Science and technology of Polymers
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Lecture - 27
Polymeric Nanomaterials and Devices

Today we shall discuss on polymeric nanomaterials and devices, mostly biomedical devices.

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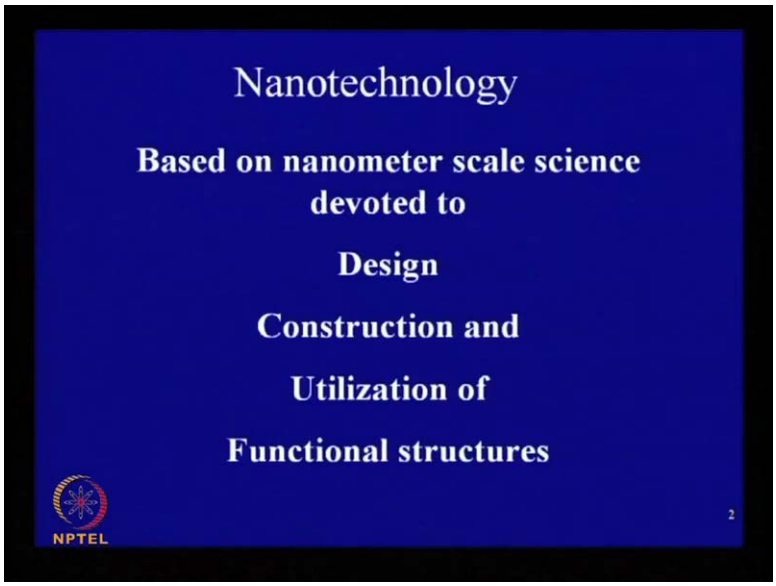

Now, you know today nanotechnology has come to the forefront everybody has got interest in this nanotechnology development of various devices. Using nano materials, which involves nano science, you know what is nano science? Science of small dimension, nano dimension, so that nano materials scale science has been devoted to design and construction of functional structures and the replacement for suitable devices.

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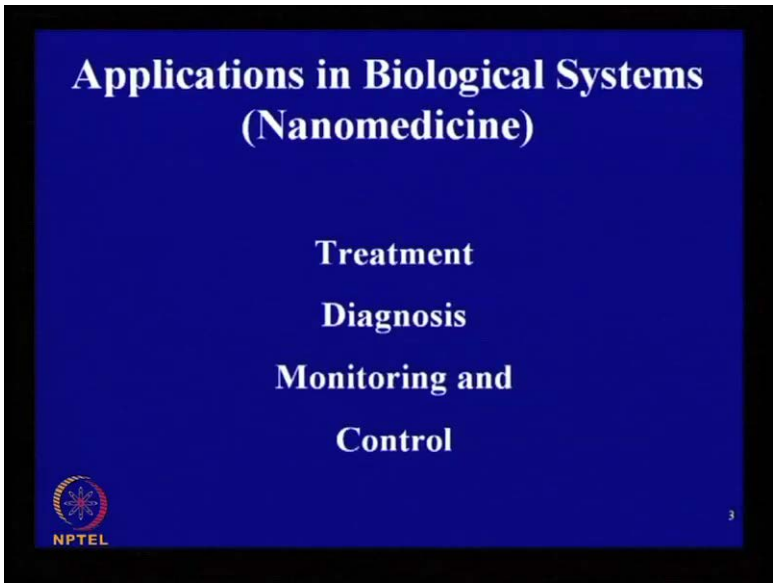

And that is in biomedical field that nanotechnology is being used for treatment for diagnosis for monitoring and control.

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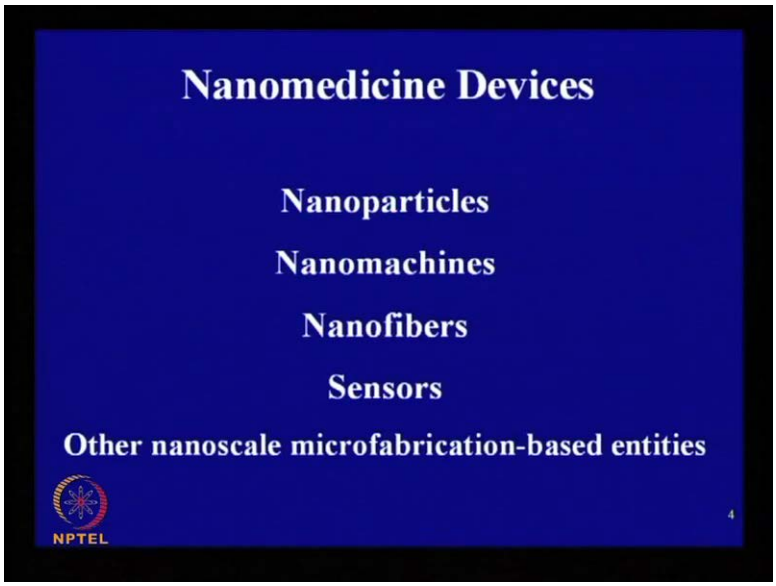

This nanomedicine devices contains nanoparticles, nano machines, nano fibers and sensors. Nanoparticles you know there are various techniques to form this nanopaarticles or nanomaterials. There are two major approaches; bottom up approach and top down approach. So, if you can make some materials made of these nanoparticles, these particles in nanodimension say might be below 100 nano meter or 200 nanometer like that. They

show some unusual properties. You know gold its color is yellow when it has been broken down to nano particles, gold nano particles its color changes from yellow to blue to green to purple to red and their properties are different.

Now, you have seen in case of carbon black carbon black there are various gates of carbon black of which one gate is channel black or sometimes hardness black. Channel black they are available in small particle size hardness black hardness carbon black is available, it is also available in small particle size 2 into 20, 30, 40, 50, 100, 200, nanometer dimension when those particles are used as filler in our compounds we get very good reinforcement properties, reinforcing properties, re-improved strength of the composite.

If I mention one aspect say in homeopathic treatment homeopathic medicine, you know homeopathic medicine that is the strength of the homeopathic medicine depends on dilusion. Higher dilusion is a stronger mission medicine, lower medicine means concentrated solutions or higher concentration solutions of higher concentration are little lower strength. What is the why this happens? You know these homeopathic medicines these are made from chemical products either synthetic products or herbal products herbal base.

In all the cases some concentrated medicine is taken and it is diluted and there is a process of dilution process of dilution. Now, simply you add that medicine in a solvent sew water and you get the dilution norm there is certain process they have certain process they give some mechanical vibration and they get higher dilution homeopathic medicines and that becomes a stronger medicine. Now, in that stronger dilution homeopathic medicine with the help of available instrumental facilities the presence of that chemical compounds of that medicine would not be detected, but still it is stronger medicine.

