**Advanced Materials and Processes**
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**Lecture – 04**
**Introduction (Contd.)**

Welcome to NPTEL. Myself Jayanta Das from Department of Metallurgical and Materials Engineering, IIT Kharagpur; I will be teaching you Advanced Materials and Processes, you can remember in the last class we had classified advanced materials based on their engineering application. And today we are going to elaborately discuss and continue our earlier classes.

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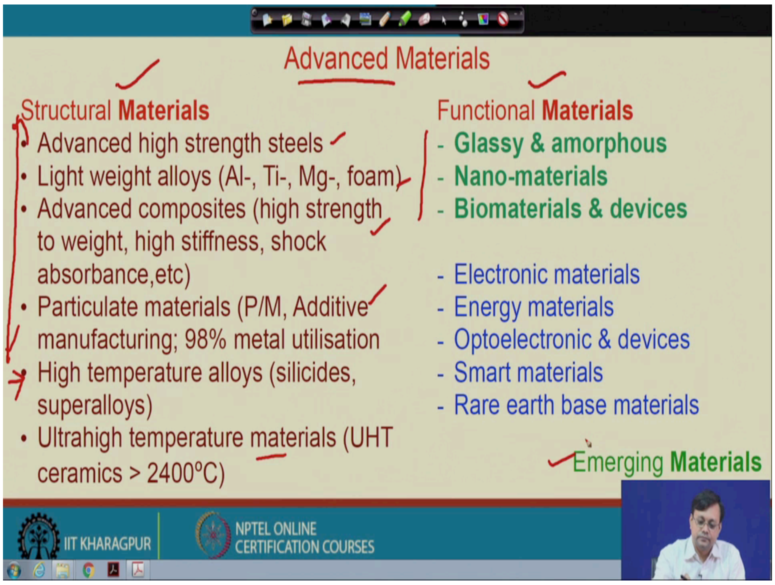


Here, you can see that we have classified the advance material as structural materials or functional materials, where structural materials are classified into different alloying element and their microstructure; like advanced high strength steel even though steel has been discovered quite long time ago, but these steels are not the mild steel or low carbon steels, but alloyed steel for advanced and very high strength applications.

Lightweight alloys, advanced composite, particulate materials are mostly the powders which are process using powder metallurgy technique; also we discussed these are the material as structural material.

And today we are going to continue the structural material as high temperature alloys or ultra high temperature materials and some of the functional materials like emerging materials.

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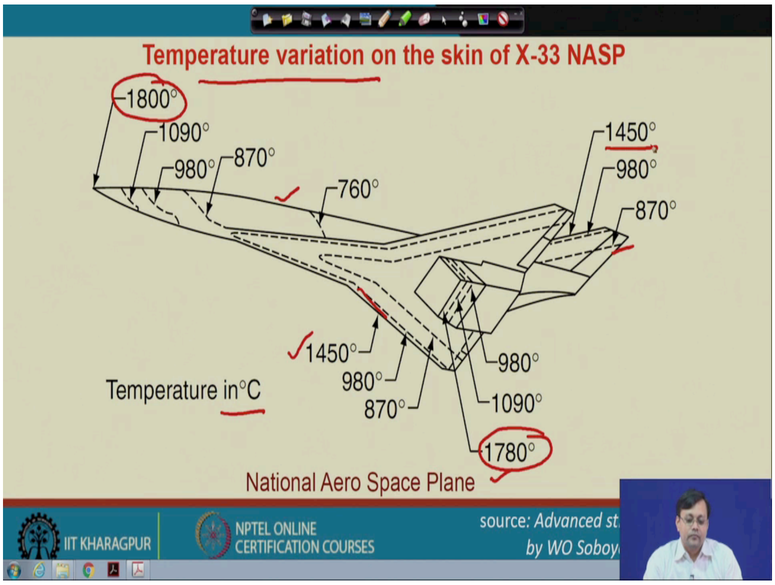


When we need to construct an aeroplane which should move in a very high speed; let us say as an example like national aerospace plane or supersonic jet. Then one has to consider the temperature variation on the skin of this flight because of the high friction between the skin and the surface and the air, the temperature basically rises.

