Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations

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Lecture-09
Surface Properties for Wear and Friction Resistance II

Hello, I welcome you all in this presentation related with the subject fundamentals of surface engineering and we are talking about the properties of the surfaces which are important from the wear and friction point of view and we have seen that there are 5 important properties which influence the wear and friction behaviour significantly these are like surface energy, chemical composition, micro structure, surface hardness and the surface roughness.

So, we have talked about the one surface property in detail that was the surface energy and we had started in the previous presentation about the surface composition or chemical composition of the surfaces. Chemical composition of the surface is important because it affects the surface energy, surface micro structure as well as the stacking fault energy and surface hardness. So, it is important that if possible then chemical composition of the surface layer should be modified.

So, that we can have the desired combination of the properties affecting the wear and friction behaviour of the material. So, how to change the surface properties those techniques will be talking like as I have said there are 2 broad approaches which are like fusion and the diffusion.

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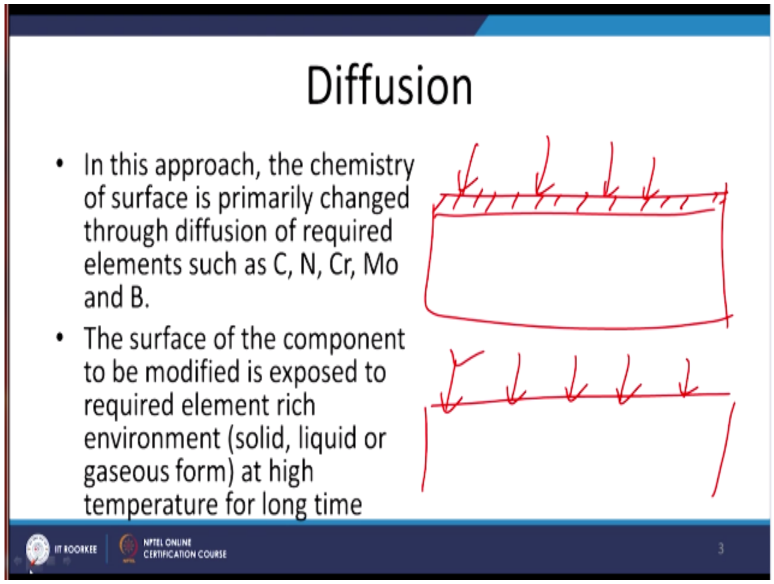

So, in case of the fusion based approach we have to melt the surface layers and then mix the elements which are to be added and in case of the diffusion based approach the required elements are diffused onto the surface. So, that required set of the constituents can be formed to have the required combination of the properties leading to the requisite wear and friction behaviour.

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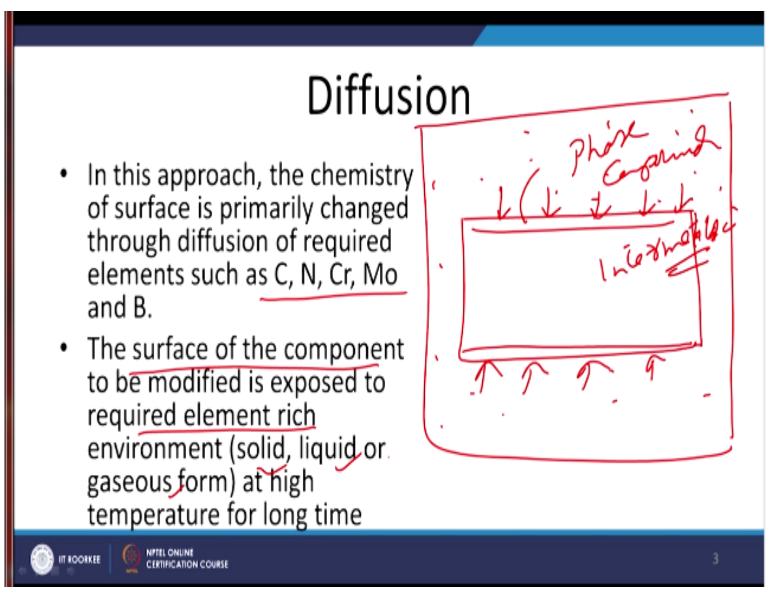

In this approach in this diffusion based approach basically what we do we take the component and suitable environment, environment of the suitable element is created in very controlled condition and then high temperature conditions are created. So, that the required element gets diffused onto the surface layers, such kind of the diffusion helps to modify the near surface layer chemical composition.

And once if it is able to diffuse then it will be able to offer it is effect in various form like forming the suitable kind of the phases, compounds or intermetallic which in turn will be affecting the wear and the friction behaviour of the material. So, the surface chemistries primarily changes to diffusion by adding required elements in form of like carbon, Nitrogen, Chromium, Molybdenum, Boron etc.,

And once it is done then will have the required compounds and the phases at the surface. So, surface of the component to be modified in these cases enriched in the required element environment which maybe in form of like solid, liquid or the gases or and then high temperature is created for a sufficient time.