In case of higher concentration medicines lower potency there sometimes one can detect the presence of those chemical compounds, why this happens? Now, my concept is there might be some sort of the separation of the molecules or dispersion or solution of those medicine medical compounds in molecular level. In aggregates they function in one way in dispersed condition in molecular level they function in other way that might be the reason, but that research has not been done we do not know, but today these nanomaterials or nanotechnology indicates that by virtue of the small dimension as well as their high surface energy they prone to be to form aggregate agglomerates.

If you can break the aggregates then we can get the dispersion in smaller dimension probably we can exploit the real properties at the molecular level. So, there are certain properties at the molecular level the aggregates aggregates of those materials may not perform the same level of properties that we have visualized in some cases. You see the color of gold changes from lum to these nano-particles their properties are also changes. So, this concept is being utilized in various fields for various purposes. We are all seen biomedical field people are trying to utilize this nanotechnology for treatment for diagnosis for machines micro machines etcetera nano machines as well as in censors. So, I will give you some exposure to you this thing those materials and some devices.

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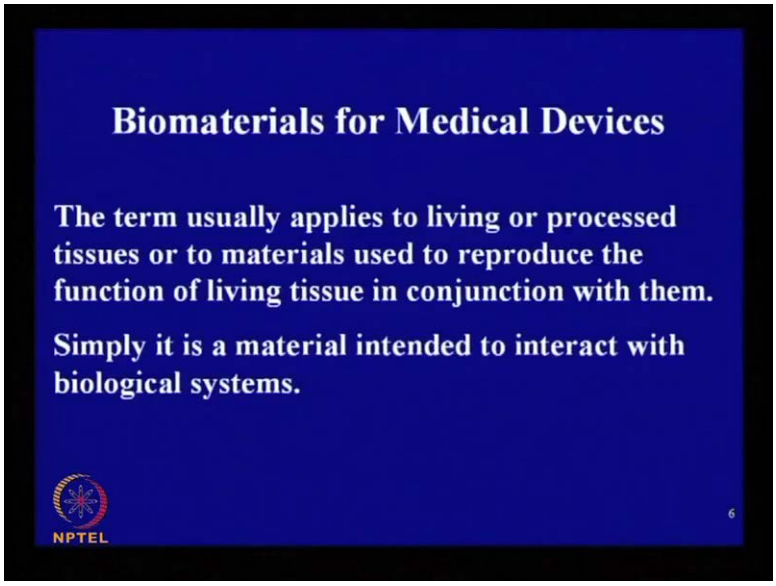

So, the term usually applies to living or processed tissues (( )) materials it usually applies to living or processed tissues or the materials used to reproduce the function of living tissue in conjunction with them. Simply it is a material intended to interact with biological system. Bio material meant for using in some biomedical device that is used in place of living tissue, so that that device can function like that of the host tissue. So, it should be biocompatible it should be it should be non toxic it should be bio acceptable and it should perform the real function what you want.

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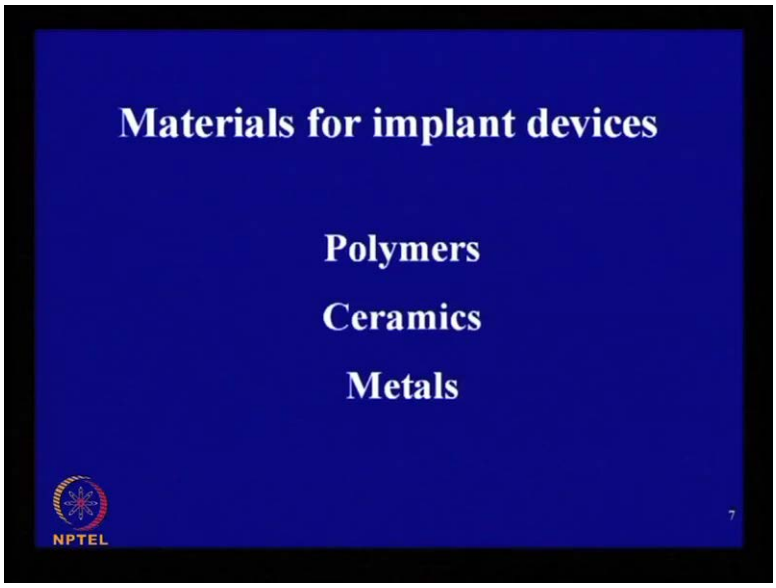

Now, what are those materials for used in implant devices biomedical implant devices? We can use polymers, we can use ceramics, we can use metals. Now, you have some exposure to polymers names of various polymers various categories of polymers you have seen addition chain polymers, condensation polymers. You know their structures addition chain polymers exclusively condensed carbon chain structures condensation chain polymers content carbon as well as other hetero atoms in its backbone structure.

Condensation polymers are more pooler than addition chain polymers right. And looking at the structure of a polymer you can predict its properties, you can predict its inertness its reactivity say for example, you want to make a device you want to some article of course, if you know the chemical formula chemical structure chemical nature of the polymer you can predict whether it will be it will remain stable or it will be unstable in the environment or within a living system.

So, polyethylene if I talk about polyethylene polyethylene is not degraded by environment it is not degradable by environment ambient environment, get it if it is exposed to ambient environment say exposing to sunlight exposing to humidity exposing to rain exposing to air etcetera all these things. So, polyethylene is not degraded that is why polyethylene is causing lot of problems nuisance in the environment. Because it is a stable polymer having carbon carbon bond and carbon hydrogen bonds, where as a polyester polyester which contains carbon carbon bonds as well as carbon oxygen bond and carbon hydrogen bonds.

Now, this carbon oxygen bonds it is located in the ester group you know this ester group is degradable hydrolytically degradable in presence of acid or alkali it can break. So, it can be degraded little naturally occurring polymers you know their structures formulas chemical composition. Naturally occurring polymers contain carbon hydrogen nitrogen oxygen sulphur all these things isn't it?

Majority of them except natural rubber majority of them contain such atoms as well as bonds are present. And those are actually those are easily degraded by nature oxidity degradation thermo oxidity degradation microbial degradation all these degradation occurs there. But if we put these polymers in living system which contain biological field, the p h sometimes is around 7.4 or within the stomach, p h may be little lower or higher. So, in those environments if polymers are put over there if the polymers get hydrolyzed within the living system then the stability of the polymer will be at stake.

