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-25
Surface Modification Techniques: Principle of Controlling Surface Metallurgy

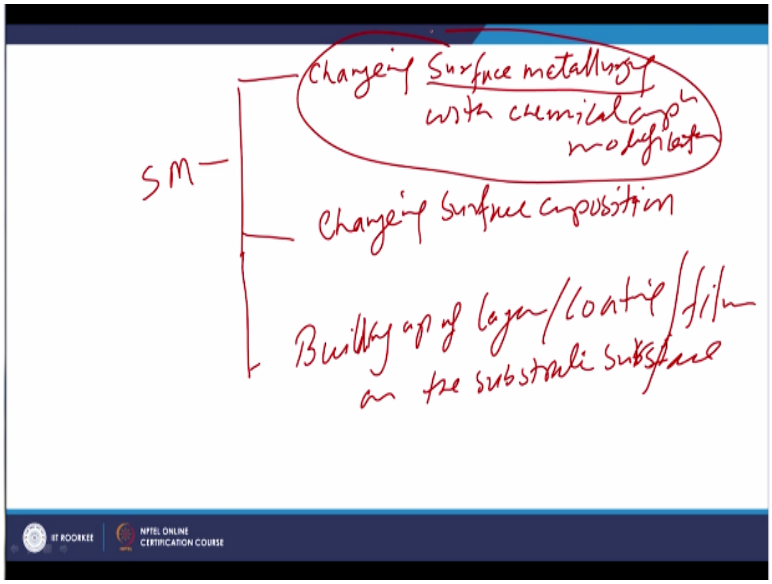
Hello, I welcome you all in this presentation related with the subject fundamentals of surface engineering and so for we have talked about the various mechanisms which cause the material removal from the functional surfaces. Then we have also talked about the various properties that affect the removal of the material from the surfaces and then what are the various materials which can be useful to develop the various wear resistance functional surfaces.

Now we will talk about another aspect wherein we will see that what are the techniques available for improving the wear resistance properties of the functional surfaces. So, that the components can perform for longer time under the tribological conditions and for this purpose what is primarily needed is that the surface structural surface composition is modified in such a way that the required set of the mechanical properties are achieved which in turn will be able to offer the required improvement in wear properties for the given service conditions.

So, the choice of the service conditions or the service conditions govern the choice of the properties that should be developed onto the engineering component surfaces for longer tribological life. So, based on the property requirement we select the suitable surface modification technique or suitable kind of material which is to be applied onto the surface. So, that the required combination of the properties onto the surface can be develop for required improvement in tribological properties.

So, as per as the techniques of the surface modification are concern there are 3 broad categories of the techniques which are used for improving the surface properties.

(Refer Slide Time: 02:22)

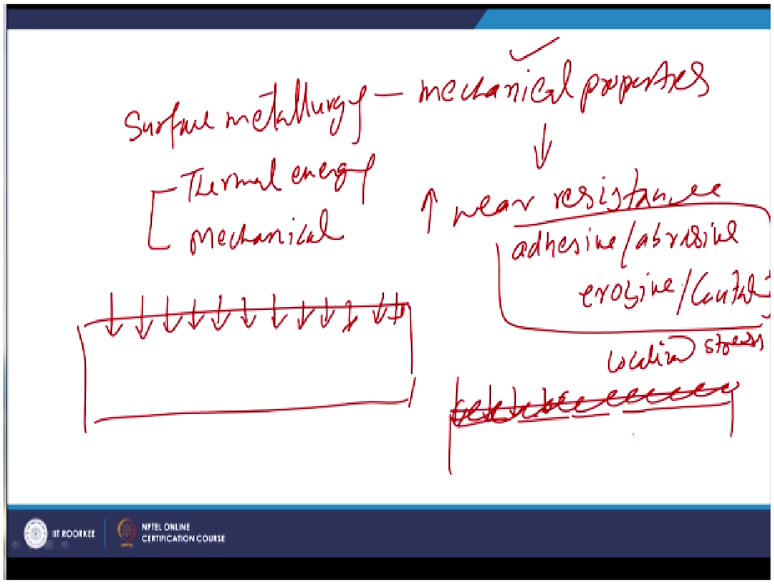


And these 3 broad categories of the surface modification include like changing the surface changing surface metrology without chemical composition modification. So, this is 1 aspect where just the surfaces structure and the surface condition is modified. So, that the required improvement in properties is achieved but this method cannot be applied for the entire range of the metal systems, there are selected categories of the metals on which these kind of this category of the methods can be applied.

