Surface Engineering for Corrosion and Wear Resistance Application
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Lecture - 59
Surface Damage - Case Studies

So, welcome to the 59th lecture of the Surface Engineering course. Actually I am coming back after quite some time, in between we have covered almost everything that we wanted to. And before we wind up the course I thought I would meet you once or twice more, primarily to impress upon you why did we study this course and what exactly would be the benefits where are we going to use them in what technological field and what advantages or what benefits we can derive from this particular course content.

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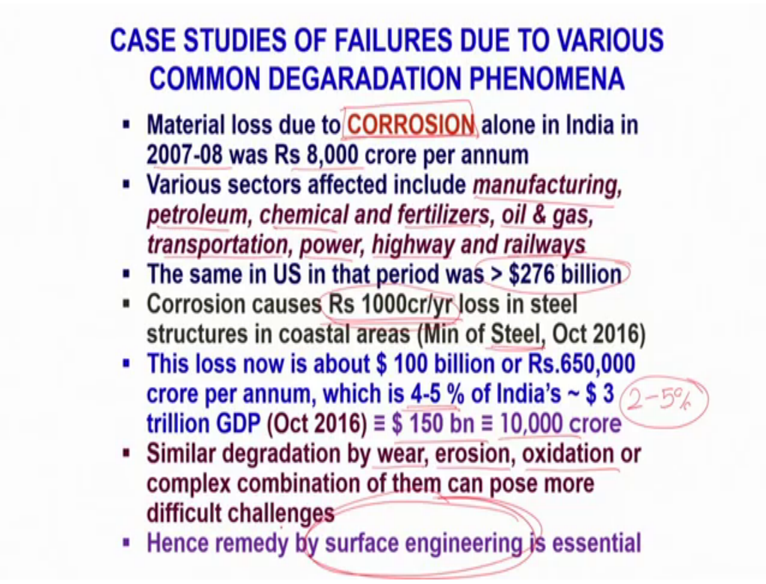

If you look at this particular view graph you realize we are trying to impress upon USO why we need to worry about corrosion. So, this is a major danger that actually threatens the integrity of metallic components primarily metallic components to a large extent. So, if surface engineering is all about tailoring the near surface micro structure and composition and not affecting the bulk. Then the obvious question is that why are we interested in modifying the surface alone and not catering so, much to the bulk microstructure or properties.

Well actually a most of the material synthesis and development programs, worry primarily about the entire bulk in various forms and dimensions be it in the form of thin films all the way to bulk structures. But then we also have a learnt in the very first lecture that, that threat always begins primarily at the surface because the intensity of a stress or mechanical activation is highest at the surface and also the chemical attack always is most intense at the surface.

So, if we take for example, corrosion as one of the possible dangers, then what we realize is that look at the figures I mean that is really staggering way back in almost 10 years ago it used to be about 8000 crore per annum. Cumulative loss only due to one single degradation process called corrosion and obviously, corrosion means degradation of metallic systems in all forms of industry, be it manufacturing or petroleum, chemical, fertilizers, oil and petroleum, transportation including automobiles, power sector, highway transportation, railways, aircrafts almost everywhere.

Wherever we use metals that simple logic is the following that mother nature preserves materials or metals in the form of more stable variation which could be oxides or sulphides or hydroxides and so on and so forth in compound form. And if you are careless and we leave metal in the open in an exposed to high temperature or even at room temperature to corrosive environment, then nature brings basically all these precious raw materials back to the pristine form.

So, that can preserve for future, which in other words nature always would like to see that its nature does not look at it as degradation; nature looks at it as an act of preservation. So, essentially what happens is that metal that we spend so much money time and effort to win from its oxides always would like to go back to its oxide or any of the compound form whereby it cannot degrade any further or change any further.

So, for example, in US there is a estimate that it can cause something like over 250, 270 billion dollar per year. So, this huge corrosion loss for example, if you think of only steel and steel structures which are existing in the coastal areas where you have lot of moisture and the air also contains quite a bit of salinity and hence, the presence of halide ions particularly chlorine. So, there it can actually lead to a huge loss of about 1000 crore per year.

Now, by and large the statistics show that typically anything between 2 to 5 percent not (Refer Time: 05:01) 4 to 5 percent, but 2 to 5 percent of the GDP is the total cumulative loss due to corrosion alone. Now India is a you know we are proud to be almost a 3 trillion dollar what GDP one of the largest in the world maybe third or fourth in terms of PPP and typically about five percent of 3 trillion dollar means about 150 billion dollar or rupees 10000 crore.

So, that is a huge sum of money which is wasted and it is not wasted without any effort to arrest it despite the fact that there is so, much of for example, all the railway wagons you will find that they are painted with a red oxide painting which is an iron oxide painting.

Similarly, all automobile bodies all other buildings and metallic systems are never exposed. As pure metal they are always coated with some paint or coating and something yet corrosion occurs. Corrosion occurs because it actually is inevitable because of various complex, synergistic action of mechanical, chemical, thermal and various kinds of other activated processes.

But surface degradation is not only about corrosion it can happen due to mechanical activation of wear or abrasion or erosion or corrosion at high temperature oxidation. Or actually more prevalent is the complex combination of say corrosion and erosion or corrosion and wear or oxidation in the presence of high fluidity or flow and so on.

