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-18
Surface Damage: Erosive Wear

Hello I welcome you all in this presentation related with the subject fundamentals of surface engineering and we have talked about the 2 big categories of the wear that is adhesive wear and abrasive wear. In this presentation will be talking about the erosive wear which is also commonly observed in the cement industries, hydro power plant and wherever the free moving particles are interacting with the mechanical components.

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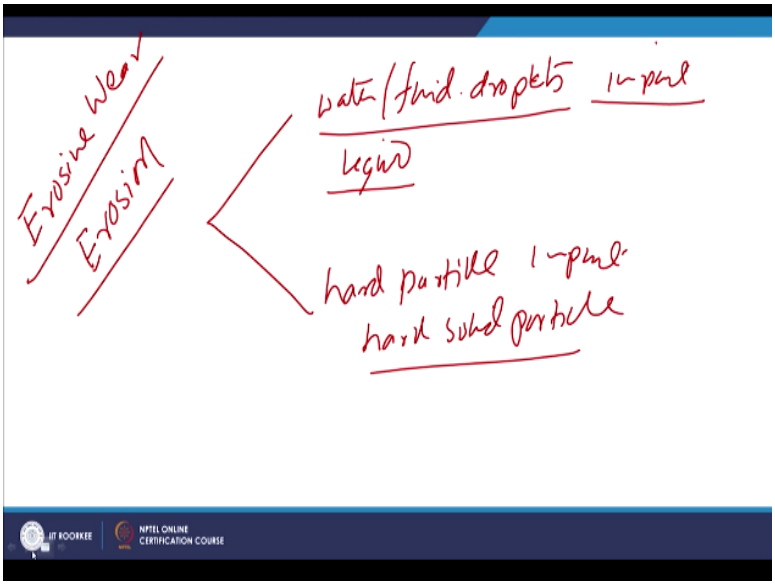

So the topic is erosive wear, the mechanism by which material loss in this mode of wear takes place is the erosion and this is caused by the 2 types of the situations 1 when the water or fluid droplets moving at high speed impact with the surface of the component being considered or hard particle impact or impingement of the hard particle on the surface of the workpiece takes place.

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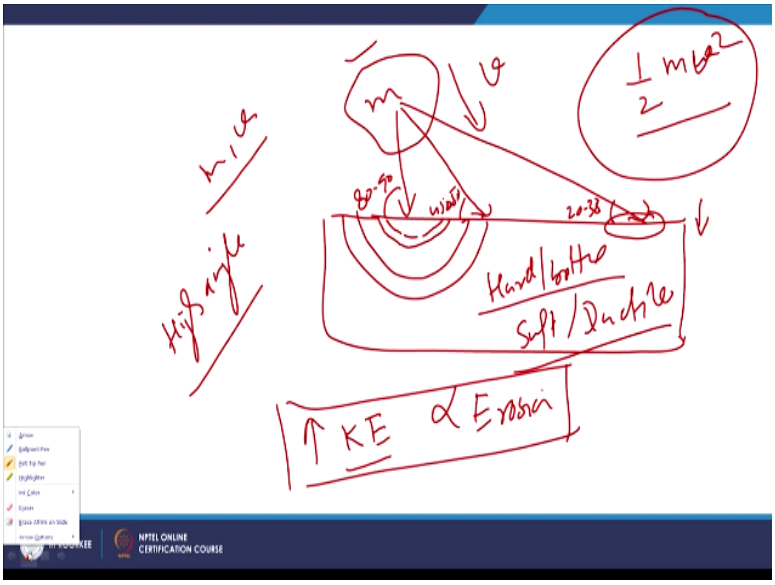

So basically it is the liquid drops of the liquid and the hard solid particles, their impingement or impact with the surface of the workpiece causes the removal of the material. Now if see schematically how does it happen then say this is a particle and this is the surface of the workpiece which is being subjected to the erosive wear. So particles will have some mass and it will be moving with same velocity and based on this we can find the kinetic energy associated with the particle like 1/2 Mv square, whenever I velocity particle moving at a certain speed impacts with the surface of the workpiece.