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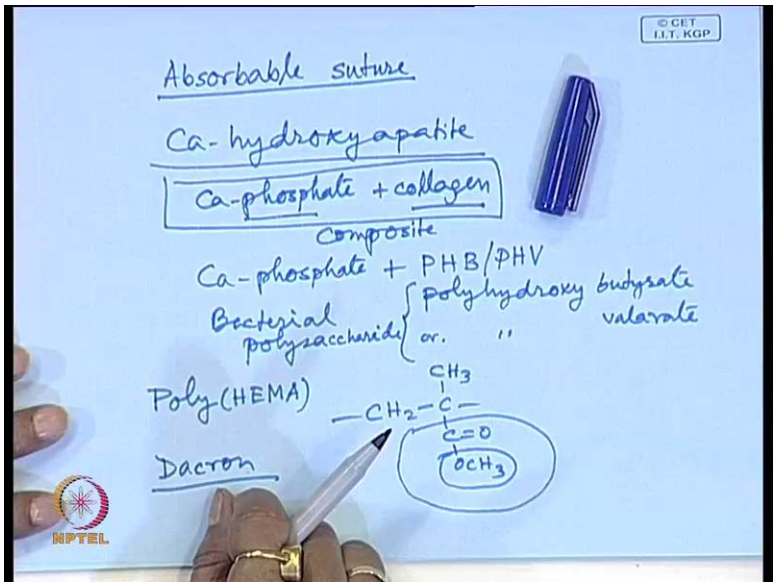

Now, there are certain requirements in the biomedical field that we need to degrade the polymer say absorbable future you know suture thread suture thread or biodegradable suture absorbable suture means when that suture threads are used for stitching purpose after surgery or for the purpose of healing a wound. So, it comes in contact with the body fluid. Now, if it is non-absorbable, non-biodegradable suture after wound healing there is a necessity of removal of the suture thread from the body that is a painful (( )). Now, if there is absorbable suture which will be slowly absorbed within the body fluid and the

degradation products will be excreted from the body slowly then that removable tape can be avoided.

So, say internal operation, suppose within the body after operation it is actually closed and stitched, now that is done by tissue adhesive or suture. Now, if the suture is used again if it is non-absorbable then it is to be again removed after the wound is healed. So, for those purpose we have to see what polymer we have to select depending on the requirement there are certain requirements say tissue engineering scaffold for hard tissue replacement say total hip joint replacement or knee replacement or finger replacement, finger joint replacement anything, for hard tissue means bone bone replacement.

What we would do we make a we make scaffold from calcium synthetic calcium hydroxyapatite, you know calcium hydroxyapatite you have heard this name calcium hydroxyl. It is a bone mineral it is present in bone normally bone, now if a skeleton or scaffold is made porous. Scaffold is made from this thing or a composite is made from this calcium hydroxyapatite or bio-glass or calcium phosphate using collagen as the matrix.

This is the reinforcement, this is the matrix, so a composite will be formed a composite, now that composite can be used for replacement of bones or else we can make scaffold from calcium hydro porous scaffold calcium hydroxyapatite. Today people are making bio ceramics porous bio ceramics, now after replacement. What happens, native bone formation will be there means it will help ostio conductivity. It will help in ostio conductivity and native bone will be formed and slowly those pores will be filled, if you take some composite made from collagen calcium hydroxy calcium phosphate or calcium phosphate or some other polymer, say polyhydroxy butyrate polyhydroxy butyrate or valarate polyhydroxy or polyhydroxy valarate.

These are actually bacterial polysaccharide bacterial polysaccharide produced by bacteria it is a polymer polysaccharide polymer. This is a biodegradable polymer or chitin or chitosan or chitosan. Now, these can be used as matrix with calcium phosphate or calcium hydroxyapatite or even a bioactive glass I mentioned earlier bioactive glass. So, what will happen these polysaccharides or collagen or or other bio-degradable say polylactic acid polyglycolic acid polylactic co glycolic acid co polymer. Now, these biodegradable polymers with this calcium phosphate or bioactive materials or calcium hydroxyapatite that will form a composite. That can used for replacement of bone slowly these polymers

will degrade within the body creates some space in those spaces the native bone tissue will be formed.

So, after surgery say after 6 months of surgery or 5 months of surgery, one can find that the artificial part which was replaced which replaced the which was put inside the body that is no longer present there is almost original bone, native bone has been formed there. So, that can help in healing of some damage bone damage or affected or diseased bone these things can be replaced there some people are using some nanomaterials. Yesterday there was a lecture in our centre they have shown some bio ceramic nano bioceramic made from nano cellulose and nano bioceramic particles.

So, we can use this polymers, polymers which must be compatible with the host system that means we will try to find we must try to find out some similarity of this polymers with the polymers present in the host tissue. Yes please, no if it is biodegradable that polymer will degrade slowly some space will be created and there native bone tissue formation starts and it will be filled by the native bone.

No catalyst, so this is the by your normal physiological system physiological process you see if there is some injury on a tissue if there is no external attack by external agency there will be normal healing regeneration of tissues by the its own system do not go to that complications at this stage, but it occurs certain (( )) you it has been found that at the age of 90 years at the age of 90 years fractured bone is repaired. How it happens? These, it happens due to falling in the bathroom at the old age people gets their bone fractured after plastering and some treatment it is cured. So, it is not that, so long the system is living.

There is all the moment there is tissue growth tissue formation either bone tissue or soft tissue you cannot say at the old age this tissue formation will be totally stopped. No, it is the rate may be slower rate may be slower the situation may be little difficult, but it is there. So, what you see polymers are used in biomedical field it is again a vast subject it is a vast subject I am giving a little exposure introduction to you. So, that if anywhere it is necessary you can explore then ceramics are also used metals are also used titanium titanium, annadium, aluminium alloy these are used for total heal processes today ceramics are also used.

