Surface Engineering of Nanomaterials
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Lecture – 03
Wear and Corrosion

Hello, today we are going to start our third lecture which is based on wear and corrosion. So, in the first light just we will discuss that, what is wear.

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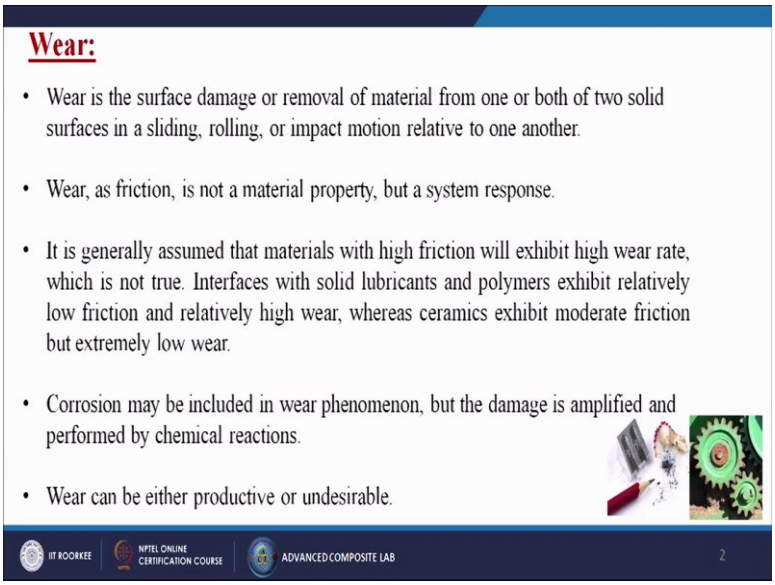

In the last slide or maybe the last chapter we have discussed about the friction. So, if we think that friction is the cause and then wear will be the effective cause of that particular friction. So, as by definitions if we go through the wear then wear means it is the surface damage or removal of material from one or both of two solid surface in a sliding, rolling or impact motions relative to one another.

So, from that particular sentence we can understand that unless and until there will be a contact in between the two surface either maybe both are soft or maybe both are hard or maybe one maybe hard one maybe soft, then only there will not be any contact wear will not takes place and it is not like that that always they will keep touch on it, either they are having a sliding motions in between them or maybe they are having a normal load acting on them or maybe there is acting some kind of tangential force in between them by which the wear can occur. Wear it is a friction is not a material property, but a system

response. So, it is not the material properties that every time it will unless and until there will be any friction occurs, wear will not be there.

It is generally assumed that materials with high friction will exhibit high wear rate. So, this is from the childhood we know that, if there is more pressure or maybe there is more load applying two mating surface the friction will be more, but maximum cases it is not. If the material is soft and the load will be more then wear can occur or maybe the opposite one also, if there is some less load also more friction can occur or maybe the more load less friction can occur. Corrosion maybe included in wear phenomenon, but the damage is amplified and performed by chemical reactions, from here we can understand that corrosions is also one type of wear mechanisms; it is a part of a wear, but it is not directly related to the wear; maybe due to wear the corrosion may occur on to the material. Wear can be either productive or undesirable, sometimes wear is helpful to us where maximum time it is give a loss to any product life.

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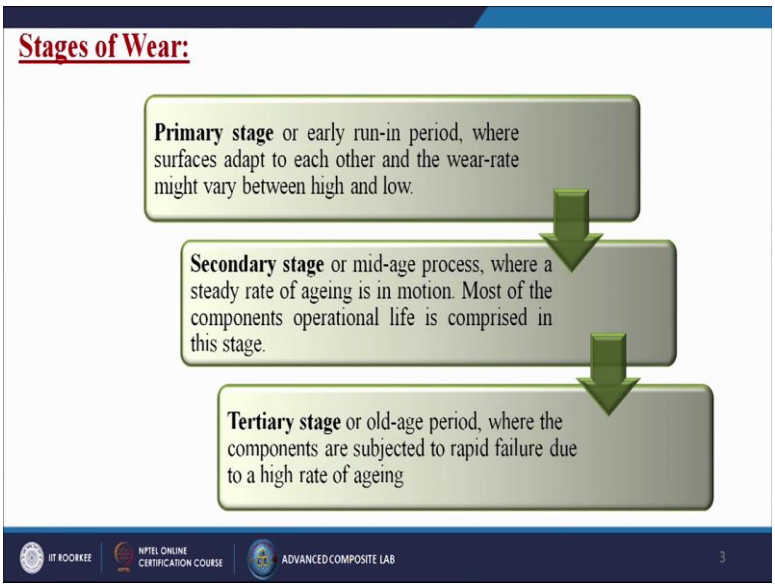

Next slide we will discuss the difference stages of wear, from this particular slides we can understand there is a primary stage then secondary stage and a tertiary stage. So, primary stage says that in which just the two samples is mating each other, second stage it will discuss that two stage are into some dynamic motions or maybe the one is in the dynamic motions another in the static motions means both are rubbing each other for a longer time and the tertiary is generally it is called the old age where the components are

subject to rapid failure due to a high rate of aging; that means, the sample both the sample or maybe both the materials are attaching together for a longer time and failure can occur anytime.

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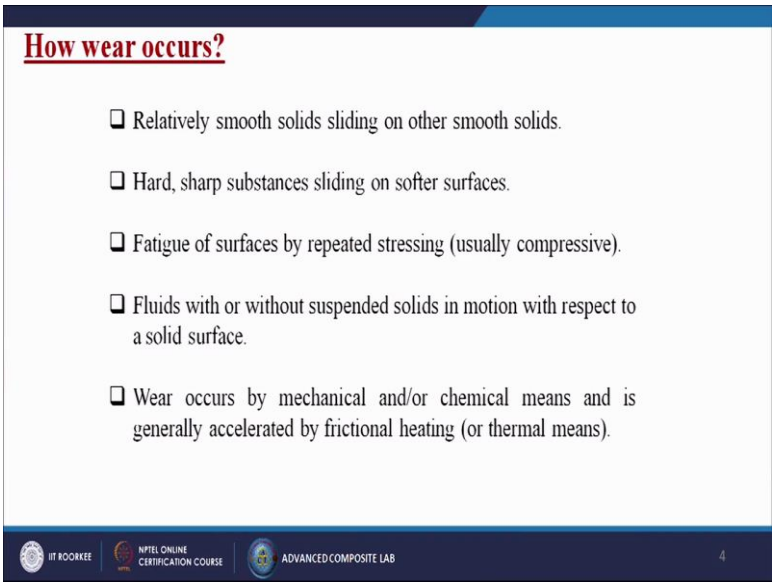

