Non - Metallic Materials
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Module - 11
Corrosion and degradation of non - metallic materials
Lecture - 57
Ceramics in biology and medicine

Welcome to my course Non-Metallic Materials and today we are in module number 11, Corrosion and degradation of non-metallic materials. And I will deliver lecture number 57, where I will be talking about Ceramics in biology and medicine.

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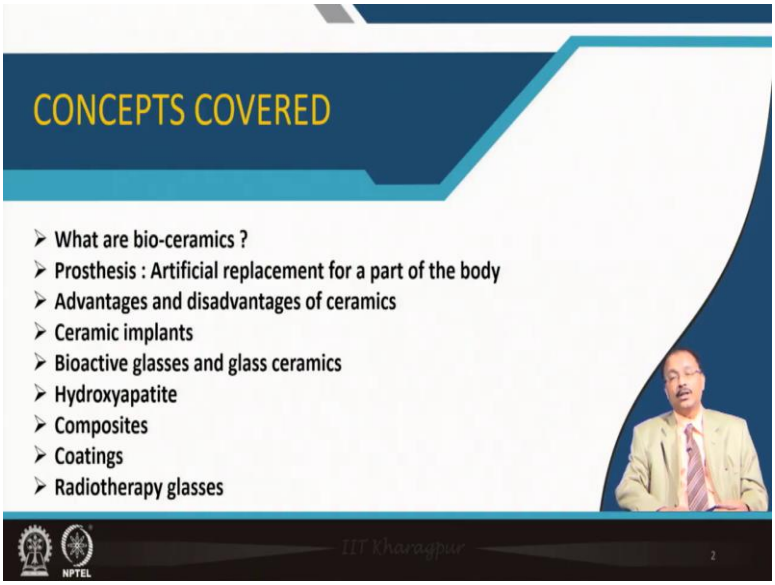

So, first I will define, what is bio-ceramic. Prosthesis is the artificial replacement of a part of the body; so some of the body part is nowadays being replaced by ceramic material. What are their advantages and disadvantages? How the ceramic implants they basically work? We will talk about the bioactive glasses and glass ceramics; then we will talk about the hydroxyapatite as a material, important material for this types of implant. Then we will talk about bio composite, bio-coatings and radiotherapy glasses.

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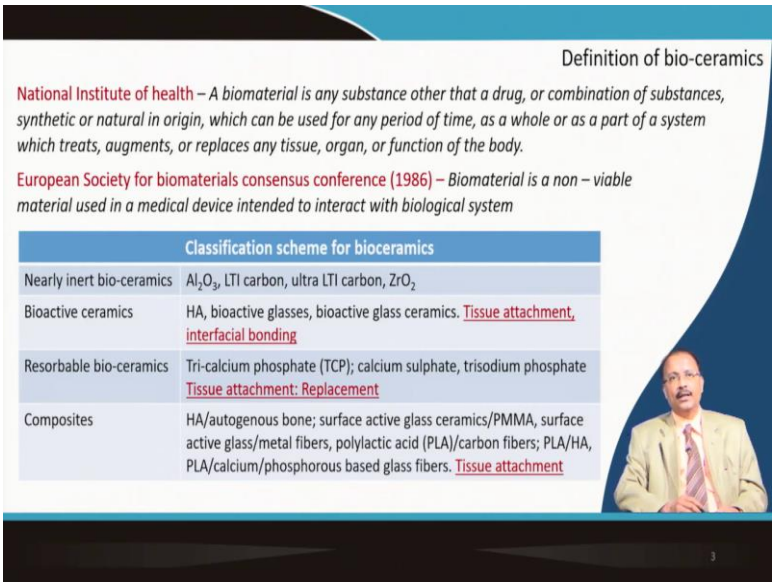

So, according to the definition of this National Institute of Health, a biomaterial is any substance other than a drug or combination of a substance, synthetic or natural in origin, which can be used for any period of time as a whole or as a part of a system, which treats augments or replaces any tissues, organs or function of the body. So, that is the definition given by NIH.

A little bit less complicated definition is given by European Society for biomaterials conscientious conference that, biomaterial is a non viable material used in medical devices intended to interact with the biological system. So, if you want to classify the scheme for bio ceramics, we have nearly inert bio ceramics, which does not interact with the body fluid or tissues; they are aluminium oxide, then disordered carbon, ultra disordered carbon, and zirconium oxide these are the forefront material.

Then we have bioactive ceramics, which is hydroxyapatite, bioactive glasses, bioactive glass ceramics, where tissue attachment and interfacial bonding between this materials takes place. So, they are not really inert. Then third category is resorbable bio ceramics, which is essentially tricalcium phosphate abbreviated as TCP, calcium sulphate, trisodium phosphate.