So, you have interplay of mechanical as well as corrosive environment and various other activations. And this is exactly the reason why we need surface engineering? So; that means, surface engineering is an act by which we try to prevent this kind of degradations.

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So, talking about corrosion just a few examples, here we are talking about galvanic corrosion or uniform corrosion. So, if you have a steel plate, so this is a steel plate which is riveted bolted on iron this is a brass plate riveted on an iron background and these are iron nails. So, these iron nails the rivets which actually fixes the brass plate on top of iron structure and exposed to very corrosive environment in the coastal area; provides you a very nice couple galvanic couple where copper or brass will be more electropositive and iron will merrily corroded becomes an anode and will actually undergo very easy dissolution.

So, you keep losing iron and iron forms rust and this is a complex form of hydroxide and because of the differences in its structure and specific volume; that means, per unit mass. The crystal structure is such that rust or iron oxide or iron hydroxide will actually expand when it forms and hence, creates enormous stress at the interface between the metal and hydroxide. And gradually the rust we all know will spoll off and when rusts spolls off then fresh iron is exposed and that gets oxidized and the process continue. So, we keep losing a lot of iron from the surface as rust.

So, this can happen over the surface uniformly we call it galvanic corrosion, if it occurs in a form which actually has a larger aspect ratio meaning the penetration is deeper than the spread in the width. So, as a result you actually form these pits small pockets where the damage on the surface is not so wide; but the damage below the surface is much deeper which is even more dangerous. So, we can see either uniform corrosion or localized or pitting corrosion can happen in the underground pipelines through which water or sewer or any other form of fluid can actually be transported. Corrosion can happen to the hull of the seafaring voyager or a big ship.

And once the ship comes back to from a long voyage, immediately its taken into the dock and possibly also to the dry dock and this whole body is now painted again. So, first we have to scrape off all the oxides all the rust and expose fresh metallic surface then we use a primer and then you know one or two different coats of painting. So, that in the next voyage it does not undergo the same amount of we try to prevent corrosion.

This can happen also not necessarily all in room temperature, but it can happen at high temperature for example, the boiler tubes we see an interplay of high temperature and corrosion or corrosion at high temperature and pressure. We also have to realize that, when the flow is happening for example, the ship hull it due to the waves it certainly experience as some fluctuation of loading, but more or less over a period of time that is evened out.

So, we expect that be it a big pillar standing at the deck of near the sea coast or any other static member essentially experiences about the same level of stress, but then if you think of this kind of a bent tube then; obviously, the amount of stress experienced at the top end will be lower compared to the amount of stress which is experienced along the bottom rim.

So; obviously, you expect a lot more damage occurring here the effect of stress along with the high pressure of the steam and its oxidative action will be higher here. So, we tend to see lot of damages happening here.

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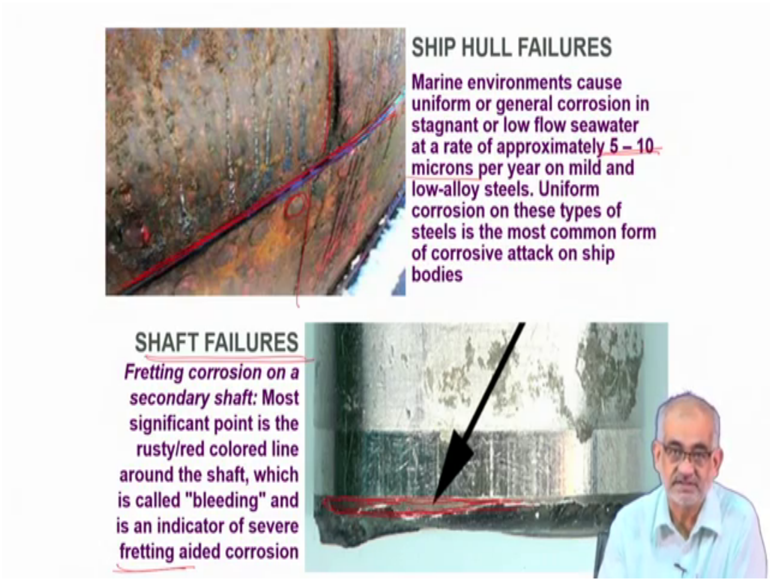

So, this is what we were discussing that in the ship hull this is the joint essentially so these are basically plates, which are riveted which are joint mechanically. So, we certainly expect that corrosion can occur around these rivets which may be compositionally different. And there is no necessity all the time we have to have pure copper and iron we may have copper based or iron based alloys which are in the electrochemical series may actually form a galvanic couple by being one as electro positive the other one electro negative or cathodic and anodic.

So, corrosion can occur even in and particularly, may be severe along these joints and that is very dangerous because if these corrosion at these joints actually penetrate then; obviously, there will be puncturing of the sheet and; obviously, the ship cannot remain floated in the water anymore.

So, we can also see such kind of damages are actually slow for example, only few micrometers per year, but that is good enough to penetrate sheet you do not expect a sheet to be a few centimeter thick it will be hardly a few millimeter thick. So, if it is 10 micrometer or 20 micrometer per year then; obviously, in 10 or 20 years the whole thing will puncture through and through.

