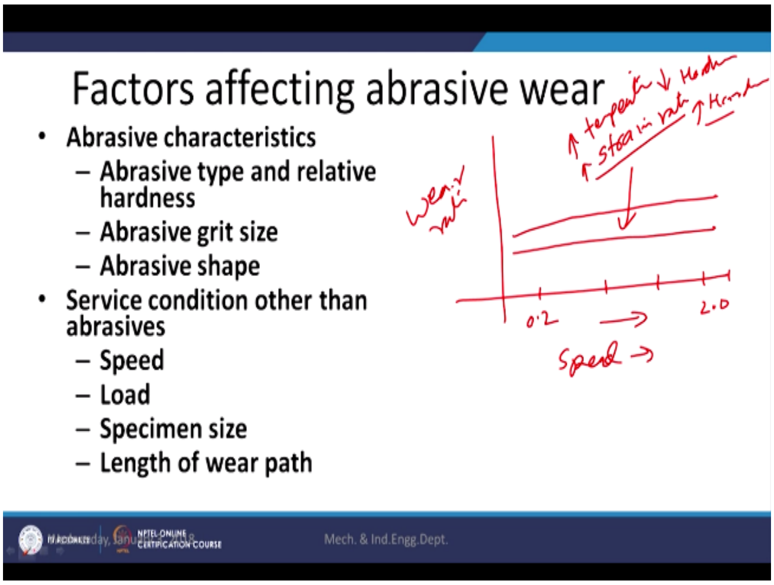

So if we put the speed of the abrasive movement like 0.2 and here if we have 2.0 and this is the speed of the abrasive movement and here we have the wear rate then this is found almost constant or there is very marginal increase. So this slope is very less, so which suggest that there is no major change in the wear rate abrasive wear rate with the change of the speed of the abrasive the act.

The speed at which the abrasive action is taking place and what are minor increase in the abrasive wear rate is occurring that is basically attributed to the increase in temperature due to the heat generation or localisation generated which will be leading to minor reduction in the hardness and second one which will the factor which will be acting in opposite way that increasing in the increase in speed will be leading to the increased strain rate of experienced by the material during the deformation or during the interaction of the abrasive particles with the surface material.

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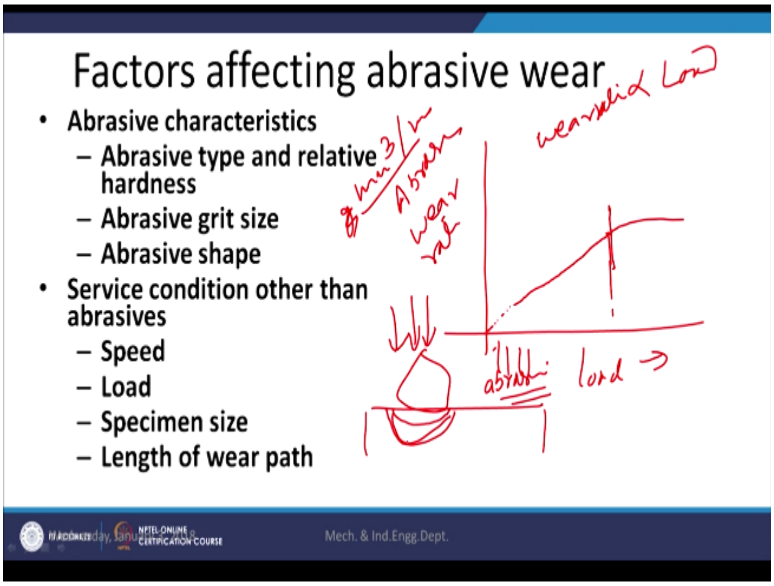

So this will be causing by hardness of the materials. So these 2 factors may neutralize that is why we may not be do not presently find a significant change in the wear rate with increase of the speed, the another important factor is the load, initially now we know that this is surface of the workpiece and abrasive and load is up right to the abrasive to the surface of the workpiece is under these conditions.

And what will happen is increase in load another the identical conditions of the abrasive retains its size and shape, then increase in load will increase the depth of indentation. So increasing depth of indentation will simply increase the abrasive wear rate under the identical conditions. But if with the increase of the load aggressively starts getting fractured, getting damaged, then the increase in the abrasive wear rate will be reduced.

Here we have the abrasive wear rate which we say in terms of like the loss in terms of like mm cube per meter or per unit time. So if you thought that then to the increase of the load there is continuous increase in the abrasive wear rate up to unlimited. Thereafter it will start getting flatten. So there may not be much increase. So there is a direct relationship means the wear rate initially wear rate proportional to the load.