Next slide will discuss that how wear occurs, so if there will be not any touch or maybe contact in between the materials as I said already so no wear will takes place. So, when there will be some mating parts or maybe some parts will stick together then only the wear can occur. So relatively smooth solids sliding on other smooth solids, second is hard sharp substances sliding on softer surfaces, suppose our shoe soles when we are walking on to the road. So, our shoe soles is made by rubber or maybe some kind of polymer which is softer then when it is coming with the contact of the bitumen or maybe some rocks or maybe some kind of dust particles, it is getting eroded, so wear can occur. Fatigue of surfaces by repeated by repeated stressing usually compressive; suppose we are peddling our cycles or maybe continuously we are giving a pressure on to the breaks due to that some kind of wear can occur. Fluids with or without suspended solids in motions with respect to a solid surface, the best example is that when the rain water is coming or maybe the tap water is coming and it is falling on a particular place, you can see that the (Refer Time: 05:25) where the water droplet is continuously dropping, it get some kind of erosions, so that is also a one kind of wear.

Wear occurs by mechanical or chemical means and is generally accelerated by the frictional heating. So, suppose two surface either maybe soft or maybe hard continuously they are rubbing each other; due to that the temperature increasing and due to that temperature the material properties is going down, so by this way also wear can occur. Next slide it is divided actually into two parts, the left hand side its depends upon the level of wear test, means if there is some wear how we can measure those wear.

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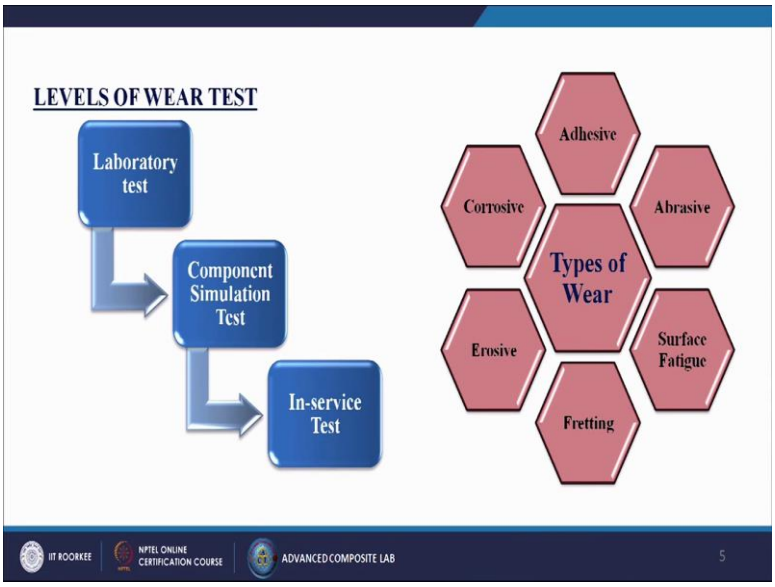

First is called the laboratory test there are several types of applications or maybe laboratory equipments are there by which we can test this kind of wear. Number one is called the profile emitter by which we can see; what is the friction of that particular material, what is the surface softness of that particular material, by scanning electron microscopy, by AFM methods. So, by there are several types of methods by which we can measure that if there is any wear occurred to that particular material or not. Second is called the component simulation test, so when we are designing some kind of materials by auto cad or maybe some kind of cam design, first initially we are drawing the material, designing the material what will be the date, what will be the size, what will be the effect everything. So after certain time, if we check that whether that material is having exactly that particular steps what we have given earlier at the time of manufacturing, so automatically we can measure that if there is any wear takes place or not by simply deducting both the values.

Third one is called the in-service test, in service test is nothing that when we are using that material for a particular applications, we can see that whatever the output it is coming from that particular machines that it is the same as it is earlier or maybe there is some noise like ball bearing, if continuously when it is continuously using in fan or something like that. We can see that after certain time we are getting some kind of noise from our fan itself or maybe the motors. So, by which we can measure or maybe test that whether the wear is there or not and the right hand side, it will give you there are total six types of wears generally we can see in our day-to-day life. First one is called the corrosive wear, then adhesive wear, abrasive wear, surface fatigue, fretting and last one is the erosive wear; in the next subsequent slide we will discuss all the wear one by one.

So, first we will start with the adhesive wear, so from the name itself you can understand that adhesives means there should be some stickiness in between the material. So, when the material will rub each other the temperature will automatically increase due to that increase in the temperature, the material will try to stick; that means, the localized welding will takes place, localize joining will takes place, but at the certain time when the material will cool down, but still the material is into the moving actions, so what will happen either which one is the soft material that will erode with the hard material; some material will come out from the softer material, so that type of wear is known as the adhesive wear.

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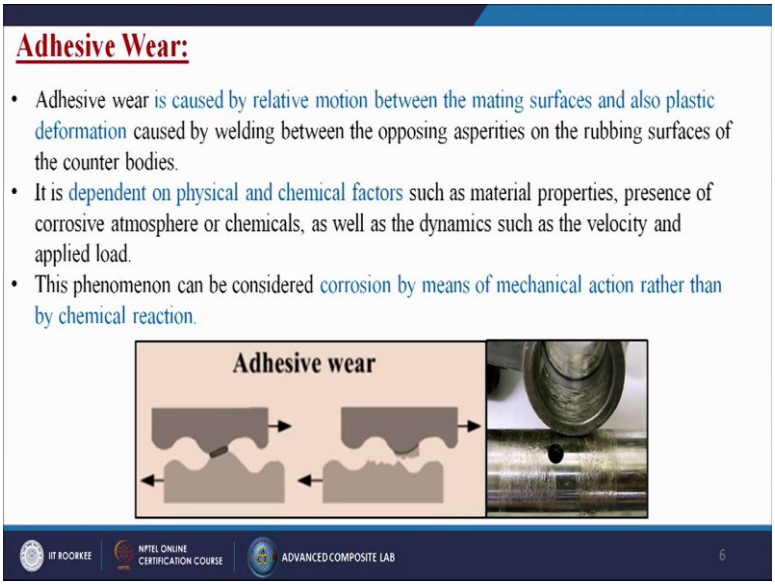

So, adhesive wear is caused by relative motions between the mating surface and also plastic deformation caused by localized welding, actually this welding means it should be the localized welding between the opposing asperities on the rubbing surface of the counter bodies. So from that figure itself you can understand that two bodies is moving into the opposite directions then when the sharp projections it is continuously touching and then some localized welding is taking place in between these two surface then when both are cooling down then suddenly what will happen some material from the softer material will come and stick together with the other material and the wear will be taking place.