And these lightweight alloys should be capable of withstanding that high temperature; one can simply guess how much temperature it can rise, but you can see here the temperature rise at the nose of a flight, supersonic jet or national aerospace plane in centigrade is something like 1800 °C, that is very high. Also here near the wing, the temperature rises up to 1780 °C or let us say 1450 °C in these edges, at the tail it reaches up to 1450.

So, even though, for aeroplane or normal regular flight for passenger carrier run reliably at low speed, but for fighter jet they are very very high speed flight and the temperature as well as due to high friction goes to very high temperature.

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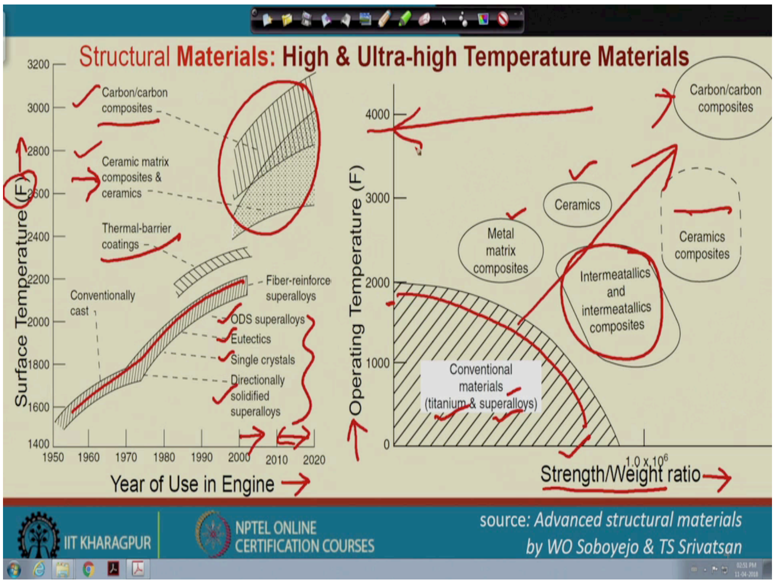


And therefore, engineer need to develop materials as per the requirement; here I show you the surface temperature that a material can withstand with the year of the use of the engine ok. So, we already talked about super alloys which can withstand very high temperature in the last class also.

But one can have a look depending on different different processing technique like directionally super cool super alloy or single crystal or let us say some eutectic microstructure super alloys or oxide disperse strengthened super alloys; all of them depending on processing we can manipulate the surface temperature so that material can withstand higher temperature, this is in Fahrenheit.

Now, as we proceed with making different engines, different version of the engine which are more capable of extracting energy; we need to go to much and much higher operating temperature. And therefore, use of thermal barrier coating has been developed, but one can have a look that during this period, during today at least the carbon composite or ceramic matrix composites provide you much more higher temperature or can withstand high temperature and this is a good news.

Let us say, I can sight you one example for re entry vehicle when a spacecraft enter into the surface atmosphere; the temperature of the surface of the vehicle go very very high, where no metal or alloy can withstand such temperature as there is oxygen in the atmosphere and therefore, there is the complete burning of those space vehicles.

So, we need to develop these carbon carbon composites or ceramic matrix composites which can withstand ultra high temperature. Here, I show you another plot with strength to weight ratio; so not only the high temperature strength is very much important. But the ratio of strength and weight is also important because weight is linked with how much fuel it will consume, a vehicle will consume.

So, the operating temperature of the alloys like conventional material, like titanium alloys or super alloys they can withstand up to 2000 F even we can develop very advance composites.

Whereas, intermetallic or intermetallic alloys or intermetallic composite can relatively withstand a little bit higher temperature; similar like composite or ceramics or some metal matrix composite or let us say ceramic composites where carbon composite always dominate over all these materials. And one has to go along this way where strength will increase as well as the operating temperature should be higher; so, that is the target.