So, they in this case, they act as a scaffold, where tissue attachment takes place and they are basically resolved. So, they are replaced eventually. And various types of composite like hydroxyapatite, auto genus bone, surface active glass ceramics with PMMA, surface

active glass with metal fibers; then poly lactic acid, carbon fibers composite, then PLA, HA composite. So, they are also bioactive ceramics and tissues get attached into it.

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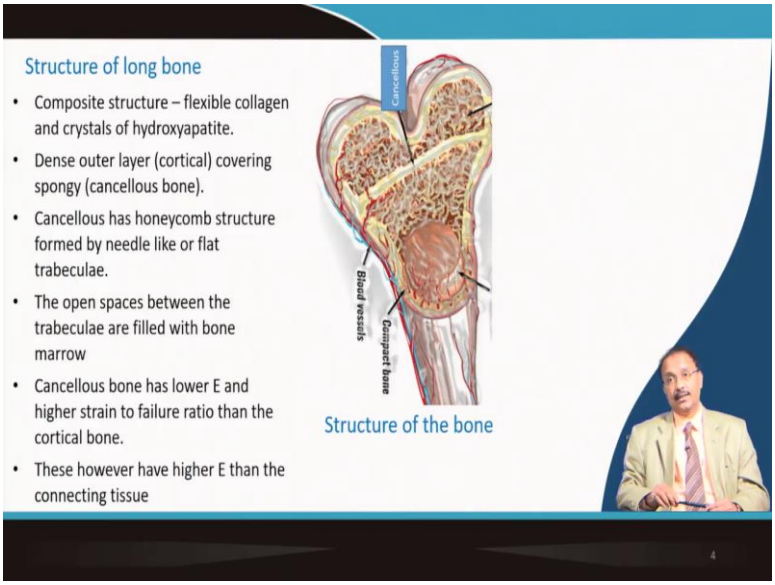

So, if you take a look of the structure of a long bone. So, they are having a composite structure, which is having flexible collagen and crystalline form of hydroxyapatite. So, they have a dense outer layer and this is called cortical and that covers a spongy bone, which is a cancellous bone. So, this cancellous bone, they are having honeycomb structure formed by this needle like or flat trabeculae. The open space between the trabeculae are filled with marrow.

So, cancellous bone, usually they have lower elastic modulus and higher strain to failure ratio than the cortical bone. So, cortical bone is dense outside bone. So, this however have higher elastic modulus than the connecting tissue. So, this is a very basic structure of a long bone in human body.

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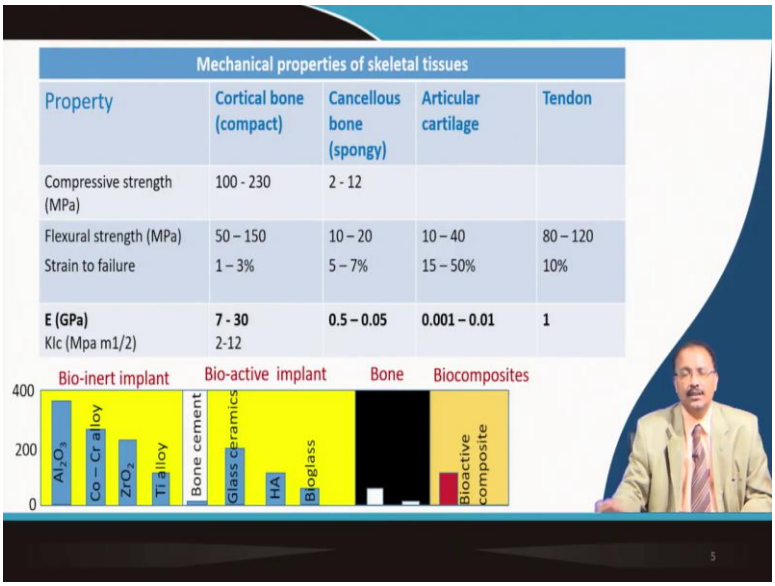

So, if you see the mechanical properties of this type of bone, you can see that you have four different components which I was talking about; one is a compact bone; then cancellous bone, which is spongy; then you have articular cartilage and tendon, so various types of muscle and ligaments.

And if you see the compressive strength here for these two types of bone, and flexural strength strain to failure, and elastic modulus, which is more important. So, you see the elastic modulus here is only in the range of 7 to 30; in case of cancellous bone it is 0.5 to 0.05; in case of cartilage it is lower than this; in case of tendon it is about 1. So, these are the body part.

Now, if you compare it with the bio inert implant or bioactive implant, this is the actual bone and bio composite. So, particularly for bio inert implant, this is very large.

So, if you want to replace this one with a bone part like cortical bone; then this is this elastic modulus is very large as compared to this one, this is also very large as compared to this one. So, that is a problem; that is a problem, because the E matching, here it is quite gradual. So, for different parts you see that, it is gradually changed; but the replacement is not that easy.