But in addition this is in a static condition. So, if you have stresses acting on it then this puncturing can happen much earlier. We can also see a failure in the shaft where for example, here this portion is known to be known to have undergone so called bleeding which essentially happens because the fretting action reciprocating action. So, this is a shaft which is rotating and during rotation the coating on the surface is peeled off and this is where it actually undergoes.

So, the fresh iron bearing portion gets exposed and corrosion happens here and then a lot more metal value actually comes to the fore. And these metals form rust and then they spoll off and then fresh metal comes out in contact with the corrosive atmosphere then undergoes corrosion again spolls off. So, this continued rusting essentially is almost like bleeding gradually from inside as if blood is oozing out or metal is oozing out.

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In all these cases I am just giving you examples which are all from practical cases say for example, a huge bridge over a river or over a railway track or over certain distances and you have multiple members and it cannot be a monolith. Obviously, you have joints and these joints could be welded joints could be riveted joints and in fact, you may have joints between 2 members which at compositionally not exactly the same.

And I told you already that there is always a danger if you have compositionally different members, joint across a particular point because now these two members because of their compositional difference can have different electrochemical potential and as a result one can act cathodic in comparison to the other which may be anodic. And the anode portion will start leaching or dissolving faster.

So, we need to prevent rusting on the bridges and that is why you would find all the bridges are painted and painted not just once painted periodically. And in fact, structural health monitoring of these bridges is a very very important activity for railways, for the public works department or all other custodians of these structures.

So, this can also happen corrosion can also happen in an oil tank and now you imagine we always thought that the atmosphere is the culprit, but this could also happen such severe damage can also happen because of the bacteria or microbes who actually tend to feed on metal. So, if you have a portion of a metal which is which apparently is not revealing much of a damage because its immersed under water or some other fluid.

And in a static condition it may allow actually bacteria or microbes to grow around the surface and if the coating or if the protection is peeled off and if the fresh metal is exposed then these bacteria can actually come and gradually grow. It can be not just bacteria, it can be born through algae or fungi or various other microbes or microorganisms which actually for some reason manage to peg to some corners or crevice. And if that happens then basically they gradually multiply they grow and when they grow they start feeding on to a metal.

So, they penetrate and they can create such a huge hole and one such hole forms then; obviously, this oil storage tank is no good anymore. So, one has to now there is no escape from it, because you actually have to have petroleum and you are to store you need metallic vessels and the petroleum will contain a lot of sulfide or sulfur containing fluid. And there are bacteria which are called sulfate reducing bacteria who actually will feed on such stock and then in the process will actually cause such corrosion even such form such holes.

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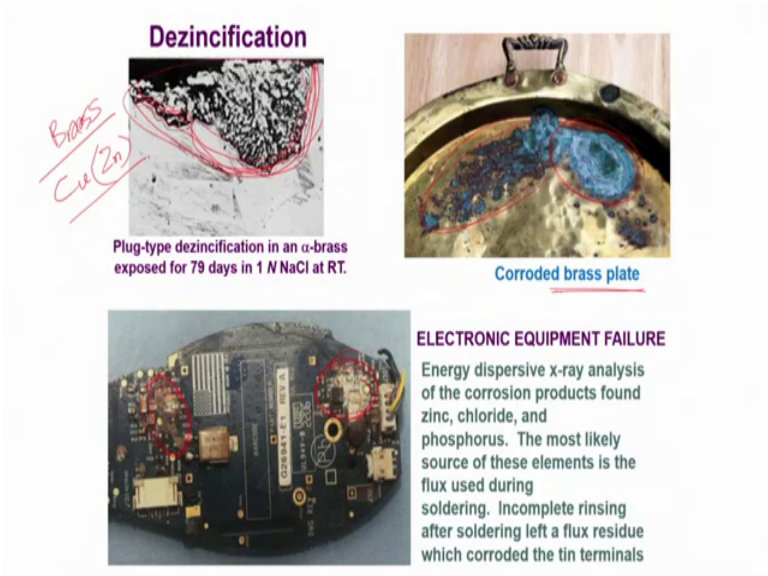

Materials can degrade over a period of time because of various other possibilities. So, even before corrosion starts because of the environmental interaction with the environment, there could be gradual loss of alloying elements. Say for example, when we talk of brass we know that in brass we are talking about copper alloyed with zinc. And this zinc is the element which actually provides the strength and various other important properties.

Now, if you expose this in an chloride containing atmosphere. So, gradually the zinc can be leached out gradually, by the action of these chloride containing maybe HCI or simply the chlorine in water can actually preferentially attack zinc and then dissolve zinc. So, you may actually have gradually create a region a localized region on the surface which because of some mechanical or some other reason probably has developed a perforation and that perforation can actually allow the chlorine ions to gradually seep through and attack dissolve zinc and then in the process you lose a lot of zinc. So, instead of let us say 30 percent zinc after a period of time this may reduce to as low as maybe 5 or 10 percent.

So; obviously, it is not only the mechanical strength which reduces in this region, even the electrochemical behavior the potential of this region also is drastically changed and that leads to a lot of failure. So, we also would have seen all these brass wires brass wares, the brass plates flower vase various kinds of art objects and so on.

And these kind of bluish green corrosion products patina is very common to form on such brass ware or brass plates even copper plates and so on. So, these are again corrosion products some kind of a sulfide and these are because of the continual corrosion happening.