In the right hand side also you can see that this kind of adhesive wear is taking place onto this surface at the time of grinding.

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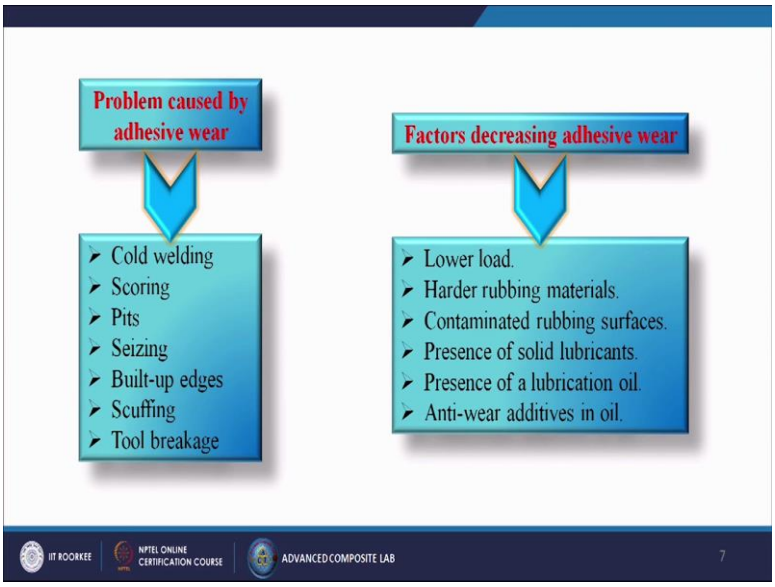

So what are the problem; caused by adhesive wear? Generally cold welding, scoring, pits, seizing, built-up edges, scuffing, tool breakage, so these actually everything is happened only that one materials is sticking with the another one and some kind of crevice or maybe the whole or maybe some kind of cracks or maybe damage parts may occur at that particular point. What are the factors? Factors decreasing adhesive wears if you lowering the load, if harder rubbing materials if you use it, contaminated rubbing surfaces if you want.

That means, any kind of lubrication type of things if you use, presence of solid lubricants which can be melted when automatically the temperature will be raised at that particular juncture, presence of lubrications oil; which the material can make more slippery and anti wear additives in oil. So, you can use certain kind of nano particles or nano fillers inside the oil so that when the temperature will go on into the increasing manner, so automatically that will absorb the temperature at that particular interface so that the friction will be less.

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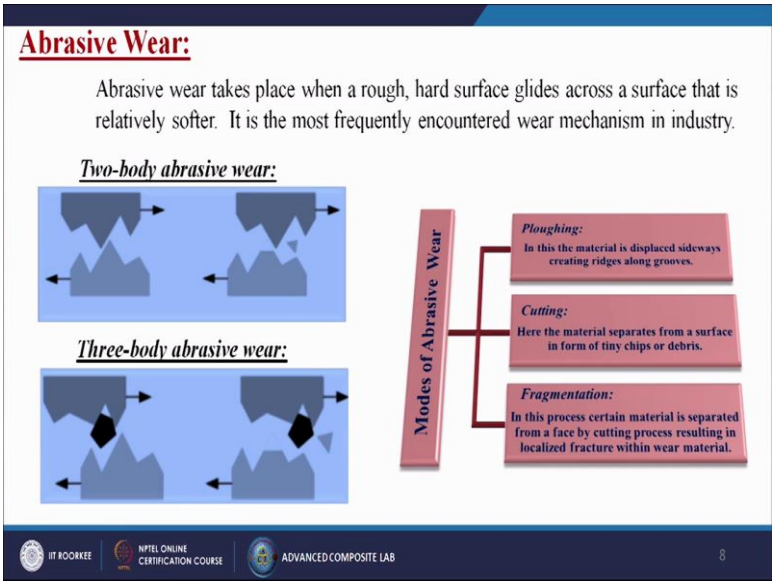

Next is called the abrasive wear, so abrasive wear takes place when a rough hard surface glides across a surface that is relatively softer, the best example is that duster because this duster this is the softer one and we are having the black board which is the harder one, so when I am trying to rub it; this softer material is rubbing continuously on to the harder surface. So, whatever the wear it will takes place over here it is known as the abrasive wear. So, abrasions the term abrasive wear has come from the term abrasion, so from the abrasions it has come to the abrasive.

So, abrasive wear takes place when a rough hard surface glides across a surface that is relatively softer. It is the most frequently encountered wear mechanism in industry because when there is some chain and pulley arrangement or maybe the some kind of belt arrangement is there because continuously belt is rubbing onto the pulley or maybe some rounded surface continuously, so there is a continuous rubbing effect in between

the belt and pulley, so you can find this type of wear. So, from that figure itself you can understand that there are two types of abrasive wear one is called the two body abrasive wear in which only the two surface is mating each other and due to that the softer surface is getting eroded or maybe the three body abrasive wear where there is a another body in between the softer and the harder one. So that body will give a effect on to the harder surface as well as the softer surface due to which after certain time, the softer surface will get eroded.

So, there are three types of modes generally we are seeing for the abrasive wears, so first one is called the ploughing, second one is called the cutting, third one is called the fragmentation. Ploughing is nothing but when there is some hard projections; it is coming to the contact of any softer materials, it is trying to take out some materials from its softer zone by its hard projections, so that is known as the ploughing mechanism. Second one is called the cutting mechanism, cutting mechanism means if there is any hard projections on the harder material, so when it will come into the contact with the softer material it will make some cut or maybe some kind of holes or maybe some kind of sharp cutting onto the softer materials, so that is known as the cutting.

Third one is called the fragmentations by which the softer material will be fragmented into small small particles; that means, the softer material will break down into the softer particles, not softer particles rather we can say that into small small particles by the hard projections or by which is produced by the hard materials. Next one is called the surface fatigue, so surface fatigue from the name itself you can understand that surface fatigue is only depends upon the load; that means, the normal load. Suppose you are having a surface and continuously you are giving a pressure or maybe load on that particular surface, due to that first initially your surface plastic deformation will takes place; that means, the elastic properties of that particular bodies will go down then surface will become harder, but still if you are going to give the constant load, so after certain time that surface will failure, so that is known as the surface fatigue.

So, the process by which surface of materials is weakened by the cyclic loading, so continuously you are maintaining a load onto your surface.

