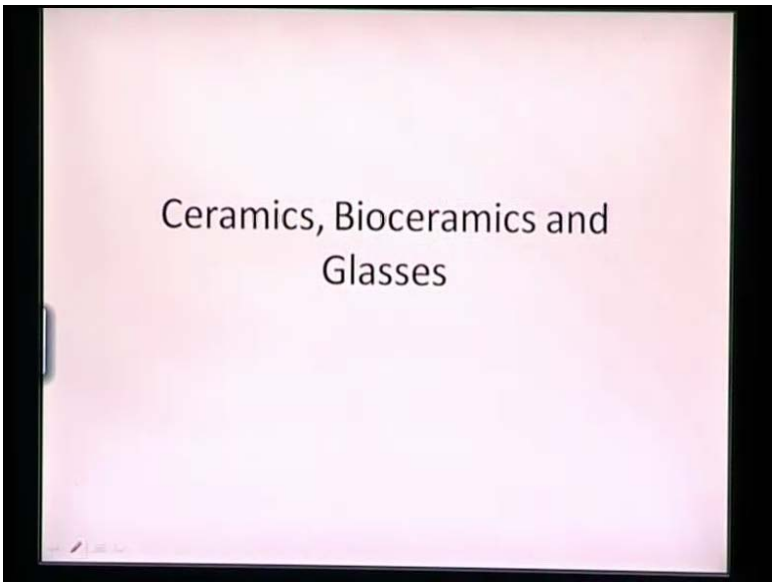
Introduction to Biomaterials
Prof. Bikramjit Basu
Prof. Kantesh Balani
Department of Materials and Metallurgical Engineering
Indian Institute of Technology, Kanpur

Lecture No. # 20
Ceramics, Bioceramics and Glasses

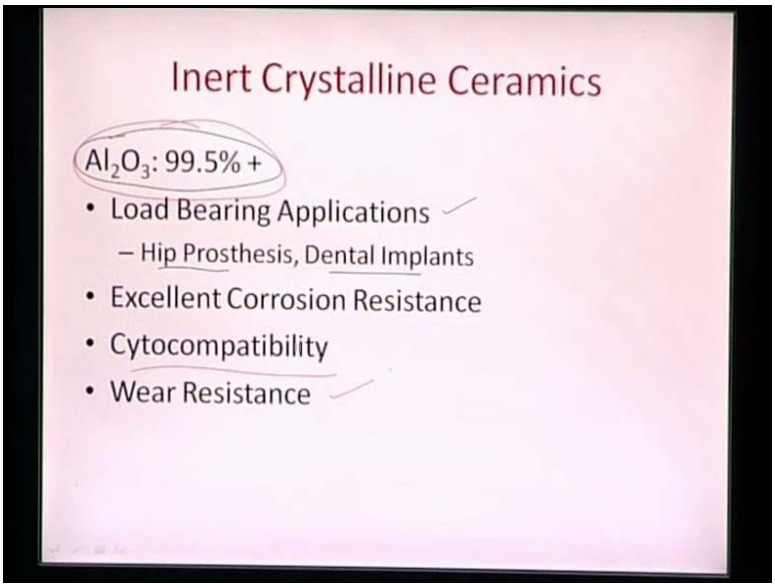
(Refer Slide Time: 00:20)



In this lecture we learn about ceramics, bioceramics and glasses. Earlier we had learnt about how what are the kind of processing techniques we can utilize, and this particular lecture we will realize how we can really tap into a material in terms of putting it for a particular biomedical application.

Once we know what kind of processing we are going to utilize, we can select a kind of material it can bioinert, it can be biocompatible, it can be ceramic, it can be anything else, so how we can really tap that material mostly ceramics and glasses in terms of its applications for a particular processing.

