**Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations**

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**Lecture-08**
**Surface Properties for Wear and Friction Resistance I**

Hello, I welcome you all in this presentation related with the subject fundamentals of surface engineering. We have talked about the various processes which are used to modify the surface characteristics. So, that the wear resistance friction behaviour of the component can be improved and how those processes can be classified apart from that will now be looking after the surface characteristics which should be considered or we should be designed in such a way that the required resistance to wear and friction can be achieved.

So, in this presentation basically will be talking about the various properties which are important from the friction and wear point of view. So, there are although can be various bigger categories like the meteorological properties, mechanical properties of the surfaces. But if we look into the finer retails of those properties then will be having these 5 sets of the properties one 5 surface properties.

One is the surface energy, the second is the chemical composition of the surface and near surface layers then the micro structure of the surface hardness of the surface and the surface roughness. These are the general surface properties which effect the way by which loss of material from the functional surfaces under the various surface under the wear under the different types of the wear conditions will be taking place which maybe in form of a like adhesive wear, abrasive wear, erosive wear, corrosive wear, fretting wear.

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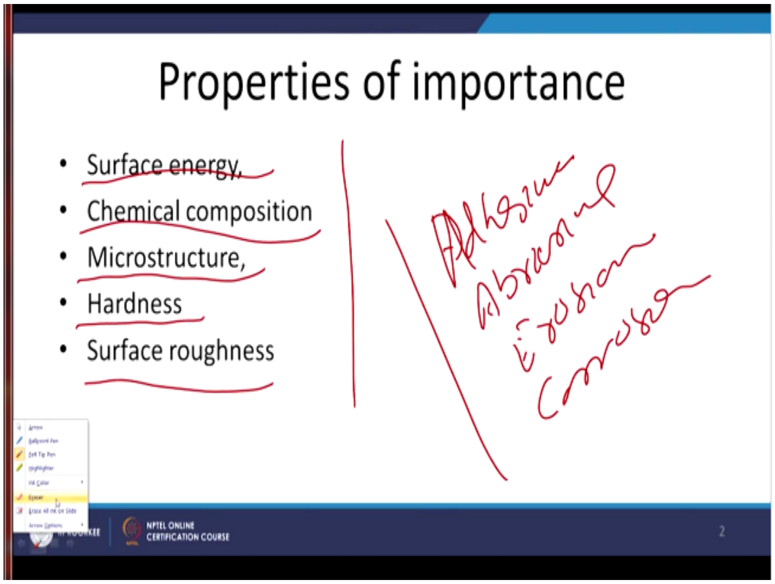


And likewise there are various types of the wear, so in general will try to talk about the way by which these properties of the surfaces affect the wear and friction behaviour of the material.

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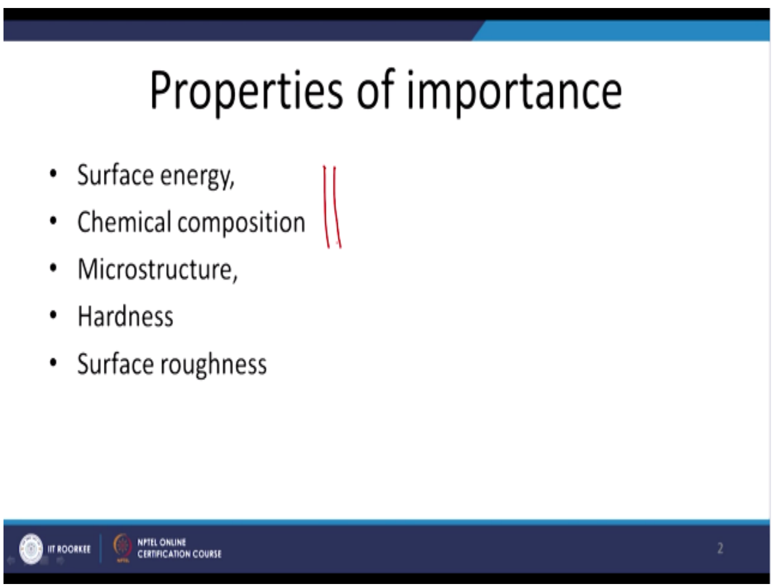


So, in this presentation I will try to talk about the first 2 properties and there after we will take up the other 3 characteristics. So, as per as the surface energy is concern surface energy which is generally measured using this parameter.

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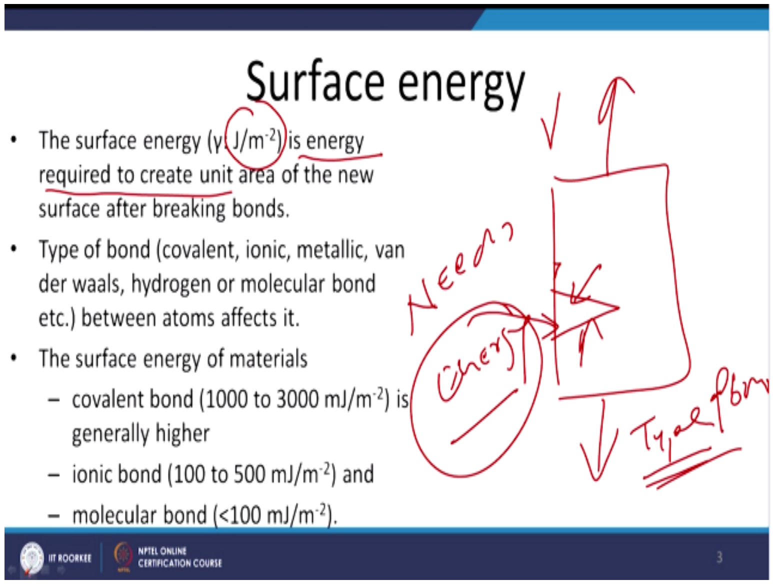


And it presented by this gamma and the joule per meter square is the unit which is use to quantify the surface energy and surface energy is about the energy required to create unit area of the new surface after breaking the bond. We know that whenever any component when subjected to the external loading. So, obviously somewhere the crack will be nucleated, so whenever 1 crack nucleates it creates the 2 surfaces, 1 surface is this and another surface is this. So, creation of such kind of the surfaces needs a this needs energy.