But up to a limit there after division in the increasing wear rate and load relationship is observed and this the curve start getting flattening this is the condition suggest that the damage to the workpiece, damage to the abrasive have started and simply increase in the load is not causing much of the indentation to cause the cutting and abrasive action and that is why increase in load increases the abrasive wear rate up to a certain limit.

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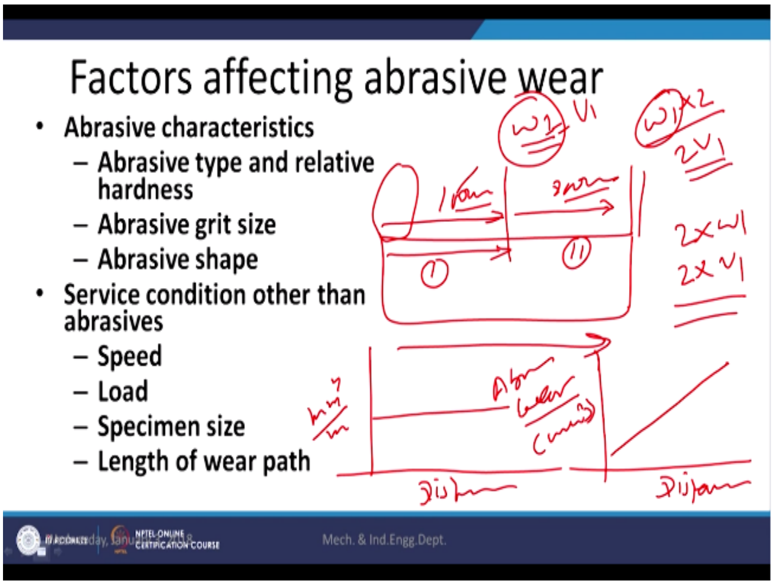

Thereafter for the increase in the load does not increase the abrasive wear rate appreciably, the another important factor is like to wear track and length. For example under the identical condition if this is the sample and if we apply the abrasive and then cause the abrasive reaction up to this line, then it will be causing the weight loss W1 or wear volume is that W1 and if this distance is linearly distance is doubled then what will see that it is the twice of the initial weight loss.

In the first stage or twice of them the volume loss which had taken place in the track 1 and this is track 2. So track 1 means when the abrasive interacts with the workpiece up to certain distance say is 100 meter and so we get the weight loss w1 and when this distance is doubled to 200 meter then will find means for another 100 meter distance of the total distance travelled will be like 200 meter.

And then again you have lost then the for the another 100 meter interaction of the abrasive with the workpiece again it will be of the same magnitude. So if we check the total loss of the material then it will be twice of the w1 or twice of the V1 and that is why normally as we increase the sliding distance or the length of the wear track under the abrasive condition that it is linearly increases the wear abrasive wear which is in terms of mm cube.

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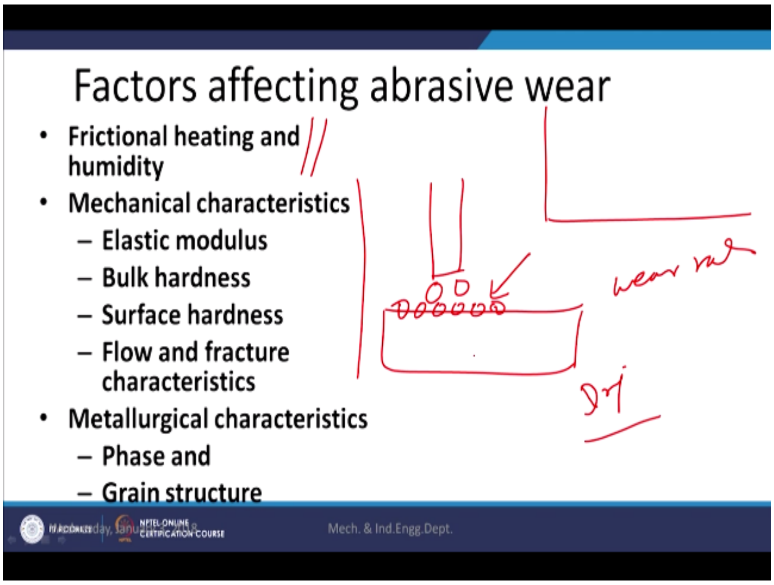

And if we measure the wear rate where mm cube per meter sliding distance then there may not be any change in the wear rate as a function of distance it remains almost constant. So this is about the effect of the wear length or these are the other factors like the mechanical properties and the effect of mechanical properties and frictional heating and humidity as far as the fractional heating and humidity is concerned what will notice.

