Materials Science and Engineering
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Lecture – 01
Introduction

Hello friends let us start with the introduction of material science and engineering, the course we want to cover in these particular lectures ok. So, if you want to see the objectives that what you will be able to do after the completion of this course ok. So, that will be that you will be able to distinguish between crystal structures ok, we will see all some the some of the terms you may not be familiar with; we will see during the your course that you will be able to understand all these terms ok, what do they mean and in fact, you should be able to use them for your purpose ok.

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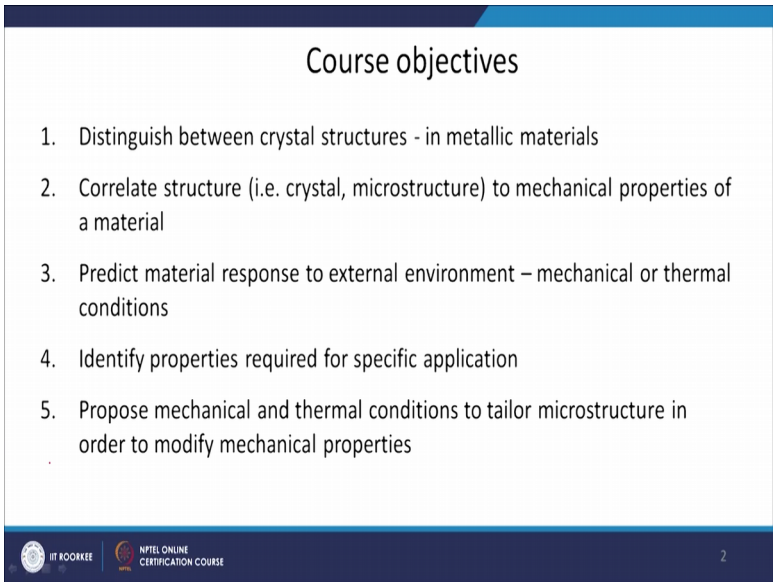

So, first will be that you will be able to distinguish between crystal structures, here we will be taking only the metallic materials ok; there are other materials also for example, ceramics and so on. So, in this we will be only concentrating or mostly on crystal structure found in metallic materials and that is some very simple crystal structures are there, then one of the most important thing is that you will be able to correlate structures ok.

So, basically the crystal structure, the microstructure and the mechanical properties of a material ok. So, again as you can see that mostly in this course we will be considered we will be concentrating on the mechanical properties rather than other properties. For example, magnetic properties or electrical properties or optical properties, then we will be able to predict material responds to external environment ok, it can be mechanical environment where you have load or stress on the material it can be thermal environment ok; that means, the material is exposed to high temperature or very cold temperatures ok.

So, what is it is response and you should be able to also predict that response that the material will do something like this in this particular condition, you will be able to identify properties required for a specific application ok. So, when I give you an application you we need a material for let us say automobile application ok, maybe the structure of the automobile or let us say I want a material for excel the excel of the automobile ok, which continuously is rotating ok. So, when it does this kind of rotation it is it is subjected to a condition what we call as fatigue loading or material may be exposed to high temperatures ok.

Again taking example from the same automobile ok, a material which is used in let us say cylinder head or a piston which goes into the cylinder actually which supplies the power to the automobile. So, all these materials have to undergo or see the condition of higher temperatures. So, we should know that which properties will be required for a particular application ok. So, by knowing that what type of loading is there what type of conditions are there, I would be able to give that with my material should have these properties ok. At a high temperature you should have good thermal conductivity it should have good creep properties ok, all these terms you will be able to understand during the course ok.

Then you will be able to propose mechanical and thermal conditions processing conditions basically, to Taylor microstructure in order to modify mechanical properties ok. So, one of the very beautiful thing about materials is that the properties are not constant. So, if you take 1 material you cannot say that this material will have only this type of property ok, I can change the properties and that is what is the when we talk about materials of basically engineering materials ok, I can change properties for example, some natural occurring materials.

For example wood, wood cannot be you cannot do any too much variation in the properties you can do some not much; whereas, all the engineering materials which we have which we use especially as a structure materials ok, you will see that I by doing different type of thermal mechanical treatments. I can change the microstructure, again the microstructure term you will be familiar with once you complete this course ok.