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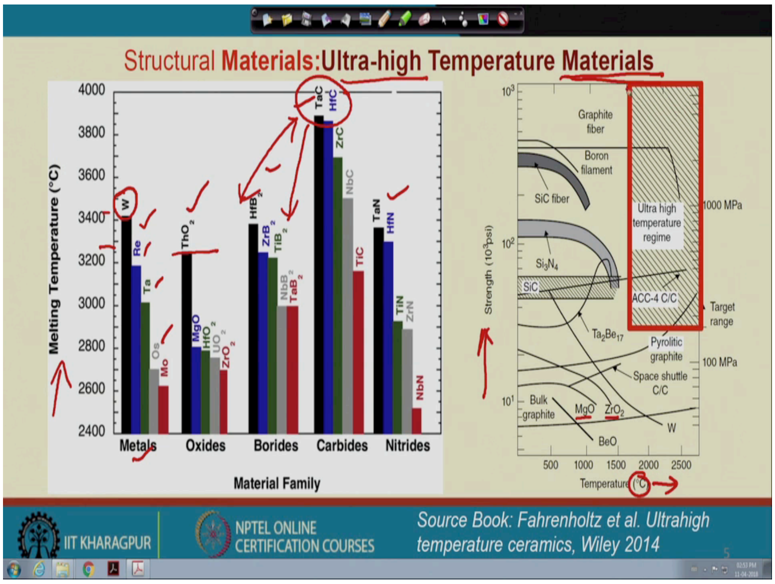


So, for ultrahigh temperature materials, here we use the terminology material specifically because there is no metal and alloy can withstand such ultrahigh temperature. And therefore, we only prefer to design some ceramics and definitely ceramics means oxide or nitrides.

So, kindly have a look here the melting temperature versus the material family like metals and alloys where tungsten has the highest melting temperature, rhenium, tantalum and molybdenum soon, where this is the melting temperature. But if we consider the oxide like thoria; thoria is often used as a hardening agent in a composite microstructure like TD nickel thoria disperse nickel which can withstand very high temperature, but you cannot go beyond this level like 3000; otherwise the particle itself will melt.

So, in this comparison we can see the borides or carbides are somehow better like also little nitrides. So, if we can develop some carbide and mix them with some borides will give you a composite microstructure with may be better compared to tungsten; pure metal or alloy.

Similarly I show you here the strength versus temperature plot; so, here it is given in centigrade where the magnesium oxide or zirconium oxide; which may withstand these range of strength and temperature level something up to 1500, but to get ultra high temperature applications we need to develop material in this domain; so, this is the domain where one need to develop.

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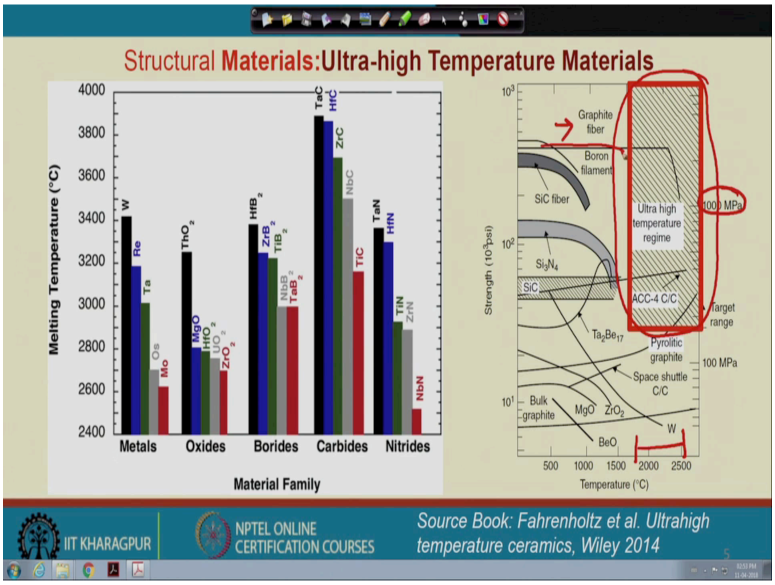


So, here let us say the strength level goes beyond 1000 MPa and temperature is somewhat in the range of 2000 °C to 2500 °C. And definitely graphite fiber can withstand such a very high strength in this temperature regime, you can see, but if it is in contact with oxygen then immediately it burns. Because graphite makes carbon dioxide or carbon monoxide and that is volatile in nature.

So, we cannot retain the strength; so, maybe beyond the earth atmosphere it may survive strength, but not in presence of oxygen. So, we need a mechanism to protect those graphite fiber even though it is used in composite. Protection mean, I am talking about from high temperature oxidation protection.