So, energy required for creation of surface is known as the surface energy and how does it happen like there is a continuity of the metal or the material but whenever crack is created crack is nucleated and it grows the surfaces new surfaces 2 new surfaces will be created and the amount of energy which is required for creation of such surfaces depends upon the way by which the different consequence of the material are held together means the kind of the bond, type of the bond which exist. So, the different materials can have the different types of the bonds which we can see here.

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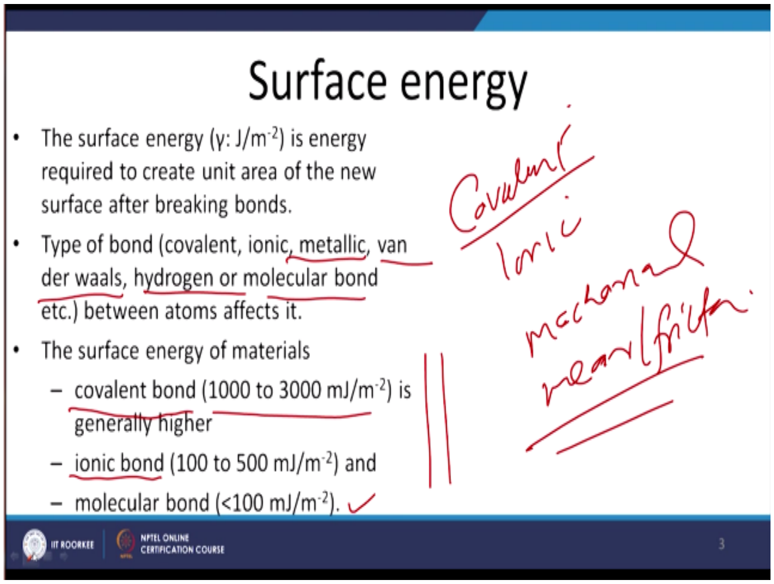


The bond is the covalent bond, ionic bond metallic bond, van der waals bond, hydrogen and molecular bonds etc., So, these are there can be various types of the bonds between the constituents which are making a particular material and energy required for breaking those bonds also varies and which in turn governs the surface energy. So, greater is the stronger is the bond, greater will be energy required for creation of the surface.

And which in turn will be governing the mechanical as well as wear and friction properties of the material. So, if we see here the way by which surface energies of the material are different types of the materials which are which will be having different types of the bonds like the covalent bond needs the maximum has the higher surface energy like 1000 to 3000 omega joule per meter square.

This is much higher than means the covalent bonds need much they have much higher they offer much higher surface energy as compare to the materials having the ionic bond and the molecular bond, so now if we see a material which is having the ionic bond.

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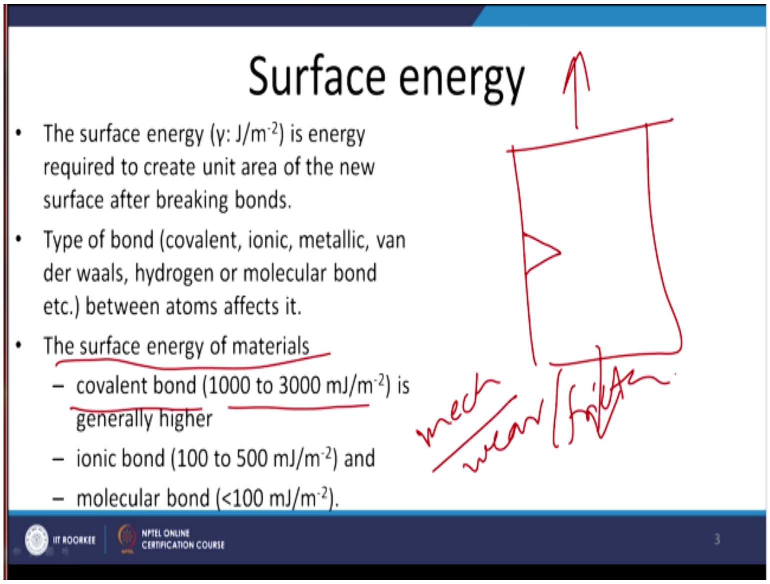


And if it is subjected to the application of the external force during the surface then the material having the covalent bond which requires much higher surface energy for creation of the new surface. Then it will require greater energy for breaking of the bonds and then subsequently creation of the new surface. So, surface energy of the material varies with type of bond and different bonds offer the different types of the surface energy.

So, accordingly the efforts required for creation of the new surfaces will be varying and this in turn will be affecting the mechanical and wear friction behaviour of the material.

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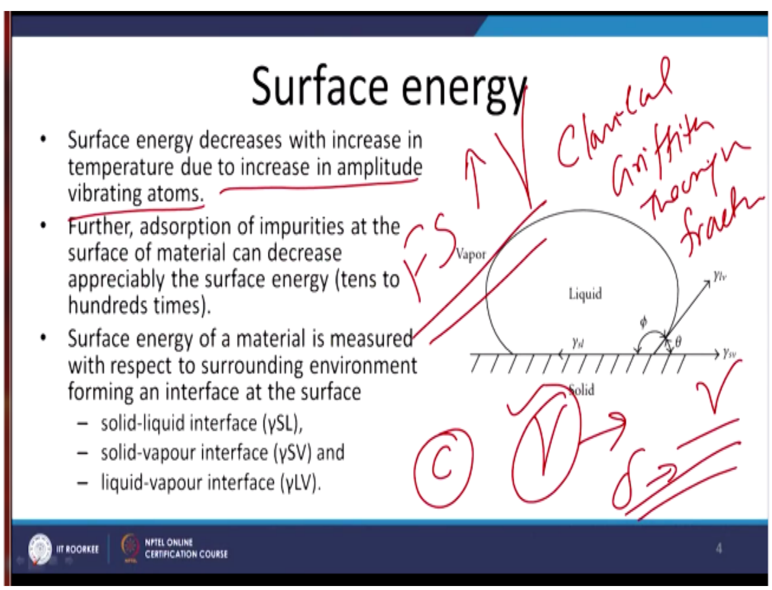