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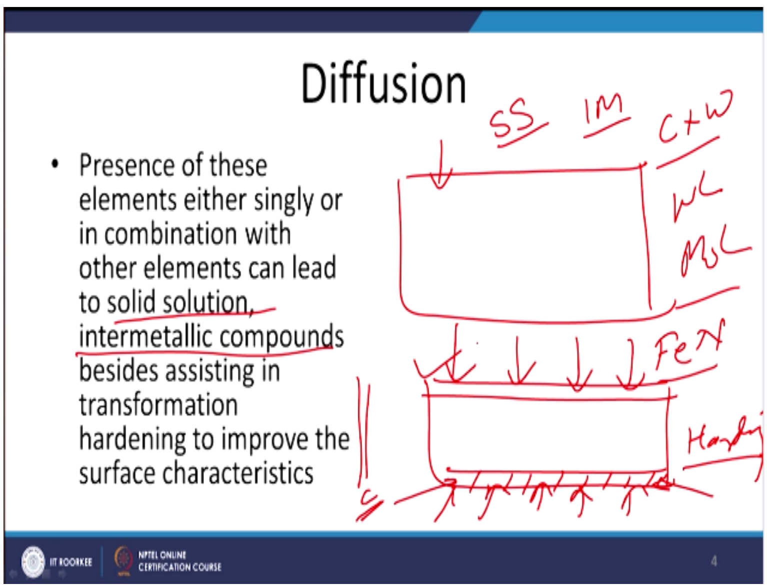

So, that diffusion can be facilitated to modify the composition of the surface as per the requirement. Whenever these are added it can work in number of ways like it can form it can simply form the solid solution like 1 element is getting diffusion and forming the solid solution or it can form the intermetallic compound like carbon reacting with the tungsten to form the tungsten carbide or molybdenum carbide.

So, similarly these elements can interact with each other or they can act singly or in combination with other elements to form the required compounds are to form just solid solution. So, that it can either directly offer the desired effect or it helps further in required transformation for improving the surface properties, one example of this is what like nitrogen addition simply leads to the formation of the iron nitride to improve the properties while the addition of the carbon near the surface layers simply in reaching the carbon content, increasing the carbon content.

But to have the required set of the properties we have to follow the suitable hardening treatment. So, that whatever carbon mean in reached that is able to form the in the martensite of the required hardness to improve the surface properties. So, in 1 case the required compounds and the phases are formed directly with the presence of certain elements either singly or in combination while in other cases presence of some elements are few elements are required for facilitating the further transformation of the phases.

So, that required set of the properties can be obtain to improve the wear and friction behaviour of the material. So, those were the approaches and there are various methods like chromizing, aluminising, vanadizing, boronizing and nitriding, plasma nitriding, carburizing etc., so those are the methods were primarily diffusion is used to facilitate the formation of the required compounds and phases. So, that required set of the properties can be obtain to improve the wear and friction behaviour of the material.

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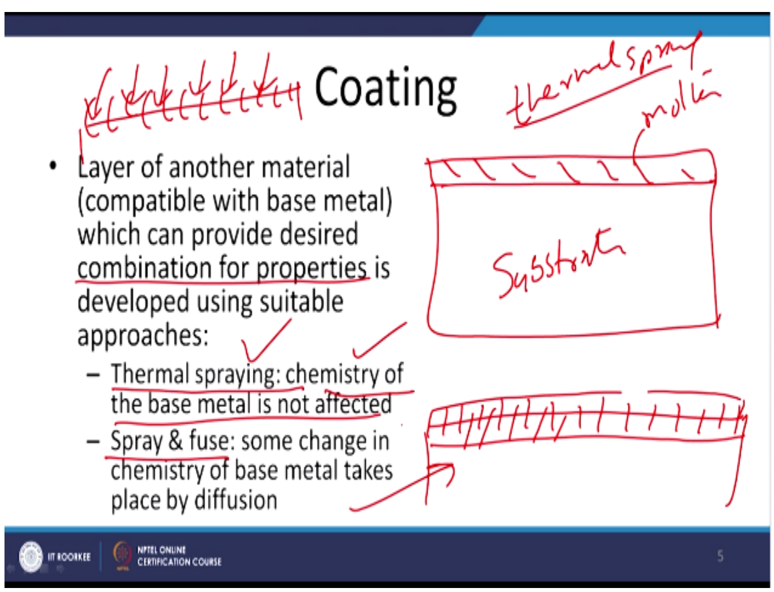

The another approach is this one where the layers or the coatings are applied onto the surface of the substrate. So, in this approach there can be the 2 possibilities where either the material to be deposited is brought to the molten state while the substrate remains in the solid state under this category primarily the thermal spray processes fall while well like the well surfacing, laser cladding etc. are those processes where even melting of the substrate takes place.

So, in this case in one of the cases where the substrate remains in the solid state but the metal to be deposited is brought to the molten state or semi molten state. In another case where the metal to be deposited is brought to the molten state at the same time up to certain depth substrate is also melted. So, in the second category of developing layer of another material which is compatible with the base material is applied.

So, that required set of the properties can be achieve to enhance the wear and friction behaviour. So, one method of applying the layer onto the surface of the substrate is thermal spraying, in this case there is no change, there is no major change in the chemistry of the substrate. Because it is not done intentionally and if it is happening then due to the diffusion little bit the coating material gets diffused into the substrate material but not up to the greater depth.