So it can impact at high angle it can impact at a low angle like this. So in this 3 cases angle of impact is close to like say 80 to 90, in this case impact of angular like 45 to 50 or say in this case it is 20 to 30 so these are 3 angles at which this particle can impact or it can impact at other angles also, but it can lead to the different ways of the material removal from the other functional surface which is being considered.

And it is the severity ability of the impact will also change with the angle of the impact, whenever it impacts depending upon the kinetic energy associated with the impinging particle or impinging droplet, it will be causing some kind of the damage on to the surface. So if the particle size is large and velocity is high it will be causing the greater damage in form of the surface layer deformation and 1 depression will be formed some kind of pit or the cavity will be formed.

But a particle move M moving with velocity V if we take it impinges at a low angle then the energy at the time of impingement and its effect will be less as compared to the case of the

impingement or impact takes place at high angle. So high angle impingement will be causing more damage to the surface as compared to the case of the low angle impingement. However depending upon the type of the metal whether it is hard and brittle or it is soft and ductile.

The at extent of erosion which will you taking place that can vary significantly, so it is the type of material of the workpiece that will govern that will significantly determine the loss of the material from the functional surfaces when impingement at different angles take place even with the particle of the given mass and the given velocity. So if we see if the mass is more for a given velocity then impact the kinetic energy will be more accordingly the effect of impact will be more.

And accordingly it will have the greater depth of the pit and greater size of the pit which will be form as compared to the case when the mass is less or the velocity is lesser so kinetic energy associated with the particle is less. So it means if we have the higher kinetic energy of the particle associated with, so increase in kinetic energy in general increased erosive or erosion of the material from the functional surfaces.

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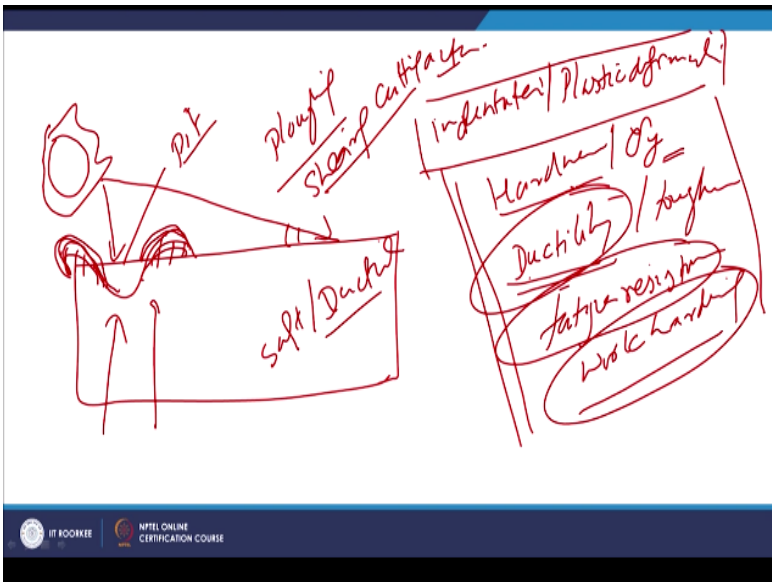

So this is 1 aspect as far as the erosion is concerned. Now as per as the different factors that affect the erosion is so in this case apart from the indentation and surface layer plastic deformation which will be governed by the hardness, yield strength of the material. The other factors that determine the material loss by the erosion is also the ductility, toughness, fatigue resistance and work hardening tendency.

So these are the important properties which will be determining that extent of indentation which will formed and how easily or with what difficulties and will be removed by the scratching action especially when the impact or impingement is taking place at the low angle. So depending up on the material properties, properties of the workpiece material of the indentation and surface layer deformation will be taken place.