So, I can tailor those microstructure and I actually I can also get the desired properties by doing this change in the microstructure and some thermal mechanical treatments can do that ok. So, we have to understand first that, what is the response of material to these conditions. So, that once we know the response we will be able to modify the response of the material by altering the microstructure. So, that is 1 of the very nice thing about engineering materials, that you can do all these things and you have to have a good understanding of materials for that ok.

Now, historically if you see materials actually define the civilization of human ok. So, human civilization is actually divided according to the material they were using in that period ok. For example, the early humans started using stones to hunt animals sometime to break whatever they have into small pieces ok.

So, they could see that some rocks are you can get very and fine edge in some rocks ok, by chipping by chipping it with another rock; I can get very sharp edges in some rocks not in all rocks the few rocks are there like that. So, they could identify that and then they created these very sharp edges in that and that can be used for hunting that can be used for breaking the bones.

For example of animal which they have hunted ok, so they started using stones. So, the early age human civilization is defined by a stone age.

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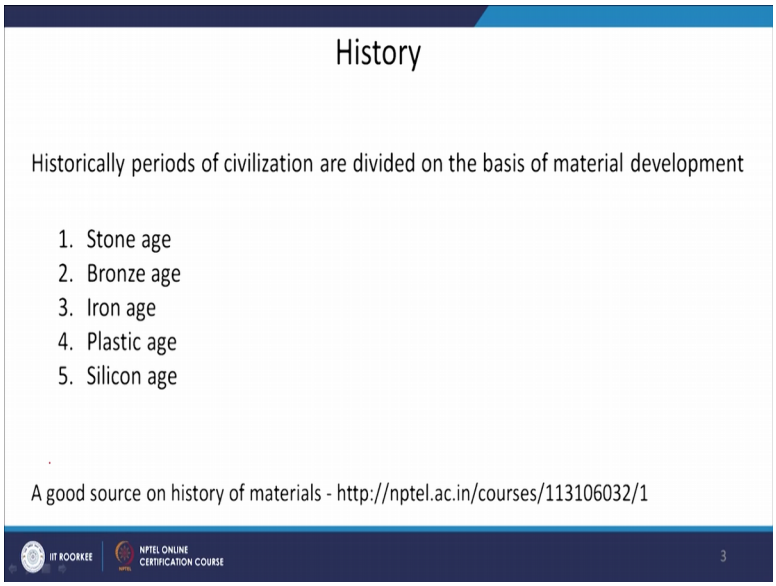

Then they started people started seeing that some material are other than stones are also existing in their natural form ok. So, gold silver can be easily found out from the mines and they are not forming any compound there as gold nuggets or silver nuggets and so on; these are these are inert material. So, you can just get it from the mines in their natural condition ok.

Then later on people started actually after mining they could get ores and those ores can be treated to extract the material out of them and then that is how they started extracting copper and so on. Now can from there the bronze age started. So, it is a basically an alloy of copper with tin or aluminum and so on the aluminum came much later ok. So, then the Bronze Age started and you can see that whoever perfected this technology they got they started dominating the others, when they had these kind of technologies.

So, material actually gave age to a particular civilization which started dominating the other civilizations then of course Iron Age came ok, iron ore was in some oxide form ok. So, to take out iron from iron ore you had to have technology for that of course, India the some tribal part of India had this technology for a very long time and they were able to make this iron and actually if you have gone to Delhi close to Kutub Minar, there is a iron pillar which is existing there for 400 or 500 years and it is it is still not rusted ok, so it has a very good corrosion properties.

Then after Iron Age actually lot of materials then started coming out, aluminum was able to extract it can be extracted from it is ore then the plastic age started, so very completely different type of material from the materials which were in existing from up to that point. So, then plastic lot of plastics were started being used in engineering applications or in daily products also and then of course, electronics started dominating then we start calling it as silicon age ok.

So, now people will debate that there are people can refer to these changes in different forms, some may say no it is not materials and you can call it as electronic age why you are calling it as material age the idea is that material kind of material started dominating that part of the civilization ok. So, that is how you can get different ages and 1 good source is also already listed in the bottom here, which you which can give you much more detail about this history of materials.