So, there is no major change in the chemistry of the substrate material and that does not affect the properties of the substrate material appreciably. Another one is the spray and fuse process where some change in chemistry of the substrate material takes place by the diffusion because in this case initially the material is sprayed onto the substrate surface and then it is fused.

So, when subsequent fusing is carried out, little bit diffusion of the alloying elements from the coatings to the substrate is facilitated, well in case of thermal spraying like coal like high velocity of say fuel spray or detonation spray there is no change in chemical composition of the substrate material or of the base materials. So, in this case there is greater change in chemistry of the substrate material while in the first case thermal spraying the change is very negligible.

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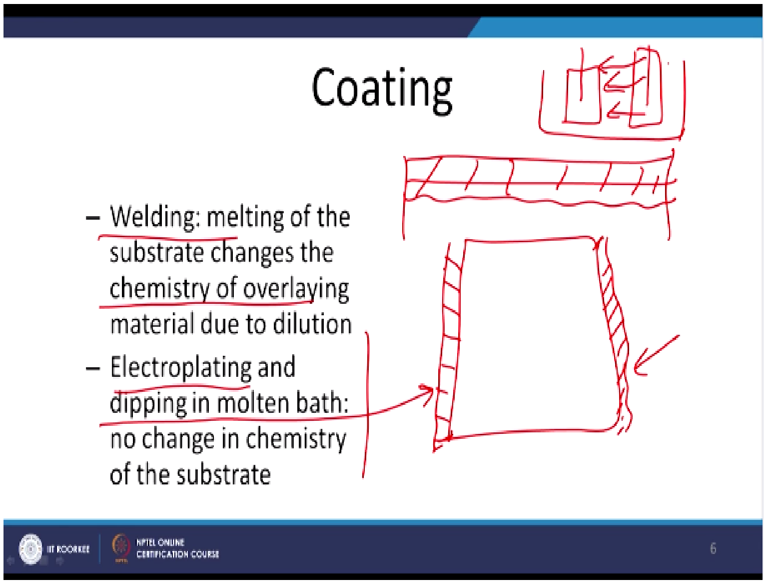

The another means other 2 methods of applying the layer onto the substrate is the like welding where weld surfacing is used here the filler as well as the substrate material both are brought to the molten state to bring the change in chemistry of the surface layers and in this case due to the melting of the case material some change in the chemical composition of the top layer also takes place due to the dilution.

And sometimes this leads to the degradation in quality of the coating material which is being deposited. Another method is the electroplating or the dipping in hot molten bath no change in chemistry of the substrate takes place. So, in both these cases just the material at the surface layer is deposited in the hot molten bath case, the metal is the component is dipped into the bath.

And then it is taken out after the solidification the coating is deposited onto the surface. So, there is no major change in the chemistry of the substrate material and just the coating gets deposited the same is same happens in case of the electroplating where bath of the electrolyte is used one there is 1 anode and there is 1 cathode. And the work piece is made cathode and the anode is made of the material which is to be deposited.

So, gradually the material will keep on depositing from anode to cathode in case of the electroplating. So, in this case there is no major change in the chemistry of the substrate but 1 coating layer is deposited onto the substrate to have the required set of the properties there can be different purposes of applying the material. So, according to the purpose suitable material is deposited onto the surface, so that required set of the properties can be achieved.

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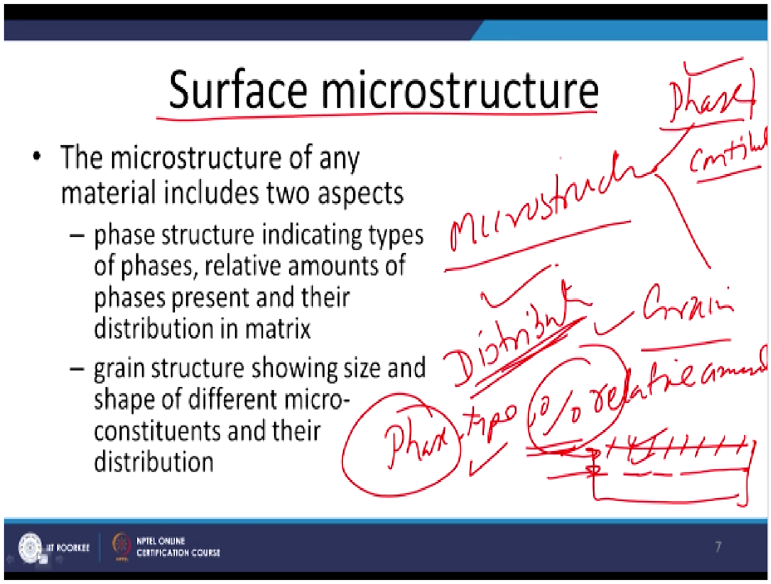

Third important property is the surface micro structure which significantly affects the wear and friction behaviour of the material. So, what are the things which are falling in this category the micro structure of the material basically comprises the 2 aspects one is the phase another is the grain, the phase means about the constituents which are present.