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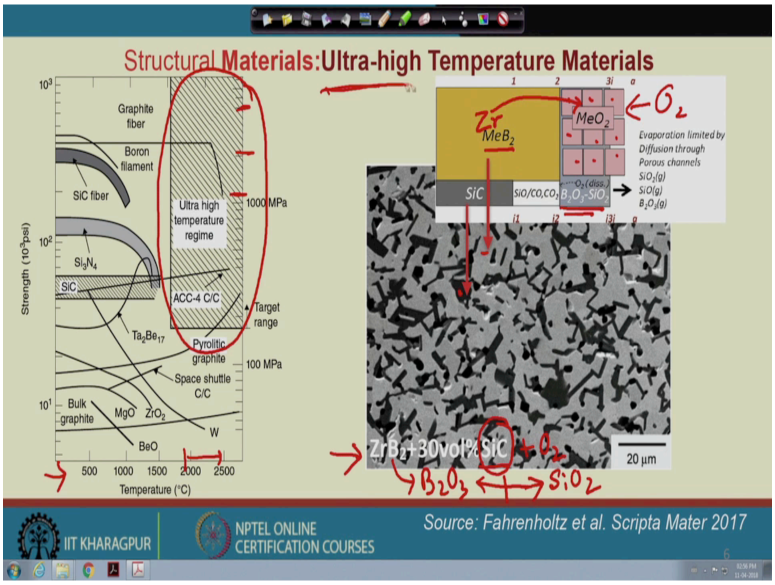


So, the same plot is shown here from the last slide and as we discussed that this is the domain of development for ultra high temperature materials and these are mostly ceramic so, that it can withstand at least 1000 MPa or 2000 MPa or 3000 MPa strength in this temperature range. So, one of the very nice example is zirconium diboride with silicon carbide composite.

So, in this particular microstructure you can see there are 2 phases, the dark phase here; the dark phase is silicon carbide and the gray phase is basically zirconium diboride; zirconium diboride. So, if this is a recent development going on to develop such kind of ultrahigh temperature ceramic, where we design purposely and we choose silicon carbide purposely so, that it will react with oxygen and form silicon dioxide. So, silicon dioxide at such a higher temperature level along with the boron oxide $B_2O_3$ form borosilicate glass and they form borosilicate glass and simply reduces the oxygen diffusivity.

So, the zirconium form oxide and remain as a disperse particles inside a borosilicate glass and these borosilicate glass simply protect the oxygen to oxygen ion to enter into the metal. And this helps the material to survive at very high temperature and this is the protection mechanism. And until we have a definite understanding on the protection mechanism, we cannot develop such kind of composite microstructure and definitely the strength level is reasonable and this is a nice example of such ultrahigh temperature materials.

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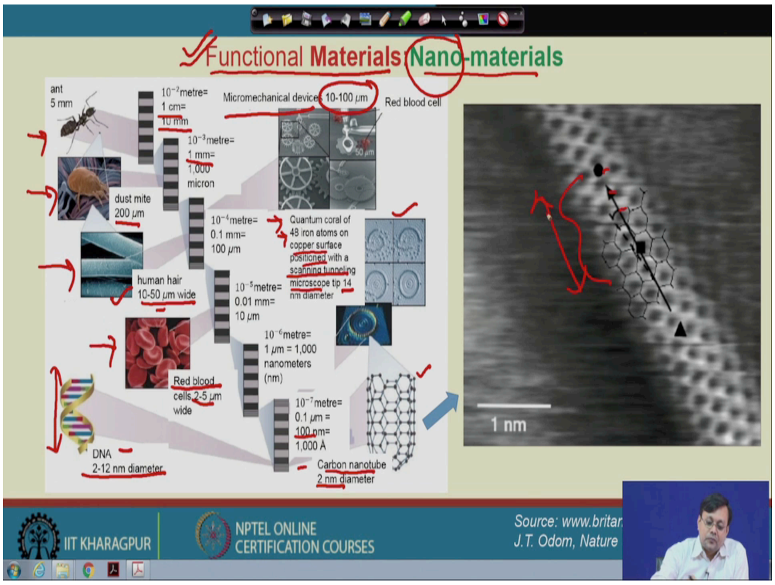


Now, let us start with the functional materials we have completed the structural materials part. For functional material, one of the very emerging material is nano-material, this is the very wide term where one can manipulate the structure in the nano level so that some functional properties can be developed or some functional properties can be evolve.