So, not just oil tanks or oil pipes or huge ship hulls or rivets and nails or simply iron structures pillars or bridges steel structures in not even all these art objects, even in miniature electronic devices you do have the possibilities of corrosion. In fact, in most of the cases the logic the architecture of the device does not fail the materials may fail and when the material fails then it leads to some kind of a short circuit or certain other kinds of problems.

So, if you look at these regions just around to these regions you do realize that the color is different here. And actually we are all aware that in micro light electronic devices locally at a particular junction the voltage can be fairly large and the current flow in limited region could also be fairly high so it can cause a local heating. And in fact, heat dissipation for heat dissipation we do allow air flow as a means of heat extraction.

We also must realize, that the whole electronic circuit is embedded in a package or a polymeric substrate in which all these electronic components are embedded. Now for connection for creating for completing the circuit from one particular device to another make the whole chip as an integrated chip, we do use a joining by way of either soldering or some cases even brazing. That means, we are using a filler metal and the filler metal actually causes localized fusion or melting of the metallic parts between two different sides and compositionally they are very close, but not exactly the same.

So, typically you can use lead tin solder these days lead tin solder is not used anymore. So, you may have let us say indium tin or say indium gallium tin or some other forms of low melting eutectic compound. Now compositionally they are very different than the aluminum or gold or whatever form of metallic interconnects you have used. And obviously, they alloy well because when you heat and melt during soldering; obviously, you form as local globule molten globule which has unlimited solubility.

So, it will immediately dissolve some of the metals around and as a result, the composition of the wires and interconnects will change and more importantly. It also allows easy electron flow even when the circuit is not on. So, in other words because of the presence of moisture or any other form of corrosive attack; it can actually undergo very slow, but definite dissolution and as a result of which there could be corrosion damage and then eventually these systems can fail.

So, its not just a big large equipment even miniature tiny little microelectronic devices even your watch or cell phone or a computer, laptop all of them are prone to such degradation.

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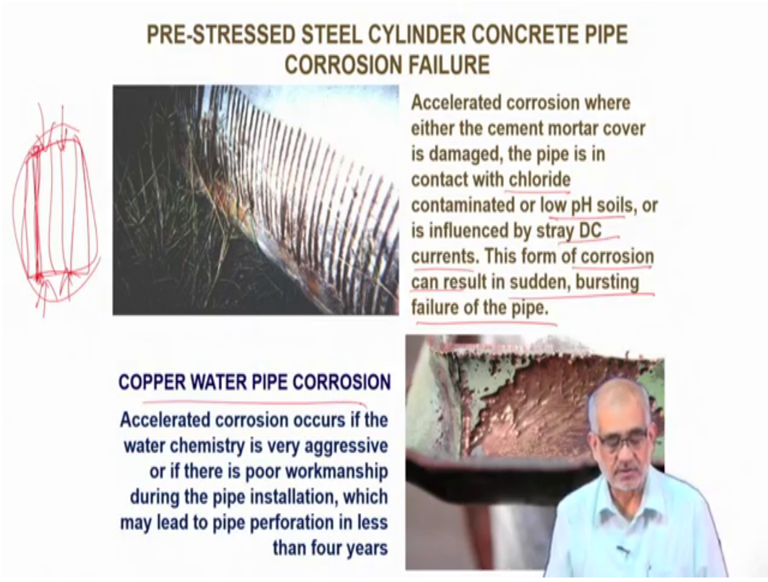

So, such degradations or possibilities of degradation is ubiquitous everywhere you cannot prevent it altogether. So, its not told you that its not it there is no necessity that only chlorine ions will come in contact with something and then cause corrosion or simply hydroxyl ion will cause the first damage and so on.

This could always be because of various combinations of a attacks. So, for example, we are aware that in the prestressed concrete structures which because the prestressing of the reinforcing steel wires or bars the concrete structure as a whole develops. So, if this is the structure we are talking about and if we have such reinforcement of steel cords or rods or wires. And if we prestress them; that means, if we for example, at this two ends if we start applying certain torsional effect because of application of screw or some other activity.

So; that means, basically this length will undergo some kind of stress will develop some kind of a stress. And when you cast then this stress will actually create a residual state of stress on the surface of the concrete which will be compressive in nature acting towards each other.

So, in so the material when you actually release will tend to relax, will tend to actually expand because you applied some mechanical forces to compress them. So, when they try to relax then they try to actually stretch along with the concrete, but by then the concrete is all cast and frozen. So, it cannot allow the rods to stretch any more. So, in the process it develops a residual stress on the surface which acts in opposite direction or compressive in nature.

Now, even in so the in order to get this effect of residual compressive stress, use of such reinforcements which actually produce residual compressive stress is very important. But the steel and concrete interface is always a very probable spot for corrosion or damage to occur, because you are crossing over there will be some amount of gap and that gap. Obviously, for the structures you cannot see that from the open from outside, but this the length scale of such air gap could be of the order of a few micrometer or even less.

Nevertheless this also is the region where you expect some moisture to be trapped because for setting the concrete you do all the time water you all the time add water. So, these kind of concrete structures will always have steel or metal concrete interface and there could be certain amount of corrosion happening because of the trapped moisture.

And in fact, they actually vastly depend on the presence of the chloride contamination or the p H level, the acidity or basicity level and also they are influenced by stray DC current, direct current presence of them. So in fact, these structures are actually given certain open circuit current so that which is in the opposite direction, so, that the corrosion current is mitigated and the effect of corrosion is reduced or remedied.