So, constituents are present means phase will include the type of the constituents which are present then their relative amount like the type A is present 80% type, B is 20 or the reverse like, so that % or the relative amount of these phases are constituents are relative amount of this phase. And how these phases are distributed sometimes will see that the one type of phase is present more at the surface than in the sub surface region.

For example in nitriding case the high nitrogen rich layer is formed at the surface while the nitrogen content in the sub surface layers is less. So, the type of the nitrides which are present in the surface are different from those which are present at in the sub surface region. So, depending upon the composition, the different types of the phases can be there at the different zones in the near surface layer.

So, what is important, what are the different types of the phases which are present what is their relative amount and where they are present that is the distribution. They are present means 1 particular type of the phase is present more at the surface or less at the surface. So, that in turn affects the surface behaviour with regard to the wear and friction. So, 1 aspect of the micro structure is the phase structure where will try to see the type of phases, relative amount of the phases very spaces which are there and how are they distributed where they are present.

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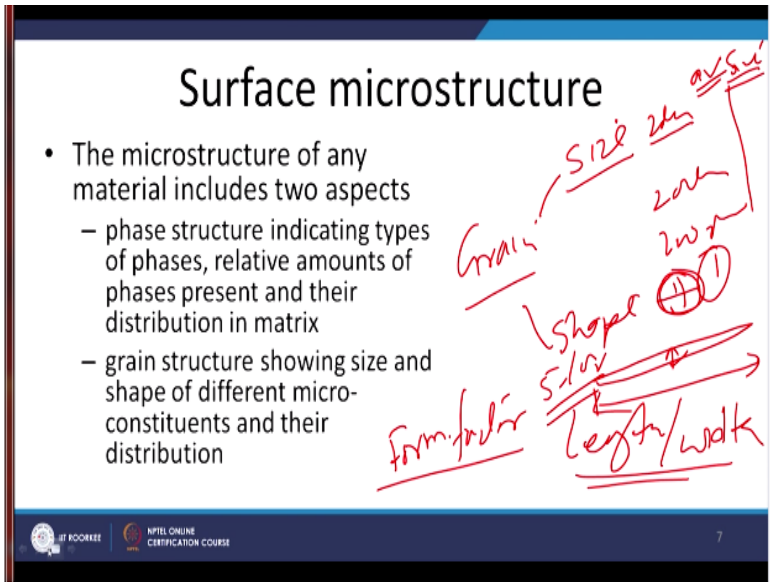

So, this is one aspect, second aspect is the grain structure or the grain, so grain structure consist the 3 components again the size of the grains whether it is just 2 micrometer or 20 micrometer or 200 micrometer. So, this will talk about this is about the average size of the grains because every micro structure will have the constituents of the different sizes, so will be looking for the average size of the grain, how will measure the average that will talk subsequently .

Then the shape of the grain, shape of the grain whether it is spherical or needle shape, these are very extreme side of the examples, spherical shape will have the length and width equal in all 4 directions well in this case the length is significantly greater than the width. So, basically the shape is characterised using 1 parameter which is called form factor or shape factor also. So, the length to the width ratio is use to characterise the form factor.

In case of the circular shape components the form factor is 1 because length and width both are same while in case of the form factor in case of the needle shape structure where length is significantly greater than the width, the form factor maybe like 5 or 10. So, depending upon the form factor depending upon the shape the different constituents can have the different types of the form factor. This about the second shape of the second phase particles, similarly there can be the phase of the different shapes for the metrics material also.

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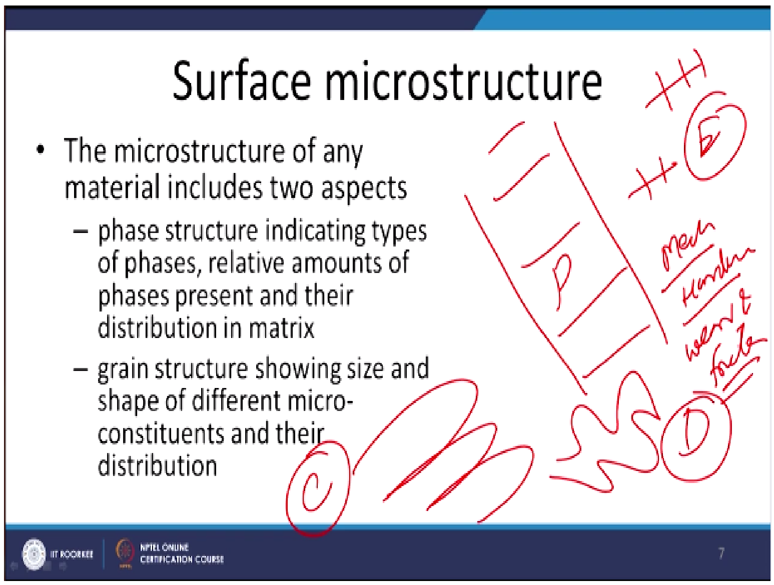

Metrics material like it can be the plain array where were big band is present of a particular phase, then there can be cellular structure like this. Then there can be dendrites like this or there can be equates grain structure like this. So, there are equates grain structure, dendrite grain structure, cellular grain structure or the plainer structure, this is about the metric structure apart from this likewise there are various other types of the grain structures.