So, this is one approach where surface metrology is controlled without changing the surface composition. The second method involves the changing the surface composition to achieve the required properties for improvement in the wear resistance and third is basically building up of a layer or coating or film on the substrate surface. So, that the required surface properties are developed for improving the tribological life of the component.

So, basically will be starting the surface modification techniques from the first category where surface metrology is modified without changing the chemistry for the required improvement in properties. So, basically this category of or this approach of the surface modification heavily relies on the changing the surface microstructure through the thermal methods or through the mechanical methods.

(Refer Slide Time: 04:46)



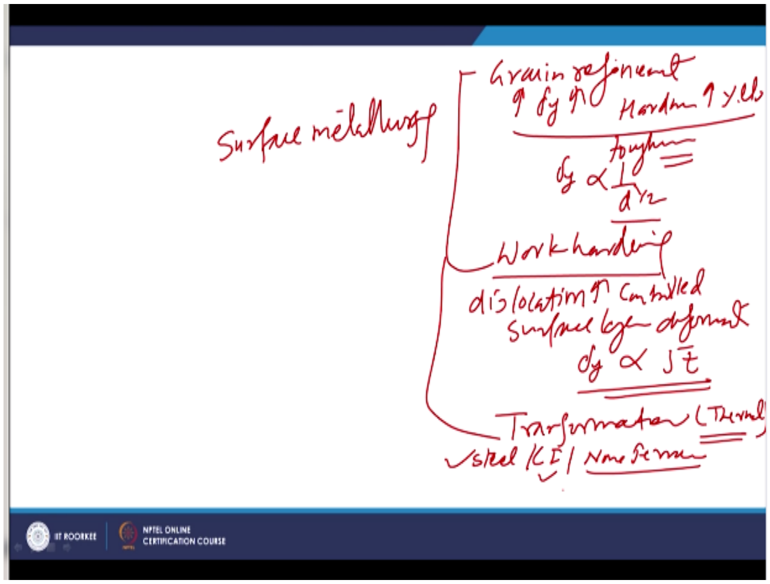
So, the as per as approach is concern surface metrology we have to modify, so that change in metrology affects or decides the mechanical properties which are being realised and this in turn leads to the improvement in the wear resistance of the material, first certain kind of the wear conditions through this approach especially like adhesive, abrasive, erosive wear and the cavitation wear.

So, these are the common types of the wears resistance of the material for these types of the wear mechanisms can be wear modes can be improved . So, what is the basic idea in this kind of the approach, basic idea in this approach is basically the surface which is to be modified is subjected to the 2 types of the energies these include like application of the thermal energy or mechanical energy.

And both these approaches are entirely different from each other and so whenever thermal energy is applied near surface layers are heated up to the required depth or followed by rapid cooling . So, that the surface microstructure is modified, surface structure is refined sometimes the transformations also take place this is what and these changes internally to the improvement mechanical properties, so the improvement in wear resistance.

In the mechanical even the mechanical energy is used the localised stresses or the application of the localised forces at the surface layer leads to the deformation of near surface layers. So, basically this method is based on the application of the localised stresses at the surface layers. So, that the near surface layers are deformed and which in turn leads to the improvement in mechanical properties.