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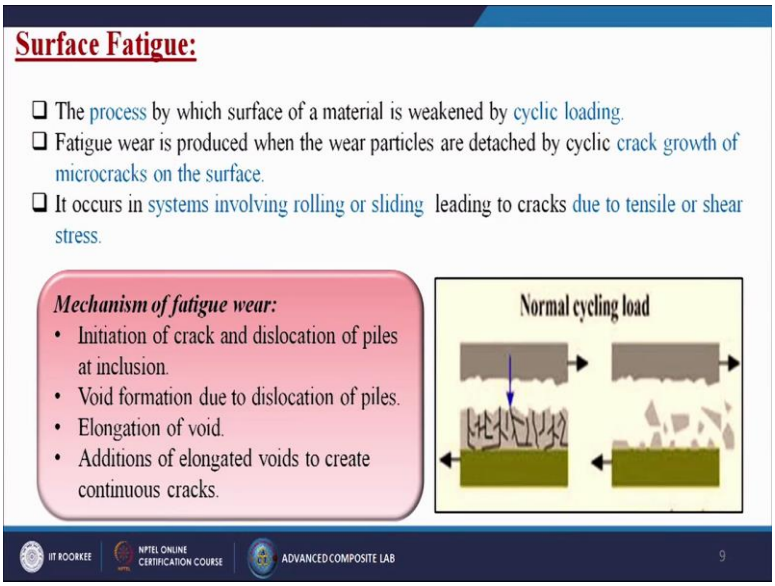

Fatigue wear is produced when the wear particles are detached by cyclic crack growth of micro cracks of the surface, it occurs in systems involving rolling or sliding leading to cracks due to tensile or shear stress. From this particular figure you can understand that you are having the surface one is harder one is softer. So, continuously you are giving a load from the top which is known as the normal load then after certain time what will happen this material will be break into small small particles or maybe small small sizes. What is the mechanism of fatigue wear, initiation of crack and dislocation of piles at inclusion void formation due to dislocation of piles, elongation of void additives of elongated voids to create continuous cracks.

So suppose you are having two material; continuously you are giving load onto to that, so what will happen fast there will be a cut generations or crack generations will be taking place then after certain time that crack will become bigger and bigger then after certain time through that crack again it will go into the deeper and the material will became into smaller size.

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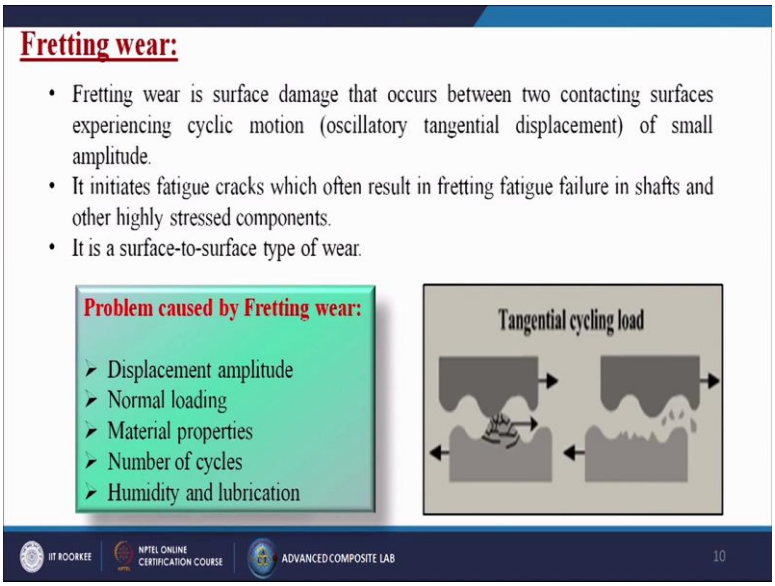

Next is called the fretting wear, so fretting wear is surface damage that occurs between the two contacting surfaces experiencing cyclic motions of small amplitude. So, it is the little bit higher version of the surface fatigue, surface fatigue we have seen that there is a normal load is acting onto the material, but here the load will be in the tangential or by sidewise that is why these kind of wear may takes place, it initiates fatigue cracks which often result in fatigue failure in shafts or other slightly stressed components. So what is happening our shafts it is rotating in a continuous manner, in a continuous rpm due to that rolling friction, some kind of wear mechanism can takes place on to the shaft itself, that type of wear is known as the fretting wear. Problem caused by fretting wear; displacement amplitude, normal loading, material properties, number of cycles, humidity and lubrications; these problem can occur due to the fretting wear.

Next is called the erosive wear; erosive wear is nothing but suppose we are using certain kind of (Refer Time: 17:41) or maybe we are using certain kinds of connectors by which our blood or sorry any kind of liquid is going through. So, suppose same thing is happened to our body also because our body there is also several veins and several kind of nervous systems are there by which our blood is going through, so when the constantly the blood is flowing through this vessels, so they are creating some kind of abrasive particles, then they are depositing that abrasive particles which is nothing but known as the cholesterol, the same thing is happening over here also.

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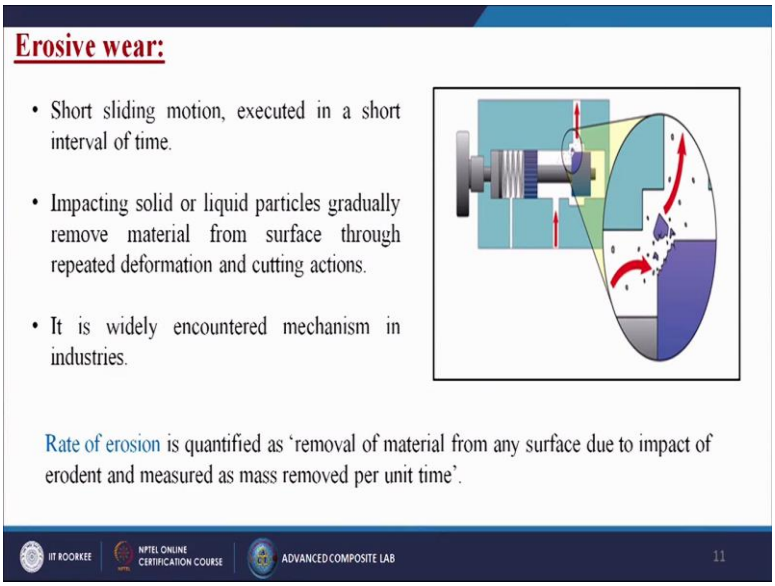

So, when the liquid is going through this parts to lubricate those materials, so due to that pressure maybe some materials getting eroded from that particular surfaces and then that material is mixing with the fluid and then same thing it is recycling repeated times. So, what is happening due to that particle it is continuously rubbing with the softer material and it is creating certain kind of wear which is known as the erosive wear.