So, unless we take care of that there could be sudden bursting failure of the pipes and that could be very dangerous. So, similar corrosion can occur in case of water pipe going underground or even over ground.

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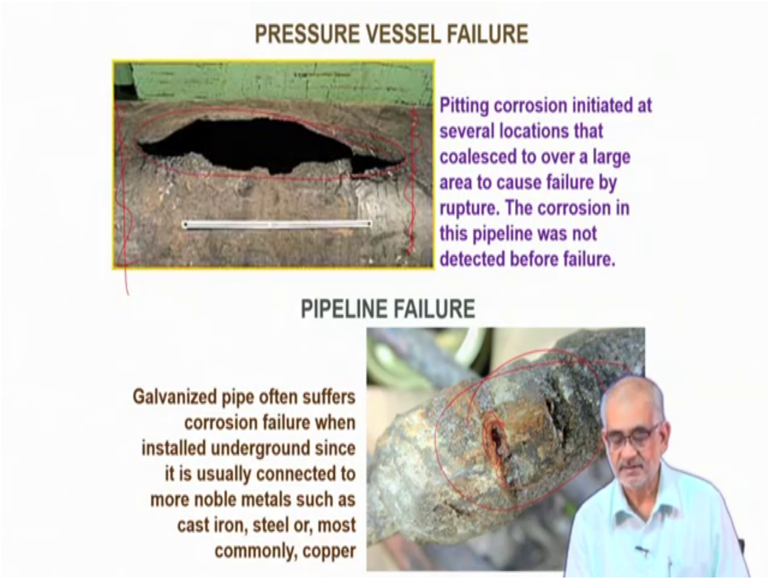

We may see I already mentioned that the combined effect of pressure temperature at an elevated temperature condition can cause much more damage to a steel tube for example, a pressure vessel. So, you for power generation you need very high amount of very high pressure of vapor.

So, you actually boil water in the boiler and then you allow the steam to escape and that steam escapes through a tube called the pressure vessel tubes and those tubes are exposed to such high temperature and pressure condition before they actually interact with the turbine. So, these ruptures are very common in the pressure vessel tubes and when such rupture happens then either you chop off from these two ends and then bring in another piece of tube and then join by welding at these two spots then these welding joints become again another possibility of future failure region. So, one has to be careful about them.

So, there could be also failures in pipelines, which is basically joined and in the joint in many cases we do not quite realize we tend to believe all our iron, but actually they may have certain they may be brass with certain amount of coating on top of that. So, we do not know really, but if there is a compositional difference for example, one can easily see that there is a compositional difference because of which maybe there was an copper and iron combination or interface because of each lot of corrosion took place and there could be failure like this.

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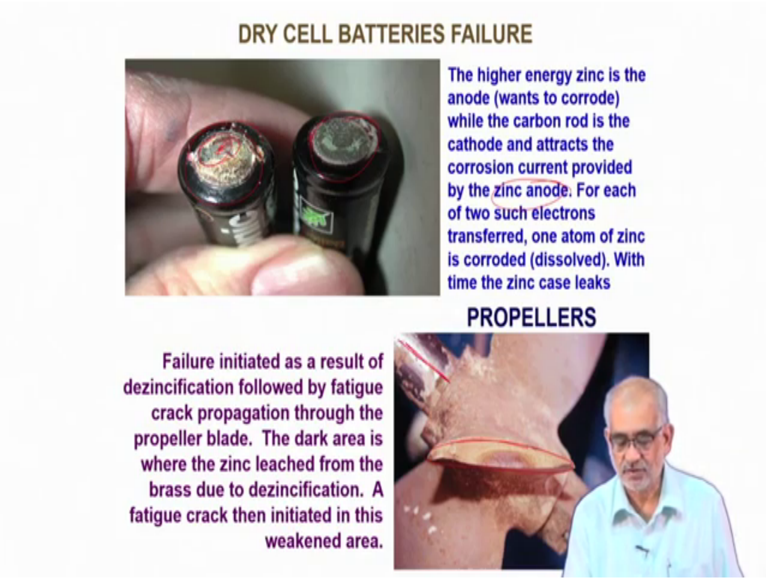

So, failure also its very common in dry cells, the storage batteries if you leave it unused for a long time a for example, inside your torch or in your radio you would have seen that if you remove the battery after a few months, you are a forgotten and then when you try to remove they tend to stick inside and when you take out you see some fluid coming out oozing out, which are the residual acid and this is the result of such corrosion such perforation or leakage happens because of corrosion.

So, you actually have zinc you do use zinc as an anode and carbon as a cathode so; obviously, zinc will always. In fact, the current is because of dissolution of zinc or oxidation of zinc. So, for every set of electrons released from zinc you do realize that some amount of zinc is being dissolved and going to solution. And that solution so over a period of time the zinc surface which is a body and which is acting as anode may actually develop such perforations or corrosion leakages or spots through which your acid may ooze out.

So, I mean you if you have a dry cell there is no escape from having a combination which gives the highest possible current and zinc and graphite rod would be an ideal combination. But if you do that then over a period of time when you have extracted as much potential as possible then, you are bound to see some amount of perforation or damages created onto the surface.