(Refer Slide Time: 07:20)



So, what are the mechanisms that are leading to the improvement in mechanical properties when there is no change in chemistry, only the surface metrology is modified which in turn is leading to the improvement in mechanical properties. So, the improvement in wear behaviour. There are 3 main mechanisms which lead to the improvement in the mechanical properties and so wear behaviour these are basically grain refinement**.**

We know that when according to the Hall-Petch relationship whenever the grains are refined there is improvement in mechanical properties under the ambient conditions while under the high temperature conditions grain refinement detoriates the mechanical properties especially the 3 persistence is adversely affected. So, the grain refinement is increasing the yield strength, increasing the hardness of the material.

And sometimes even improvement in the percentage elongation that is the ductility is also observed. So, these properties in combination improve the toughness. The second and here the yield strength is found inversely proportional to the average grain diameter. So, a square root of the average grain diameter. So, finer is the grain structure this will be leading to the better hardness better yield improved yield strength.

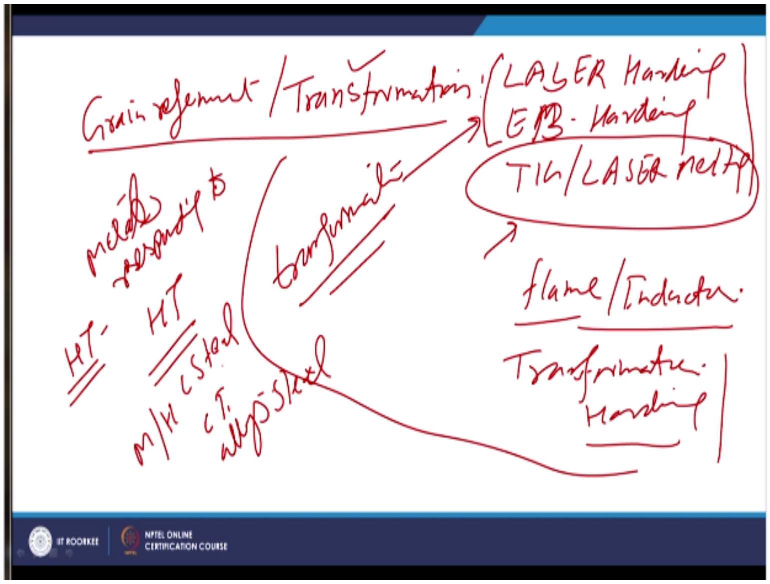
Another mechanism which helps in improving the mechanical properties of the surfaces through the application of the mechanical energy or thermal energy is the work hardening, in work hardening we know number of the dislocations are increased through the controlled surface layer deformation and this increase in number of dislocations increases the yield strength in proportional like this.

So, as the number of dislocations increase there is a increase in the yield strength of the material and in that case of the transformation hardening this is the third mechanism will this is basically applicable for the thermal methods where control application of the heat to the surface layers help in achieving the required microstructure at the surface in order to achieve the improvement in mechanical properties and wear behaviour.

So, in this case the basically this method is applied to the ferrous metals like steel cast iron and also it can be applied to the non ferrous metals as well, it relies on the 2 approaches 1 either the transformation hardening will be occurring or the grain structure will be refund if the melting is taking place. So in thermal methods if the transformation hardening like in case of high carbon and medium carbon steel is facilitated.

Then it will leading to the improvement in hardness through the martensitic transformation and the same concept is applicable in case of the cast iron also. So, these are the 3 approaches or 3 mechanisms which work behind the improvement in mechanical properties through the structural modification of the surfaces and which in turn leads to the improvement in wear behaviour or wear resistance of the material.