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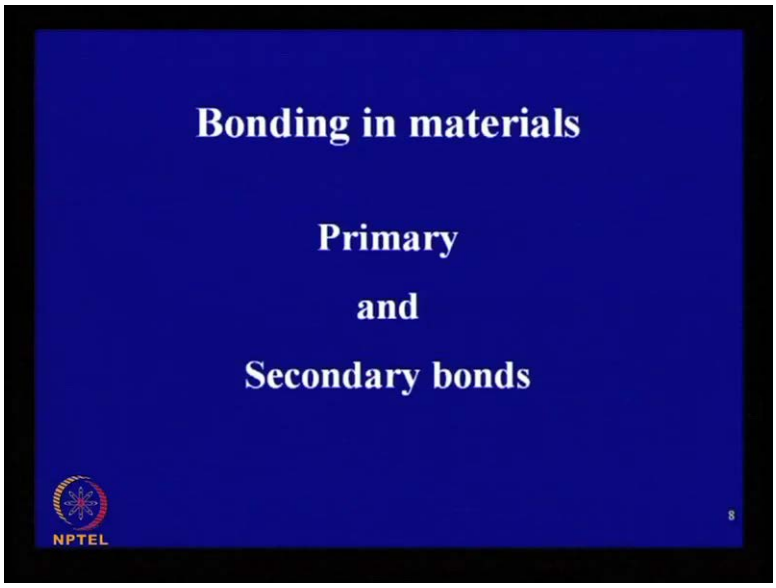

Now, since you are material scientists you should not keep aside the concept of bonding always you should think in terms of chemical bonding present in a in those materials and devices. Primary bonding and secondary bonding, nature of bonding nature of primary bonding nature of secondary bonding and total quantity of primary and secondary bonding present so you should take care of that properties requirement biocompatibility.

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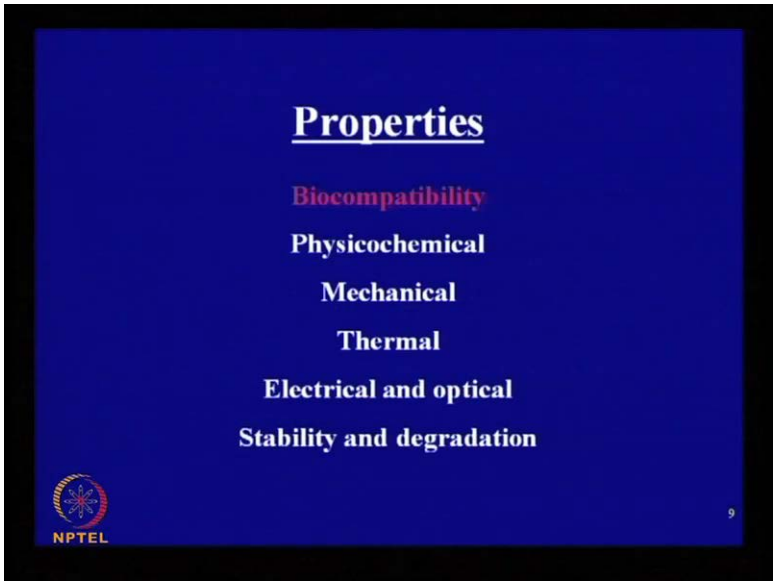

That means the external or foreign system foreign body should be acceptable or should be accepted without any hazard, without any toxic effect in the body. If it is not if there is cell

proliferation cell growth tissue growth say all those things in presence of foreign bodies, then we can say this material is biocompatible. There is methods of testing also to test the biocompatibility of a material be it polymer be it ceramic be it metal there are tests are available standard tests methods are there.

That means what we do what is normally done in order to test the biocompatibility take a specimen on the material put in a culture media containing certain cells if in presence of that specimen, cells continue to grow or proliferate populate. You say there is no toxic effect so you can say in one way it is biocompatible, but this is invivo test. So, by test we can say whether it is biocompatible or not also this is not complete.

You have to go through also invivo test you have to put that specimen inside a living system animals you have to go to for animal testing. Means you put this thing in the animal you see the heart beat behavior change of high beats behavior and the change of body temperature etcetera. All these things if those are those remains unaffected it can be set fight that yes it is acceptable by the living system biological system biocompatible. So, this is a second stage second step success, third step success is if you want to apply in humans.

Then in the third step it should be applied in humans system again some monitoring system should be there through some monitoring system if there is no adverse effect. By putting this thing inside the body then it can be recommended as suitable biocompatible material biocompatible device which can be used their physical chemical properties, physical properties as well as chemical properties you know. What are the physical properties you know, chemical properties? You know mechanical properties strength aspect tensile strength modulus long break hardness their compressions rate.

And sometimes dynamic properties dynamic mechanical properties etcetera then thermal stability also has to be considered at body temperature at body temperature whether those materials and devices are stable or not sometimes some materials need electrical conduction. So, electrical properties as well as optical properties and stability and degradation how long they are stable if there is slow degradation in presence of body fluid say you have to test it through simulated body fluid and you have to see if there is any degradation. If you take out the specimen you have to analyze specimen and you have to analyze the surrounding medium say fluid or tissue if there is any degradation product or

not if there is some degradation product you have to see what ere the degradation products are those toxic or not those things have to evaluated for this materials.

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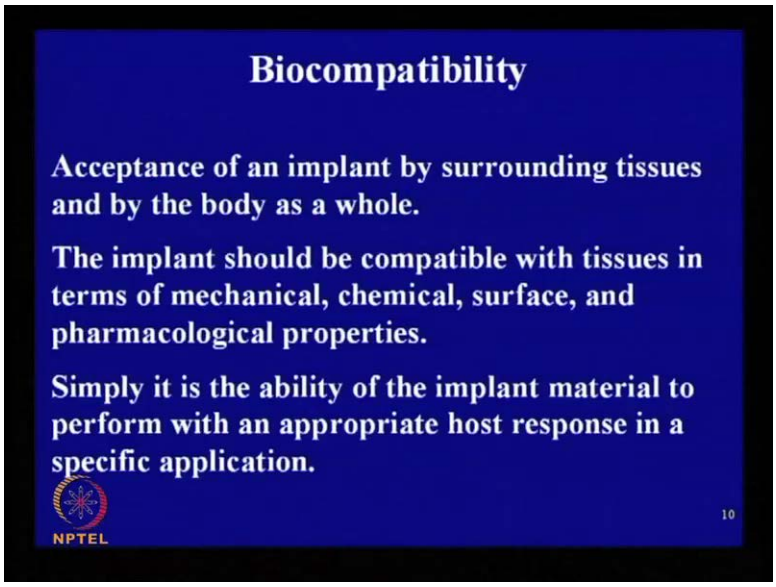

So, acceptance of an implant by surrounding tissues and by the body as a whole can tell you about the biocompatibility. The implant should be compatible with tissues in mechanical, chemical, surface an pharmacological properties. Simply it is the ability of the implant material to perform with an appropriate host response in a specific application host response response of the host after accepting after putting.