Let us compare what we understand by this word as nano, if we consider an ant; a ant has a size of 1 centimeter. And now if we think about a dust mite, it has a size of 1 millimeter; however, if we considered the human hair that has a thickness of 10 to 50 micrometer. Whereas, if we think about a red blood cell; it is somewhat 10 times lower than the human hair, it is something in the range of 2 to 5 micrometer. And interestingly the DNA in the human body that is in the range of 2 to 12 nanometer.

So, when we are talking about nano-scale; we are talking about something in the range of a DNA actually. So, from 100 nanometer to let us say some nanometer range; now let us consider the some of the engineering component that has been develop these days; how small, people have engineered and made such tools. The micro mechanical devices are very much popular these days as any MEMS their length scale is in the range of 10 to 100 micrometer.

So, almost in the scale of human hair only ok; so, or let us say somewhat in the range of a dust mite. Whereas, if you think about such kind of microstructure these are taken of a quantum coral of 48 atoms in a copper surface positioned and this microstructure has been taken using a STM; it is scanning probe microscope the name is scanning tunneling microscope.

And here the tip itself which helps to develop such a microstructure is 14 nanometer in diameter. And now we are trying to develop materials in the scale of 2 nanometer in diameter; those are called as carbon nanotube ok. So, this is an image of a carbon nanotube and the microstructure; if you look at these are atomic resolution microstructure where individual atoms can be seen.

So, this is a length scale of 1 nanometer; so, few atoms are positioned here. So, we are trying to develop understanding how to manipulate this length scale of structure that the atomic structure and to engineer a device. So, length scale is important for developing such functional properties and so, nanomaterial is a well known functional material.

Not only these nanomaterial, when we think about in case of a metal and alloy with a grain size of 100 nanometer and then if we employ Hall-Petch equation then strength can be increased up to 10 times ok. So, in structural purpose, these terminology nano itself is very much important, on the other hand for developing functional properties also the nanoscale engineering is also very important.

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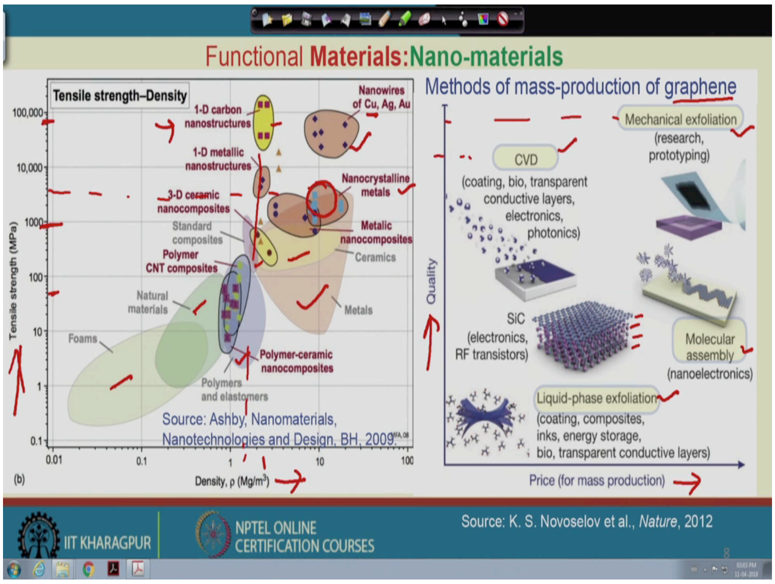


Now let us have a look at the typical as we type of plot a like a density versus tensile strength. This plot I have shown you earlier that here the foam slice, foams mean that a material along with some air bubble like some of the natural material, some of the polymer or polymer ceramic composites and these are some of the standard composites and here the ceramics lies and here the metals are lying.

So, the density in case of a metal is high as well as the strength you can reach up to 1000 MPa, but when we develop some metal with nano crystal and grain size then definitely the strength could be increase up to up to let us say 5000 MPa. So, 5 times we can increase or if we can develop some nanowire even using copper, which has strength of only something like around 100 MPa to 200 MPa; we can easily reach up to such a scale. Even for 1 dimensional carbon nanostructure, we can go up to very high strength level as well as we can decrease the density.

So, you can see that  such a functional structure we need to develop for strength purposes also. On the other hand, there are some mass production of these kind of carbon nanostructure or often known as let us say grapheme, here the price of production and a quantity is important. So, I like to show you this plot with let us say differently process like chemical vapor deposition or let us say exfoliation process like mechanical exfoliation or molecular assembly or let us say liquid phase exfoliation. So, in all these process the price may vary at the same time the quantity of material that we can produce also vary.