So, its not that if you are careful enough you can completely prevent corrosion you cannot because, the whole action of battery power generation itself is corrosive in nature. So, you have to be careful enough, so there has to be a life and beyond that life you have to discard and replace with a fresh battery. Look at this impellers or these propellers of a so this is the shaft on which this propeller is rotating and these blades, they actually also undergo a huge amount of erosion corrosion combination of them.

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So, mechanical forces along with airborne moisture and other gases. On the other hand apart from corrosion or which actually requires an electrolyte so, typically for a corrosion to occur you need anode cathode and electrolyte if its high temperature; obviously, a single electrode degradation can happen which is typically the case of oxidation. But room temperature or high temperature mechanical activation can lead to a lot more damage not severe damage called through a process called wear.

So, and you know very well that two mating surfaces or surface and a flowing medium solid all of these can actually cause damage to each other because of frictional forces or because of surface asperities interacting with each other. So, they can be because of reciprocating nature of motion they can be because of temporary cold welding between the two mating surfaces or because of particles or surfaces having certain amount of roughnesses and interacting to smoothen out the roughnesses and forming such degradation of material.

It can be also because of the rotating or alternating stress cycles and such severe damage can happen on to the rim of a tire or of a wheel. It such erosive wear can happen in the piston of a pump, because of during rotation it probly can interact with fluid which carries some particles in them.

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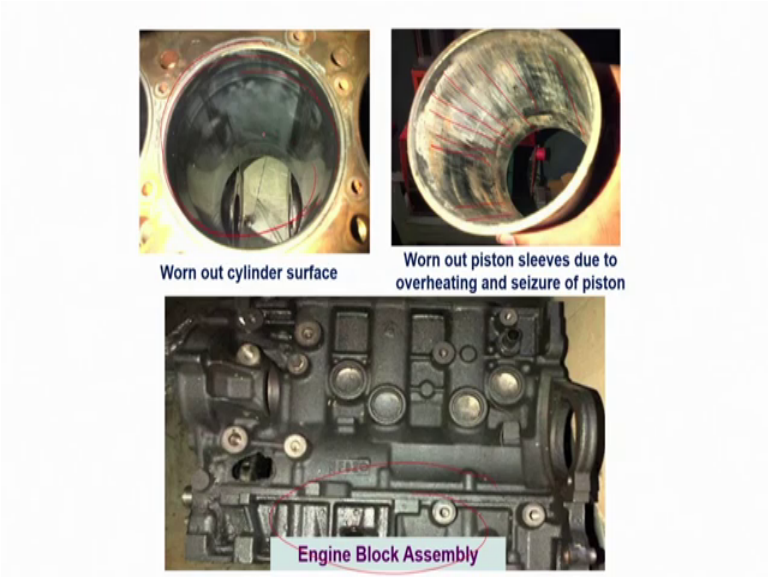

This is the engine bore the bore of an engine automobile engine or some other IC engine. And the piston moves up and down and you can easily see that you have longitudinal marks, in the inner surface of the piston and these marks essentially represent the wear damages caused by the piston moving up and down.

In fact, one of the key design element here would be to make sure that you have enough lubrication between the piston and the inner bore wall. So, that they do not fall with each other or they do not come direct contact with each other. A very thin lubrication film should actually make sure that they do not rub against each other non uniformly. So, the overall engine block the function of the engine block to a large extent will depend upon the functioning or prevention of wear at this positions.

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So, similar things can happen in all other rotating or members or components, which are undergoing various cyclic deformation or cyclic motion which could be in the bearing.

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It could be in the shafts of a lift or an elevator or a chain pulley system on the gear systems like this you are seeing all these roughnesses developed because of these are the teeth of the gear which is rotating. Let us say like this, but during rotation it actually undergoes such wear at the teeth.

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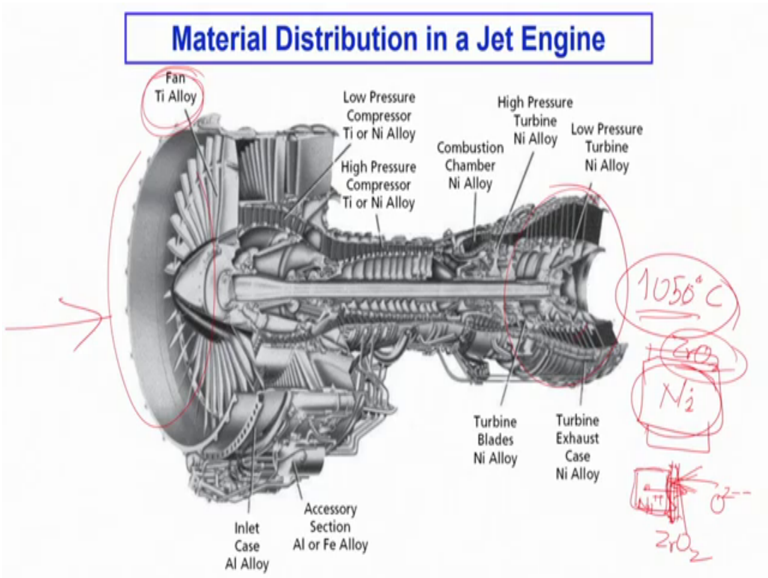

One very important aspect is this turbine engine in fact, I would have mentioned earlier also that this is the marvel of engineering, that in this compressor part or in the high temperature turbine zone. The combustion zone the temperature here could be in excess of somewhere around 300,400,450 at the most so 3 to 400 degree centigrade. So, you are happy using titanium alloy. And this titanium alloy certainly undergoes oxidation, but there is a limit. So, you we know exactly what would be life of these blades here compressor blades.