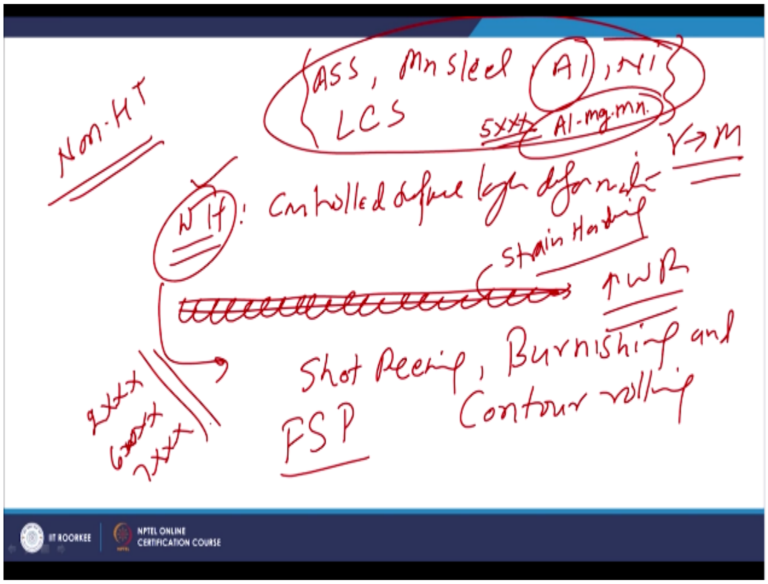
(Refer Slide Time: 11:28)



If we see the mechanisms which use the grain refinement and the transformation hardening mechanisms, then methods which use these 2 mechanisms for improving the mechanical properties include the laser hardening and then electron beam hardening and then TIG or the laser melting. So, in case of the melting basically the refinement and the transformation hardening both are effective while in case of the laser hardening and electron beam hardening it is basically the transformation hardening which is effective for improving the mechanical properties and the wear behaviour of the material.

Apart from these methods the flame hardening and induction hardening also uses the principle of the transformation hardening for improving the mechanical properties of the surfaces and so the wear resistance of the material. On the other hand so these transformation hardening methods are especially applicable to the heat treatable metal systems means the metals which respond metals responding to the heat treatment. So, heat treatable metals like medium or high carbon steels, cast irons, alloy steels are can be subjected to these methods where in transformation is used for improving the wear resistance of the surfaces.

(Refer Slide Time: 13:31)



Then there is another category of the metals where in non heat treatable metals like austenitic stainless steel high manganese steel, aluminium, Nickel alloys and low carbon steels. These are methods which do not get harden much on the due to the transformation like this kind of transformation is basically involved in austenite to martensitic transformation which is not available in this kind of metal system.

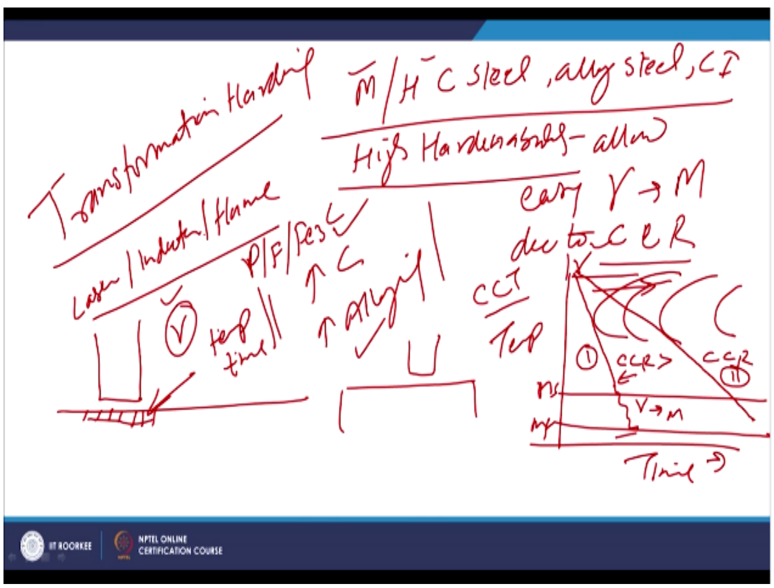
So, such kind of the metal systems are the surface metrology or such kind of the metal systems is improved through the work hardening approach, work hardening approach where controlled surface layer deformation is achieved. So, what will be doing near surface layers will be deformed using the controlled application of the force to the near surface layers, so these are deformed and due to the plastic deformation material is strain hardened and this strain hardened material will be leading to the improvement in hardness, tensile strength, residual compressive stresses.