So, now if will see surface energy we know that surface energy of the material decreases with the increase of temperature and this happens due to the increase in amplitude of the vibrating atoms. Further the methods are there to alter the surface energy there is a there is 1 very famous classical Griffith theory on fracture which says that the surface energy directly affects the which actually relates the discontinuities and surface energy with their stresses required for the growth of the crack if it is existing in a material.

So, the size of the crack and surface energy these 2 are used and according to this higher is the surface energy greater will be the stress required for the fracture. So, the fracture stress increases with the increase of the surface energy. So, because it directly governs the energy required for creation of surface and which in turn is influenced by the kind of bond which exist between the metals. So, actually there are different approach is the surface energy of the material can be altered like in 1 typical example.

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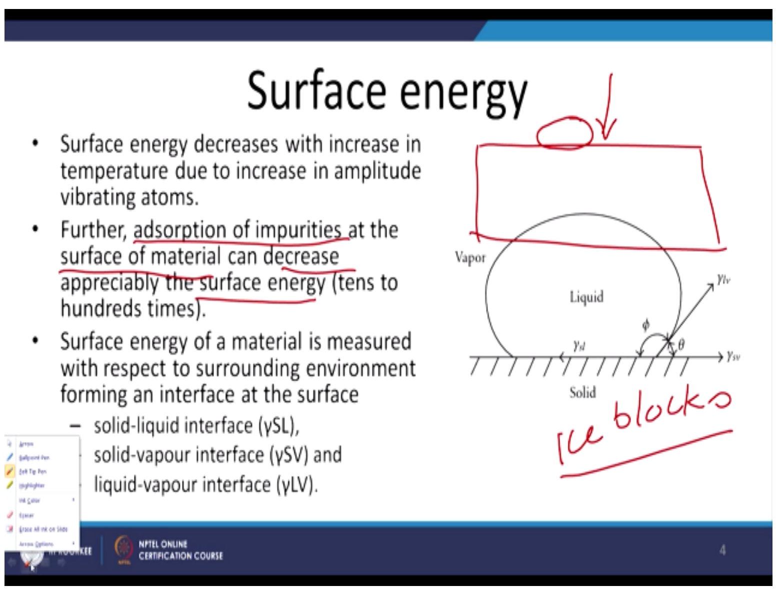


If this is a component and if you want to break this, so what will be doing we will apply certain kind of the chemicals at the surface. So, surface energy is reduced and that will help incretion of the new surface using the lower level of the energies or lower level of the stresses there is 1 typical example where ice blocks are broken using some kind of compound at the surface, so that the surface energy of the ice is surface of the ice reduced.

And then ice can be broken using much lower amount of the impact force required for the fracture of the ice block. So, means by changing the composition or surface impurities of the material it is possible to alter the surface energy and which in turn will be affecting the way by which surface will be behaving under the influence of the external stresses.

So, absorption of energy at the surface of the material can decrease the surface energy appreciably and which can be use to regulate the surface behaviour as per the requirement whether it is like for fracturing we have to reduce the surface energy.

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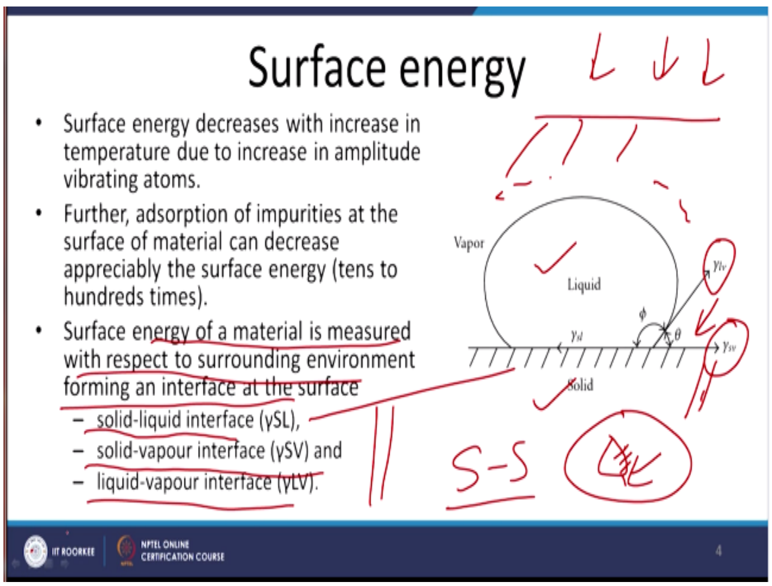


And for increasing the strength we can increase the surface energy. There are various types of the surface energies and surface energy is very is measured with regard to particular kind of the environment like this solid is in contact with the liquid. So, surface energy of the solid liquid interface will be expressed like the gamma SL which will indicate the solid-liquid interface surface energy of the solid-liquid interface.

And similarly if this is a solid and in contact with the gases like air then it will be solid-vapour interface, so once solid. So, that is this 1 the solid surface in contact with the gases, so there will be solid-vapour interface surface energy and the liquid in contact with the gases surrounding the molten metal. So, the interfacial energy in that case will be termed as the gamma LV or which is a the liquid-vapour interface energy.