And or the extent up to its deformation will be taken place if the material is extremely hard and brittle metal is very high it is sex done instead of the surface layer deformation the cracking tendency will be more and that will further start promotion the loss of material by the erosion. So if we see what are the mechanisms which are playing an important role in governing the removal of the material from the functional surfaces, say if the particle which is a having the sharp edges like this impinging with the surface of workpiece at a low angle like this.

So it will be causing the ploughing and some time sharp edges causes the shearing to remove the material by cutting action. So low angle impingement causes the ploughing and removal of the material by cutting action through the shearing. On the other hand if the impingement of this kind of particle is taking place at right angles then this will be the more phenomena of the soft and ductile metals.

On the other hand if this kind of the workpiece metal is subjected to the impingement at high angle then sidewise flow will be take all the material will be displaced like this side wise. So this kind of the extensive flow of the metal sidewise here it will be forming a pit where sidewise actually there is no removal of the material but material flows sidewise which is formed as per the shape of the particle which is impinging.

But if the continuous deformation of such kind of the material takes place then it will get work hard and eventually it will be removed. But the removal of the material is less if the soft and ductile workpiece material is subjected to the high angles impingement means erosion by the particles which are impinging at high angle. So this is the case when sidewise primarily sidewise flow takes place and subsequently continued action of the particles impinging participated we get work harden.

Then it will also be experiencing the fatigue action due to the continuous impingement of the particles and then eventually when it loses its work hardening capacity that cracks will develop and the particle will be removed. But the removal of the material in this case is not at that high rate as compare to the case when the soft and ductile material is subjected to the impingement by the erosive particles at low angle and material will be removed by the cutting action to the shearing.

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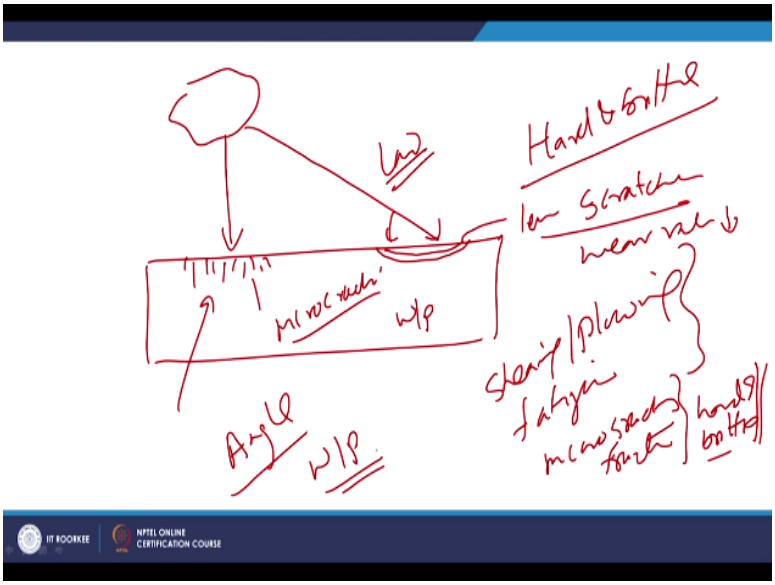

So if we see the soft and ductile materials it is the fatigue resistance the ductility which will be important and the work hardening behaviour which will be important to look into the way by which material is being removed from the functional surfaces. On the other hand if we take an example of the hard and brittle material. In case of the hard and brittle material like this.

So impingement of the sharp articles edges and corners if the impingement it is taking place at a low angle is a particle is substrate is hard and brittle. So it will not allow the indentation to happen easily and that is why the abrasion and scratching will be very less. So less scratching in this case due to the limited indentation and therefore wear rate is also less, when the impingement is taking place at a low angle while if the same particle is impinging at high angle.