And these have significant effect on the mechanical properties, hardness. So, which in turn affects the wear and friction behaviour of the material. So, it is very important to see what kind of the micro structure of the material especially of the near surface layers is present. So, depending upon the type of wear being experienced by the material it will have the different effects on the wear behaviour of the material.

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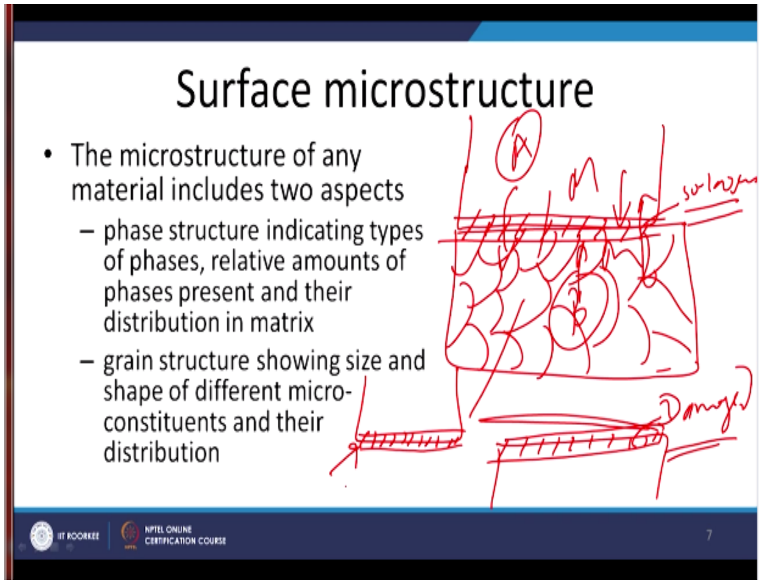

But there is another side of the microstructure also what is that like say the every bulk material will have it is own micro structure will have certain kind of the phases, size and shapes . So, this is about the bulk material but whenever the material is subjected to say adhesive wear say metal to metal wear is rubbing is taking place. So, this metal to metal rubbing causes the very near surface layer deformation.

So, this will deformation maybe up to like say 50 to 100 micrometer and this deformation is so high that all subsurface structure all this kind of the structure will get damaged like this, it will be elongated strained, broken down, refined, fractured. So, near surface layer structure during the metal to metal wear conditions is damaged completely and new kind of the structure is for used which in turn will be which in turn actually determines it is the response to the wear and friction behaviour.

But the initial structure of the base material affects the mechanical properties in general of the bulk material. So, and further whenever the metal to metal wear takes place what will see the near surface layers of both the sides will have the constituents from both the sides like the A and B these are made of the 2 different metals. So, the diffusion transfer of the elements from the A side will be taking place to the B side and the B side will taking place to the A side.

So, if we will see the A side surface layer structure and composition, it will have elements from the B side as well as. Similarly the structure and composition of the B side will have the elements from the A side and this structure is completely damaged. So, but so therefore the composition and the micro structure of actual sliding surface is more important to see the way by which it is the wear and friction behaviour will be influenced. This is about the actual structural aspect which is produced during the sliding condition.

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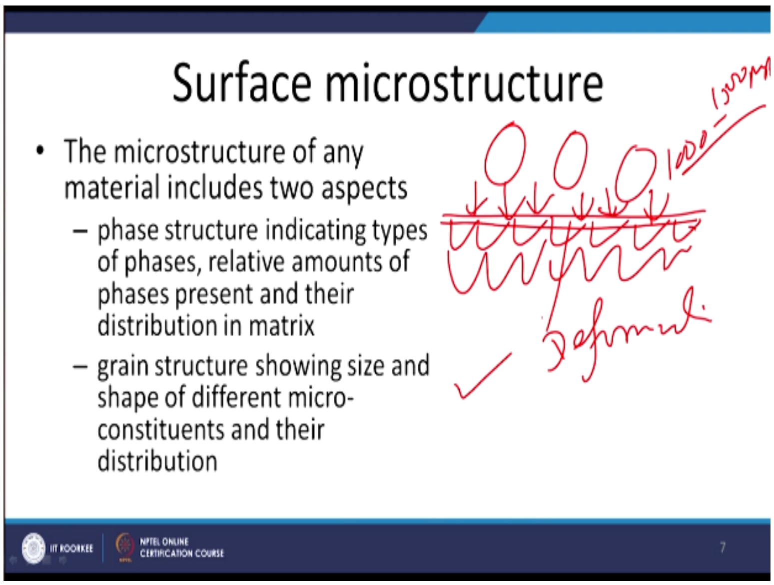

Similarly under the cavitation conditions whatever surface layers are there like this with they will have their own structure but whenever the there is a like cavitation conditions. So, these bubble burst and busting of the bubbles generate the pressure waves or shock waves which will be building up high pressure which can ranged from 1000 to 1500 MPA such high level of the stresses will be developing the near surface will be leading to the near surface layer deformation.

So, the initial structure is deformed even under such kind of conditions where cavitation or impact of the solid particles onto the surfaces taking place. So, structure gets modified under these conditions, so it may be important to have some kind of a structure through the initial structural modification. But under actual tribological conditions the structure gets modified even the composition gets modified.