Like solid-solid interfaces like in the metrics there are certain particles, so there will be interface between the 2 metrics and the second phase particle there will be interface between the 2. So, the kind of interfacial energy which exist between the solid and solid that will be governing the resistance to the crack nucleation at the interface. So, the mechanical resistance will be affected accordingly.

So, surface energy of material is measured with respect to the surrounding environment forming an interface at the surface and accordingly will see that solid surfaces or the solid vapour interfaces will be having in the different ways say the surface energy of the solid-solid interface determines the fracture resistance.

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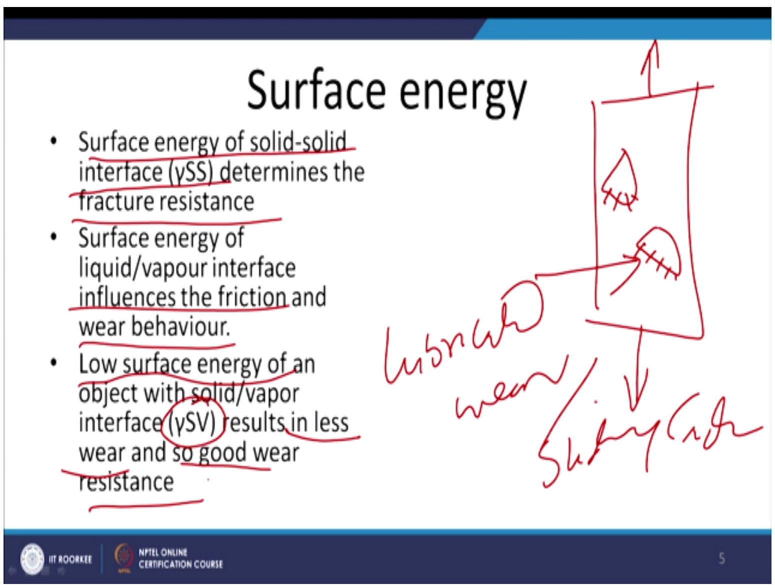


As I have just said this is the solid and having the solid second phase particles, so there will be solid-solid interface and energy between them, energy at this interface will be determining how much resistance it will offer for creation of the crack and then it is a subsequent growth. So, the fracture resistance is influenced by the surface energy of solid-solid interfaces, surface energy of the liquid-vapour interface influences the friction.

And wear behaviour especially under the conditions under the lubricated wear or the sliding conditions while under the dry sliding conditions where the 2 metallic surfaces are interacting with each other under the dry conditions at in that case the solid-vapour interface surface energy will be important and low surface energy of an object with a solid-vapour interface results in the less wear and which is good for the good wear resistance.

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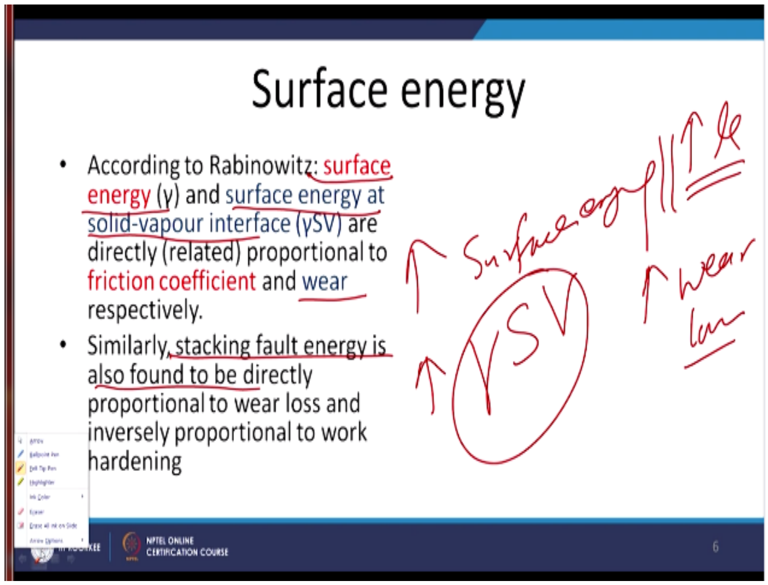


According to the Rabinowitz very famous tribologist, he and in his book he suggested that the surface energy and the surface energy at the solid-vapour interface or directly proportional to the friction co-efficient and the wear respectively. So, surface energy higher the surface energy higher will be the friction co-efficient and higher is the surface solid-vapour interface energy greater will be the, so greater is the this solid-vapour energy greater will be the wear loss of the material.

So, it is preferred that from the friction and wear point of view it is preferred that the surface energy and the solid-vapour interface energy is low. There is another form of energy which is very commonly used is the stacking fault energy which is found directly proportional to the stacking fault energy is found.

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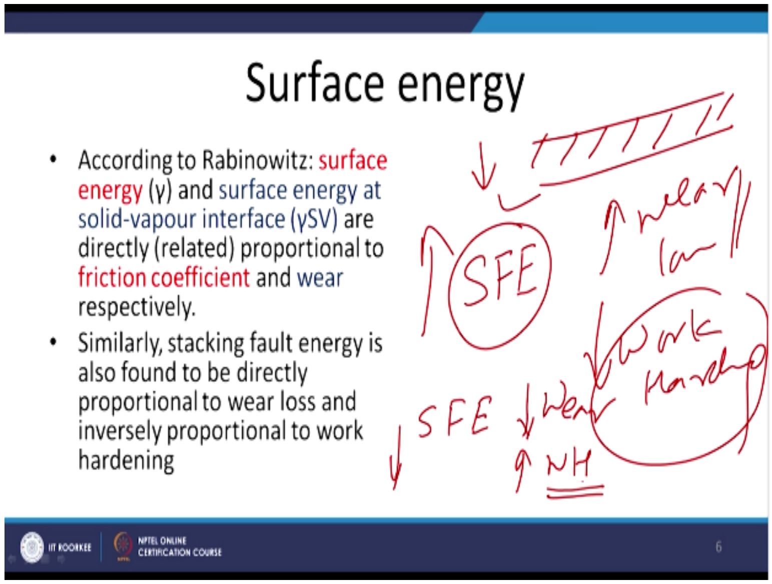


So, SFE stacking fault energy is found directly proportional to the wear loss, so higher is the stacking fault energy greater will be the wear loss of material and inversely proportional to the work hardening behaviour. So, if we see this friend is so if we see this 1 if the material is having the higher stacking fault energy then due to the surface layer deformation under the wear conditions there will be the faster removal of the material from the surfaces.