So, here we see a little engineering aspect that from an atom by atom layer how we can make those kind of graphene structure and we can achieve a very very high strength level and low density level. So, here this is the importance of nanoscale structures and engineering with nanoscale structure.

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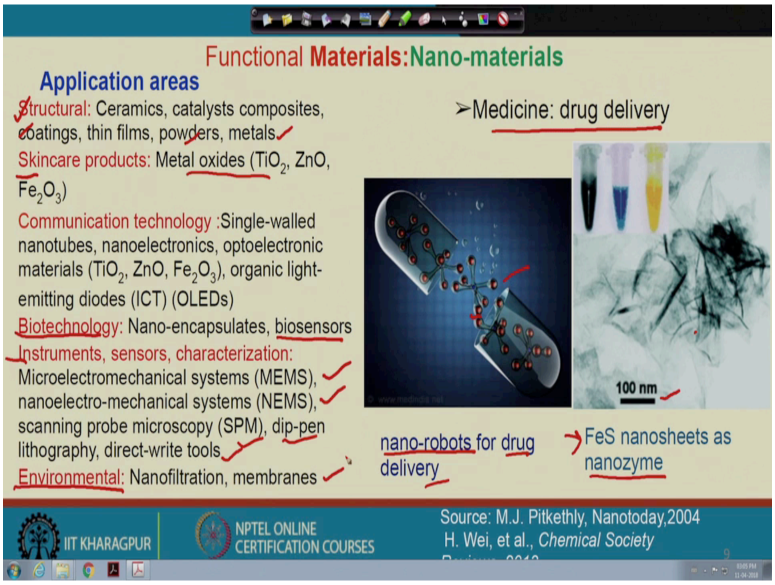


Also the nano material are very much popular in several other areas, one area I already told you about structural purpose, where let us say ceramic and let us say some powders and metal nanostructured or let us say coatings those can be used as structural material.

At the same time, for medical purpose or let us say some skincare products, where metal oxides are used in the in the size of nanometer. Also for drug delivery also these kind of nanostructured are very much important because of their small scale and the functional properties; I will discuss with you within a minute.

So, here you can see some of the nano robot used for drug delivery and they purposely go to some of the places in the human body to deliver the drug. And let us say iron sulphide which is also known as some nanozyme and these are some nanosheets are shown here; those are in a very small scale used for as an enzyme in human body.

At the same time, the for biotechnology purposes; we can use these nano encapsulate biosensors, let us say some of the instrument sensors which are important. The micro mechanical systems are also seen, let us say the nano electromechanical systems from the nano structures develop, they can be also used, let us say some of the dip pen lithography or direct writing tools and also for environment of purpose we use nanofiltration and membranes. So, you can see that there is a large application areas of the nanomaterial and nanostructures.

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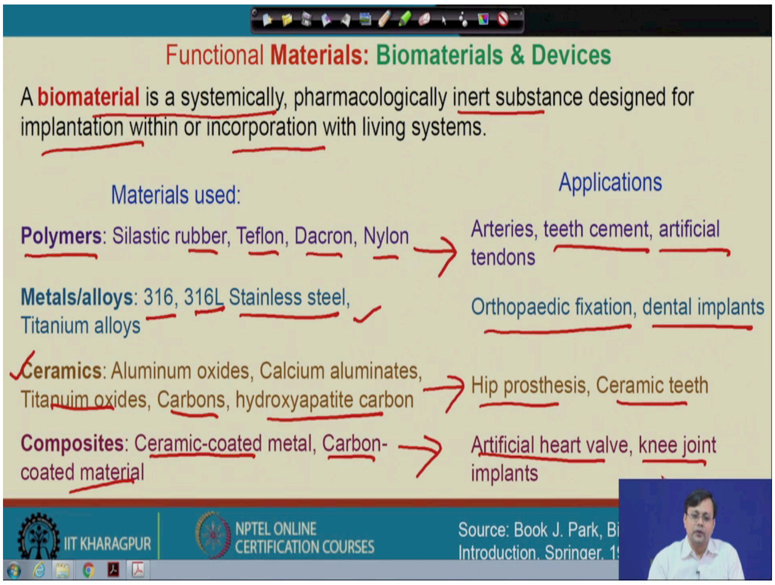


Now, that is also a lot of development of the biomaterials, which are also considered as a advance material. So, the biomaterial this terminology means that which is a systematically and pharmacitically used an inert substance which are designed for implantation within or incorporation with the living system.