And these factors intern improve the wear resistance of the material, so this is the main approach and the these kind of the metals which are subjected to the improvement wear resistance to the work hardening approach the methods which are based on the work hardening approach include the shot peening, burnishing and contour rolling. So, in these methods basically the near surface layers are deformed and there is another completely newer process is the friction steer processing where near surface layers are deformed severely.

So, that they get work harden and improvement in mechanical properties is observed not all categories of the metals means not all categories of the aluminium alloys are non heat treatable there is one category that is 1 series 5000 series aluminium alloy having the aluminium magnesium and manganese. So, this kind of this series of the aluminium alloys are work hardenable.

On the other hand there are other series like 2000 series, 6000 series and 7000 series aluminium alloys are heat treatable. So, they respond very nicely to the heat treatment and alteration in micro structure for improvement in mechanical properties.

(Refer Slide Time: 16:42)



Now coming to the first category of the methods like transformation hardening, what is the basic principle in these methods. So, transformation hardening method, these method is applicable to the medium or high carbon steels, alloy steels and cast iron as I have said, these steels offer very good or high hardenability and so means these kind of the metals allow easy austenite to martensitic transformation due to low critical cooling rate.

Now what is this basically we know that to understand the critical cooling rate and hardenability concept we need to see the CCT diagram of these metals higher the carbon content, higher the alloying concentration in steels basically the CCT curve knows of the CCT curve is shifted towards the right. And when we cool it from the austenitic state then shifting of the curve towards the right indicates that cooling rate required for austenite to martensitic transformation is getting reduced.

If this is the MS and this is the MF line corresponding to the martensitic transformation this start and finish, this is the temperature, this is the time in the x-axis. So, what it shows that if the nose of the CCT curve due to the higher carbon content and alloying element is shifted towards the right, then it will be leading to the reduction in critical cooling rate which means even simple heating of the surfaces followed by even slower cooling will lead to the austenite to martensitic transformation while in other cases when the CCT diagram is having the nose on the left side leading to the higher critical cooling rate.

So, this critical cooling rate is greater for this curve as compare to the another this curves CC or critical cooling rate. So, critical cooling rate for curve A is higher, then the critical cooling rate for curve 2. So, because of this difference means higher critical cooling rate means we need higher cooling rate on the surfaces in order to facilitate the austenite to martensitic transformation.

This is the MSth end line and this is Ms line and this is the zone where austenite to martensitic transformation in will be taking place. And here complete austenite to martensitic transformation will be occurring, so when the critical cooling rate is low especially in case of low carbon steels or when the alloying concentration is less in the steels. Then the higher critical cooling rate will make it difficult to transform austenite into the martensite.

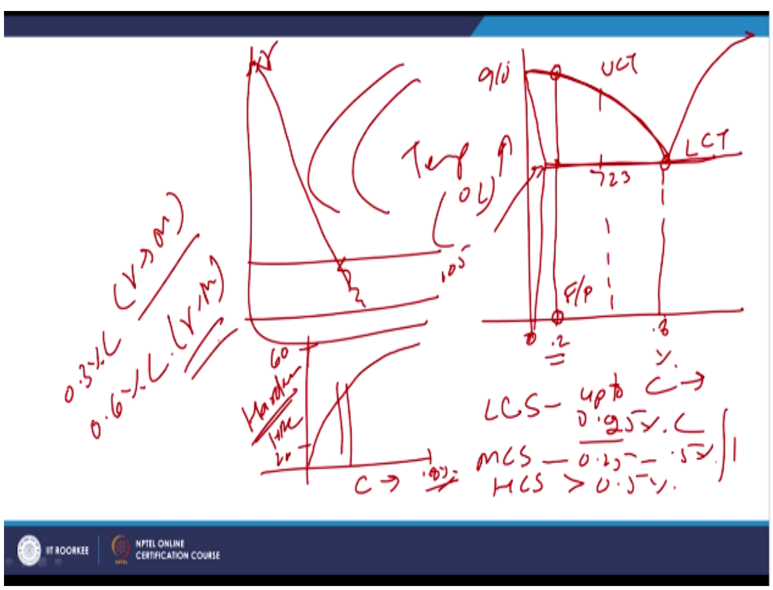
And that is why when we say that medium and high carbon steels when they are heated high enough to the austenitic temperature in followed by the cooling rate which is high enough not very low. Then it will facilitate the austenite to martensitic transformation for required hardening purpose. So, the basic principle in this approach is that we use suitable heat source, heat source maybe in form of laser, induction heating, it maybe in form of flame.