And that is why the wear loss will be high on the other hand when the stacking fault energy is low then material tends to harden rapidly it is inverse relationship higher this stacking fault energy lower will be the work hardening characteristics. So, material do not materials will not be hardening much despite of the surface layer deformations. So, the loss of the material will be faster while in case when the surface stacking fault energy is low material surface layers will be work hardened rapidly.

And so, they will be resisting the abrasion and the surface layer deformation quickly and which in turn will be resisting the loss of material from the functional surfaces. So, stacking fault energy is one of the important parameter it is always preferred to have the low stacking fault energy. So, that the material loss in form of wear is less and the work hardening tendency of the material is high.

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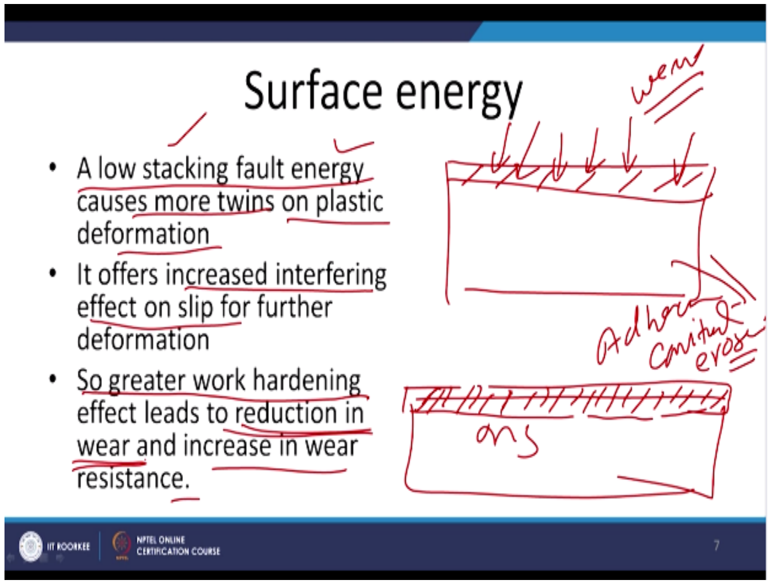


So, this is what I have just explain the low stacking fault energy causes low stacking fault energy under the during the deformation under the deformation conditions material having the low stacking fault energy under the deformation conditions will form the more twins on the plastically deformed surface and these twins are interferes with the slip movement which in turn will be resisting the deformation and resistance to the deformation of the surface layer under the wear conditions.

Especially when there is a metal to metal wear or under the abrasion conditions also. So, when the material is having low stacking fault energy it results in the more twins on the deformation and increased a number of the and these twins will be resulting in increased interfering effect on the slip of the material having the more twins especially in case of the low stacking fault energy materials and that in turn resist the deformation.

So, for greater work hardening effect and if the material surface layers are being work harden or they are having the greater work hardening effect then it will be leading to the reduction in wear and which in turn will improve the wear resistance. So, what is preferred that if the material is say mild steel then we would like to have the surface layers design in such a way engineered in such a way that it has the material of the low stacking fault energy at the surface.

So, that it work hardens rapidly under the wear conditions especially under the adhesive wear conditions under the cavitation conditions and solid particle erosion conditions. So, because in all these cases some kind of the it is a near surface layer deformation will be experienced by the material and if it is having if the surface layers are having the low stacking fault energy then these will be work hardened very rapidly.

And will which in turn will be reducing the resistance will be reducing the deformation and the reduction in deformation of the surface layers in turn will be increasing the resistance to wear.

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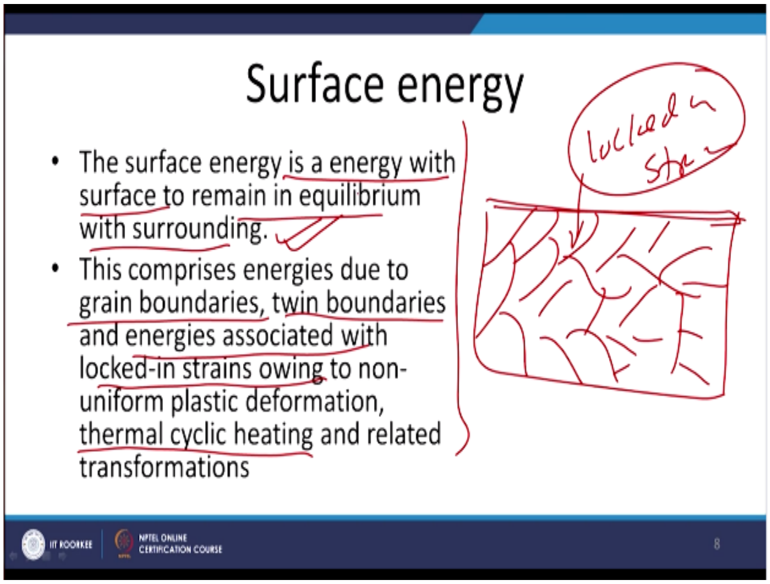


So, if we have to understand in another way surface energy is energy with surface to remain in the equilibrium the all the materials will have the different consequents of the different sizes and different shapes. So, the energies are associated with each of these such as the grain boundaries which are present in the material, twin boundaries which are present in material.