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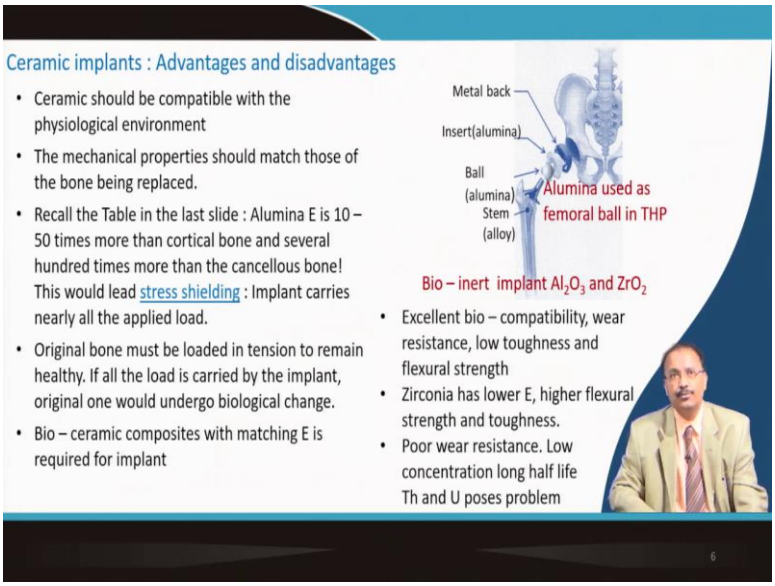

So, if you tabulate the advantages and disadvantage of a ceramic impact; first and foremost this ceramic should be compatible with the physiological environment in the body and the mechanical property should match those the bone being replaced.

So, in the last slide, alumina is having the elastic modulus about 10 to 50 times more than the cortical bone and several hundred times more than the cancellous spongy bone. So, this phenomena will in fact impart if a thing, which is called stress shielding. So, the stress shielding means, the impact itself, the sorry the implant itself will carry nearly all the applied load.

So, original bone they must be loaded in tension to become healthy. So, if all the loads are being carried by the implant, then the original bone will become weak and several biological change will take place in the original bone. So, one needs to have this bio ceramic composite with matching value of the elastic modulus and that is required for the implant. So, this stress shielding is one of the major disadvantage.

So, here is the typical example of a femoral ball, which is this alumina, this one; this is being replaced along with its insert and a metal back cover. So, if you compare alumina and zirconia, this two ceramic material; they have excellent bio compatibility, nice wear resistant, low toughness, and flexible strength that is a problem for alumina. Flexural strength as you know, and toughness for all ceramics the problem is there.

Zirconia has relatively lower value of E. So, this problem of stress shielding is not very prominent here. It has also higher flexural strength and toughness; but wear resistance is poor and sometimes from the raw material if it is not very pure, you have radioactive element.

So, the very low concentration, very long half life thorium and uranium that may be there in this kind of implant and it is there in your body. So, that may create long term problem and one should actually pay attention to that.

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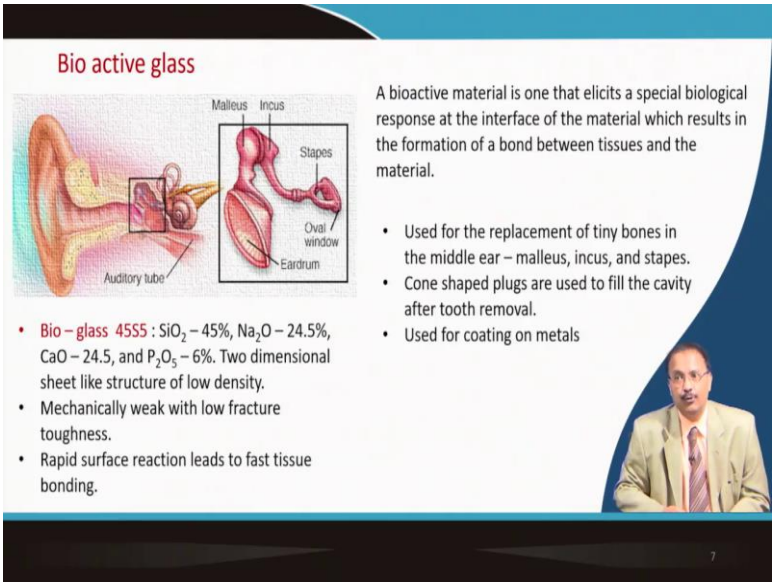

In case of bio glass, there is one composition which is universally accepted and this was invented in University of Florida. This bio glass is abbreviated as 45S5 and silica percentage as you can see is 45 percent and apart from that sodium oxide 24.5, calcium oxide is also 24.5 and potassium pentoxide is 6 percent.

So, it is having a two dimensional sheet like structure and having low density. They are mechanically very weak and having low fracture toughness. Rapid surface reaction is possible in this glass and that is why they are bioactive glass. And first tissue bonding can take place in this type of glass.