That if the abrasives interacting with the workpiece in the human environment and the human environment is causing the chemical action with the surface of workpiece which are and what are chemical compounds being formed at the surface and can easily abraded then such kind of abrasive action on to the chemical compounds being formed in presence of the human environment, then it will be increasing the wear rate.

So as compared to the dry environment human environment will be causing the greater abrasive wear it if it is a indirect workpiece surface and forming some of the soft compounds on the other hand if the frictional heating is too much then it will lead to the rise in temperature of the surface of workpiece which will be softening the workpiece material and increasing the indentation depth by the abrasives and which in turn will be increasing the wear abrasive wear of the material.

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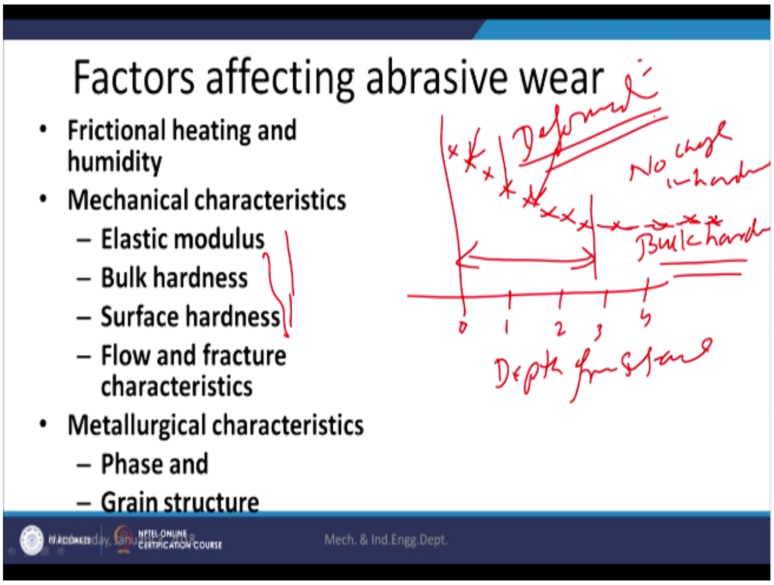

Similarly effect of the hardness so we have already talked hardness and softness of there is a difference in the bulk hardness and surface hardness in the sense that if this is the surface. So distance from the surface is like surface is 1 mm, 2 mm, 3 mm, 4 mm increasing depth from the surface. Then what will notice the surface which has been subjected to the abrasion it will have the higher hardness.

Because the surface is experience the deformation and which will be causing the work hardening. So then the surface and near surface layers have the higher hardness as compared to the subsurface region. So this is a distance of which will say work hardening effect can be noticed and below that there is a subsurface region where there is no change into the hardness into the surface layer deformation.

So this is basically the bulk hardness, what matters in the abrasive wear or in all forms of the wear is what are the actual surface properties and the surface properties are actually modified during the operation or during the abrasion or during the adhesions or erosion. So we are more concerned about the surface properties which are usually higher due to the surface layer deformation under the actual service conditions like in abrasion, adhesion etc.

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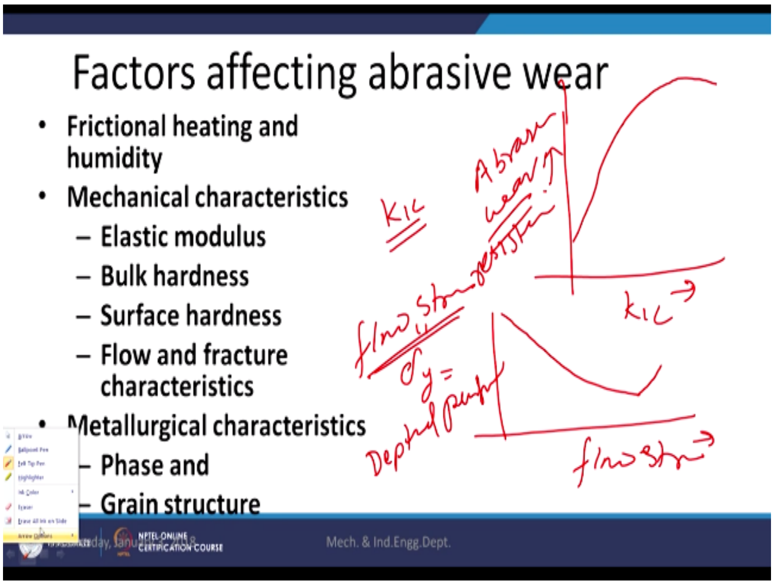

And other important property is the flow characteristics or fracture characteristics, for fracture characteristics like we have fracture toughness of the material, so fracture toughness shows the resistance to the crack growth and resistance to the fracture by the crack growth. So if the K1C of the metal was the fracture toughness of the material is high initially it increases the fracture toughness significantly.