So, in these methods the source is applied onto the surface, so that near surface layers are heated to the austenitic temperature range and this austenitic temperature range is again found a function of the composition of the steel about that the composition of the material about that I will talk in the next slide and once it is heated to the austenitic state followed by the rapid cooling it will lead to the transformation from austenite to the martensite.

And since martensite being hard and so that it improves the hardness of the surfaces and which in turn improves the wear resistance of the material. So, as per as this heating, so heating temperature and time at that temperature is important for transformation of soft phases which are present normally in steel in form of the pearlite and ferrite and these phases has to transform into the or iron carbide these phases should transform into the austenite for formation of the homogenous austenite.

There has to be sufficient temperature must be sufficiently high above the upper critical temperature as well as at that temperature it should hold for sufficient time. Now we will see what are the factors that affect that the austenitizing temperature the temperature up to which the surfaces must be heated for homogenous austenitic transformation like say this is iron carbon diagram simple.

(Refer Slide Time: 22:22)



And this is the eutectoid point corresponding it will like say 0.8% carbon is iron carbon diagram here we have temperature this is 727, this is 910 degree centigrade, this temperature in degree centigrade and carbon content here 0 and this value is also very very low like 0.05. So, from the carbon content point of view now when the carbon steel carbon content in the steel is like say 0.2.

Then fully austenitic transformation fully means at the room temperature it has primarily it has ferrite and little bit pearlite at the room temperature. And when we heated above the upper critical temperature limit, that is the upper critical temperature line is this and this is the lower critical temperature line. So, UCT and LCT, so for fully austenitic transformation of ferrite pearlite in the austenite.

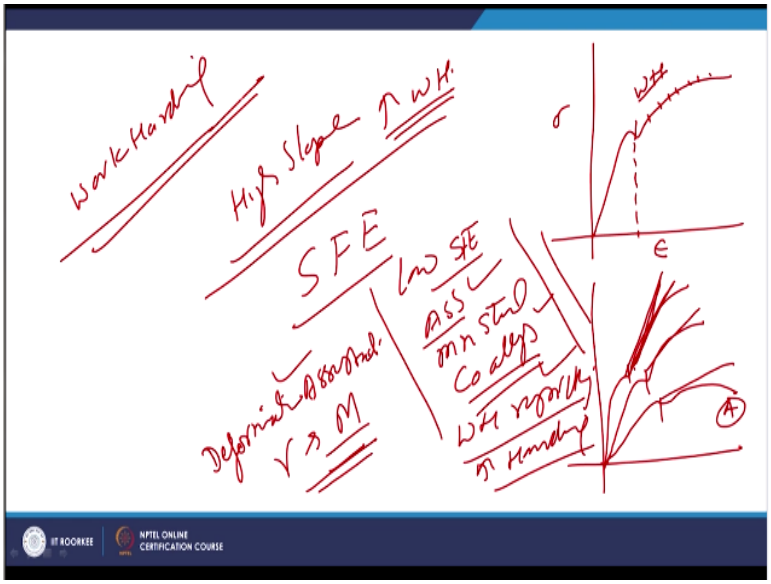
We need to heat it up above the upper critical temperature and the value of upper critical temperature will keep on changing with the change in percentage of the carbon present in the steel. And if the steel is having like say carbon content up to from up to like say there are low carbon steel up to 0.25% carbon, medium carbon steel 0.25, 2.5 and high carbon steel when the carbon content is greater than 0.5%.