So, here it is a very basic structure of the mid ear and you can see there are three types of bones; one is this malleus, another one is incus, and third one is stapes. So, this bioactive material that has a special biological interface, which can result the formation of a bond

between the tissue and the material; this is unlike the other type of implant, which is otherwise bio inactive.

So, it has been used for the replacement of this tiny bones in the middle ear, that I mentioned either malleus or incus or stapes. So, it is in the form of a cone shaped plug that is used to fill the cavity after tooth removal.

So, there also it is used, very light weight and eventually the tissue can grow on top of it. And sometimes it is also used to coat the metal to have the both the property of this bioactive property as well as the inert property and the strong property of the metal; if you need both of them, then a coating form is a usual one.

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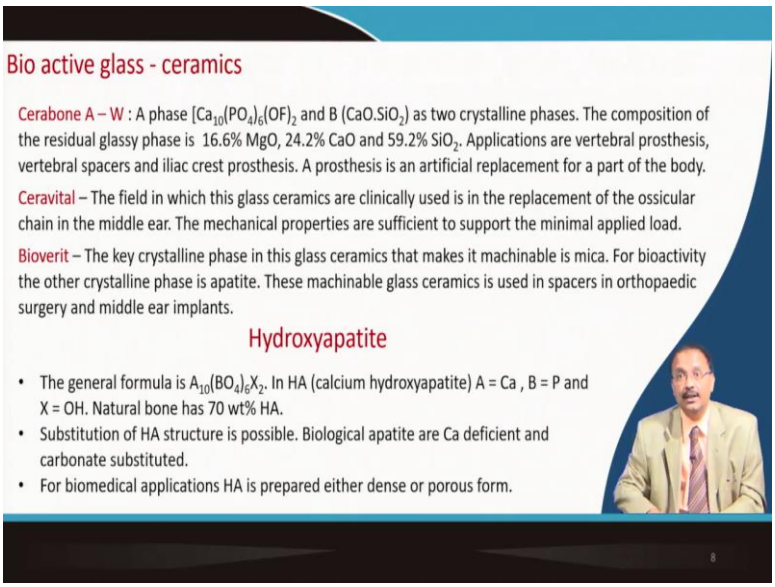

Bioactive glass ceramics is also there and there are three composition; the first one is cerabone A-W composition. So, this A phase is calcium phosphate base phase and B is calcium silicate base phase; they are two major crystalline phase, because this is a glass ceramic. The composition of the residual glass is having 16 percent around magnesium oxide, 24 percent of calcium oxide, and 59 percent of silicon dioxide

So, typical application is vertebral prosthesis, which is very common in case of slip disc, this spacer is important. And also iliac crest prosthesis this type of material is used. And as I said that, the prosthesis is an artificial replacement for a part of a body. Second type

is ceravital, the field in which the glass ceramics are clinically tested is there is the replacement of the ossicular chain in the middle ear. So, that already I described.

The mechanical property of this tiny glass pieces, they are sufficient to support the minimum applied load. So, mostly they are used in middle ear of human body. Third one is bioverit. The key crystalline phase in this glass ceramic that make it machinable with added advantage is mica. So, for bioactivity the other crystalline phase is apatite; these are machinable glass ceramics, that is basically used as a spacer in orthopaedic surgery and also this is used in middle ear implants.

The general formula of another bioactive material is the so called hydroxyapatite. The general formula is A 10 B O 4 6 and X 2. So, in case of hydroxyapatite, we call this is a calcium hydroxyapatite. So, A is calcium and B here is phosphorus and X is hydroxyl ions. So, the natural bone of the human body they are having about 70 weight percent of hydroxyapatite.

So, it is possible for you to replace, substitute hydroxyapatite; biological apatite are calcium deficient and carbonate substitute. So, calcium is replaced and also instead of phosphate, carbonate is substituted. So, this can be made either porous or dense depending on the type of use that you need.

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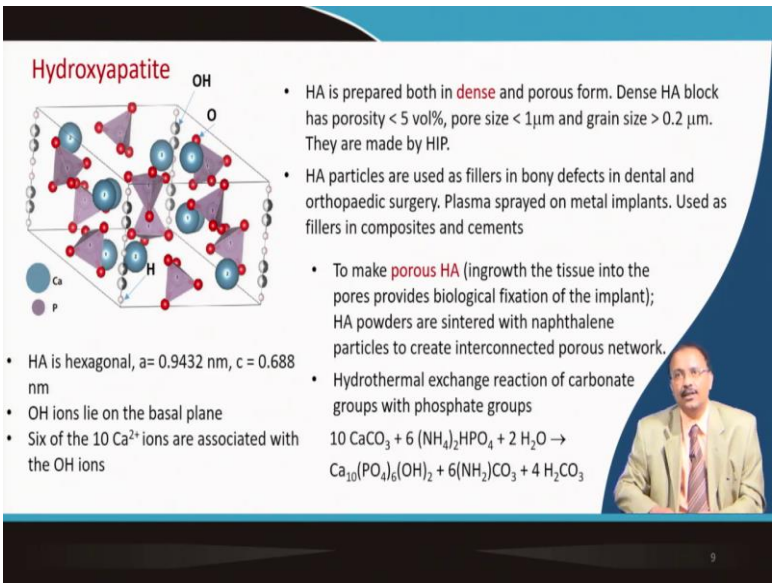