(Refer Slide Time: 00:50)



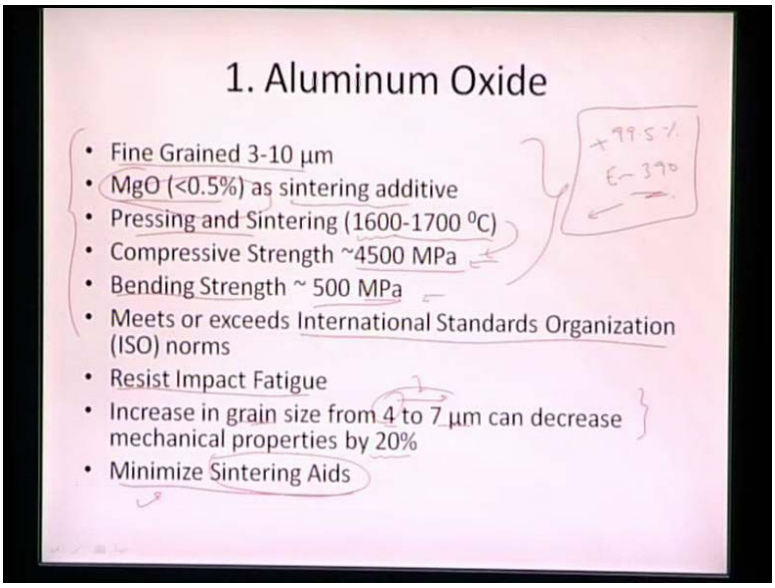
So, coming to the inert crystalline ceramic, so there are couples of variety of crystalline materials which are inert in nature, so in this particular case we can see that aluminum can be utilize, as a material for basically for the load bearing applications, such as Hip Prosthesis or Dental Implants.

Because it has it is highly inert in nature, and we can really seen that it can impart high corrosion resistance to any entity, once it is inserted into the body once it is highly pure more than 99.5 percent. It can serve as a load bearing implant basically for hip or dental implants, at the same time it does not induced any toxic effects.

So, in that particular manner it is also cytocompatible in nature. So, that is what we can see in terms of cyto compatibility that our aluminum oxide is highly cytocompatible. At the same time aluminum oxide as is being ceramic, it has highly wear resistance as well. So, we can see that alumina its hardness is 9 on the mole scale.

So, we can utilize ceramic aluminum oxide ceramic for a high wear resistant application. So, aluminum oxide is able to provide as high wear resistant, excellent cytocompatibility, and at the same time it has very high corrosion resistance. So, it can be utilized as the scoffer material for the load bearing applications, such as Hip processes or Dental implants and that particular manner.

(Refer Slide Time: 02:09)



But one more, they are certain conditions to it so, let us first talk about aluminum oxide the inert as inert material. So, aluminum oxide has to be very fine grade through 10 microns, because it comes from the fact that if we have a very course grade aluminum oxide, and as well as the two adjoining bodies they are basically going undergoing contact with one another.

So, once abrasion is occurring all the grains will starter removing off. So, grain size is very huge say more than 100 microns to that particular order, we will see the grains are coming off around the same order.

So, once the grains are very fine it can impact much superior wear resistance to aluminum oxide. I have to densified we had a magnesium oxide which is less than 0.5 percent as the sintering additive, and then sintering has to be done at very high temperatures, because melting point of aluminum oxide is to order of more than 2000 degree centigrade.

So, we need to do pressing and sintering at very height temperatures to the order of 1600 to 1700 degree centigrade, and the high destination also leads to very high compressive strength, which is to the order of 4.5 Giga Pascal's. Since, it is a ceramic it has the very good compression strength, but not that good of a tensile strength.

So, and generally this always implants they are under compression. So, generally this alumina oxide can show a very good compressive strength, being ceramic. It has a bending strength of around 500 Mega Pascal's, and these are the these are certain conditions which are imposed by the international standards organization. So, that once we have a particular aluminum oxide it should meet or exceed all those ISO standard or norms.

So, it also consists of some purity level. So, aluminum oxide has to be purer than 99.5 percent plus so, apart from that it should have a good compressive strength, it should have a good binding strength, it should also have a young's modulus to the order of 390 Giga Pascal's, and once it is meeting those standards international standards, then it can also resist impact fatigue.