Now, if for you want to see the importance of materials I have taken here couple of examples and I am trying to cover a very broad range to kind of get you a hang of materials and also to make you appreciate that materials are not only a structural materials and it is not only about some engineering application kind of, there are lot of time it is aesthetics also which can which can like dominate that how the material has to be synthesized ok.

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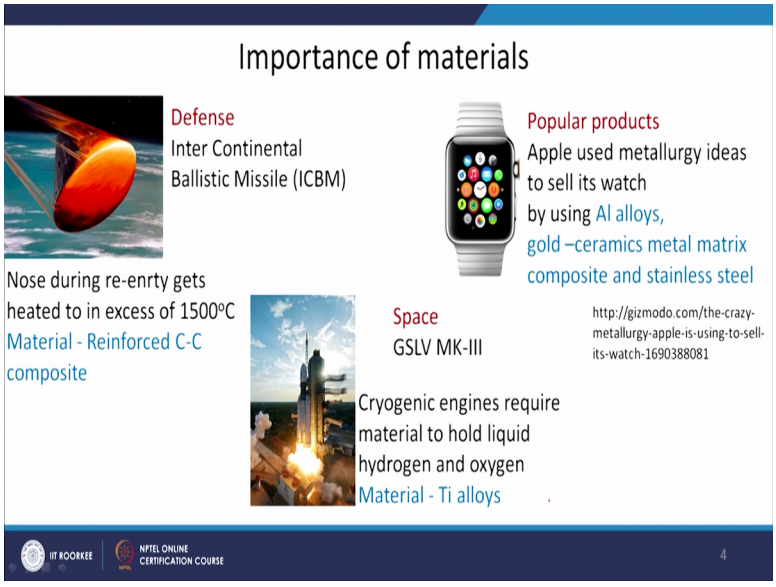

So, let us take an example of defense application right now ok. So, you must have heard of a heard about intercontinental ballistic missile ICBM, which has a very high range and right now is you if you are going through newspaper there is lot of tension between North Korea and USA ok, that they are able to make an imbecile which can go up to USA ok. So, it has to cover a very long distance so and for that it has to go into very rarefied atmosphere here and then come back into the atmosphere and also you want your massage should not be intercepted by other missiles or maybe a fighter jet. So, you have to take it to very high altitude and then it has to re enter the atmosphere ok.

The problem is that when you re enter the atmosphere because of the friction and with your very high velocity of the projectile, the heat generated at the surface is very high ok. So, it can be in excess of 1500 degree Celsius and most of the materials which we use or know they kind of melt at this temperature ok.

So, you have to have a material which can be used in this kind of missile nose, actually nose gets heated up to this high temperature because that is what is seeing the friction of the air and now you can understand that I have a technology to launch a launch a missile I have a whole jet propulsion technology ok. But I do not have the material which can withstand that temperature, so my whole technology is waiting for the material development and all these are not easily available lot of these are classified information and countries do not give it to each other.

So, you have to develop your own materials from the know how you have about the materials. So, that is how reinforced carbon composites were developed to code or to cover the nose part of the material and these are able to withstand this kind of very high temperatures ok. Another example now from space, so again you must have heard about GSLV MK-3 ok, recently launched with a very high payload and large number of satellites and again for developing this kind of rocket there were other rockets are already developed which were working on the solid propellants ok.

Now to have a higher payload capacity and a higher range ok, you want a engine which can directly take liquid hydrogen and oxygen combine them together to generate the thrust required and now hydrogen and oxygen is of course, in gaseous form at room temperature, but at very low temperatures cryogenic temperature they are in liquid form ok.

So, now my material development has to be such that that it is able to handle that temperature, because you have to store hydrogen and oxygen within the rocket and they are going to combine and give you the thrust which is required so and of course, well you must have seen when the rocket gets launched there are. So, many vibrations oh and it has a very high thrust ok.