So, if the carbon content is too high like this then upper critical temperature will be coming down once we have got the fully austenitic state then as per the carbon content the cooling from the austenitic state rapidly will be leading to the transformation of austenite into the martensite and leading to the required hardness, there is another aspect that the maximum hardness which can be realised to the austenite to martensitic transformation is also found the function of the carbon content.

And if we draw the relationship between the hardness of the martensite and the carbon content that it is found to increase continuously and this will be going up to the 0.8%. So here high carbon martensite will be higher than the low carbon martensite. So, this is showing the hardness like say increase in harden like 20 HRC to the 60HRC, so there will be continuous increase in hardness.

So, it is not guarantee like 0.3% carbon steel when subjected to the austenite to martensitic transformation will not be getting too high hardness, hardness will be limited. But if the carbon content in the steel is like 0.6 then this kind of transformation will be leading to the high hardness. So, despite of the martensitic transformation we do not get very high hardness, if the carbon content is low.

(Refer Slide Time: 25:44)



So, it is so what it suggest that not all types of the steels can be subjected to the transformation hardening for improvement of the surface properties. Now another aspect as I have said now another aspect is that the work hardening metals. So, what is work hardening we will need to see little bit this thus we can understand from the simple engineering stress and stress diagram.

So, if we see here this diagram the deformation actually plastic deformation sets in after this much strain. So, this is this we can say as elastic strain and beyond this will there will be plastic strain. So, if we see after once the plastic deformation sets in there is a continuous increase in the stress required to cause the further deformation. So, increasing stress requirement to cause further strain is attributed to the work hardening of the material, different materials work harden at different rates.

Like we may have 1 plot of this kind for 1 metal A the stress sustain diagram for another metal will be like this and for third metal it maybe like this. So, since the actually after the deformation this slope which is achieved especially once the plastic deformation sets in that indicates the rate at which the stress requirement is increasing with the increase of to cause the further strain.

So, this slope of the curve in the plastic strain zone that indicates the rate at which is material the material is getting work hardened, higher is the slope of the curve greater will be the work hardening tendency of the material. So, this slope or this work hardening tendency is related with the stacking fault energy of the material. The material having the low stacking fault energy, low SFE like austenitic stainless steel high manganese steel, cobalt alloys.

So these when they are subjected to the deformation they work harden rapidly and cause significant increase in the hardness. These also experience the deformation assisted austenite to martensitic transformation, so work hardening rapidly and experiencing the deformation assistant austenite to martensitic transformation.

And these combination leads to the improvement in the hardness and the wear resistance of the low SFE materials like especially austenitic stainless steel manganese steels, while in other cases like cobalt alloys. Of course austenite to martensitic transformation will not be applicable but these low SFE materials will be experiencing the much higher work hardening rate and leading to the improvement in the hardness and wear resistance of the material.

This kind of the approach is good means this kind of the materials as well as improvement in service property can be easily achieved using the methods which are based on the work hardening like burnishing, shot peening or friction mixture processing. Now here I will summarise this presentation, in this presentation basically I have talked about the 3 broad categories of the surface modification techniques.

And which are primarily like improving the surface metrology without changing the chemical composition or changing the surface metrology through the change of chemistry or building up of layer of the suitable materials. So, that required combination of the mechanical properties can be achieved for improving the wear resistance, at the same time I have also talked about the various mechanisms and the principles on which these methods are based.

And the methods which are used for improving the surface properties without changing the surface composition and the only the surface metrology modification helps to improve the mechanical properties and the wear behaviour of the material. So, primarily I have talked about the principles which are used for improving the surface metrology, so as to improve the surface properties and the wear resistance, thank you for your attention.