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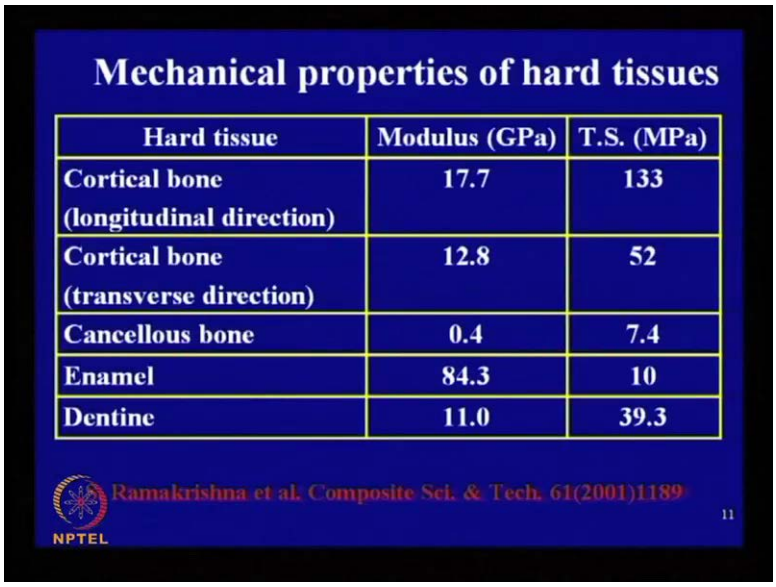

This thing behavior of the host mechanical properties say cortical bone cancerous bone enamel dentine materials. The modulus, then modulus tensile strength, then mechanical properties of soft tissues those are the mechanical properties of hard tissues. These are the mechanical properties of soft tissues cartilage, ligament, tendon, skin, arterial tissue in two directions intraocular lens. So, you see the requirement of this indicates the requirement of mechanical properties of the materials which are to be used of such biomedical devices. Now, there one can apply the nanotechnology in the fabrication during the fabrication of such devices.

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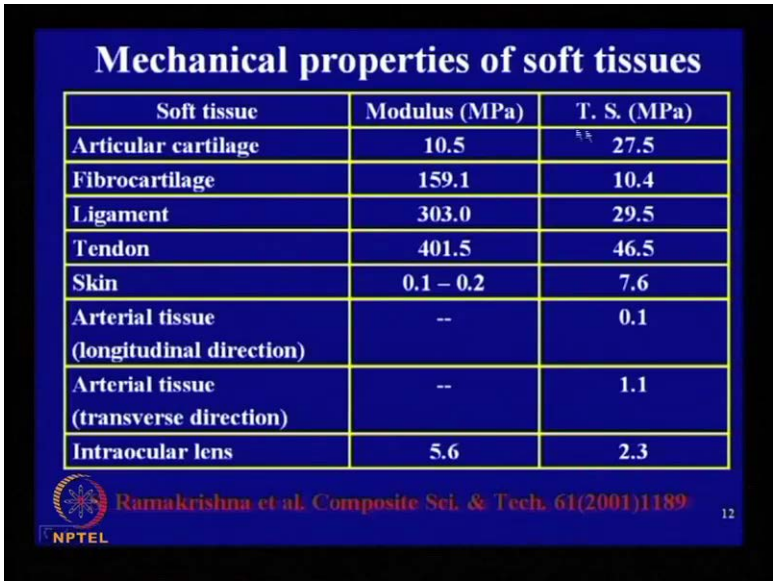

So you see this is the tensile strength and this is the modulus tensile strength, this is wrong actually this should be Giga Pascal this should be Giga Pascal not mega Pascal modulus is higher anyway.

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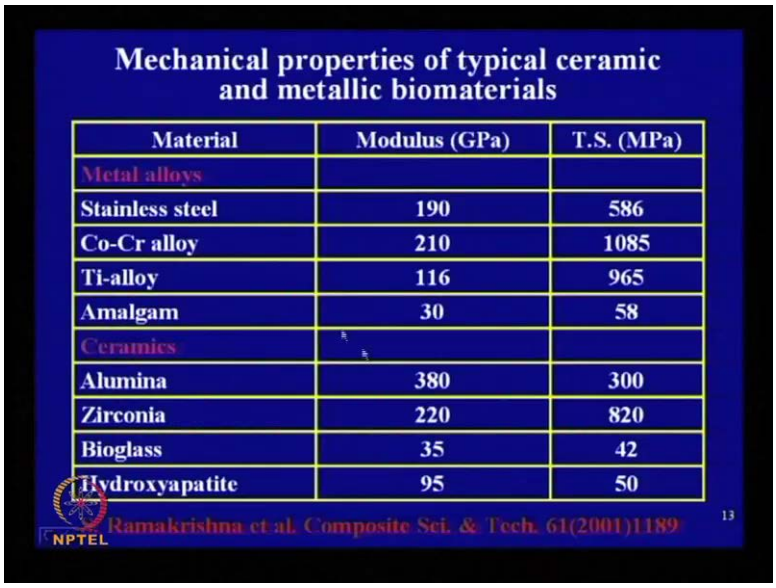

Then mechanical properties of typical ceramic and metallic biomaterials you can compare the tensile strength and modulus of some metals and ceramics. You compare metals are stronger tensile strengths are more in case of metals and hydroxyapatite you see. Hydroxyapatite this is a bone mineral and alumina very hard ceramics alumina zirconia all the hard ceramics, so their properties are higher than those of hydroxyapatite. Here is a problem, if you want to replace any part of the body with such foreign materials like metals and ceramics properties matching is very difficult to obtain isn't it look at the properties they are very strong, so there is a mismatch on this properties.

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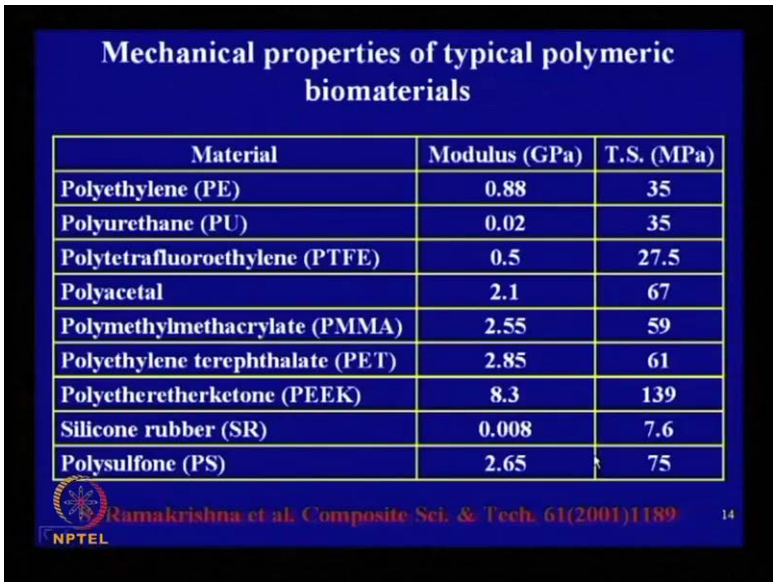

Then you look at the polymers the mechanical properties say modulus and tensile strength these properties are close to those of soft tissues. And mechanical properties of some composites can be brought very close to those of hard tissues that is possible with polymers. That can be tailored again following this nanotechnology. Nanotechnology I mean you have to follow certain process, so that nanodimensional enforcement is possible to form say think of cellulose cotton if you want to make nano nanodimensional cotton fiber.