So, the material has to withstand those kind of vibration, those kind of mechanical stresses at a very low temperature; again it will be dependent on the material development. So, the technology is very simple you have hydrogen oxygen you are combining to get the required thrust ok. But the material which will be required for storing these materials it is such a low temperature ok. So, you have to develop those materials and there are few titanium alloys are there which have which have very good property at cryogenic temperatures ok.

So, again a very different example then, so you have coming from very high temperature application to a cryogenic application ok. Now let us take a very popular product ok, so apple watch was a craze that I think a couple of years back when they launched it and if you might have seen the videos the initial promo videos which were there on the internet from apple ok, they are kind of for a very significant segment of that video was devoted to metallurgical developments which they try it for making this watch ok.

They were talking about high strength aluminum alloys they were talking of about, metal matrix composite matrix composite of gold and ceramic ok, because they wanted to have a lot of gold coating on the surface and they wanted it to have a very good hardness ok, gold is very soft and it has a very low strength that is why you do some allowing to increase the strength.

So, what they did is they added ceramic particles in that to increase the strength and to have a good maybe a scratch resistance and also to give a nice hue to the surface of the this watch. So, they developed all this aluminum alloys high strength aluminum alloys of course, some were already developed they might have used it or they might have developed also, because they did not give any details of these alloys they use stainless steels ok.

So, the idea is that from a very defense space to a very popular product and they are talking about materials. In fact, this apple is talking about material development and

means as far as I am concerned if somebody is using a certain thing in his head in the advertisements; that means, it has come to a certain level that you are able to use that in the advertisement and you want to advertise the material as such ok.

One of the biggest kind of change which brought apple properties in terms of for laptop also they use aluminum covers ok. So, till that time it was only plastic cover were there for the laptops, so they brought in aluminum and these were anodized aluminum again very good scratch resistance is there. So, it will not with the time it will not the surface will not be looking bad and it will be looking as a new laptop ok. So, from plastic again you can see that now metals are again coming into the and into the vogue and people are using and advertising them another very different kind of flavor, if you want to bring it to this discussion that material behavior in biotechnology.

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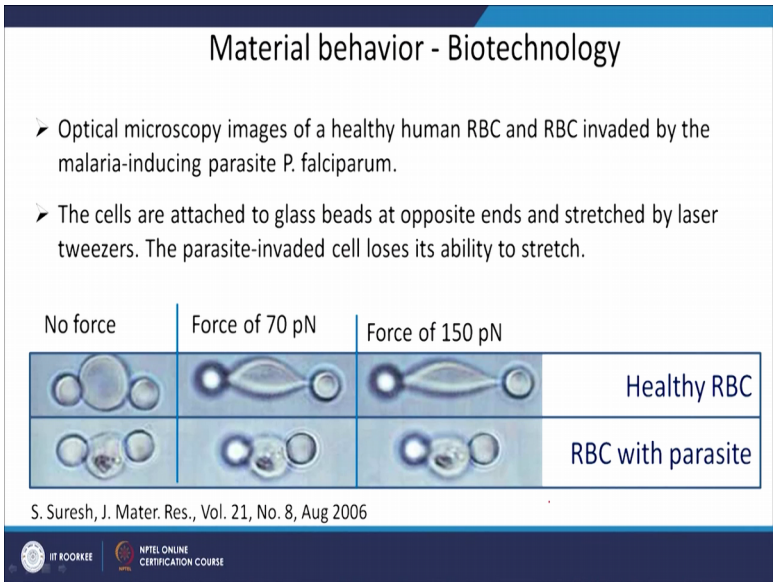

Some you must have already seen that people use prosthetic say, if something if you have some problem in born you have some kind of implant there ok. But sometime now people are also using the material concept to know that whether you have some kind of disease or not ok.

So, for example 1 example is here and the source is listed in the bottom ok, where they are trying to see that this is RBC cell red blood cell in the middle and there are these 2 tweezers. So, these are actually laser tweezers some very sophisticated experiments they have tried. So, this is a RBC and there are 2 tweezers and they are deforming this cell, so

you can understand this sale is at a microscopic level and you are trying to deform and for deformation the force also you can understand it is only 70 Pico Newton very small force.