And thereafter it starts getting flattering, so abrasive wear behaviour of the material can be compared and we may notice that far as the fracture toughness of the metal increase in general resistance to the abrasive wear resistance basically, abrasive wear resistance increase with the increase of fracture toughness. Thereafter it starts getting flattering. Similarly the flow characteristics of the material it is not just the yield strength of the material, if the material is under the anneal condition then flow stress and yield stress both are same.

But if the material is subjected to some kind of the deformation effect either during the service or it has experience the work hardening effect, then we need to consider the flow stress. So the flow stress besides the size of the material under the influence of the abrasion or under the influence of the abrasives. So which will be responsible for determining the depth of penetration by abrasives.

So if the flow stress of the material is increased then of course it will be reducing the abrasive certainly up to some extent but a significant increase in the flow stress which material used in to behave like a brittle material also, so too high flow stress measure the material in that case will be very high yield strength in that case will be losing its ductility hardness will be increasing.

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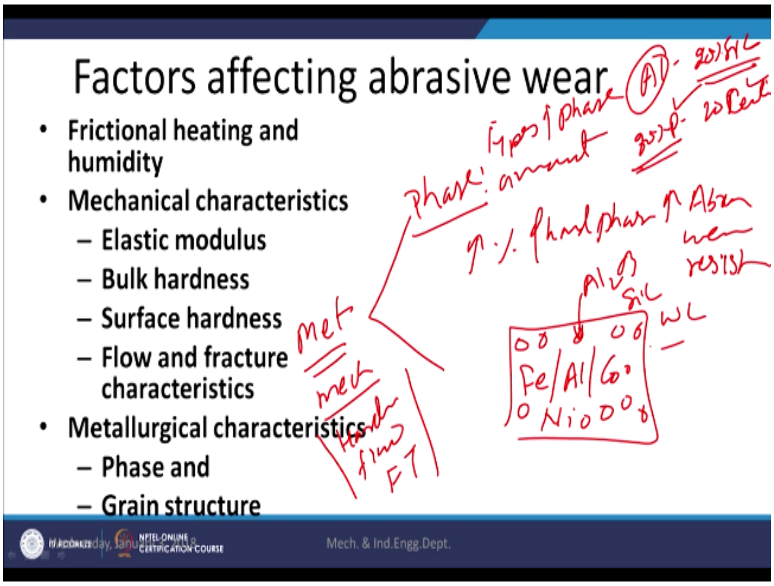

So that may again that situation may again may not be favourable and abrasive may start increasing especially about the impact conditions. Now the another important aspect is the factor which will be affecting the abrasive wear is the metallurgical aspect, we know that the metallurgical properties significantly affect the mechanical properties like hardness flow stress, fracture toughness and therefore it is important that the metallurgical effects are made to relate the mechanical properties and mechanical properties and then there were tribological properties.

So as far as the metallurgical properties are concerned we need to consider the phase structure means what is the different phases, what are the different types of phases which are present, what is their relative amount of the different phases like the matrix is aluminium and that 20% of the silicon carbide. If this is so this is the matrix 1 phase and this is the another phases.

Similarly we may have the 80% of the pearlite and 20% of the cementite Fe3C. So these are the 2 phases the type of phases pearlite and cementite and what is the relative amount of proportion of the phases. So increasing percentage of hard phases in general increases the abrasive wear resistance and therefore the efforts are made especially in case of the saoft matrixes to reinforce the hard particle.

So that the abrasive wear resistance can be enhances, so soft metal matrix like iron, aluminium, Cobalt, Nickel. These are soft and completely tough so efforts are made to reinforce some hard particles in the matrix of the soft particles. So that their resistance to the abortion can be enhanced and it can be in form of like reinforcement of Al2O3 silicon carbide tungsten carbide etc.