So short sliding motions executed in a short interval of time, impacting solid or liquid particles gradually remove material from surface through repeated deformations and cutting actions, it is widely encountered mechanism in industries. Now from here we can understand one term that is called the rate of erosions, so rate of erosions is quantified as the removal of material from any surface due to impact of erodent and measured as mass removed per unit time. So, how much material it is removing from a particular body within a stipulated time, so that is known as the rate of erosions.

Next is called the corrosive wear, so from the name itself you can understand that corrosive wear is only dependent upon the corrosions of that particular material. What is corrosions, it is a mechano-chemical process, so first the material will be chemically attacked then automatically its mechanical properties will go down by which the wear will takes place, so it is a combined effect of chemical and mechanical actions.

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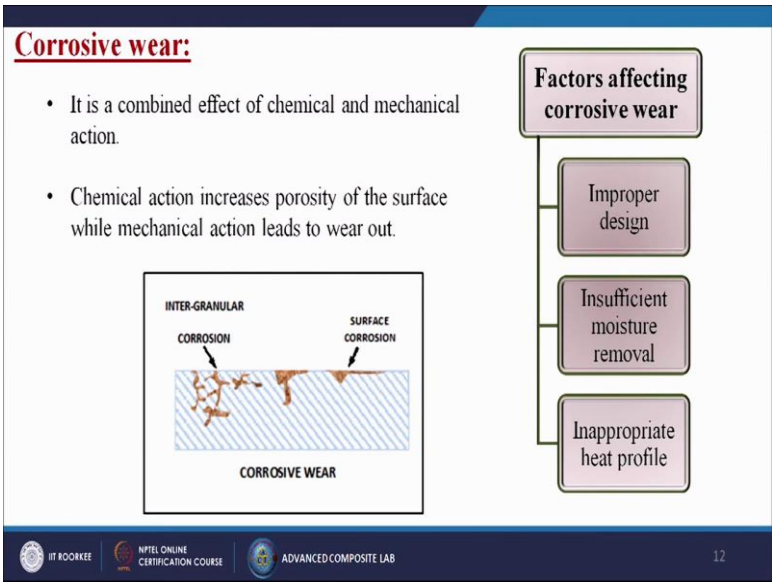

Chemical action increases porosity of the surface while mechanical action leads to wear out. So from this particular figure you can understand that this is there is certain kind of examples of inter-granular corrosions and here this side is called the surface corrosion. So what is happening initially if there is any small pores or maybe cracks which is happened by chemically. So, automatically some water or maybe moisture will go inside; then slowly slowly it will create certain kind of rusting or corrosions or maybe some kind of chemical reactions in between that by which the void space will be increased and then what about the type of wear will takes place, that is known as the corrosive wear.

Factors affecting corrosive wear first is called the improper design insufficient moisture removal in appropriated profile; that means, we have designed some materials which is having some kind of surface softness or maybe which is having some kind of cuts or maybe which is having some kind of pores by which maybe water or maybe the moisture from the environment or maybe when we are using that materials for a particular purpose either any chemicals like any strong acid or something which is going inside the material then it is reacting with the material by which holes and pores is creating and through that holes and pores, still the water particle or maybe the chemicals is still going on and it is widening the voids and then after latter stage the material will fell.

So, there are several stages of the corrosive wear.

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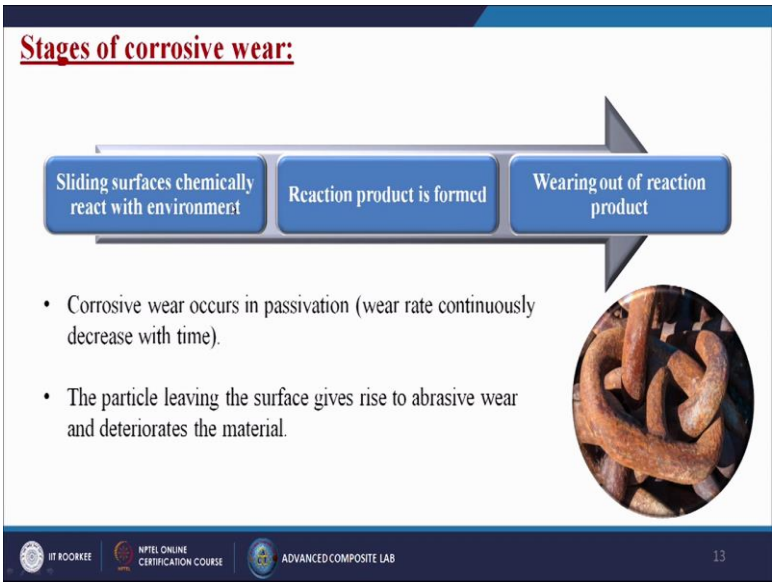

First one is called the sliding surfaces chemically react with the environment, then reaction product is formed then wearing out of the reaction product. Corrosive wear occurs in passivations wear rate continuously decrease with time because generally corrosions is taking place onto the surface. So, when you are having a new surface area generally in our technical term we can call it as a virgin surface area, so that can react easily with the environment, but after corrosions when there will be some kind of oxide formations will be taking place or maybe some kind of sulfide formations will be taking place after that there is no virgin area which can react with the environment itself that oxide or maybe sulfide film will act as a barrier layer in between the environment and neon material, so over the time your corrosion rate will be decreased.

The particles leaving the surface gives rise to abrasive wears and deteriorates the material, so from the right hand side this is the example of a chain generally which we are using for the ships or maybe the boats. So, you can see that after keeping it in a long time into the water or maybe into the environment some rusting is taking place onto heat. Next is called the how to measure that what is the amount of wear actually taking place so the wear coefficient generally denotes is by k.