So, crystal structure wise, hydroxyapatite is a hexagonal crystal structure and as you can see this OH ion lies in the basal plane. So, these are the OH ions; these are the OH ions, they are lying in the basal plane. And 6 of the 10 calcium plus 2 ions are associated with OH ion. So, OH is this part and calcium is this big one. So, total there are 10. So, out of this 10, 6 are associated with the hydroxyl ions.

So, as I said this hydroxyapatite they can be prepared both in the dense form or porous form. So, usually dense hydroxyapatite block has porosity about 5 volume percent, pore size is less than 1 micron and grain size is about 200 nanometer. Usually they are made by hot isostatic pressing. So, this HA particles they are used as the fillers in the bony defects or in dental orthopaedic surgery; they are also use plasma spread on the metal implant and used as fillers in composites and bone cements.

So, to make it porous; because we want to make it porous, so that the tissue can grow into it. So, pores are provided with biological fixation of the implant. So, this HA is sintered with naphthalene particle to connect the interconnected pores; because naphthalene will burn out or sometimes the exchange reaction of carbonate group with phosphate group that is also possible.

So, this reaction is shown that, this basically replace exchange reaction the carbonate groups with phosphate groups to make the hydroxyapatite in a porous form.

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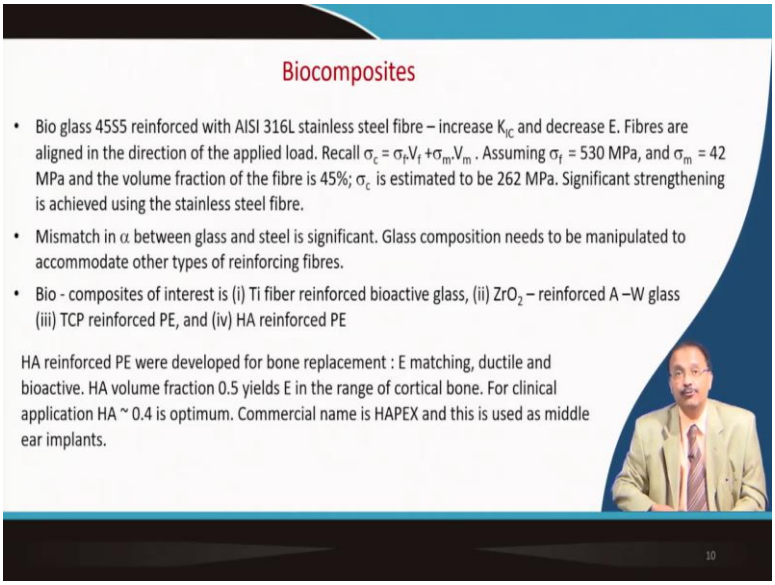

Bio glass is used in a composite and as I said that they are very fable. So, they need to be reinforced. So, usually stainless steel is a specific A1S1 316L stainless steel fibre is used to increase the fracture toughness and decrease the value of E. So, the fibres are usually aligned in the direction of the applied load.

So, that already I have shown that, if you have a longitudinal orientation of the fibre and applied a tensile load; then the elastic modulus and the most of the load will be carried by the reinforcing agent. So, the composite stress value that you can estimate from here. So, this estimated value is about 262 Mega Pascal. So, significant strengthening can be achieved starting from 42, it has increased to 262; of course the fibre is having much larger fracture stress.

Mismatch between these two is a problem. So, the glass composition needs to be manipulated to accommodate the other type of reinforcing fibre. So, titanium is one of them. So, titanium fibres is used to reinforce this bioactive glass; zirconium dioxide reinforced that A-W glass whichever I have talked about in the last slide; or TCP tricalcium phosphate reinforced P E polyethylene; and hydroxyapatite reinforced polyethylene, these are the composite bioactive composite that is used.

So, this eh a reinforced PE was originally developed for bone replacement. So, E matching ductile and bioreactive in its property; volume fraction of your hydroxyapatite should be important. So, if the volume fraction is about 0.5; then you will see that the value of E is in the range of the tough bone, cortical bone.

So, usually for clinical application, the hydroxyapatite is about 40 percent in volume fraction that is used and this is commercial and the commercial name is HAPEX. And this type of thing is used in middle layer implants, this type of biocomposite.