How you can make you know cotton contains cellulose molecules cotton. In this cellulse molecules, in the cotton fiber highly crystalline and that is the reason for its insolubility infusibility cotton, which contain an hydro glucose unit rings an hydro glucose unit an hydro glucose unit those an hydro glucose units unite one after the other to form a cellulose molecule.

There is extensive intermolecular hydrogen bonding between cellulose molecules through hydroxyl group to primary hydroxyl sorry, 1 primary hydroxyl group and 2 secondary hydroxyl groups are there by virtue of that hydrogen bonding between those hydrox hydroxyl groups. There is intermolecular hydrogen bonds present in cotton cellulose cellulosic materials. If you want to make, if you want to make nano fiber out of this cotton fiber it is difficult.

Difficult in the sense it is not soluble in the solvent, it is no feasible, you have to do now if you can. Find I technique to break the hydrogen bonds intermolecular hydrogen bonds. Then you can separate the cellulose molecules means your cellulose molecules from each other. Then only it is possible to form nano cellulosic fiber. Once this nano cellulosic fibers are formed you know this hydroxyl group will be exposed or opened hydrogen bonds will be broken again there is every tendency of reformation of hydrogen bonds there is the problem, that is when you make some nano particles a partical in nano dimension eventually there will be recombination to form the aggregate that means it becomes difficult to maintain the nano dimension.

So, if it is possible to prepare this nano unit in C 2 in C 2 that means if immediately some some your third things thing comes between 2 units nano units, then that will prevent their combination recombination. Then only you can get dispersion of nano units in a matrix. So, in case of celluloids say what you can do you have to break the hydrogen bonds. How

to break the hydrogen bonds? There are two ways thermal and chemical or else, if you apply thermal energy that should be in such a mount.

So, that it only reaches the energy of this that hydrogen bond which can break isn't it? You can use some chemical energy some chemical materials chemical compound chemical agent. If it can provide that energy close to that of hydrogen bond breaking energy then that can break and eventually you have to disperse those nano fibers preventing recombination. So, we can imagine one thing a cotton fiber or any other natural fiber that is a bundle of fibrils a fiber is bundle of fibrils fibrils are having smaller diameter than fiber. A fiber can be considered as a bundle of fibrils, so your job would be to separate those fibrils from a fiber by breaking intermolecular hydrogen bonds.

Now, again each fibril can have large number of cellulose molecules a bundle so fibrils can be bundle of cellulose molecules. And fiber is bundle of fibrils, so in each step you have to break the hydrogen bonds. Now, there is a technique called steam explosion technique. what is that steam explosion technique? You take this fibers in an auto, you put these fibers in water or take a dispersion of this fibers in water take that dispersion in an auto club close, the auto club. Start heating means, if it is electrically heated put on the switch, so it will increase the temperature. So, that water will vaporize and form steam so if you go on increasing the temperature.

So, you will have steam at higher temperature a superheated steam will be there, so in that condition what will happen water molecules will go in between those fibrils as well in between those cellulose molecules and the energy available over there is sufficient to break those hydrogen bonds. So, water molecule can be penetrated in between those fibrils and cellulose molecules then what you have to do suddenly open the auto (( )) is at high pressure sudden go for sudden release of pressure, what will happen? So, inside the fiber there are water molecules in between fibrils and cellulose molecules so on sudden release of pressure there will be some bursting effect.

So, water molecules are water molecules in between the fibrils those are under pressure, so outside that when the pressure is released, so that fiber will be burst out. Fibrils will be separated fibers will be separated, this is one way and that will be dispersed water is there. So, then that will those cellulose molecules will try to form hydrogen bond with water molecules not with another cellulose molecule, so intermolecular hydrogen bonds will be

broken, but intermolecular cellular hydrogen bonds will be broken. But some hydrogen bonds between cellulose and water will be formed is it clear. So, what will get we can get dispersion of nano cellulose fibers in water this is one way in another way.

You can go for ultra ultrasound treatment if you expose this system (( )) that slurry or dispersion to ultrasonic ultrasonic your energy environment by the sonication the hydrogen bonds can be broken depends on what frequency of ultrasonic energy at what frequency you are using you are applying. So this way you can make nano fibers, so these techniques are been followed wherever one technique is suitable you selection of any technique is up to you which you can really handle. So, this way one can get nano fibers, so here you see if you can make fibers from these polymers in nano dimensions or killers say clay nano clay etcetera.

So, if you can disperse these polymers you can make nano devices nano composite devices for biomedical application and there will be intimate contact between the fiber and the matrix if intimate contact between the fiber and the matrix. Then only you can get the nano effect, what happens in macroscopic composites? In macroscopic composites this reinforcement either in the particular form or in the fiber form those are in bigger dimension bigger dimension.

So, total interface area between the reinforcement and the matrix less there, now if you think of say five gram of material if you can break it to nano dimension you calculate you can calculate the total amount of surface area of the particles available will be available in the nano dimension. Say 10 nanometer suppose 10 nanometers 5 gram of 10 nanometers of a material you can calculate the surface area considering assuming it as spherical particle.

Then you compare this total surface area with that of 40 gram of the same material having say micro dimension you will find that the surface area available from that nano the smaller amount of that nano material will be higher than that one. So, what it is giving it is giving that more surface or interface per contact between the matrix and the fiber. So, you can get fruitfully the nano effect nano composite, so this is the concept only thing you have to make the experimental you have to develop the experimental set up then only we can get the success otherwise it is difficult.