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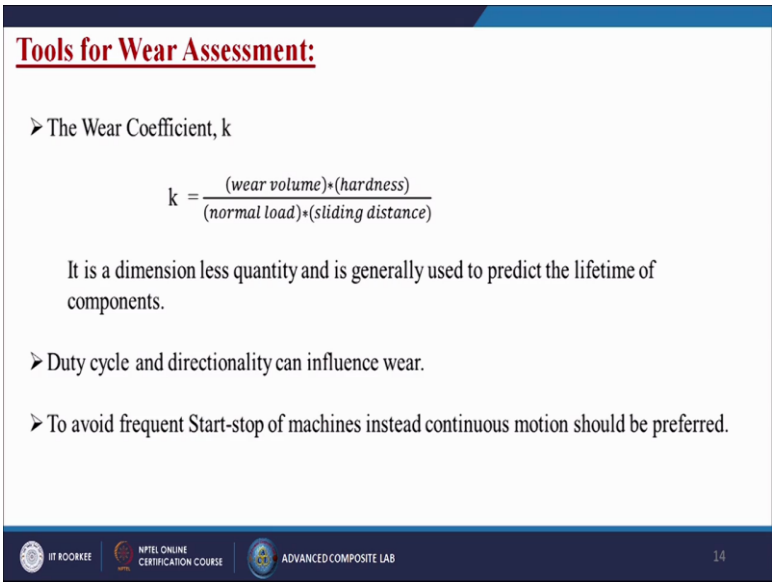

K is equal to wear volume into hardness divided by the normal load and sliding distance, so it is a dimension less quantity and is generally used to predict the lifetime of a component. So, when you are designing any kind of products, so by keeping all these value we can easily calculate that what is the wear rate of that particular material and if I do not take any kind of precautions, so how much time this material can work.

Duty cycle and directionality can influence wear, to avoid frequent start stop of machines instead continuous motions should be preferred. So, these all are the remedies or maybe the precautions we can say. Next is called the how to control wear, so there are several methods by which we can control the wear.

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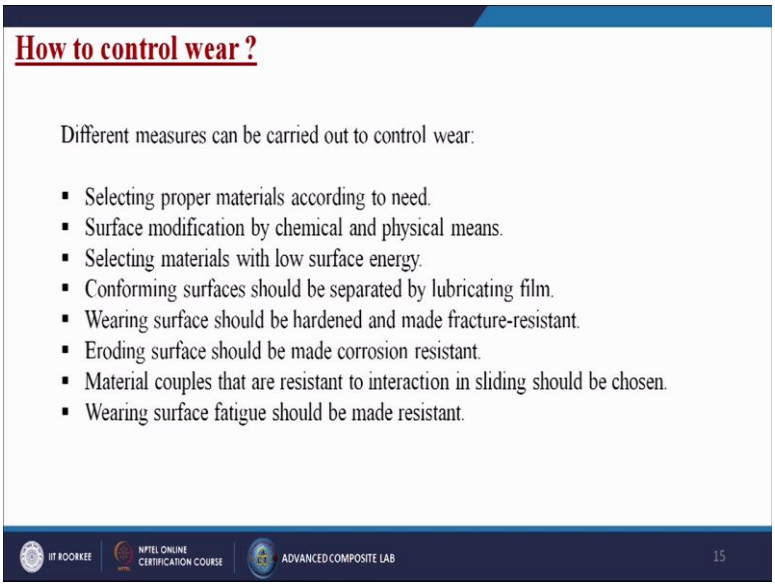

First one is called the selecting proper materials according to the need, so whatever the material we are going to choose, it should be chemically alert so that it will not react with the environment or maybe with any acids or maybe the base, surface modifications by chemical and physical means by any using any type of coating, so that it will not directly come into the contact with the environment or maybe the moisture or maybe the water molecule, selecting materials with low surface energy so that it will not absorb any material which can be harmful to them.

Conforming surfaces should be separated by lubricating film; we can use certain kind of lubrications so that there will not be any direct contact with the base metal. Wearing surface should be hardened and made fracture resistance so that there will not be any cracks or pores so that water molecule or maybe any chemicals can go inside the material. Material couples that are resistant to interaction in sliding should be chosen, wearing surface fatigue should be made resistant. So, these all are the remedies, but whatever I have explained here this is the standard one, but there are n number of remedies which we can adopt to safe our material.

Next we will go into the details about the corrosions.

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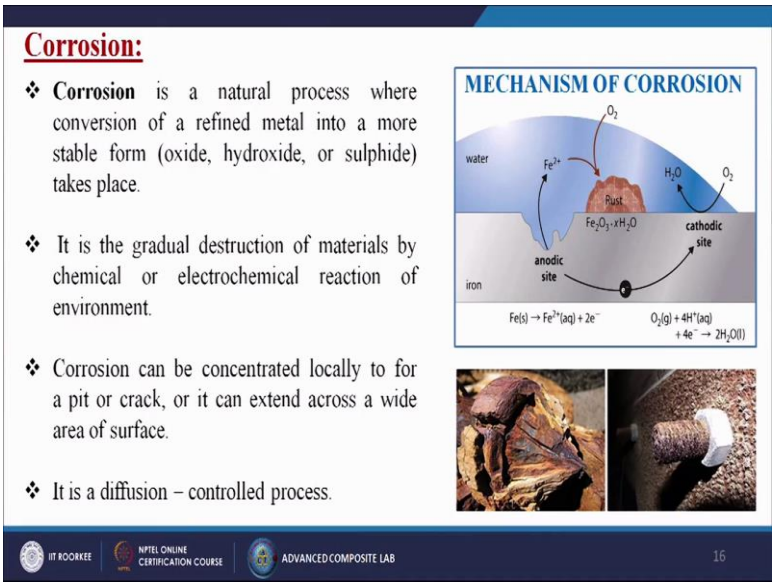

So what is corrosions; corrosions is a natural process where conversion of a refined metal into a more stable form. So, best example is that iron suppose we have made any product of the iron and we are keeping it into a environment, what will happen after certain time that iron it will absorb the water molecules from the environment itself, reaction will be taking place due to that iron oxide will be formed; which is a totally different state from the iron, but which will not carry any properties like iron, but it will be into the stable form; that means, the rusting or maybe that iron oxide generally in normal terms we are calling it as rusting, it will stable for a longer time on to the material surface.

It is the gradual destruction of materials by chemical or electrochemical reactions of the environment, corrosion can be concentrate locally to for a pit or crack or it can extend across a wide area of surface, it is a diffusion controlled process. From here we can understand that suppose we are having any material, you have done some kind of coatings, but after certain time either may that coating has come out or maybe there is a crack in between that coating; still that water molecule can go inside through this coating and it can react with your base metal. So, either the corrosion can takes place through whole surface or maybe there are some cracks or pores by which the water molecule or maybe the water vapour can go inside and it can do the reaction.