Then it will be the high impact will have the tendency to cause find cracks here and there since the material is hard and brittle it will not so much tendency for the plastic deformation and therefore formation of such microcracks will lead to the removal of the material, once (())

(12:22) of these cracks take place. So in case of the brittle materials the much higher wear rate is caused by the particles impinging at high angle.

And through the microcracks and brittle fracture the material loss takes place, so it is about the shearing, drawing, fatigue is in case of the soft and ductile material, microcracks, microfractures are responsible for hard and brittle materials which will be causing the more wear from the material. So less or the low wear low erosive wear for low angle impingement as compared to the high angle impingement in case of the hard and brittle material.

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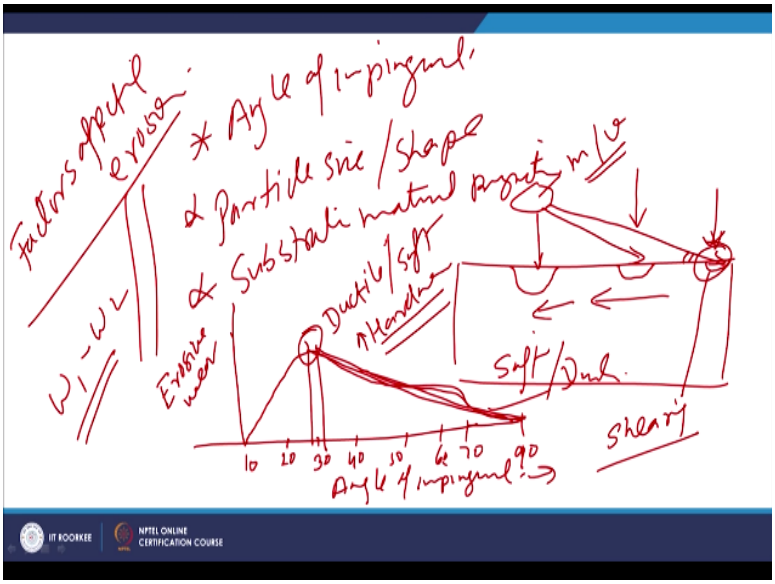

So angle of impingement and the workpiece material properties these are the 2 crucial parameters which govern the loss of material from the function of surfaces by erosion another important aspect here is the factors which govern the erosive wear so factors affecting the erosion. So factors affecting the erosion includes like angle of impingement of the particles.

The second one is the particle size, then a particle size and the shape, the third is about the substrate material properties ok and so these are the 3 important parameters which will be considered here when will see that what are the factors that affect the erosive wear. So as I have said if we take 1 particle which is impinging at a high angle, low angle and further low angle.

So impact extend severity of impact is less when the impingement takes place at low angle as compared to that at high angles. So if we consider the extent of the indentation which will be formed in case of soft and ductile metals that will be deeper, somewhat shallower and further

shallow in case of the low angle impingement, because the extent of the effect of the impact on the low angle impingement is less under the identical conditions of the mass and velocity of the particle.

So the depth of penetration is less in case of the low angle impingement as compute the case which will be observed in case of the high angle impingement and this is what we can relate it with the way by which materials behave under the different conditions, in case of the soft and ductile material if we see. In this case although the depth of indentation is less, but the material is subjected to the more cutting action by shearing.

And therefore loss of material in case of the low impingement is more by cutting action through the shearing and the ploughing on the other hand when the impingement in case of soft and ductile materials when it takes place mostly the ploughing takes place which does not lead to the match of the material lost from the functional surfaces. So if we see the effect of the angle of impingement for soft and ductile material if we keep on increasing the angle of impingement from 10, 20, 30, 40, 50, 60, 70 up to say 90.

This is angle of impingement which is increasing and here we simply write the erosive wear which we can simply determined from the material weight of the material in before the erosion test and weight of the material of corrosion test. So this difference will give us the erosive wear and if we divided by density than will be getting the erosive wear and volume of the erosive wear.