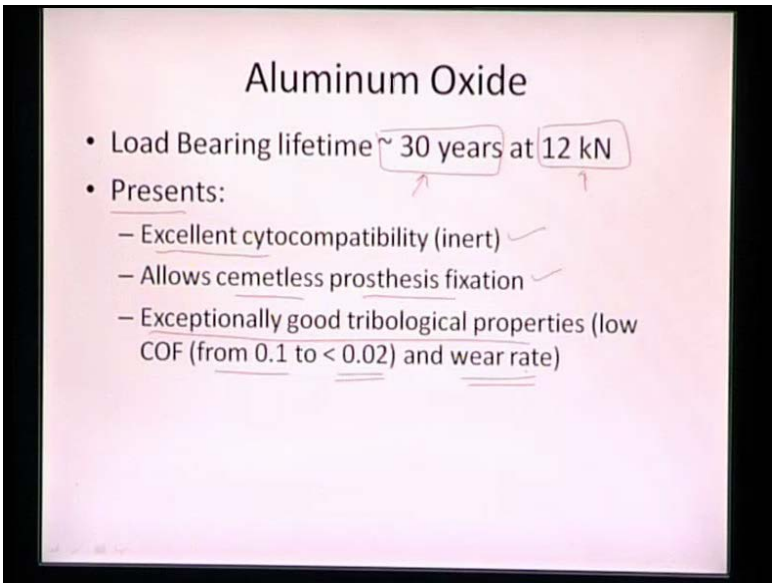
And one more thing what researches has seen it that, once we are increasing the grain size say from 4 to 7 microns. So, just increases form 4 microns to 7 micrometers, then it can decrease the mechanical properties by approximately 20 percent.

So, that is that is a deteriorating effect of increasing a grain size, even if you are going from say 4 micrometer grain size to say around 7 or 8 micrometer grain size, we are expecting a deterioration of mechanical properties by approximately 20 percent.

So, once the grains are much more course or they will also impact poor wear resistance to the aluminum oxide. So, that is the overall thing what we really can see, the same time we have to minimize the sintering aids we are adding magnesium oxide as the sintering additive. So, that we can achieve a sintering at much low temperature, and we need to minimize the sintering aid, because you also want to keep aluminum oxide as pure as possible.

So, that is the overallity that we want to keep minimize the sintering aid to the same time we should be able to achieve high mechanical properties, and also we want to maintain a lowest grain size that is possible around less than 2 or 3 to 4 microns. And then it should also have young's modulus, and some porous binding strength and compressive strength levels.

(Refer Slide Time: 05:24)



So, that is what overall idea about using the aluminum oxide, and it has been seeing that the load bearing life time can be as highest 30 years, at a load of around 12 Kilo Newton.

So, once we are designing an implant for a particular youngster like, once very, very young patients are basically they undergo bone fracture or something like that, we need to have we need to design aluminum oxide the felicity of it should be very, very highly critical, because if it face earlier the person will have to go, and we will have to undergo surgery for more than twice or thrice during their life time.

So, we need to see that the load bearing a life time is approximately 30 years, at a load of around 12 Kilo Newton, but at the same time we need to make it much more cytocompatible, while maintaining spermaceti between the two contacting surfaces to maintain the grade of aluminum oxide that it has to be pure, such and such mechanical strength in terms of its compression strength, fatigue strength also maintain its grain size

So, these are all certain extra additional features, which need to be incorporated in terms of designing aluminum oxide specifically in youngsters. So, that they do under to go undergo surgery for more than once during twice during their life time.

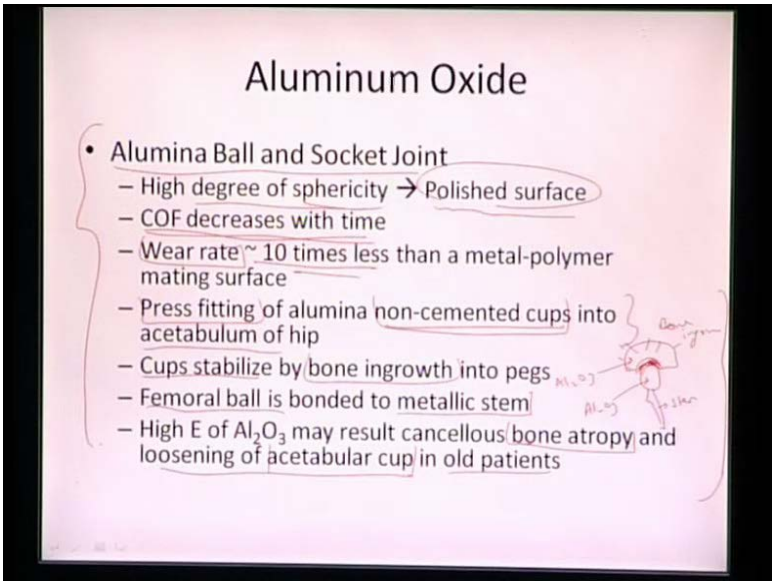
So, that presents that aluminum oxide it has a excellent cytocompatibility that makes it inert, it can also allow cement less processes fixation. So, that is once more advantage