Energies associated with the locked-in-strain which happens due to the differential change in volume especially under the non-uniform volumetric change or non-uniform plastic deformation or thermal cyclic heating or the meteorological transformations. So, all these will be leading to the some kind of the locked-in-strain. So, this locked-in-strain energies associated the grain boundaries and twin boundaries.

So, some kind of energies are associated with the material and in to have some kind of equilibrium with these energies surface energy is required. So, surface energy is the energy with surface to remain in equilibrium with the surrounding.

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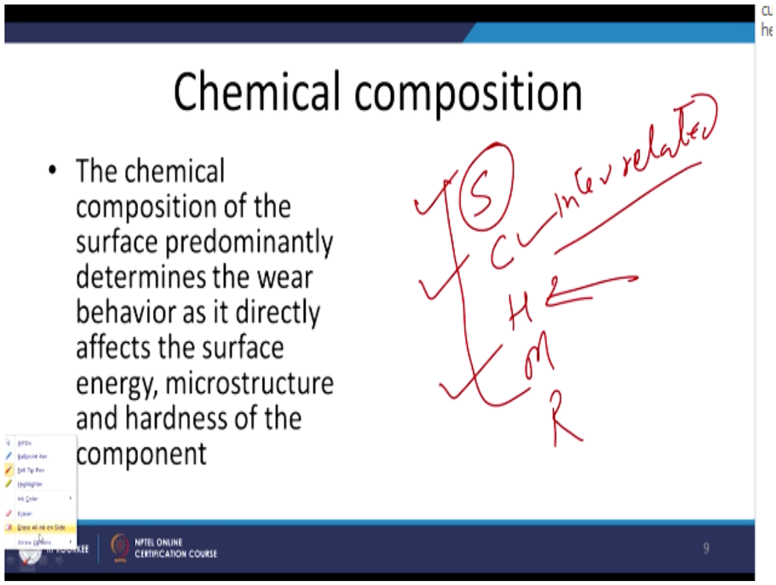


Now another important characteristic of the surfaces that will be affecting the wear and friction behaviour of the material is the composition. So, if we see all these properties like surface energy, chemical composition, hardness of the material, micro structure and surface roughness except the last one all these first 4 properties are somehow interrelated.

So, that is what will be talking like we have talked about the surface energy and it is required the surface energy low to have the good resistance to the wear and friction higher surface energy results in the larger wear particles which in turn is also in the higher wear rate as well as the high surface energy also causes the greater friction. But these surface energy of the material is also found to be sensitive of the chemical composition and the micro structure.

Similarly the hardness of the material is also found to be in dependant on the chemical composition and the micro structure of the material. So, somehow all these characteristics are interrelated and which will have the impact on the wear and the friction behaviour of the material.

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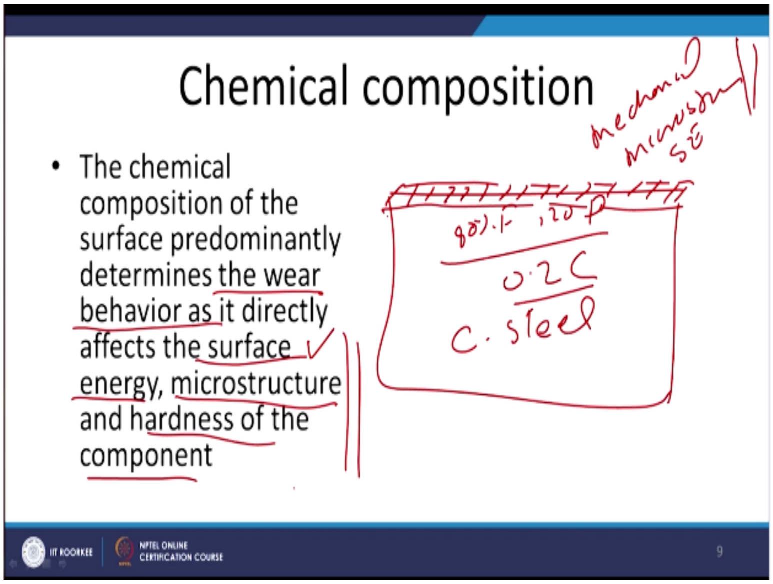


So, they since the chemical composition is of any material which is made of a particular compositions say if it is simple carbon steel having 0.2% carbon. In that case it will have mostly have say 80% of the ferrite and 20% of the perlite this will having particular for each composition they are particular set of the phases which will be there under the normal conditions.

If we want to change the surface properties of such kind of the material then by altering the chemical composition of the surfaces we can have some another set of the micro structure present at the surface we can have another set of the mechanical properties another set of the micro structure and another level of surface energy. So, alteration of the chemical composition affects all these characteristics.

And that is why chemical composition of the surface predominantly determines the wear and friction behaviour because it directly affects the surface energy, surface micro structure and the surface hardness. Since these 3 characteristics are being influenced due to the change in chemical composition of the surfaces. So, it is important that surface if it is possible to regulate the surface characteristics surface chemical composition.

Then it will be regulated in such a way that we are having suitable combination of the these surface properties like the surface energy, micro structure and hardness of the material surface.