So if we see there is continuous increase in the erosive wear up to 30 degree there after it starts decreasing continuously like this. So initially in this case at about 30 degree the removal of the material by shearing action is the maximum. So it experience is the maximum erosive wear and before that the severity of the impact is less that is why the depth of indentation is also left and at about 30 degree it causes enough depth of indentation.

And removal of the material by shearing action while at the higher for further angle of the impingement the more ploughing action takes place despite of greater depth of indentation we do not get much of the removal of the metal from the functional surfaces and that is why we see that material erosion, erosion of the material at the higher angle of a impingement in case of the soft and ductile metals it decreases, ductile and soft metal source.

So this is 1 thing, so in this case to deal with this difficulty it is important which those metal systems which will be experiencing the erosion due to the impingement of the erosive particles at low angle, it is good to increase their hardness. So that the erosive wear resistance can be enhanced. But this hardness also is to be increased up to a limit otherwise it will back fire or it will start increasing the erosion.

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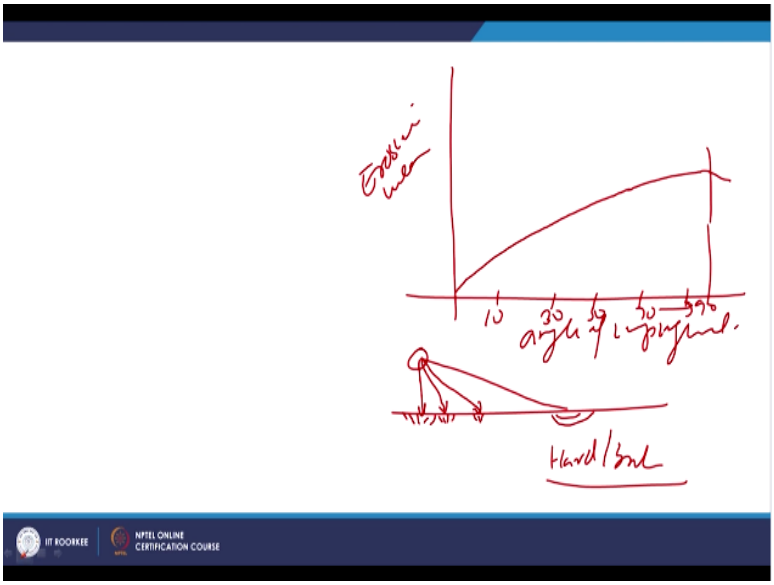

The another plot where angle or impingement in the x-axis and erosive wear on the y-axis, in this case at low angle we know that if the material is hard and brittle. So with the low angle of impingement there is not much depth of penetration not much scratching. So the wear it is less, so like say 10, 30, 50, 70, 90 degree of the angle of impeachment. So limited depth of indentations is very less.

And therefore we get the very low wear rate, so wear it will keep on increasing as the angle of impingement is increased and it reaches to the maximum here. So because in case of the hard and brittle material as the angle of the impingement increases the severity of the impact increases and since the material is hard and brittle in nature. So it promotes the cracking. So rather than so increased cracking and their collusion increased micro fracturing leads to the removal of the material from the functional surfaces.

And that is why in case of the hard and brittle materials increasing angle of the impingement increases the erosive wear up to the 90 degree and thereafter it reverses.