with aluminum oxide at the same time it can also show exceptionally good tribological properties, and COF can go from 0.1 to less than 0.02.

So, if we have two contacting surfaces such as, of metal and polymer. That will tend to show much higher coefficient of friction, because polymer is very soft, metal is very strong. So, basically was they are among the contacting surfaces they tend to have very high coefficient of friction whereas, if you start using aluminum versus, aluminum contact surface. It can reduce the coefficient of friction at the same time its wear rate will also be get decreased.

So, that is the advantage of utilizing aluminum oxide, as the contacting surface both for ball as well as socket. So, once they are in contact with one another they will tend to a very low wear rate, and because they both are ceramics, and they tend to the similar chemistry, they will undergo very low wear rate. And it wills much coefficient of friction, will also be much lesser than that of a metal versus polymer contact.

(Refer Slide Time: 07:44)



So, that is the overall deal with enhanced wear resistance of aluminum oxide, and specifically for alumina ball and socket joint, it should also have a very high degree of sphericity.

So, it that can be provided by polishing the surface, because we already know that once we have very high porosity of very high surface roughness that will also tend to induce

much more a locking between the surfaces, the mating surfaces. And that can also induce very high coefficient of friction, and that will remove the smoothness which will come out at the surface level, because surface is the one which comes in contact first, and that decides what is the overall reaction or the kind of reactivity which is happening at the surface, and that will provide the smoothness with that at which the two meeting surface will interact.

So, once we have very poly surface we can get a very a high degree of sphericity, and because of that we can also have we can also expect reduced coefficient of friction with time, and wear rate can be 10 times less, as compared to the rate of a metal polymer mating surface. Because they will have very high coefficient of friction as well as one is polymer, one is metal.

So, metal will tend to each every the polymer it will start yielding the polymer, because the drastic difference between the their harnesses.

So, once we have alumina versus alumina surface, they will have a very low coefficient of friction, and that will also have very low wear rate which is approximately 10 times less than that of a metal polymer surface. And again we can also do press fitting of alumina on the non-cemented cup, so that is that what leads us to the cementless fixation of the particular implant. So, we can also achieve the non-cemented cups into the ace tabular of the hip, so we can get the particular joint of the acetabular cup with the ball. So, we can get it we can get that without any cement fixation. And again the cups they get stabilized with time by the bone in growth.

So, we have certain pegs into which this basically the bone will start growing and that will how that is how, it will secure the cup. So, we can see that we can have very nice way of an engineering this particular cup alumina cup that we have a cup, and all the pegs they are being inserted with bone in growth, and that is how the cup is basically stabilized to later on it has a press fitted kind of a spare on a ball, which takes care of the overall stability of the overall joint. And again and the femoral ball is basically bonded to metallic stem.

So, we have a particular ball and then we have femoral step which basically joints, and then we have ace tabular cup, and that thing is basically fixed with the bone in growth, and this is a stem, and over that ball is again made up of aluminum oxide AL2O3