So, you have to have to measure also this force. So, you can see when it is healthy it is able to deform, so it has elasticity you will be able to deform it ok. But if it is infected by this malaria and you inducing parasite P. falciparum ok, then you see that it has become hard and in the bottom figures these 3 figures if you see ok, the cell is now hard again these 2 tweezers are there they are trying to stretch it, but they are not able to stretch it. So, this one is infected with a parasite and the top 1 is not infected with parasites, so it has elasticity.

So, you can understand that just by infection the cell behavior has changed and it is not a chemical change, it is a mechanical change I am able to see that I am not able to deform the infected one, but the healthy one is ever you are able to deform ok. So, this type of analysis can also be done to know that whether somebody's infected by some disease or not ok; so again another idea for material behavior taking from biotechnology.

Now, taking for electronics for example, another we have lot of fancy idea of those electronics you can do this and you can do that ok. But again the basis is material development because, all the semiconductors which are developed using silicon. Of course so silicon is an intrinsic semiconductor and you add do pant to make it a extrinsic semiconductor and this do pant can be pentavalent doping elements or travel end doping elements and depending upon which you are adding you can have either P type semiconductor or n type semiconductor ok.

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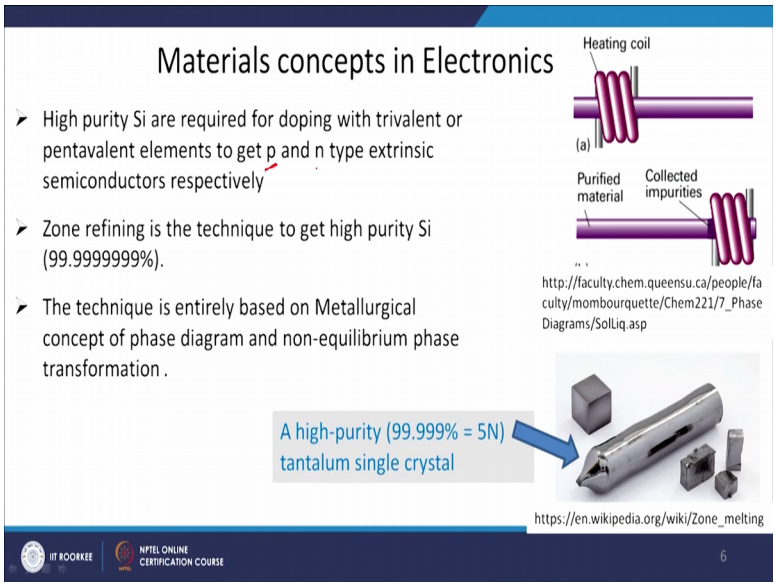

So, but to get this semiconductor you do not want any other impurity in silicon ok, there wise although all the properties will not be there which you want ok. So, you want only that type of property either it has to be a p type that means, lot of holes or it has to be n type means lot of electrons. So, silicon has to be very pure for that and to get this silicon pure silicon the only technology is the zone refining and which is based on only on the metallurgical concepts ok, a phase diagram and non equilibrium phase transformation.

So, these two ideas actually give you this high purity silicon and the purity can be 99.99999 I think I have covered all the 9 and percentage. So, you can understand that the impurity level is at around 0.000000, again if I am missed 1 0 you can add 1.00001 percent is the impurity level in this.

So, you can understand the kind of purity you can get or you need silicon to have a good semiconductor and when you have a very high purity silicon, only you will get a good semiconductor extrinsic semiconductor. So, that when you add these do pant you get either p type semiconductor or n type semiconductor and 1 zone refined tantalum single crystal is shown here ok. So, you can get single crystal also by this particular technique, which is what is used in all these solar panels and all that you must have if you have are looking at some technical aspect of solar cell they want a silicon single crystal ok, then only they get very good for efficiency.

If it is not single crystal it will perform as a solar cell, but the efficiency will go down ok. So, one example of tantalum single crystal is shown here, you can see the finish the shine on this surface compared to the other products which are shown here and it is around 99.999 percent purity ok. So, again for electronics you need material you have to depend on the metallurgical concept to get those materials.