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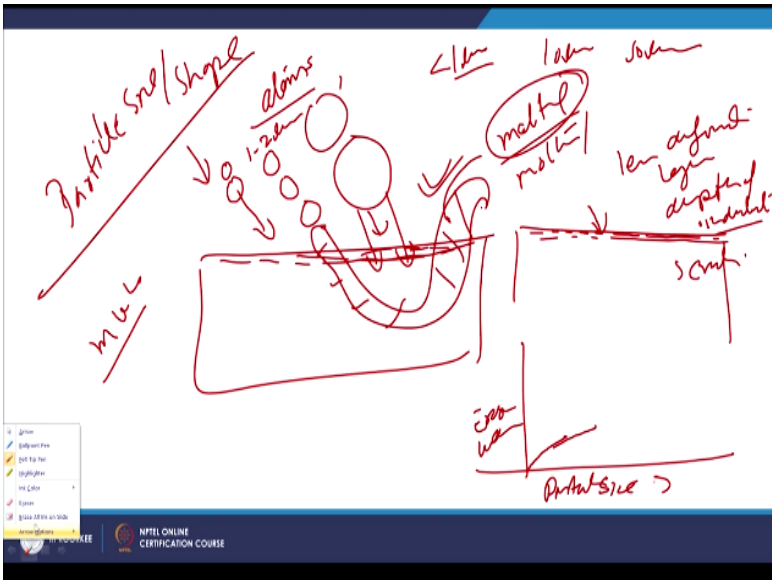

So this is 1 aspect and the second aspect is about the particle size. So particle size and shape, now the erosion can be placed through a very wide range of the particles it may be in form of the atomic size of like say less than 1 micrometre or 10 micrometre or 50 micrometre, so they are very large size range. So whenever the atoms are directed on to the surface like in electron beam or ions when they are directed on to the surface will be seen that the surface layers.

Of course up to the atomic level they will be causing damage to the surface and removing some of the atoms. So removal of the material in form at the atomic level takes place when the atoms are directed onto the surface. On the other hand when very small size the particles of like say 1-2 micrometre are directed at high velocity on to the surface says the mass of the diameter is very less.

So that have very less limited mass and despite of high velocity if the mass is unlimited then it will not have much of the kinetic energy and limited particle impinging on the surface with the limited particle energy will be leading to the very less surface layer damage surface layer deformation. So in this case very less surface layer is affected and therefore depth of indentation is also less and scratching is also less.

So in this case when the particle size is very less due to the limited kinetic energy the surface layers which are affected by the impingement or impact that is very less and therefore removal of the material from the functional surface is also very limited. So this is what we can see when the particle size very less the removal of the material by the erosion is less. So

here we have size of the particles, when the particle size increase likes say that 10 micrometre or 50 micrometre.

So when the particle size is very big having lot of kinetic energy moving at a very high speed it impinges with the surface of the workpiece if the material soft and ductile it will be causing huge super plastic flow of the material sidewise, even this particles may get attached with the surface of workpiece if they are if the surface of the workpiece is made of very soft and very ductile it can retain the abrasive particles.

Otherwise it will be causing the plastic flow or kinetic energy of the impact is too high it may also cause apart from the super plastic flow, it may cause the melting of the surface layers with very high kinetic energy particles, if the surface layer melting is taken place obviously the some of the molten particles will be removed and remaining molten particles will be resolidyfing or will be solidifying again on to the surface.

So these are the other mechanisms apart from the indentation is stretching on the micro fracture and microcracking, the super plastic flow and the melting of the surface layer is depending on size of the particles it will be affected. So in general initially with increase of the particle size there is increase of the erosive wear of the material. So this is what we can see as far as a particle size is concerned.

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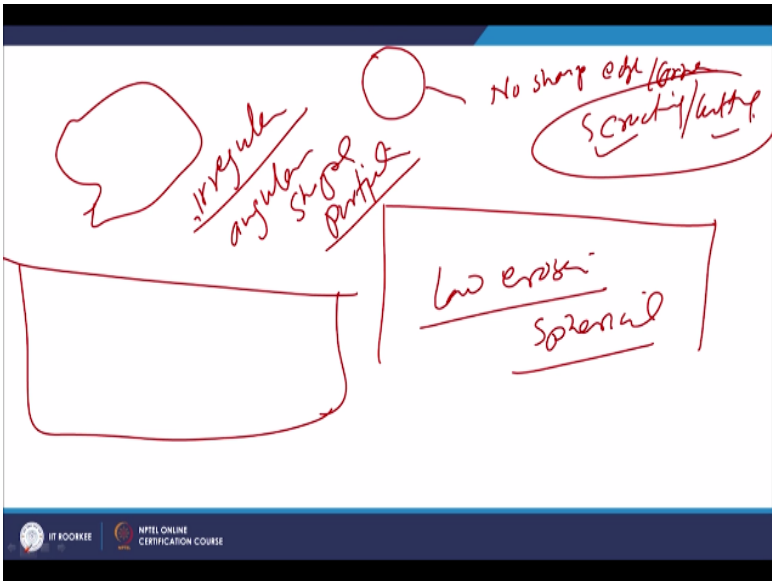