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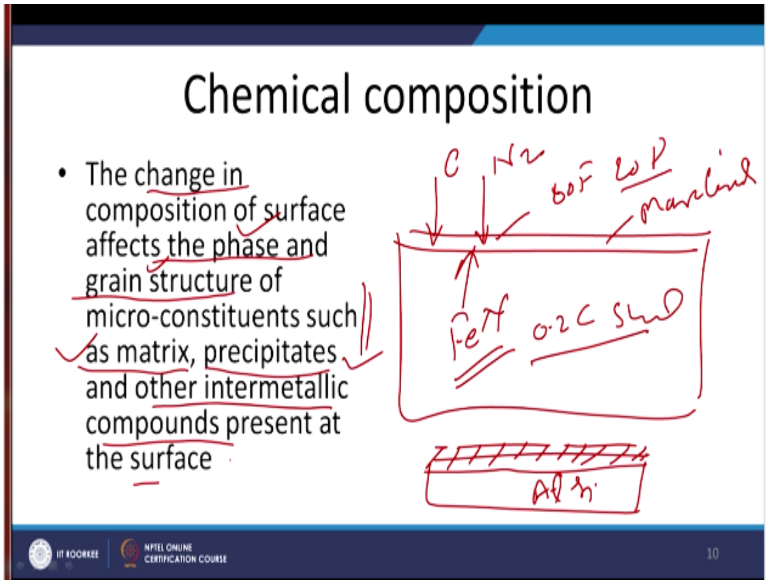


So, the change in chemical composition according to this one since the chemical composition effects the surface energy micro structure and hardness which is have 1 type of the mechanical property. So, it is good to change the compositions if possible, so that we have required combination of the micro structure change in micro structures have it can change the different type of phases which are present and it is grain structure.

So, change in grain structure and phase structure is possible and which can lead to the variation in the matrix phase which can lead to the formation of the various types precipitates and various types of the compounds. So, for example if this is the surface of simple 0.2% carbon steel which had like say at the surface 80% ferrite and 20% of the perlite. So, we can change this by changing the surface composition say introducing the carbon at the surface.

So, this increased carbon content will be increasing the perlite under the normal condition but if controlled treatment is carried out it can lead to the production of the martensite at the surface layer. Similarly we can introduce nitrogen also, so introduction of the nitrogen at the surface we will be leading to the formation iron nitride. So, it will offer as the different set of the properties which were not actually present at the surface of the simple mild steel or low carbon steel having 0.2% carbon steel.

So, it can be any other material, so like we can take simple aluminium silicon alloy and it is surface can be modified in such a way that it has a desired composition. So, that it results in the desired set of the mechanical properties, micro structure and the surface energy to offer the required wear and friction behaviour. So, change in micro structure can lead to the variation in these aspects like physics can change, grain structure can change.

And as per as micro-constituents which are present there can be variation in the matrix there can be variation in the precipitates and the intermetallic compounds which are being formed due to the change in chemical composition.

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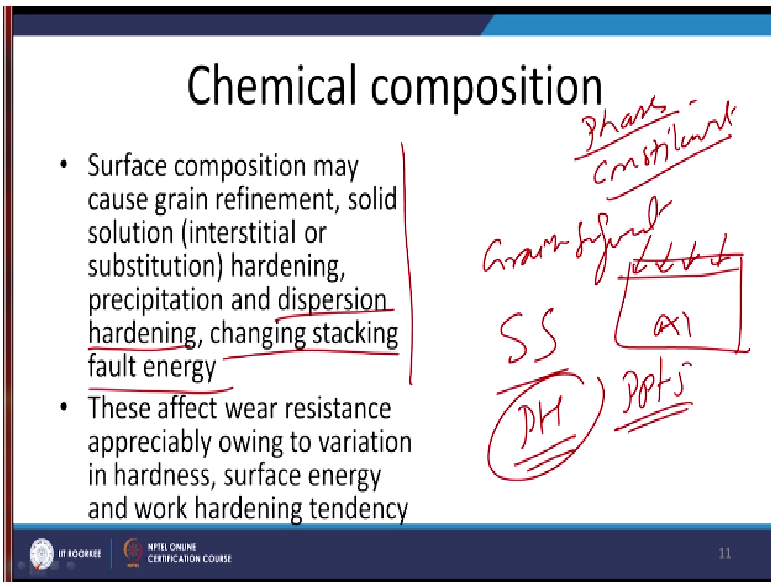


So, what can be done and how the change in chemical composition can affect 1 aspect is that it will change the phases, it will change the constituents which are present at the surface. Apart from these change in phases and the constituents which are present it can lead to the grain refinement means we can add just at the surface layers those constituents which will help to refine the grain structure of the surface layers.

So, the properties are enhanced, it can lead to the formation of the solid solution like addition of the alloying elements can form the solid solution and enhance the hardness and so wear resistance it can also lead to the precipitation hardening like in presence of certain alloying elements under the controlled treatment condition, we can have certain kind of the precipitates which will offer as the desired set of the properties.

Similarly we can introduce certain kind of the dispersion harden hardening constituents like in the metrics of the aluminium we can at tungsten carbide, chromium carbide at the surface layers. So, the composition of the near surface layer is altered and we are having the desired constituents and desired properties and the surface in terms of the wear and friction behaviour. Similarly these change in chemical composition can also alter the stacking fault energy of surface layers just an example of that what.

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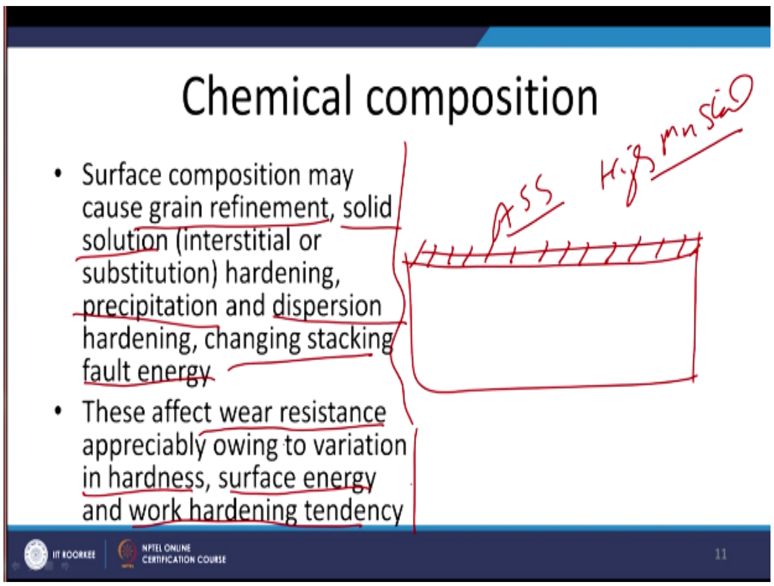


We can see here like simple carbon steel which does not show much of the work hardening behaviour. So, if the surface layers are deposited in such a way that it is having the austenitic stainless steel or high manganese steel. So, both these offer good work hardening behaviour because of the low stacking fault energy. So, despite of the high stacking fault energy of the simple carbon steel if it deposit a layer of the low stacking fault energy material at the surface it will result in the good wear and friction behaviour as per our requirement.