Again as I told you if somebody is started using in advertisement that means, that idea is in vogue or that field is in vogue; for example, all these recently launched cars they are advertising that they are using now advanced high strength steels for of course, they have very high strength. So, you can reduce the weight of the car at the same time, when you are having any unfortunately any car accident. So, under those impacts it is able to withstand the crash ok. So, it will not crumble it will be able to withstand the crash ok.

Recently also you must have come across in the newspapers that none of the Indian cars are able to withstand the crash impact ok. So, now, they are going to this for this high advanced high strength steel, which has very high strain and by that they are to reduce the weight. So, of course, their fuel economy is going up, at the same time they are they are having very high strength. So, they are able to withstand the impact during any crash ok.

So, again if you see the recently launched cars and if you go to their website you will see that for the exterior and the structural component, they are advertising these that they are using this kind of materials now. So, again earlier nobody was talking about any material, now they are talking about material and that is a good sign that the material development is there new requirements are there ok.

So, in my introductory lecture, which I gave there also I talked about that your government policies keep changing ok. So, for example, they will say that now the in viral environmental impact of your car should be this much ok, so it is its emission should be this much. So, for that you have to reduce the weight. So, you have to develop new materials to reduce the weight, so whatever you are doing earlier you have to change it ok. So, this these are dynamic fields it will keep changing according to the environmental concerns government regulations and so on ok.

Another example of materials or metal materials concept is material failure now another again one of the very popular example is the failure of titanic ok. So, it is in it is in maiden voyage itself it unfortunately it is sink and the reason.

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For that was that the ship was going through very cold water in Atlantic ok, Atlantic is very close to the north pole and one iceberg up is a big iceberg came and hit the ship ok.

So, normally if you have a good material that is what you see in the cars also, if you have a small your you have experienced this small accident in your car has experienced a small accident you will see a dent only it will not break into 2 part ok. So, normally if iceberg hits unfortunately you should have a dent at most, but in this case actually it fractured started cracking and under the heavy load that this was the biggest ship of that time in terms of the weight, also it was the most powerful ship of that time.

So, it is velocity also must be very high and they wanted to reach USA in a particular time. So, they were also I think going at very high speed ok. So, very big mass big velocity and when it hit the iceberg. So, the energy of the impact must be very high the momentum must be very high. So, it is the impact kind of kind of loading ok, but if I you have a good material there would not be any problem. The problem was that at that time the whatever is still they were using it had very high sulphur and phosphorus content and when you have this high sulphur phosphorous is that your low temperature properties are not good for that steel ok.

So, actually still the start behaving like a brittle material at low temperature. So, under in that temperature of Atlantic sea the temperatures were very low, so it behaved like a brittle material. So, when that ice berg hit it the fracture started and under the weight of the ship it started growing and then the whole ship broke into 2 parts ok. So, there is a brittle transition. So, what otherwise a material should have behaved as a ductile material, now it is behaving like a brittle material and that was the cause of the this accident ok.

In fact, the material failure ideas you can also use for some very good purpose for example, this Mahabali in Mahabalipuram there is a big pond or you can say a tub like that in a single rock and you can see the finishing and the curvature they have got very nice circular curvature, with a very good finish and you must be wondering that at that time it is I think 400 to 500 years old; how they produce this kind of nice surface finish and nice circular curvature and for that they were using the concept of failure of materials also only ok.

So, the rock is again a brittle material it behaves like a brittle material. So, it can be easily if you hammer it will fracture into multiple parts. If you take a good ductile material let us say aluminum and if you heat it, it will not fragment into multiple part it will just deform ok. So, what they used to do they used to have these holes as you can see here lot of holes and then they used to put a wooden peg into that and after that they used to pour hot water ok.

So, because of this wooden peg and you are pouring hot water it used to expand and when it used to expand it used to apply stresses on this you can say is ligaments which are left and because of that stress this part used to fracture. So, whatever profile you want for example, here you want a circular profile you make these holes and then when you do that what will happen that the whole thing will fracture and you will get a very nice surface finish ok.

So, very interesting technique to get huge shapes like this in a single rock now according to me you will be able to appreciate and understand materials much better if you think that they also behave like what we do ok. So, if you bring a human perspective to the whole understanding of the materials ok, it will be you will be able to appreciate that

what does it mean why or how I can easily understand the material behavior if I compare it with the human behavior ok.