So, we incorporate some artificial materials into the body and pharmacologically they are termed as a biomaterial. Usually a there are several materials are used which are also under development and also presently used in several purpose; I as a polymer material these rubber material let us say some teflon and Dacron, nylon they all are used often. At the same time, the stainless steel are very often used as a as a implant material like 316; this is a one great of stainless steel or low carbon 316L; they are also often used.

So, we can see that such material required for implantation of biomaterial, like ceramic or aluminum oxide and calcium aluminate, titanium oxide, carbon, hydroxyapatite they are all used as ceramic material. In case of composites, the compo ceramic coated metal or let us say carbon coated materials; they are also often used as biomaterial.

The most of the application areas of polymer biomaterial like teeth cement or let us say artificial tendons and for orthopaedic fixation; we often used the metals and alloys also some of the dental implants we use and hip prosthesis and ceramic teeth from ceramic materials are also used. And also in case of composite we use some artificial valve or let us say some knee joint implants are used. So, you can see that these are the material or areas of materials that required for the development for the human benefit.

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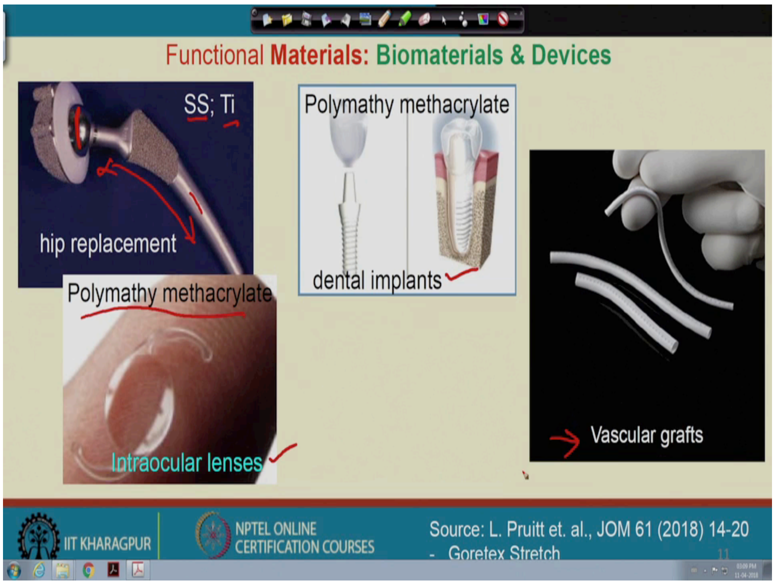


I show you some of the example of such implant materials; you can see we often use these intraocular lenses for our eyes and these are some polymer material and polymathy materials. Also for hip replacement you may have seen such kind of such kind of replacement material; biomaterial which is made out of stainless steel or titanium these parts.

And these are the parts which are usually made from ultrahigh density polyethylene ultrahigh molecular weight polyethylene. So, there is a huge opportunity of developing these kind of biomaterials and also you can see here these similar type of material are used also for dental implants also, some sort of grafting materials we use.

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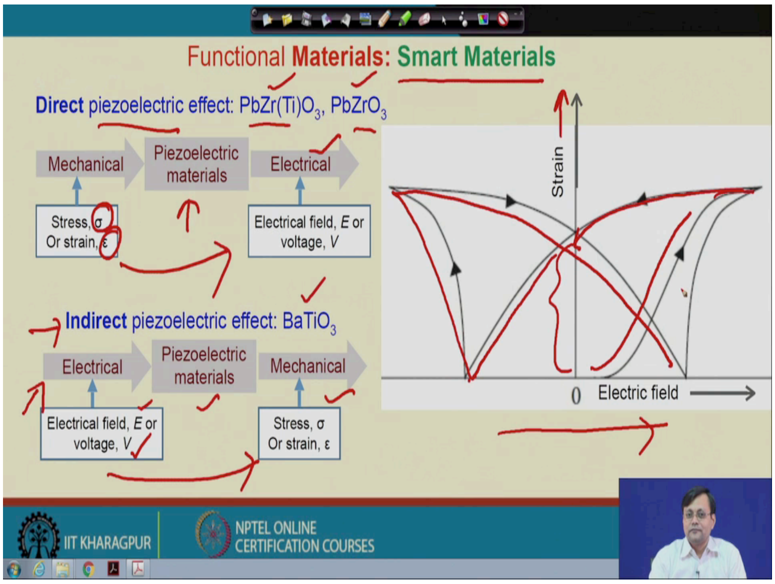


So, that is a definite need and for a general awareness of so many different functional materials Now, another category of functional material is the smart materials. Here we use this material because you can see these are basically some oxides.