Here the temperature is much higher something like about 1050 degree centigrade so; obviously, at this high temperature the nickel based super alloy turbine blades actually undergo, the biggest threat they actually have to one has to take care of his oxidation at the very beginning then comes all others like high temperature creep or high temperature strength requirements for to prevent erosion and various other process.

So, these are all surface damages so, even in this side when you are sucking in air so, along with air you may suck in lot of solid particles. So, the turbine blades undergo very severe hit from the sand particles or whatever particles get sucked in. So, these titanium alloys should have sufficient erosion resistance right, here apart from modern erosion because by now you do not expect so much of particles to flow all the way there, but you certainly expect much higher temperature and high temperature attack. So, you have to take care of the thermal fatigue the creep damages because you are subjecting to elevated temperature at constant load and most importantly oxidation at that temperature.

Now, when you want to prevent oxidation of nickel based super alloy you have to realize that if the body is made of some nickel base super nickel based alloy then, on top of that ideally you would like to have coatings of let us say zirconia ok. Now zirconia; obviously, if it can bond well with nickel there is no problem then it can prevent counter ionic transport for nickel to undergo oxidation, you require the cations the nickel to go out and anioned oxygen to come in.

So, you if you can create a barrier here in the form of the zirconia, then these nickel ions or iron ions they actually are not able to go and meet the oxygen oxide ions coming from the air and hence oxidation can be prevented. But the biggest problem is that how do you make sure that this zirconia which has a direct band gap and which is oxide having a very different crystal structure, very different coefficient of thermal expansion, density and all those physical properties than the base metal based on nickel.

So, the bonding between these two becomes the biggest challenge. So, all the aircraft manufacturers for that matter all high temperature and metallic systems would always love to create a technology which actually can allow them to combine the oxide with the metal very nicely and very efficiently at the interface.

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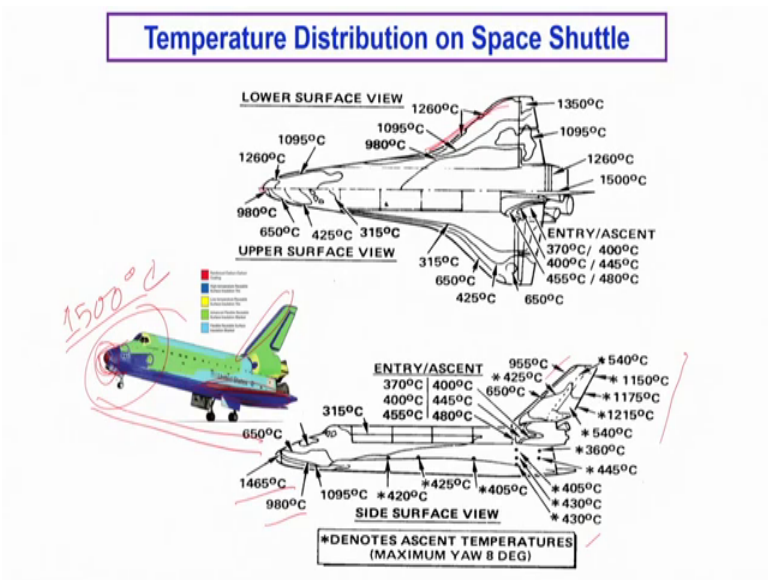

To even going beyond the earth surface, if you want to be an astronaut and plan to go to the moon and come back; then you would require such a reusable vehicle space shuttle. So, for reusable space shuttle if it has to go to the outer space and come back, the regions which actually will undergo the biggest temperature threat would be all these portions. So, the leading edges, the fins, the nose cone and so on.

So, the temperature here could be in excess of 1500 degree centigrade. So, now, we are talking about a temperature regime which is even higher than the turbine blade temperatures. So; obviously, you require tiles or you require ceramic systems which actually can prevent such high temperatures.

So, now, we are talking about this high temperatures and this is the temperature distribution as you can see, that varying temperatures and in addition to that there will be a enormous amount of pressure force of air which these leading edges and the nose cone will have to withstand when it will try to return from very rarefied condition in the outer space and enter into the earth atmosphere which is pressure wise much higher.

So, the frictional forces will raise the temperature immediately to such high values and this can cause a huge threat to the structural integrity of the system. The infamous disaster for the US space shuttle which was trying to enter and we lost one of the finest scientist and astronauts Kalpana Chawla in that accident, that happened primarily because the prevent the heat resistant tiles from the nose cone actually fell off.

And when they fell off they exposed the metal inside and the metal came in contact with air at that high pressure, at that point and in no time the metal actually got heated up to such an extent that it caught fire and once metal gets to temperatures in excess of 7000 degree centigrade, even a single spark can immediately convert this whole structure into a fireball.

So, you cannot prevent that. So, in order to prevent any such accident from happening you have to have a very good protection system here. So, that is again is an activity which is only at the surface not necessarily for the entire bulk. So, you can make a zirconia, complete zirconia based shuttle that is too brittle and mechanically there will be very little toughness available. So, it has to be a metallic system, but with the protection of these kind of ceramic coating or tiles which can prevent such high temperatures.