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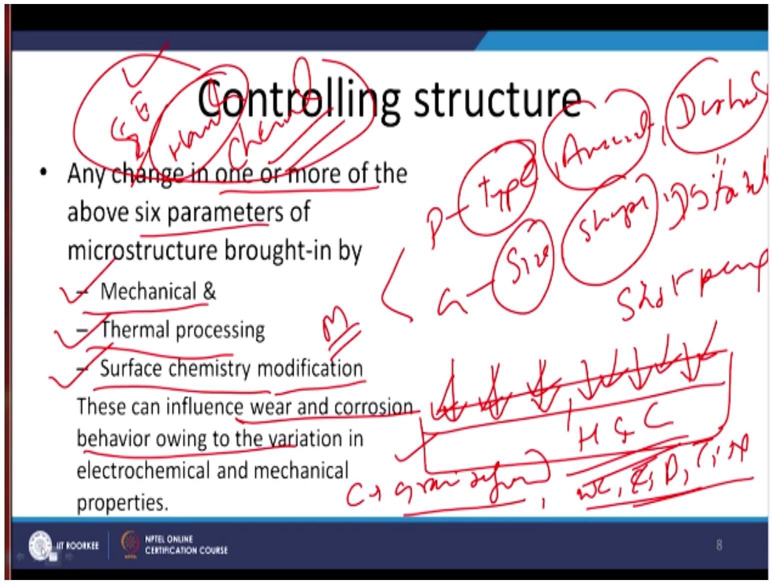

Now will see some other aspects related with the micro structure any change as I have said the phase and the grain each has the 3 constituents like the type of phases the relative amount of the phases and distribution. Similarly in the grain structure side the size, shape and distribution, so where fine and wear course the size course grain size are present. So, all these are the part of the micro structure, so change in any of these 6 characteristic will be leading to the change in the micro structure of the material.

And which can be used favourably to alter the surface properties to alter the surface energy to alter the wear and friction behaviour of the material. So, any change in 1 or more of the above 6 parameters will be leading to the change in micro structure and this can be brought and buy controlled mechanical processing, control thermal processing and controls surface modification, mechanical processing means the surface layer is subjected to the localised stress application, it maybe in form of short peening, it maybe in form of varnishing, it maybe in form of contour rolling.

So, that the surface layers gets deform work harden and offer the required set of the properties another one thermal processing. We increase the temperature either to introduce some of elements at the surface or just to have the required structural modification of near surface layer through the micro structural transformation through the control heating and cooling. So, control heating and cooling will be leading to the required structural modification and that in turn will be governing the wear and friction behaviour.

Similarly the surface chemistry is modified by changing the so the surface micro structure can also be altered through the modification of surface chemistry like they are certain elements which will be used as a grain refiner certain elements will form certain compounds carbides and borides like tungsten carbide, titanium boride, titanium nitride etc. So, those elements which are forming either acting as grain refiner or forming some kind of the intermetallic compounds and unique kind of phases which will be able to offer the required set of properties.

So, the structural modification through the mechanical processing, thermal processing or the surface chemistry modification can alter those properties as I have said surface energy hardness and chemical composition and so surface energy and hardness variation these 2 itself will be affecting the wear and friction behaviour of the material according to their chemical electro chemical properties and the mechanical properties.

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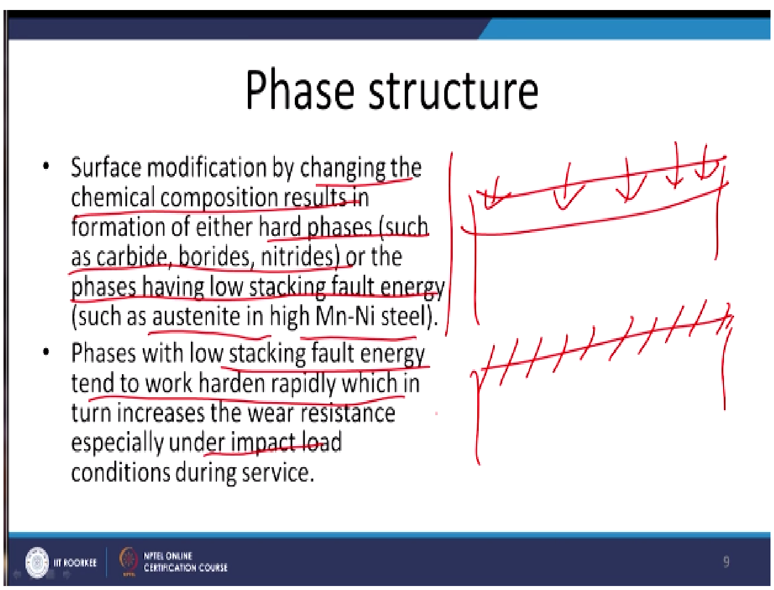

So, as I have just explained, the phases structure side the surface modification by changing the chemical composition results in the various types of the phases such as formation of some hard phases carbides, borides, nitrides or the formation of some of the phases like those which are having the low stacking fault energy like austenite and the high manganese steel these will be leading to the formation of some kind of the phases.