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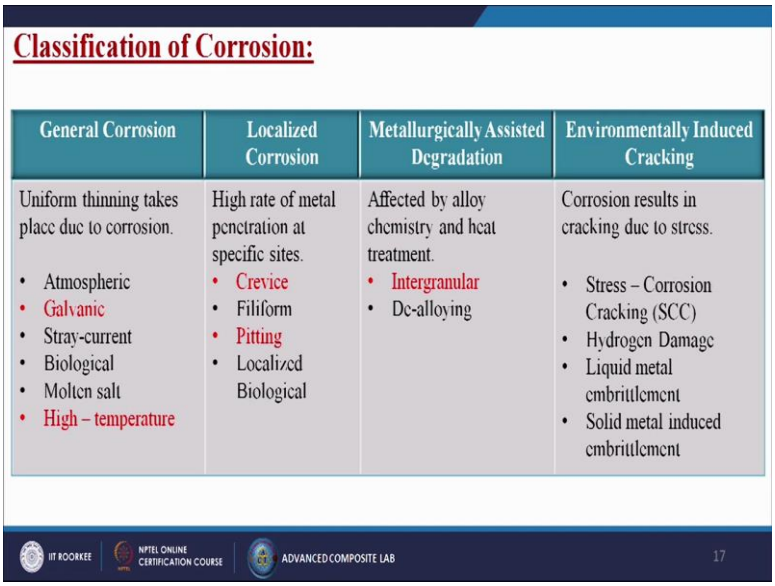

Then there are several types of corrosions, so based on that how they are occurring or maybe where they are occurring. So, first one is called the general corrosions; that means uniform thinning takes place due to the corrosions. So, there are several times atmospheric, galvanic, stray-current, biological, molten salt, high-temperature. So, here you can see that we have mass some types of corrosions by great; that means, these all generally we are seeing in our day-to-day life.

Next is called the localized corrosions which is known as the high rate of metal penetrations at specific sites, some kind of crevice, filiform, pitting, localized biological. Metallurgically assisted degradations affected by alloy chemistry and heat treatment some intergranular or maybe the de-alloying and then last one is called the environmentally induced cracking, corrosion result in cracking due to stress; stress corrosions cracking, hydrogen damage, liquid metal embrittlement, solid metal induced embrittlement. So, these all are the different types of corrosions generally we see or maybe we face day to day life.

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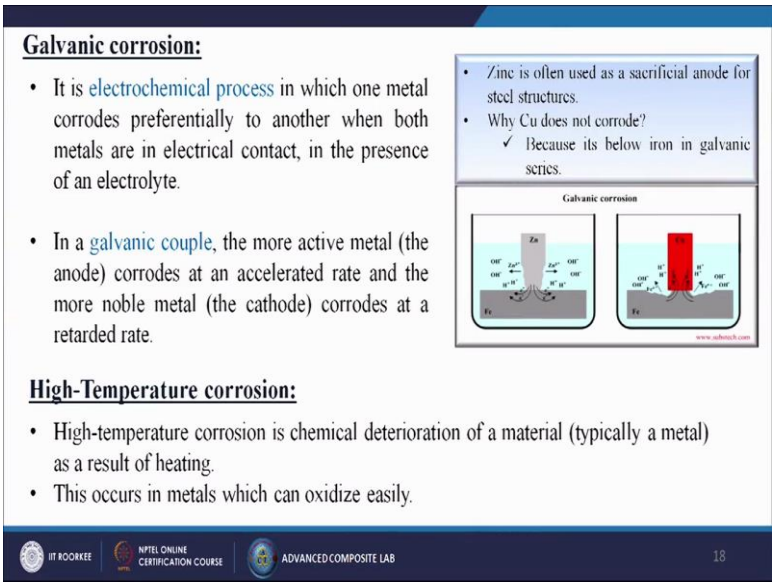

First one is called the galvanic corrosions, so from that particular name you can understand that when a material we are dipping into some liquid or maybe two solid material are there into some common solutions then maybe some chemical reactions takes place in between them. So, it is electrochemical process in which one metal corrodes preferentially to another when both metals are in electrical contact in the presence of an electrolyte so; that means, that electrolyte should be common for both the materials. In a galvanic couple, the more active metal the anode corrodes at an accelerated rate and the more noble metal cathode corrodes at a retarded rate, but both the case the wear will be taking place, but one cases it will be faster, one cases it will be slower.

So, from this particular figure you can understand that when you are putting zinc and iron in a common electrolyte. So, the zinc is getting eroded faster than the iron why because in the galvanic series, zinc is higher in galvanic series than the iron itself and when we are going for the copper and iron case the iron is getting eroded than the copper why because it is below iron in the galvanic state. So, which material in the galvanic series into the top that will erode more than the which material is into the bottom right. So, from this particular case we can understand or maybe we can easily detect that which material will be eroded faster, which material will be eroded slower.

Then next one is called the pitting corrosions, it is localized form of corrosions by which cavities or holes are produced in metals.

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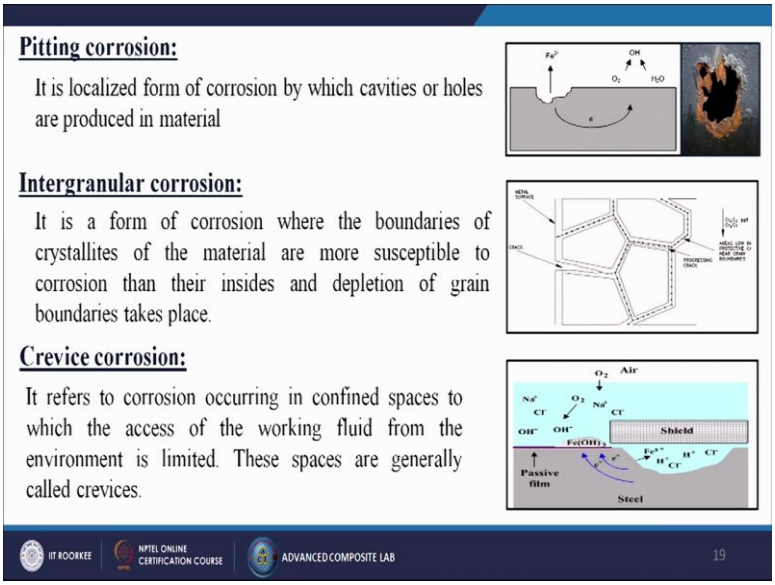

From that particular figure you can understand that we are having some base metals, after that we have done some kind of paintings or maybe some kind of coatings on to that particular material, but somehow we have done certain kind of holes or maybe we have did the penetration onto that material and the virgin material has come out due to that some corrosions can takes place which is known as the pitting corrosions.