And this is a piezoelectric material from barium titanate or lead zirconium titanate and lead zirconium oxide. The effect one need to look at what you really do using this piezoelectric materials; there is very interesting phenomena. Because if we take such piezoelectric material and we apply some stress or strain; then we can generate some electrical signals and this is very interesting actually and so, we can take this signal and use as a sensor.

Now, there is also indirect piezoelectric material where we simply keep some electrical field let us say either voltage or current. And these material basically expand or contract and give you some mechanical responses. So, either from a electrical to mechanical or from mechanical to electrical signal; we can use these piezoelectric effect and these are very smart material considered as a smart material.

Because if we have a look here this curve is known as a butterfly curve actually; here electric field versus strength is shown here if we give some electric field current or voltage; then definitely it give some mechanical stress or strain. And then if we reduce the electric field to 0, then there are some residual strain even in the material which could be recovered when we give some negative electric field.

Now, if we again go further then it goes here then again it returns back. So, you can see that this is a very very interesting phenomena and this plot looks like a butterfly. So, these are very interesting a smart material that are often used.

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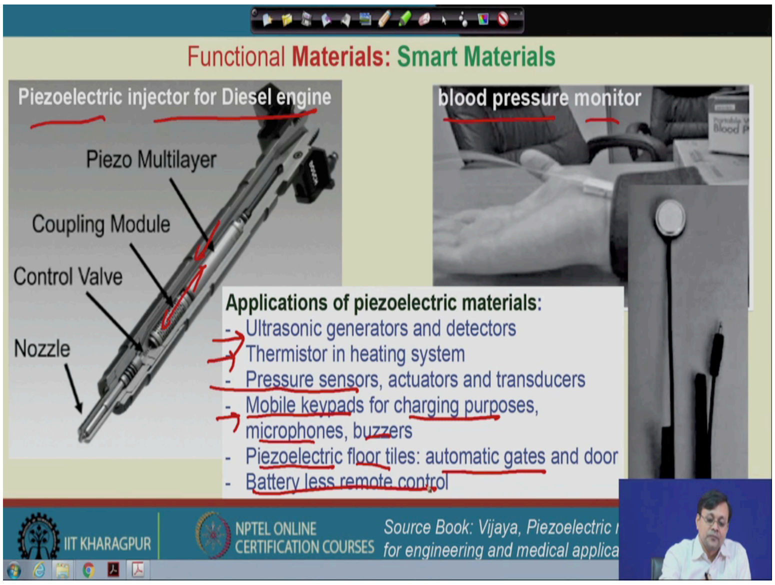


I show you some of the example here because we can generate some ultrasonic pulse. So, we can continuously give a frequency of electrical signal, which can convert into mechanical pulse or let us say some thermistor or maybe some pressure sensors we can develop and we can also use this piezoelectric effect for injection of diesel engine. So, what we do here we give some electric pulse and this go move up and down and inject the fuel into the engine.

Or maybe we can use the blood pressure monitoring system using this as a sensor. Also we can use some mobile keypads for charging purpose because we use this keypad we give mechanical stress in the keypad and that extra energy can be used for battery charging. Also we can use for microphone buzzers because it give mechanical signal using electrical signal, we can use for floor tile it helps some automatic get open entry and so on or maybe simply battery less remote control we can use.

So, there is a large application of these smart materials you can see; so, there is a large opportunity of this piezoelectric material. So, today we had a look and we had discuss about a different a class of a functional material, we have just started the discussion today. And tomorrow will continue this discussion and we had completed discussion on structural materials like ultra high temperature materials.

And these are the materials which falls in the category of advanced materials and definitely we not only need to know the understanding and basic or the mechanism of the different properties, how the properties evolved in these material, but also we need to learn different processes now. So, here we end today and see you in the next class.

Thank you.