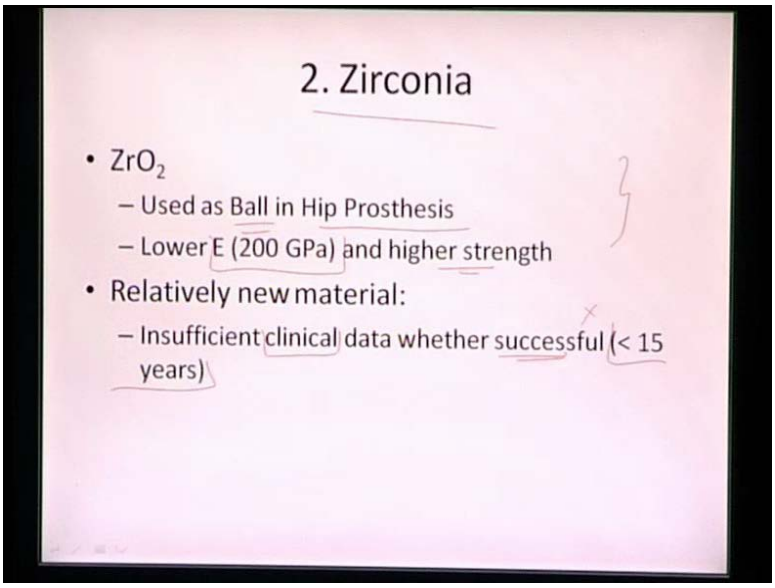
ceramic and this can also be AL2O3. So, in that manner we can achieve alumina versus alumina interface out here at this location, and that is that will provide a very low coefficient of friction, and it will have very low wear rate as well.

And again, there can be one problem with utilizing aluminum oxide is that it can result the bone atrophy, because ones the modulus is very high, and wear it is low, and then the nearby bone that nearby cancellous bone will start basically thinking that I am not needed, because the lode is being bond by aluminum oxide itself, so I am not needed. So, it might lead to cancellous bone atrophy ones we have aluminum oxide ceramic as well, and because it has very high young's modulus and binding strength and compression strength. So, the bone may start thinking I am not required here at all, because the load is totally being bond by aluminum oxide.

So, that is one problem which can lead to the bone atrophy, and it can there by lead to the loosening of the ace tabular cup, specifically in the old patients. So, that is one problem which we can face with aluminium oxide. So, that part needs to be counteracted with certain mechanism, but the overall philosophy using aluminum oxide is, because we can maintain very high sphericity.

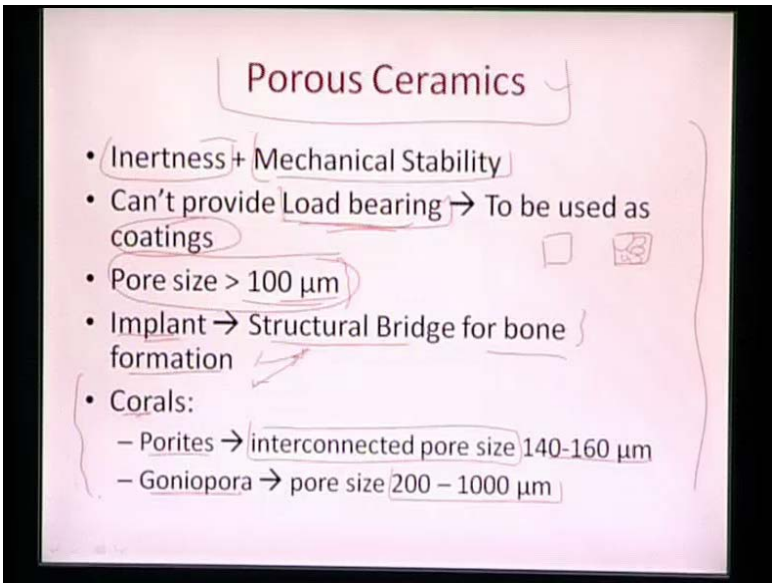
So, it can lead to very smooth surface, and ones it has a smooth surface, again it is a alumina to alumina contact that will reduce the coefficient of friction, and the where it will decrease approximately ten times as come to that of a metal polymer joint, but the only and the cup part get stabilize by the bone and growth along the cup area, and the ball is basically being bounded to the metallic stem part, femoral stem, and then the problem with aluminum oxide is it can lead to the bone atrophy the cancellous bone atrophy, and that might lead to loosening of the of the ace tabular cup specifically in the old patients. So, that might result with the utilization of aluminum oxide.