So, that either they will result in the required hardness or they will be reducing the stacking fault energy by having the required material at the surface the phases with the low stacking fault energy tend to work harden rapidly which in turn increases the wear resistance especially under the impact conditions during the surface. So either we can introduce these elements on to surface.

So that required compounds are formed which will change the microstructure or by we can build-up a layer of the required material like had field steel or high manganese steel or the austenite layer which shows the lowest stacking fault energy, so it tends to work harden very rapidly and offer the required wear resistance

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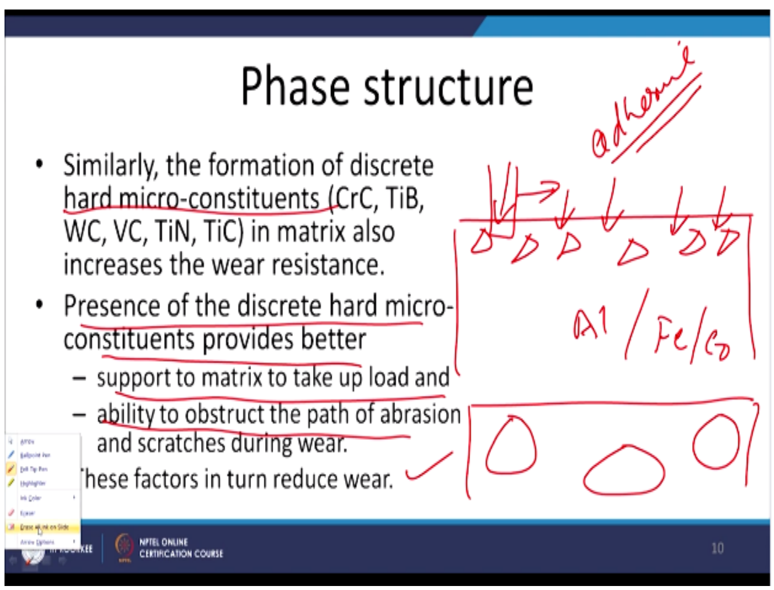

Similarly the formation of the discrete compounds in form of the this is about the phases, so the formation are different types of the phases will affect the wear behaviour in different way say formation of the discrete hard particles is good especially from the abrasive and adhesive wear point of view like say this is the soft metrics of the aluminium or simple iron or the cobalt which is soft and tough.

So, presence of these compounds hard and brittle compounds in the metrics it will resist the it will properly it will support the soft metric material effectively these particles once they are formed they will support the soft metrics effectively against the external load or they will resist the abrasion also say this is the abrasive mark it has intended. But whenever it moves due to relative movement the abrasive particle path will be abstracted by these hard particles.

So, they will increase the abrasive wear resistance, so adhesive wear resistance is enhanced due to the improved ability to support the metrics against the external load and abrasive resistance, abrasive wear resistance is improved because of the increased ability of these hard particles to resist the path of the abrasion or abrasive marks during the scratching or the abrasive wear conditions.

So, presence of the discrete hard particle constituents provides much better wear resistance in 2 ways 1 it is supports the metrics to take up the external load and second it increases the ability to abstract the path of abrasion and scratches during the abrasive wear conditions. And these 2 factors in turn improve the adhesive and abrasive wear resistance. So, not just the presence of these particles is important.

But the good distribution of these particles is also important, like say we may have just few constituents like this very big in size. So, this may not be very good way to have such kind of compounds where just very few large size hard particles are present here and there they may not be able to offer the required support to the metrics. And act as abstraction to the path of the abrasion and abrasive and scratches.

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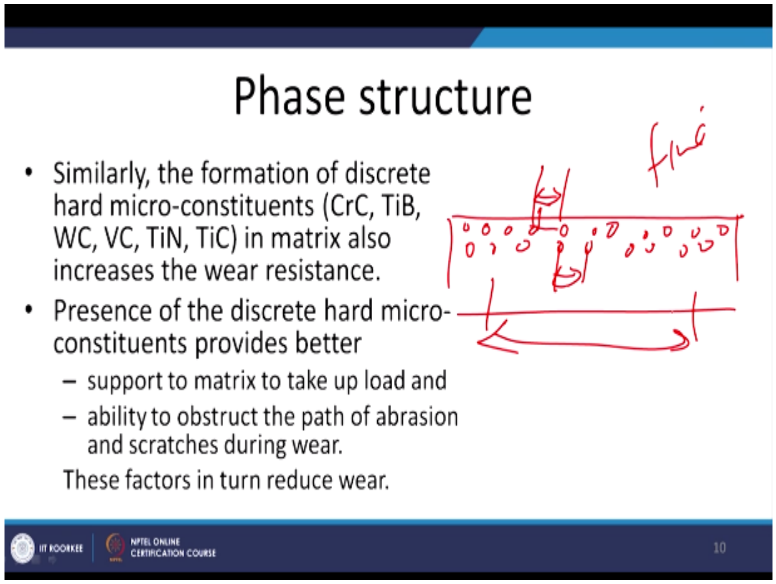

So, it is good that whatever we have added that is well distributed they are fine in size and distributed in the metrics. So, the path of this particles is effectively checked by these hard particles at the same time inter particle distance is also reduced, this is called mean free path between which the abrasive path will be formed and then it will be obstructed. So, if this path is big mean free distance is big then this will be the size of the abrasive mark.