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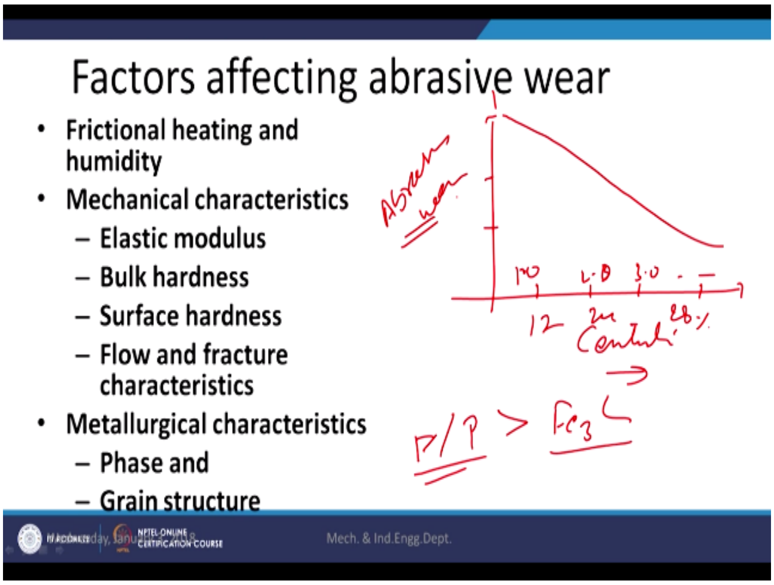

As per the purpose and compatibility. So in general if you see as far as the type of phase is concerned in case of the simple iron-carbon system increasing percentage of the carbon like 1, 2, 3, etc. so the increasing this will be increasing say the fraction of the cementite on the x axis if we have like 12, 24, 28% of the cementite in the x-axis and the in the y-axis what we have the abrasive wear. Then what we will notice that there is continuous drop in the abrasive wear with the increasing fraction of the cementite.

Because as compared to the pearlite cementite and pearlite and ferrite, cementite Fe3C is harder significantly harder, so which in turn causes the abrasive through by reducing the indentation and therefore abrasive wear resistance is enhanced with the increasing fraction of the cementite and similar kind of further studies can be undertaken for wearing fraction of the different hard consistent in the soft and tough matrix.

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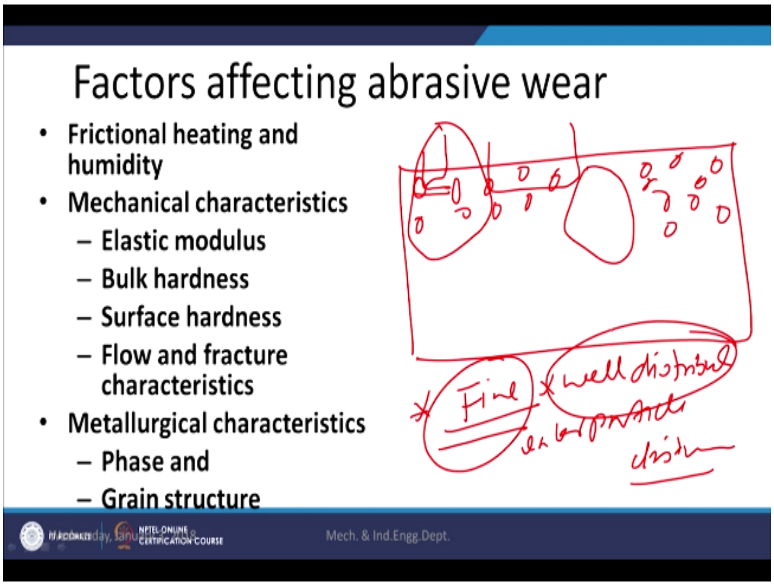

Similarly apart from the fraction of the hard phases may be reinforce in the soft and tough matrix, it is important that not just fraction is important but how they are distributed and what is their size. So just big size particles may not be enough it is always good at particles are small in size and they are well distributed. This will help in 2 ways so what is the important that fine particles and well distributed particles.

So that interparticle distance is less to cause the abrasive if there is abrasion is cause then the soft material in this case and then the path of the abrasion or the stretching will be stop by this hard particles, but if the abrasive or widely space then the abrasion will take place very easily. So in order to have good abrasive wear resistance it is important that the particle size is fine and it is well distributed.

How would I get size of the particles to reinforce will determine the size of the abrasive that will be causing the abrasion under the actual service, so considering the services the type of the abrasive, the abrasive size must be considered for designing the surfaces so that we can have the consequence of suitable time and suitable size in surface layer, so that we can offer the required abrasive wear resistance. Now here I will summarize in this presentation, in this presentation basically we talked about certain factors like abrasive properties.

The surface conditions like low, high speed and the metallurgical factors like phase and grain structure and the way they use affect the abrasive behaviour of the wear material, thank you for your attention.