(Refer Slide Time: 12:15)



And second unit material is Zirconia. So, zirconia is also uses of ball in the hip prosthesis and advantages of zirconium is and it has a lower E value or the lower young's modules, but it is a it has a higher strength, and zirconia has been used very recently it is it has been very less time. So, there is not sufficient data clinically which is available to state whether zirconium is highly successful or not. So, because there have been less than 15 years of data which is available for zirconia. So, people do not really know about what will happen zirconium is being used, but it appears to be a very promising material to be used, as the ball in the hip process, because it has very high pressure toughness as compare to that of alumina, at the same time it has low modulus as the metal that of alumina. So, it can provide a better compatibility with bone and the only problem is it does not have sufficient data. So, that we can clinically see that is so and so. And then we should be able to start using them.

(Refer Slide Time: 13:18)



So, that is still missing in the research part and that has to be taken here, and second part apart from the inert materials second thing is porous ceramics, and we learnt about how porous ceramics can really assist the cells to basically get in and they can really anchor themselves to the porous at the porous region, and they can extend up to the around 100 microns as well into the implant material.

So, they basically allow inertness plus some mechanical stability, that is what they can be achieved from the porous ceramics, but at the, but ones the ceramic is getting porous and porous they cannot provide the load bearing, because if I have a solid material it can provide means certain load bearing part, but ones I have start having some porosity into the material then; obviously, the overall modulus or the overall strength of the material goes down drastically.

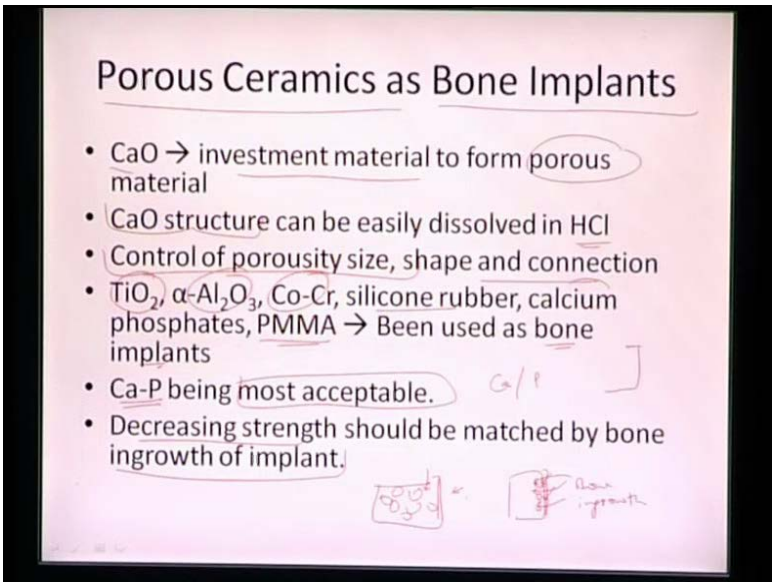
And if porous size is and porous size sometimes they are required in excess of 100 microns. So, those cells can really come and they can attach themselves or get in contact. So, basically implant it should have a structural bridge for the bone formation. So, basically the implant should have some structural bridges of the porosity to that bone can really grow and it can form out there. And that porosity can be induced in that manner that we have certain corals, and they are certain porites Goniopora, and they already have interconnected porosity which is the order of 140 to 160 microns or in Goniopora the pore size can be as highest 200 to 1000 micrometers. So, if we can somehow convert that

calcium carbonate the calcium carbonate part to hydroxyapatite via some hydration technique we can get hydroxyapatite which is totally porous.

So, that is how we can engineer that we can utilize certain corals which already have some porosity in them, and then we can somehow convert that calcium carbonate upon hydration to hydroxyapatite, in terms of tapping the advantage of that particular thing. So, we can see that we can porous ceramics are highly important, and they are well known for their inertness and they can also provide mechanical stabilities. So, cells can really grow into them, but the problem is; that means, they cannot provide load bearing capacity. So, they have to be used as coating that is keypad out here that once we have porous ceramic, we can utilize them for as coatings and the coating for the coating the pore size has to be approximately greater than 100 microns.

So, that cells can though they can extent, and they can get mechanical interlock and that can provide us structural bridge for the bone formation, because bone has for start throwing it should interconnected, and that can be attain either via creating certain porosity into the material or we can utilize certain corals which are calcium carbonate, and they already have interconnected porosity and we can convert that particular calcium carbonate via some hydration technique to hydroxyapatite to utilizes porous materials.