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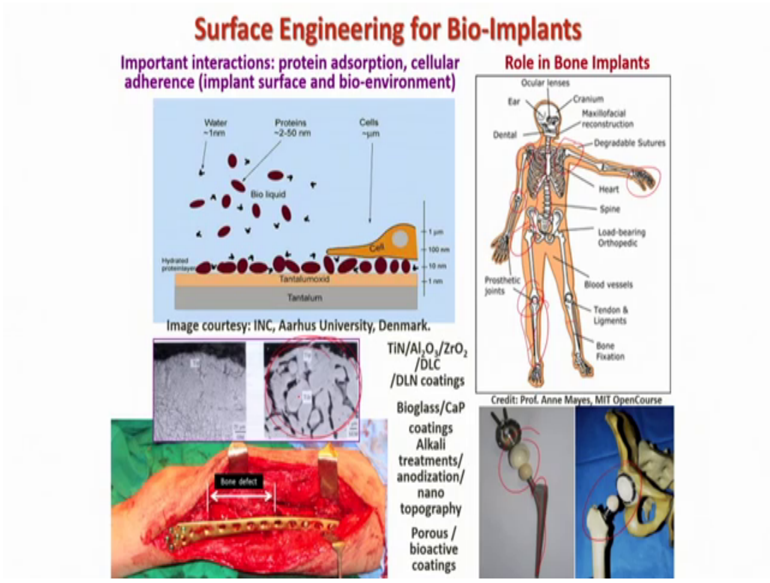

So, these are all about so, far we have discussed all about these inorganic systems mostly various either static or dynamic systems. But what about human body itself? I mean that is also another region where threats to various threats to various forms actually pose a huge danger and a challenge. In fact, we are all aware that for various orthopedic reasons maybe an accident maybe, deformity maybe, illness maybe a degradation over a period of time like this.

The senior people the aged people undergo hip joint replacement or knee joint replacement joins one like this. So, in various forms these structure is made up of ceramic materials I mean essentially, the bone materials are all calcium various forms of calcium based inorganic compounds ceramic materials and these are the regions say the elbow the knee the hip and even the fingers in all the places we have various joints even along this vertebra.

So, everywhere we have so essentially these are ceramic systems which are subjected to various kinds of loading, various kinds of forces and of very irregular type. They are not necessarily all the time you do not carry every time the same load you do not walk exactly on the same road or you do not run on the same terrain or and or the vehicle you are traveling in can cause various kinds of vibrations which are not exactly the same.

So, the body is subjected to various kinds of mechanical forces and thrusts and as a result of which there could always be damages at these joints before any other place or because of accident or a blow there may be a fracture in the bone or somewhere. So, you need to replace them and when you have to replace them you have to realize that you cannot replace them with metal for example, if you replace one leg with a metallic system then there will be a huge density difference and weight difference. So, you possibly cannot walk.

So, you have to ideally you would like to develop a material which whose core will be metal like this. But will have a coating of some compound which could be very close to the bone composition something like a hydroxyapatite, which actually can also integrate well with the body. So, body fluid will not body fluid may cause corrosion and damage and start leaching from this metallic stem which could be let us say titanium or maybe stainless steel or cobalt based alloys or something.

But then if it is coated with hydroxyapatite then the body fluid actually does not cause any damage and on top of that, there could be natural bone growth on this or tissue growth on this and the metallic system can integrate well with your body over a period of time.

So, this is also a surface engineering activity highly a surface engineering activity for a for an unfortunate cancer patient, if you have removed this part of the bone and if you want to replace with a metal piece like this the surgeon will be very find it very easy to do that in no time he will do it, but this portion will undergo huge amount of corrosion over a period of time and very soon you may have to replace it back again.

So, you need to protect this and in order to while you are trying to protect this metallic system, protect from leaching due to the interaction with body fluid you actually have to take care of the surface and that is surface engineering. You can you may need it from various kinds of mechanical activation or interaction you may also need to create the tip of an electrode which for example, neurons are nothing, but electrodes to which you the body exchanges information in the form of ionic transfer.

And the typical dimension of the tip of a such an electrode or neuron would be in the order of a micrometer. So, if such neutrons get damaged or for whatever reason stopped functioning or starts malfunctioning if you want to replace within with a artificial neuron or artificial electrode. So, you have to have a tip which is as small as thin as our hair a few tens of a micrometer and on the tip you may also like to create such very intentionally you want to create such highly irregular and rough surface.

So, that specific surface area is lot higher and you can actually allow lot more ions to be exchanged with the fluid around and that is how you can actually allow information to be exchanged very efficiently. So, all these examples I thought I would bring to your notices you studied so much about anything starting from surface engineering of steel to various non ferrous metals even bit of polymers and ceramics and you studied diffusion based thermally activated various kinds of coatings various kinds of mechanically activated systems and so on.

All these are essentially various approaches and various possibilities of trying to protect the surface primarily metallic surfaces, from corrosion and various other kinds of damages. So, these are the case studies for you to if you ever encounter a question from within as to why did I study surface engineering. Then this today's lecture and all these slides are there to help you to answer as to why surface engineering is so important ok.

Thank you very much.