Second one is called the inter-granular corrosions, generally these kind of corrosions we can see when we are making some kind of alloy materials or maybe the composite materials, so that corrosions can takes place through the crystal structure or maybe the granular side of that particular material. So, the material it is having two stages so made by two different materials or maybe more different materials. So, maybe they are some weak adhesions in between the metals or maybe there is some kind of phase separations in between the metals, so by which we can see that crack may generate in between that which is known as the inter-granular corrosion. It is a form of corrosions where the boundaries of crystallites of the material are more susceptible to corrosion than their insides and depletions of the grain boundaries takes place, another one is called the crevice corrosions. So, crevice corrosions is nothing but suppose you are having a material by which there is maybe some cracks or maybe pores is already present and

suppose you are dipping that material into some liquid or maybe you are keeping that material into the water sorry into the environment and some water molecules or maybe water vapour can deposit onto that particular crevice and slowly slowly it can react. So, due to that by what type of corrosions generally we can see that is known as the crevice corrosions.

So from that particular figure you can understand that there is a steel, here it is having some passive film which is giving a barrier in between the environment or maybe the water and with the steel, but still some kind of holes has been created or maybe some kind of spots or maybe some spots has been created onto the steel surface by which this environmental air or maybe water particle can come and directly react with this. Here we have used the sodium chloride; salt solutions, where the hydrogen and chlorine can react with that and due to that the corrosion can takes place which is known as the crevice corrosion.

Then next slide we will discuss; till now we are discussing about the several types of corrosions, now we are going to do some kind of modifications or maybe some kind of remedies by which we can stop the corrosion process to our materials.

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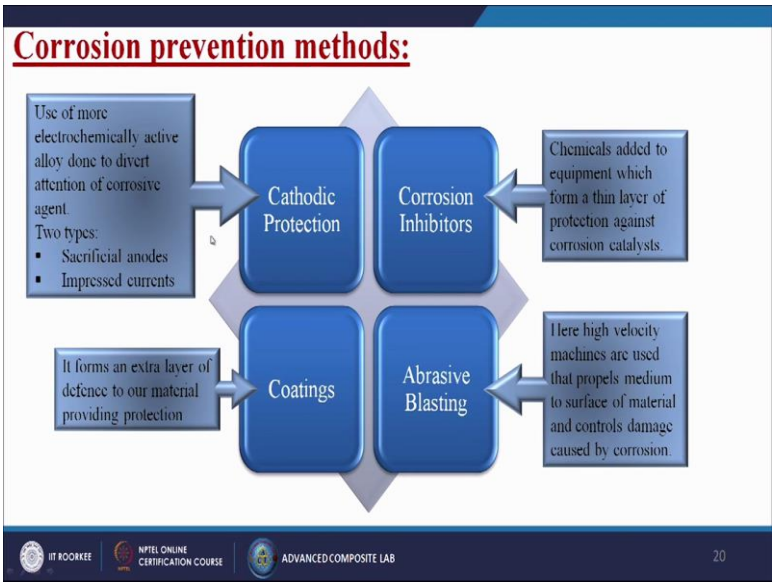

So, corrosion prevention methods first one is called the cathodic protections, so use of more electrochemically active alloy done to divert attentions of corrosive agents like sacrificial anodes some impressed currents either we have to change the currents so that

there will be less potential difference in between the anode and cathode so that chemical reaction will automatically go down or maybe we will put certain kind of more stronger anode materials which will react directly with the electrolyte, but not the ordinary cathode or anode will react. Second is called the coatings we can do some kind of coatings which will not react with the water molecules or maybe with the environment or maybe the chemicals, so that it will form some kind of extra layer or defense to our material some by providing some protections.

Third one is called the corrosion inhibitors nothing that we are adding some kind of materials with our base metal at the time of preparations which is by the best example is that suppose we are making some kind of composites or maybe alloys or maybe blends by which we are adding some kind of materials then when it will react with the environment; means like air or maybe some kind of water molecules or maybe chemicals then automatically that will make some kind of layer film onto its that is nothing is known as the self defense. So, the material itself will (Refer Time: 34:58) or maybe will create a barrier layer onto it and last one is called the abrasive blasting.

Abrasive blasting is nothing but the some kind of special methods, suppose you are having some surface which is has been affected by kind some kind of corrosions or maybe some kind of chemical reactions. So, by abrasive blasting means abrasive particle will come, it will heat your surface so that the whatever the oxide formation or sulfide formation has been taken place it will come out and you will get the virgin surface. Next slide just we will give; all the summary till now what we are discussing about the corrosion.

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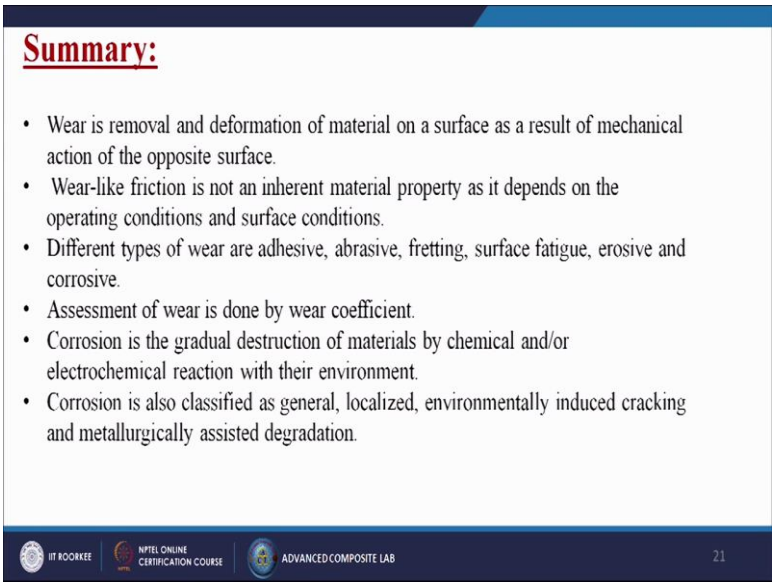

So, wear is removal and deformation of material on a surface as a result of mechanical action of the opposite surface. Wear like friction is not an inherent material property as it depends on the operating conditions and surface conditions, different type of wear are adhesive, abrasive, fretting, surface fatigue, erosives and corrosives which we have already discussed. Assessment of wear is done by wear coefficient, corrosion is the gradual destruction of materials by chemical and or electrochemical reactions with their environment; corrosion is also classified as general, localized, environmentally induced cracking and metallurgically assisted degradation.

So, the wear is a prime factor for losing the material properties also its totally depends upon that how the material will react with the environment, how the material will give its best properties to the environment itself. So, by reducing the wear we can use that material for a several time and for longer time.

Thank you.