(Refer Slide Time: 16:08)



And porous ceramics they are highly potent bone implants, and first of all we can utilize calcium oxide that can form an investment material to form porous material. So, we can

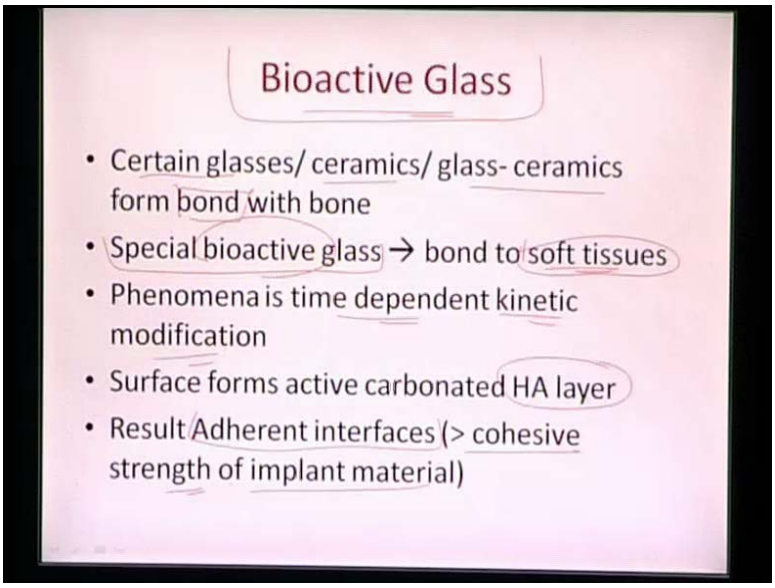
some calcium oxide phase, and that will serve as cap hold and then we can easily dissolve Co structure in HCl, and basically now we control the porosity size we can control the porosity shape. So, we can mix calcium oxide with some material another material another ceramic as a combination, and the size of calcium oxide will decide what is the kind of porosity, how well connected it is, what is the size of porosity, how the pores has been distributed? Those all things we can control with calcium oxide, and then calcium oxide can be dissolved via HCl or the hydrochloric acid, and now what is remaining is a oral structure which is highly porous.

And also certain other materials such as titanium oxide or alumina or cobalt chromium or silicone rubber or calcium phosphate or poly methyl acryl ate the certain materials, which have been use as the bone implant already, but among them calcium phosphate is being the most acceptable, because it has chemical it basically it is nothing but a structure of whatever bone has combination of calcium and phosphorous.

And again one more problem with the this problem material is that once we have some porosity that is basically reducing the strength and that decreasing strength should be matched by the bone and growth of the implant. So, once we have certain material which has certain porosity, and soon we will see that, because of the porosity there is much degradation or much more wear of the porous region. So, once this particular part is getting degraded we should also have that bone, which is basically get the implant material which is getting degraded that being that thing is being captured by or being replaced by bone ingrowths. So, once we have bone ingrowths happening at the region where we are seeing a detonation of the implant material that is basically balancing it.

So, we have porous material let us once it is highly porous, it is it has very low strength. So, it will undergo much more wear or much more degradation. So, as soon as it is getting degraded, the new cells which are forming they should start or replacing the damage material. So, that is how it can really balance? So, that overall strength can be provided by the new bone cells which are forming at that particular location, and that is how the overall porous material, how they can really benefit the formation of a new a or new bone or new bone cells out there.

(Refer Slide Time: 18:38)



And one more way of classifying the material is apart from we had the porous, porous materials we also have the inert materials, this another glass called bioactive glass. And these certain glasses or ceramics or glass ceramics various glasses of this bioactive glass, they can form bond with the bone, and this there are some special bioactive glasses which can even bond to soft issues.