The shape of the particle is the another aspect like if the surface of the workpiece is subjected to the impingement by the spherical particles since it has a no sharp edges corners to cause a

scratching or cutting then this will be leading to the low erosive wear. So low erosion is observed in case of the spherical shape particles which have rounded corners not the very short edge and sharp corners.

On the other hand angular particles having very sharp corners whenever such kind of impingement takes place it promotes the scratching and the cutting action and therefore the material loss in case of the irregular or angular shape particles, this promote the erosion significantly because their sharp edges promotes the stretching and cutting action. Now another important aspect related with this is the material properties.

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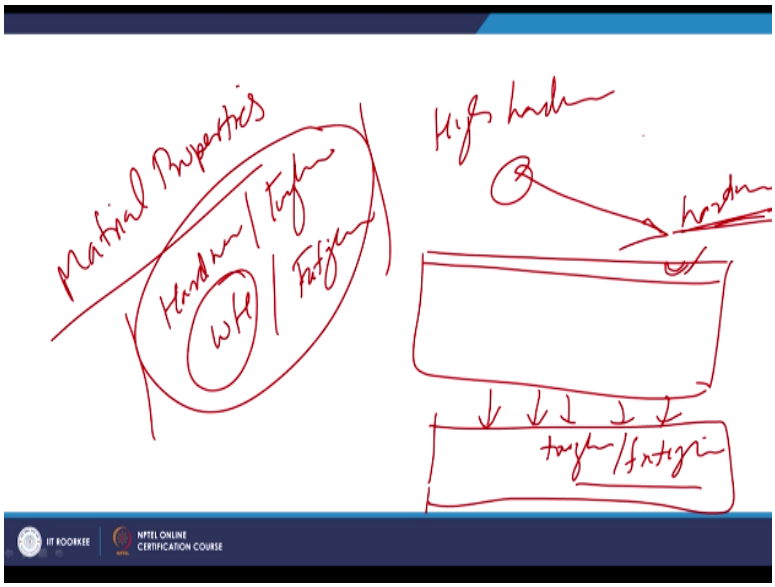

So as far as the material properties are concerned it is not just good to have very high hardness, it is required that the material should have the good combination of the hardness, toughness, work hardening behaviour and the fatigue resistance. If material is having these characteristics then in general under the normal conditions of the reason it will offer very good erosive wear resistance, but since many of these are the contradicting properties.

So as per the actual situation we need to see whether the hardness of the surface has to be increased or we need very good tough surface, in any case the increased work hardening behaviour will be resisting the erosion of the material and increased fatigue resistance will also be resisting the erosion of the material. So say in case of the low angle erosion we need to have the good hardness while in case of the high angle impingement it is required to have good toughness as well as fatigue resistance.

So that the crack nucleus and micro fracturing microcracking tendency can be reduced increasing hardness will be reducing the depth of indentation and scratching and thereby low angle impingement will be resisting the removal of the material. So maybe the surface hardening, carburizing, case hardening or development of the hard surfaces through the thermal spray coating for wild surfacing can be useful for improving the erosive wear resistance of the material.

Now I will summarise this presentation, in this presentation I have talked about the general principle of the erosive wear what are the important mechanisms and factors that govern the erosive wear behaviour of the materials, thank you for your attention.