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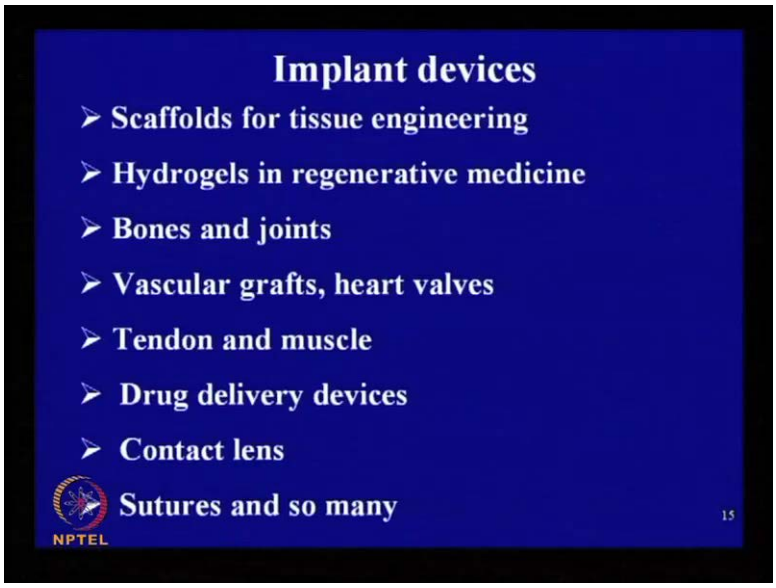

Implant devices, scaffolds for tissue engineering. Now, to talk about scaffolds, now, today people are making scaffolds from nano fibers nano fibers, people are making silk nano fibers silk is a natural fiber now that is actually dissolved in a suitable solvent. Then by nano spinning process or by electro spinning process, so that solution that solution of that silk in a suitable solvent is spun through nano opening. Then electric field is applied across this spun fiber say fibers are drawn fibers filaments are coming down from the nano that spinneret and some electric field is applied.

So, at that high electric field the fiber dimension becomes very thin that helps actually that your application of electric field at high voltage helps in getting very thin fiber. So, people are making conducting polymer nano fibers by that technique. I have seen that setup that device people are making nano conducting polymer nano fiber people are making are making silk nano fibers collagen nano fibers protein nano fibers by this technique.

And those are used for making scaffolds those scaffolds are used for tissue engineering that means scaffold is a support scaffold is a support on which tissues are grown cells are grown to get a proper tissue in a proper cell. And dimension in the last class. I I was telling mio cardial tissue construction by cells (( )) engineering mio cardial tissue construction by cells. Engineering without using any scaffold with the help of that stimuli responsive polymer or thermo responsive polymer, but you can use some scaffold for tissue engineering.

So, that scaffold can be porous support of course, there should be porous support or a network hydrogel or gel materials where ample space is available for tissue growth tissue accommodation there, ultimately if the scaffold is biodegradable, then by slow biodegradation. Ultimately we can get a native tissue hydrogels in regenerative medicine in regenerated medicine bones and joints vascular grafts heart valves tendon and muscle drug delivery devices contact lens sutures.

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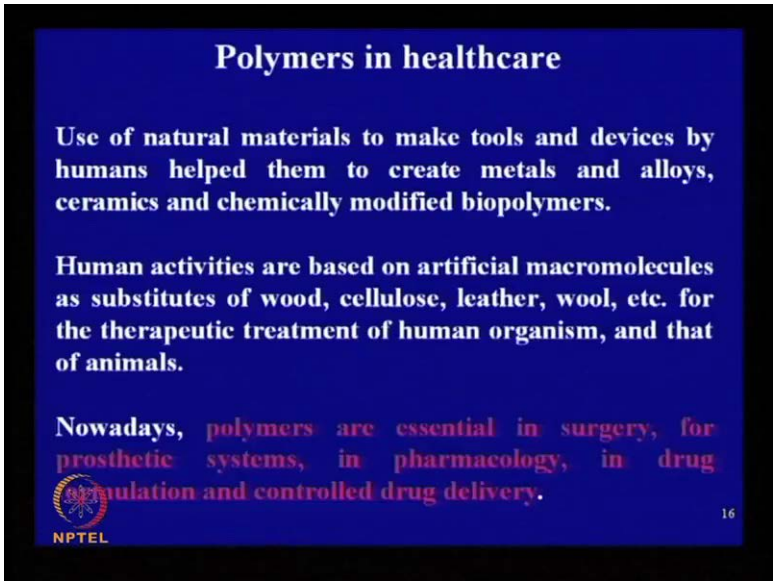

So, many large number of applications can be mentioned polymers in health care. I I have told many things, now look the examples of polymers polymethyl methacrylate. This acrylate polymers this acrylic polymers, because of their excellent refractive index.

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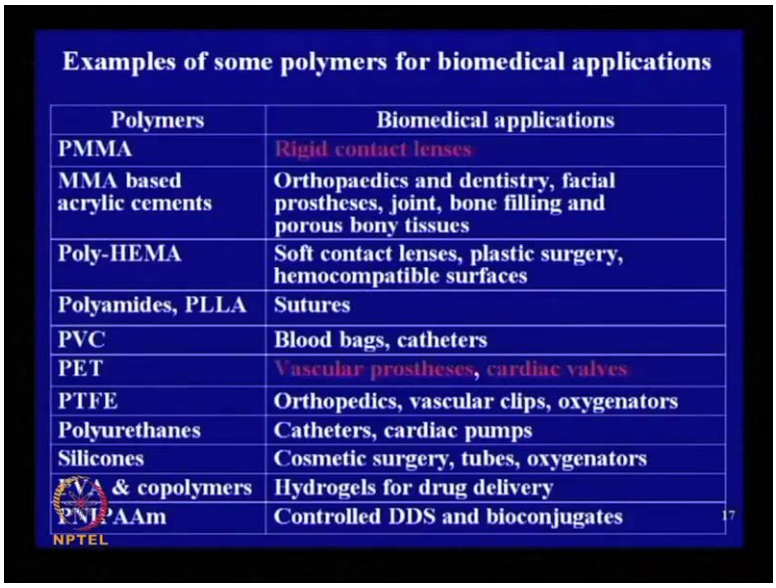

Those are used in optical devices, so contact lens rigid contact lens earlier for rigid contact lens manufacture or preparation PMMA was the ideal material, but it created certain problems of hydrophobicity hydrophobicity and lack of porousity, all these things media properties because it should permit water molecules sodium chloride and other things. So, today today's optical or contact lens is being made of these acrylate polymers, but not PMMA or a copolymer with other monomer with methyl methacrylate have you heard this name polyhema polyhydroxy methyl methacrylate you know methyl methacrylate.