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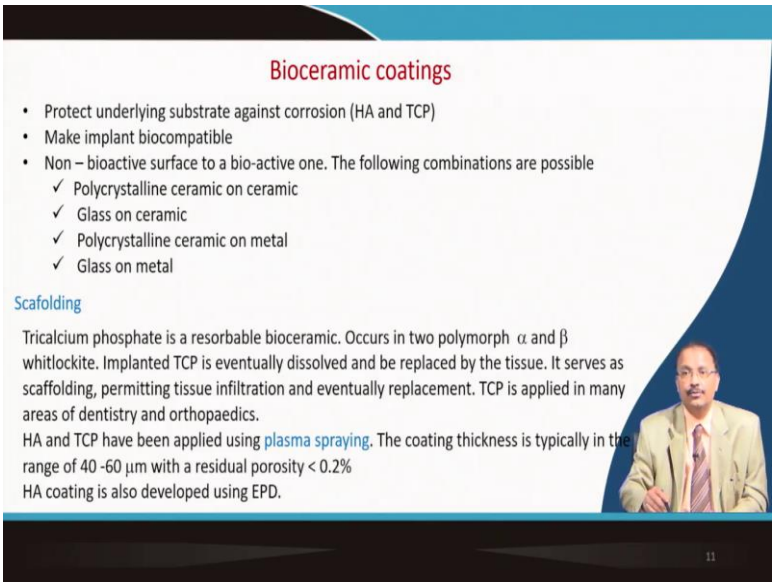

Apart from biocomposite, one can use bioceramic coating as well. So, this coating they basically protect the underlying substrate against corrosion. So, hydroxyapatite and tricalcium phosphate they are used; that basically makes the otherwise not biocompatible material, they can make it biocompatible.

So, non bioreactive surface to bioreactive one that is possible and various types of combination people have tried and still they are doing as a part of their research. So, polycrystalline ceramics to ceramic, that is one combination; glass 2 ceramic combination is also possible; polycrystalline ceramic on metal that can be used; glass on metal that also can be used to make this type of bio ceramic coatings.

Then scaffolding is important and usually tricalcium phosphate is a resorbable bio ceramics. And it occurs in two polymorph; one is alpha and beta whitlockite. Implant tricalcium phosphate is eventually dissolved and replaced by the tissue inside the body. So, it acts as a scaffolding, permitting the tissues to infiltrate and actually replace it.

So, TCP is mainly used in dentistry and orthopaedics to restore the broken bone or broken teeth. And this hydroxyapatite and TCP, they have been used by plasma spraying, which I describe in one of my earlier lectures the operation principle. The typically the thickness for this coating is in the range of 40 to 60 micron with a residuals porosity about less than 0.2 percent.

And this hydroxyapatite coating can also be developed by electrophoretic deposition, which I described in earlier slides.

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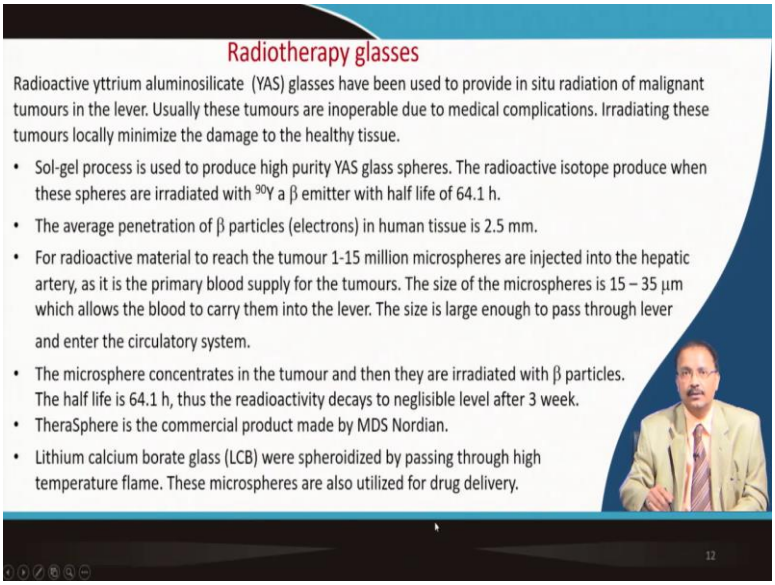

Radiotherapy glasses they are important; one particular example is radioactive yttrium aluminosilicate glasses. And they I have been used to provide the in situ radiation treatment to malignant tumour in liver. So, usually this type of tumour is inoperable. Lot of medical complication is there to operate this kind of tumour. So, you will have to irradiate locally this tumour to minimize the damage of the surrounding tissues.

So, sol gel process that is used to make very high purity atrium aluminium silicate glass sphere. And then radioactive isotope is given in this which, is irradiated by 90 yttrium which is a beta emitter and the half-life or 64.1 (Refer Time: 26:21) meter is not very long, it is about 64.1 hour.