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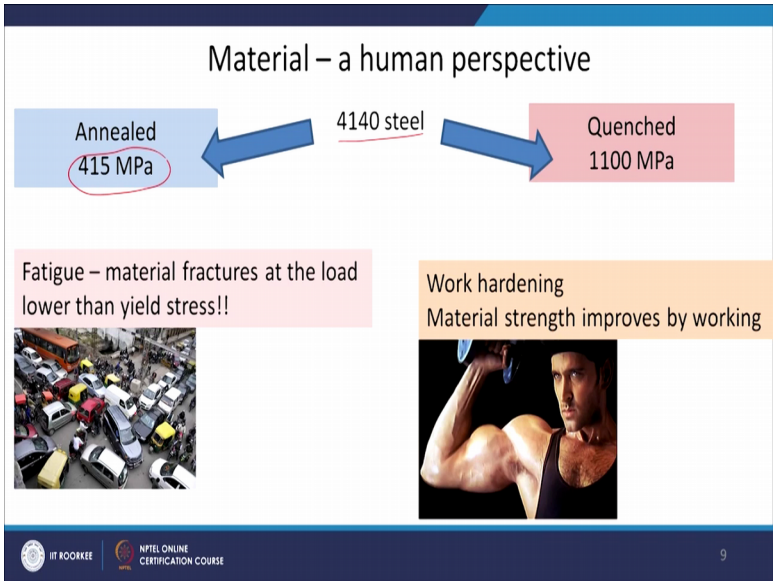

So for example, if I take simple 4140 steel ok, if I do an annealing this is 1 kind of treatment ok. So, if I do an annealing I get a strength of 415 mega Pascal ok, if I do it after heating and then quenching means I am doing a very fast cooling ok, in this case in annealing I am doing it a very slow cooling ok; then I am getting a lower strength, if I do the same treatment I take to higher temperature.

But now I am quenching this material then, I get a very high strength ok. So, the same material, but 2 different treatments were given to it ok. So, one turned out to be low strength another turn out to be high strength and I usually kind of jokingly compare it with the seventies movies ok, usually in seventies lot of movies has had this stories that twin brothers are there one went to the police officers house after, of course getting separated from their family in kumbhamela and one went to the maybe dacoits home ok.

So, one turning out as a good citizen another is of course doing bad things ok. So, 2 different conditions starting from the same family or from the same you can say condition, but 2 different conditions were imposed, so one turning out to be a something else one turning out something else ok. So, same material done if you do annealing it is a different strain, if you do quenching it is a different strength ok.

Another example and this is for fatigue ok, a fatigue is a kind of a material kind of a condition imposed on the material where it goes under cyclic loading ok. So, continuously the loading cycle is changing. As I told you there example of shaft of the automobile where it is rotating, so it goes from tensile to compressive to ten zero to compressive and so on and when you have this kind of condition the material fails at much lower load ok. So, much lower then it is a yield strength also which you get from a static condition ok.

So, it will fail at much lower load ok. So, again I compare it with kind of a for example, a traffic jam ok. So, if you are in a traffic jam you are continuously maybe honking or others are honking the their horn ok, also you continuously you are changing the gear you are placing the clutch sometimes you are placing the brake or you are placing the accelerator and so on.

So, it is a continuously changing condition for you and supposing that somebody comes in front and blocks your or cuts in front and blocks your way you will feel very agitated of course and suppose normally you are very silent guy and you do not get agitated much easy, in that condition you will get agitated by a certain small incident like that which you will not do in as normal circumstance ok.

So, that fatigue on your mind that you are continuously doing this operation make you agitated at much lower threshold ok, so your threshold has come down ok. So, this is 1 of the case condition where again you can very nicely relate it with the material behavior and how the human behaved in the similar conditions and both have the same type of behavior issues ok.

Now, you must be wondering why I am putting Hrithik Roshan here. So, I am taking it as an example of work hardening this is one of the way to increase the strength of the material by working on a material ok. So, if you take aluminum a small sheet and you hammer it ok. So, earlier you may be able to deform it very easily, but after hammering you will see that it is not all very difficult to deform it ok. So, basically you have done some working on the material, of course at a micro structural level there are a lot of understanding you have to gain to understand this kind of behavior.