And it will be leading to the increased removal of the material and if this distance is very narrow then the extent of the abrasion will also be limited. So, fine and well distributed particles offer much better resistance to the adhesion as well as abrasion as compare to the course and big particles.

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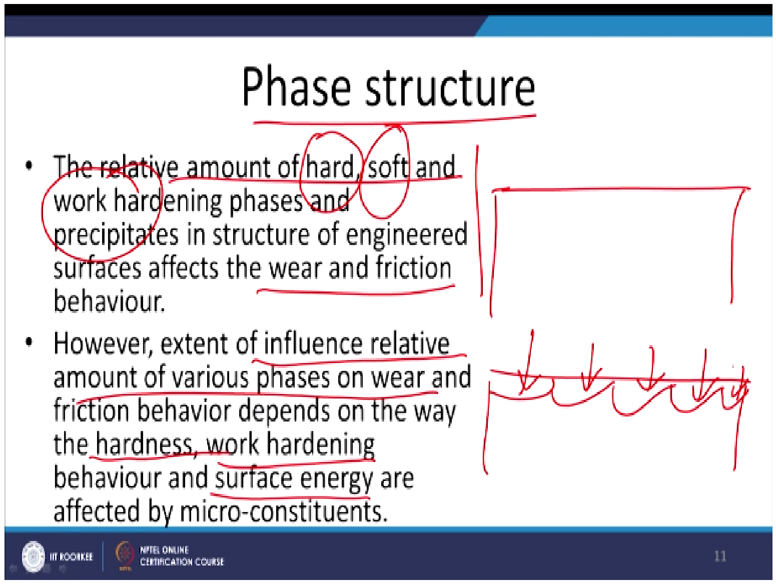

So, what is the important as per as the type of phases are concern relative amount of the hard and soft phases and work hardening phases precipitates in their structure. In their structure all these things affect the wear and friction behaviour say in what amount hard phases are present in what amount soft phases are present, in what amount work hardening phases are present. So, they are relative amount affects the wear behaviour significantly.

So, amount of the constituents on the engineered surfaces, so would be such that it is able to offer the required set of the surface properties to have the required wear and friction behaviour, influence of relative amount of the various phases on wear and friction behaviour depends on the way by which hardness is affected work hardening tendency is affected and the surface energy is affected.

For example like work hardening behaviour if the austenite is present in limited quantity it will provide the required improvement in the hardness due to deformation. Because excessive increase in the work hardening will also increase the tendency for cracking and reduced resistance to the wear. So, good combination of the hard, soft and the work hardening material will certainly help to improve the wear behaviour of the material. So, as I have said not just the presence of certain constituent is important but their good distribution is also important.

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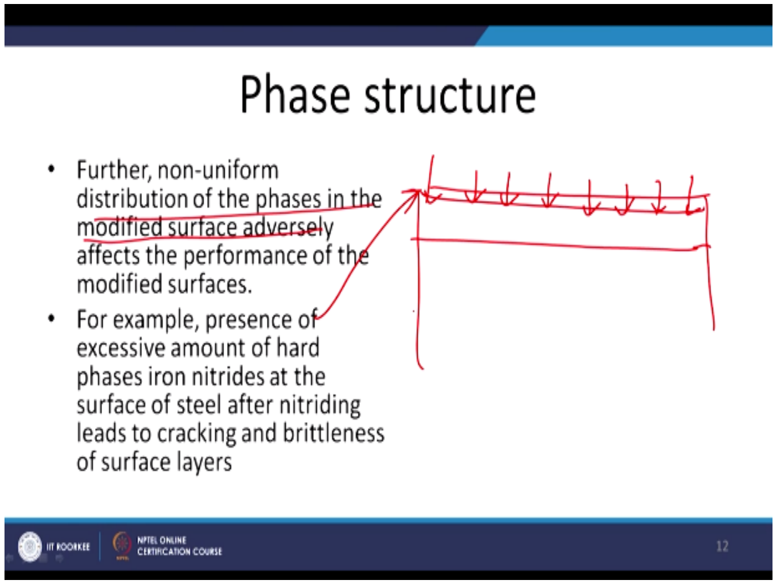

So, non-uniform distribution of the phases in the modified surfaces is also not that good and good example of this is what like during the nitriding large amount of the high nitrogen rich iron nitride is formed just at the surface layer which leads to the imbritllement of the surfaces while the low nitrogen rich nitrides are formed in the sub surface zone with the required combination of the hardness and the reasonable toughness.

So, that it can really offer the required set of the properties, so not just the higher hardness is and is important but it is also important that how the different constituents are distributed in the metrics to offer the required set of the properties. Now I will summarise this presentation, in this presentation I have talked about the 2 important surface properties like 1 chemical composition.

And another is the micro structure all the some of the aspects of the micro structure and it is effect on the wear and friction behaviour is yet to be completed that I will take up in the subsequent presentation. Both these properties are important with regard to the surface energy and mechanical properties which in turn affect the wear and friction behaviour of the material significantly, thank you for your attention.