This is this is methyl methacrylate in case of polyhema this group is replaced by hydrox ethyl group hydrox ethyl group now you see by placing that hydroxyl ethyl group it increases the balkanization of this portion CH2 CH2 group additional carbon that regulates the hydrophilicity and hydrophobicity as well as tracking OG the molecular tracking. So, what we need we need some space to passage for the passage of this water and other salts, so things tears suppose tears not only that it should maintain a proper flexibility or it should be it should remain moist all the time.

It should not get dry or if it is hydrophobic in nature if it cannot invite water molecules it cannot like water molecules. Then that will cause irritation that is why today co polymers I do not know the composition this is not disclosed, but copolymer of Polyhema Hema with MMA MMA hema or sometimes in place of hydroxyl ethyl group. There may be other

alkali group, also then polyamides poly lactic acid PVC PVC for bag for blood bag blood bag you have seen blood bag for collection of blood that is made of PVC.

Although it is banned today that is flexible PVC plasticized PVC it is banned globally, but in India nobody bothers, so we are using this plasticized PVC bags. The problem is it gives a life to the blood to say for 30 days only at 4 degree Celsius 30 days life is available again. It has been found within 30 days there is rupture of your blood components due to the presence of plasticized blood components over there, now plasticizers are ester plasticizers. Now, those ester plasticizers are hydrolyzed to form monoester those monoesters actually come out from this PVC plasticized PVC film and mix with the blood that contaminates.

The blood that it brings some toxicity to the blood that is why this plasticized PVC is banned still people are using in our lab we have developed some PVC that film for blood bag without using any plasticizer catheters. You have seen catheters flexible tubes soft tubes transparent tubes IVC stem IVC stem those are made of PVC vascular prostheses vascular prostheses. You see mess or leads or fabrics made of polyethylene triethylic fiber this is called dacron fiber dacron dacron fiber dacron fiber trade name of polyethylene tri ethylyte dacron fiber that is used for making vascular. That means your veins or arteries along with some fluorinated polymer fiber fluoro polymer fibers.

If anybody of you is interested literature is available you can go through, you can see there is a course on biomaterials you can take that course also to get in details polyurethane. Although, these polyurethanes are made from what polyurethanes are di isocyanides and diol. You know iso cyanides are highly toxic. Now, once this iso cyanide groups react with hydroxyl group forms urethane bond once this urethane bond is formed it is non toxic because of that this polyurethanes are used in biomedical implants. Also, (( )) fibers polyurethane fibers those are used in biomedical field, so they are used in catheters cardiac pumps sometimes your oxygenator blood oxygenator membranes silicones you know silicone is an inert material silicone rubber that silicone is used for making cosmetic surgery.

Say breast replacement, breast implant or cosmetics other nose replacement nose surgery or finger joint fingers artificial fingers those are made from these silicones polyphenyl alcohol and copolymers for making hydrogels for drug delivery purposes and polyene

isopropyle acrylamide nipam polymer. In the last class I told you that is used for making thermo responsive controlled drug delivery devices as well as for bio conjugates for separation. And other things, these are various photographs of composites made from carbon fiber and epoxy carbon fiber polyether ethyl ether ketone you see for joints bone plates made of composite materials.

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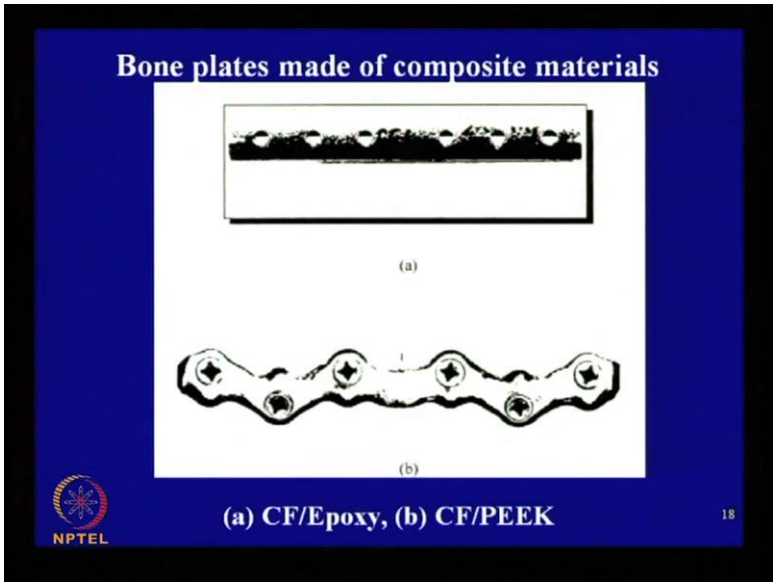

These are commercially available today these composites high performance composites. So, these are used in aerospace used in automobiles as well as in structural items, here also you see these are used in bone materials.

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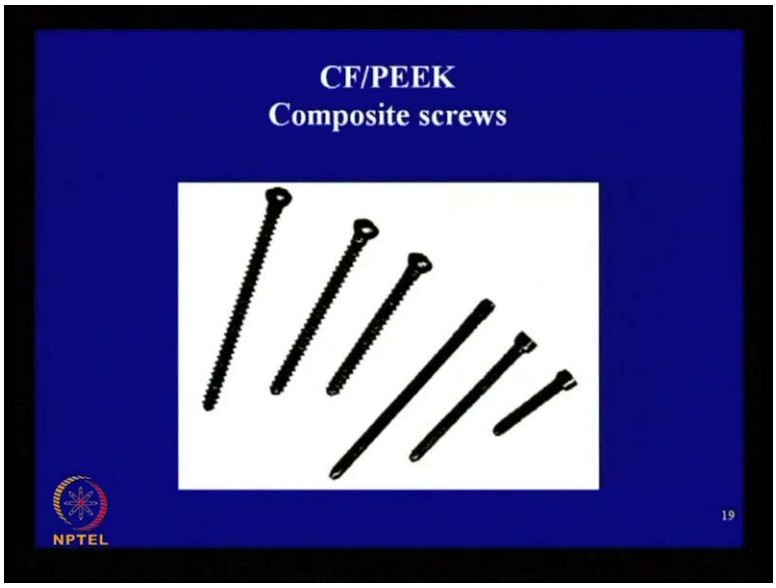

Screws you can have metal screws, now metal screws are being replaced today by these composite screws made from carbon fiber and peek poly ethyl ether Ketone hip joint hip prosthesis hip prosthesis. Again the same carbon fiber peek injection molded composite are being used today. So, it will take some minimum time to explain these things. Next class I I will see to cover these portions.

Thank you.