But if you just see at a macro level, you are seeing that after I am you have hammered the material now it is very difficult to bend it; for example, and you can again compare it

with the people who do bodybuilding ok, they have to work on their muscles ok. So, you keep pumping the iron and you will see that your muscles are developing your strength in the muscles are developing with working ok.

So, again in material also you do working and you get hardening you get very hard material for humans, also when they work their muscles strength increase ok. So, there is a hardening you can see feel it that the muscles are getting hard ok. So, again you can see that very nice there is there is a very nice correlation between how materials way or how you want behave in the similar conditions ok.

Now, to end this lecture I just want to again bring a new flavor to it to the idea of the materials that suppose you take this.

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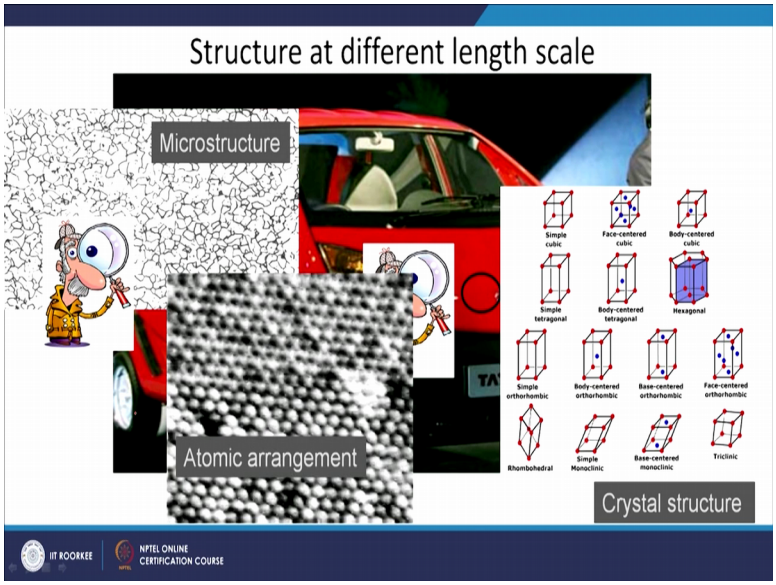

A very popular example Nano which was launched by Tata at one time and suppose now you can see there are lot of materials here, for example bonnet is a some steel sheet is there some glass material is there some plastics are there on the bumper ok; suppose I want to say that what is inside this bone, but this material on the bonnet what is inside ok.

So, suppose I am taking a magnifying that going into it ok, so what I will see a microstructure ok. So, on the surface you do not see anything, but actually inside the material there are lot of features there are lot of things are there and you will see some

dark areas some bright areas, of course we will see what do we mean by that. So, there are a lot of features are there inside the material which you do not see from the outside and this is called microstructure.

Suppose I am interested to go more into detail of this that what is at the next level of this ok, then I will go at the atomic scale and I see that there are nice atomic arrangement in the material ok, so atoms are arranged in a very nice fashion ok. Suppose I want to say that how these arrangements are there, then I can say that these are arranged in this fashion which we call as crystal structure ok.

So, in the subsequent side slides or presentations you will see that what do we mean by this. So, you can see that as I you are going to a smaller scale length ok, there are more details in the material. So, what you see from the outside actually there is a micro structure if you go into more details you see that there are at a atoms arranged in a specific fashion and those atoms how they are arranged can be classified into this 14 ways which are called crystal structures ok.

So, with that I am hope that you will be able to appreciate that the study of materials is a very interesting subject and it covers a very wide areas and it is very important that the development of materials is very important for lot of technological developments, which we will which are going on right now and which will come later on ok.

So, the understanding of this material behavior or materials will be very helpful for a mechanical in here ok. So, when it he designs or he uses some material, he will be also appreciate we will be able to appreciate that when is taking this material what is happening inside ok. Why your supplier is giving this material to you for wrap for whatever mechanical properties you want ok.

So with that thank you and we will see you in the remaining course.