So, the compositional modification can affect the wear and friction behaviour in various ways which includes like grain refinement, solid solution is strengthening, precipitation hardening and dispersion hardening, it can also cause the transformation hardening like in carburizing where carbon content has enriched increased and thereafter control heat treatment leads to the formation of the marten site should can also be informed.

The transformation hardening and then changing this stacking fault energy by having a particular kind of the surface material at the surface. So, these characteristics affect the wear resistance of the material why because when our these kind of the hardenings and change in behaviour will be taking place, this will be leading to the improvement in the hardness surface energies and the work hardening tendency. So, wear and friction behaviour will be influenced because of variation in these 3 characteristics.

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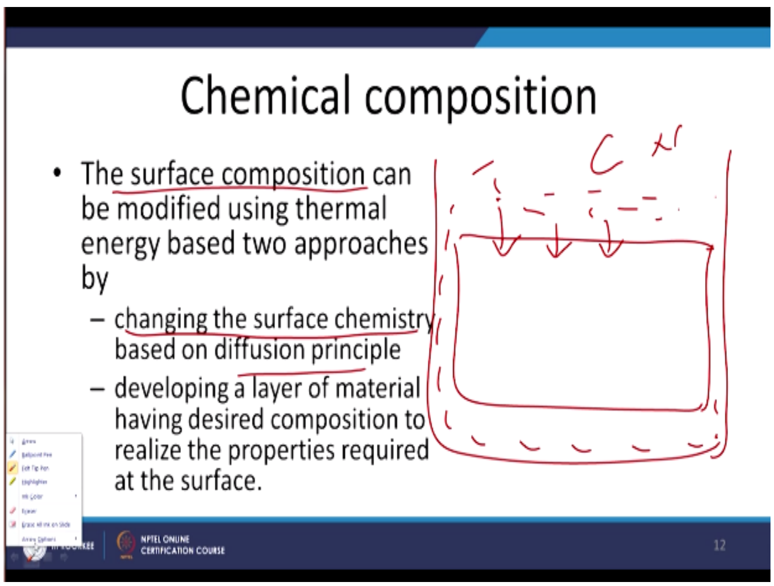


So, what we can do for changing the chemical composition basically these are the thermal methods which are used. So, surface composition can be modified using the thermal methods. There are 2 approaches one the component whose surface composition is to be modified will be exposed at high temperature in the environment of a which is rich in the required element say it may be carbon or nitrogen or vanadium or anything else.

So, these will be diffusing into the surface, so diffusion is 1 approach where changing the surface chemistry based on the diffusion principle.

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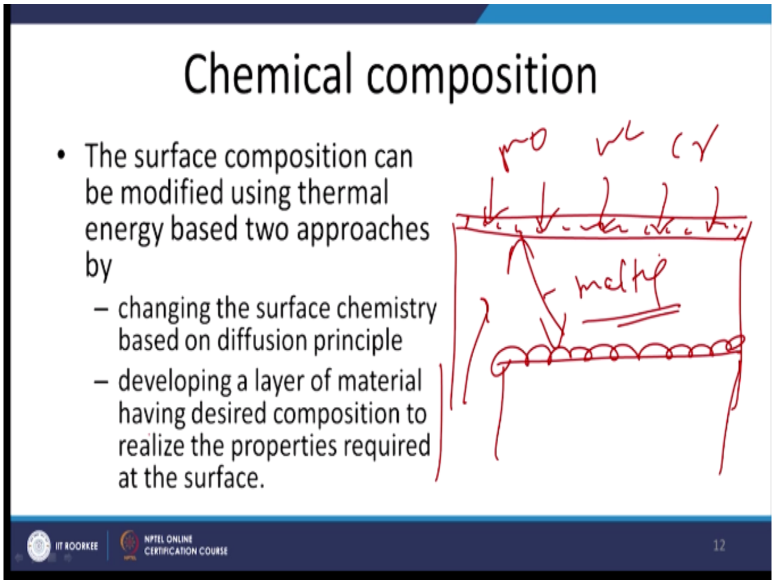


Second is where surface layers second approach is what where surface layers are brought to the molten state. So, surface layer will you brought to the molten state and then required elements which we want to introduce at the surface will be brought in. So, developing either melting the substrate layer and then introducing the required elements like tungsten carbide or introducing the chromium or molybdenum at the surface or we can just simply deposit without melting the substrate material we can deposit only at of the required material by development of the coating.

So, both these will be involving both these approaches involve basically the melting or the fusion of the surface. So, developing a layer of the material having the desired composition to realise the properties which are required to regulate the friction and behaviour of the material, further aspects related with the approaches will talk in the next presentation and I will summarise this presentation.

In this presentation basically I have talked that they are 5 important surface characteristics that matter for the wear and friction behaviour of the material. These are the surface energy chemical composition, micros structure surface hardness and the surface roughness. In this presentation basically I have a liberated the surface energy and chemical composition and the way by which it can affect the wear and friction behaviour of the material, thank you for your attention.