So, the average penetration of this beta radiation in human tissue is about 2.5 millimetre. So, it is not very in depth penetration that is occurring. So, for radioactive material to reach the tumour, actually 1 to 15 millions of microspheres are injected into the hip hepatic artery; this is a primary blood supply for the tumours. And the size of this microsphere is usually from 15 to 35 micrometer, which allows the blood to carry them to the lever.

And the size is large enough that it will not pass through the lever and enter to the blood circulatory system. That is also important should not go everywhere in the body. So, this microsphere concentration in the tumour and is they are concentrated; because it is going through blood and then they are irradiated with beta particles. The half life as I said is about 64.1 hour; so the radioactive decay after 3 weeks it is negligible, the patient can go home.

So, TheraSphere is the commercial product made by a company which is MDS Nordian in US; they make this this kind of radiotherapy glasses. Lithium calcium borate glass usually that those are also used. So, they are spheroidized by passing through high temperature flame to make a perfect spherical and maintain the size, so that through the blood stream they can go.

So, this kind of microspheres they are also utilized for drug delivery.

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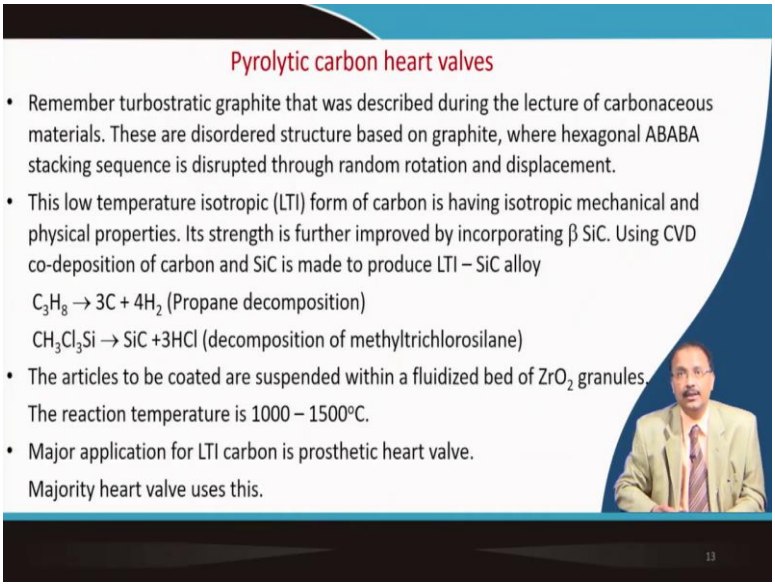

Another important thing is pyrolytic carbon heart valves; you remember when we will we were talking about the carbonaceous material, then the otherwise hexagonal graphitic layer, we talk something which are disordered structured material. So, that material is used, this is low temperature isotropic form of carbon, which is not as regular as the normal graphitic layer.

And the it is fable, it does not have very strong, it is not very strong; so it needs to be in improved by incorporating beta silica. So, CVD process is used. So, propane is first decomposed and then silicon carbide is prepared by the decomposition of methyltrichlorosilane.

And the article that to be coated are suspended in a fluidized bed of zirconia granule and reaction takes place with 1000 to 1500 degree Celsius. So, this LTI; this low temperature isotropic carbon, they are used mainly to make the prosthetic heart valve. And majority of the heart valve today, they use this LTI silicon carbide reinforced material.

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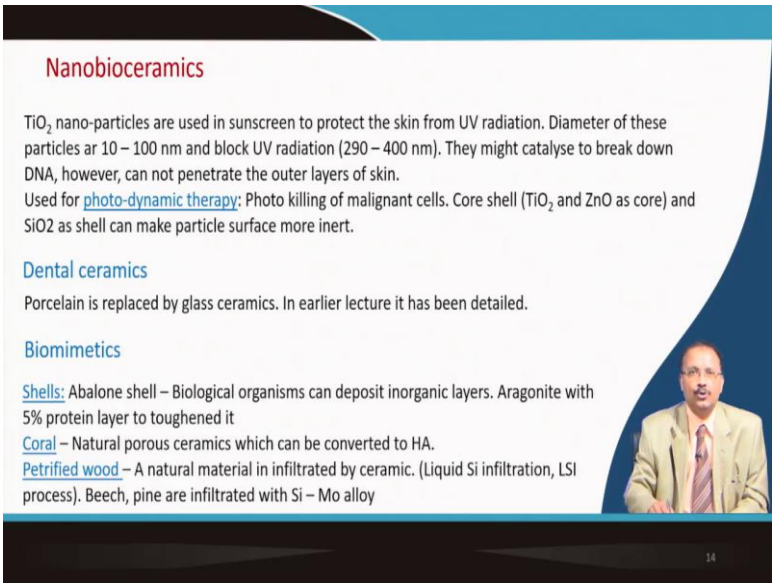

New field is coming up which is nanobioceramics; tridenia is one of them, which is being used for cosmetic purpose and this are good to block UV radiation. But there is a problem, it can catalyze to break down the DNA; but they cannot penetrate the other layer of the screen.

So, they are used for what we call photo dynamic therapy. So, this is a photo killing of the malignant cells at the surface of the skin; sometimes core shell structure of titanium oxide and zinc oxide they are core and shell is silicon dioxide. They can also be used for making the particle surface a bit more inert.

In dental ceramics, the glass ceramics that is used; I have separately covered it in one of my earlier lectures that, how this is exactly done. And biomimetics is another field which

is coming out quite rapid; you know the shell these are abalone shell, biological orgasm can be deposited on inorganic layer. So, aragonite is one of them, which is a flaky structure and 5 percent protein layer is there to toughen it.

Coral is another example; this is a natural porous ceramics, which can be eventually converted to hydroxyapatite. And there is another interesting thing that is called petrified wood. So, what is done, liquid silicon infiltration is done in the wood by beach or pine that is infiltrated by silicon and molybdenum alloy. So, that is giving this what we call petrified wood.

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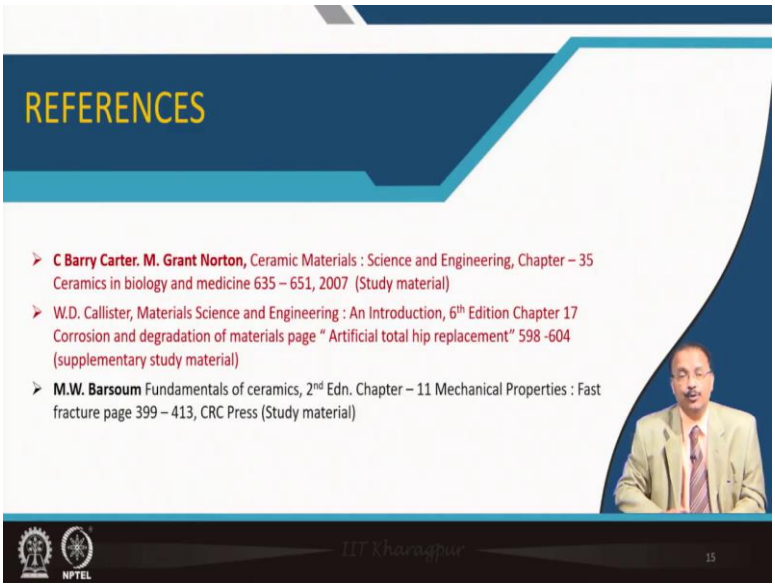

So, the study material is the book by Barry Carter and chapter number 35 ceramic in biology and medicine; apart from that you can consider the relevant chapter, chapter number 17 by the book by Callister and also the book by Barsoum.

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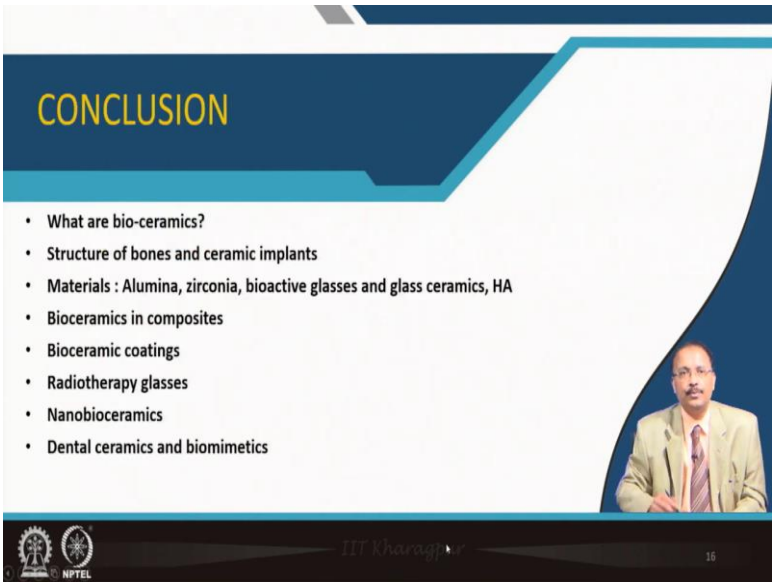

So, in this particular lecture, we talked about what about the bioceramics; then structure of bones and ceramic implants; then we talked about material, alumina, zirconia, bioreactive gases, glasses, bio ceramics, hydroxyapatite, bioceramics and composites. Then we talked about bioceramics coating; radiotherapy glasses to treat liver cancer; then small introduction of the nanobioceramics; and finally, dental ceramics and biomimetics were covered.

Thank you for your attention.