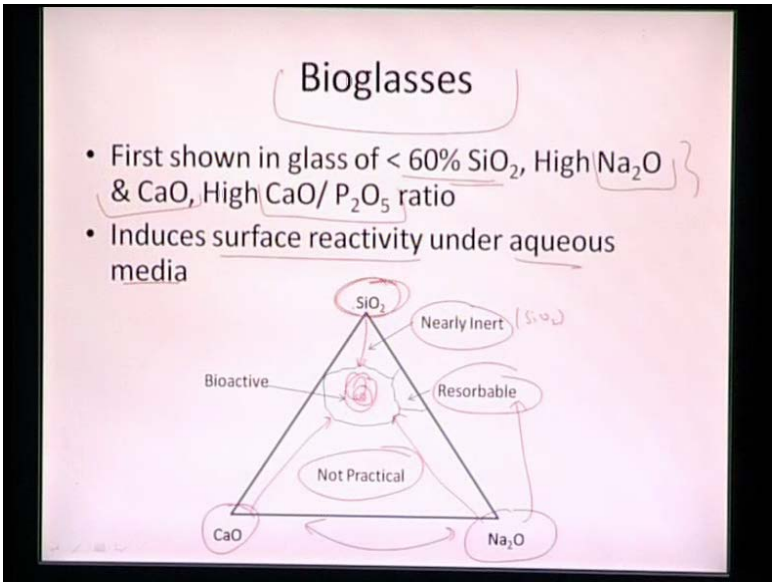
So, we have our heart tissues and we also have soft tissues. So, we can have even some bioactive glasses which are highly special. So, they can bond to even soft issues and again the phenomena is time dependent and also need certain kinetic modification of those particular material. So, that it can. So, that the surface can form carbonated hydroxyapatite layer which is highly compatible to the cells, which are bone cells which are growing and at the same time the result adherent interfaces.

And that once a surface cell in adherent, then its strength or the cohesive strength can increase at of a implant material. So, that is the overall strategy about it that we are have certain glasses ceramics or glass ceramics, they can basically bond to hard issues or soft issues, and again we can induce certain time dependent factors of how it is getting dissolved, and how new cell is taking place of it we can also modify the surface.

At the same time we can also induce some bonding between the material and the cells, and the bonding is, so strong that it is much higher the interface strength is much higher

than that of a implant material itself. So, that can basically allow the cells to keep remaining there, and they will keep bonded to the implant material.

(Refer Slide Time: 20:23)

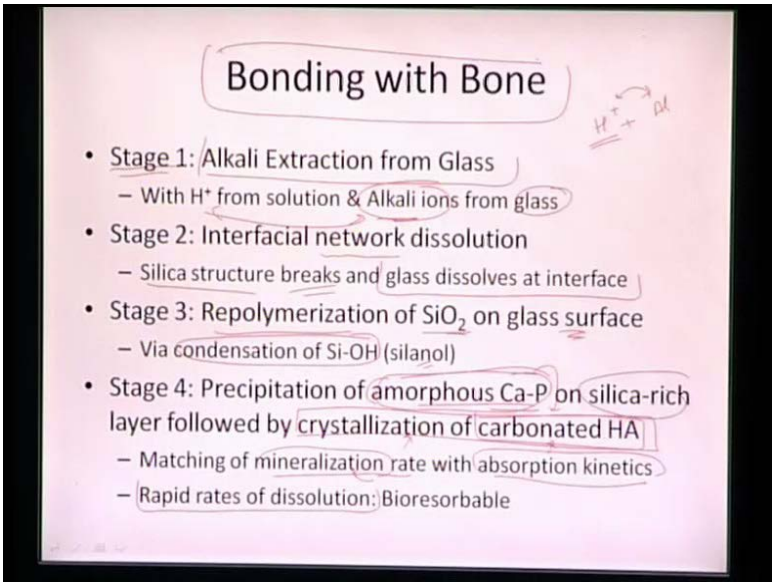


And this particular type of activity was first shown in Bioglasses, and that Bioglasses are combination of silica which is less than 60 percent, typically 55 percent is utilized, high sodium oxide and calcium oxide. The same to maintain high calcium oxide by P2O5 ratio and this particular material induces some surface reactivity, once it is put in aqueous media. So, that is what our picture is we take this material put it into the body, and once it is getting exposed to some liquid media or aqueous media it starts hydrating it, and that is how it will result some bonding with the bone. So, this is how the combination of silica, calcium oxide and sodium oxide is available, that we obtain certain region, certain combination of the silica, around 60 percent of silica and some combination of CaO and Na2O to result of bioactive region, and certain region which is higher in silica it is highly inert, because of formation of silicon oxide, and again certain content of Na2O can also make a resorbable.

So, we can have certain material which can get resorbable into the body. And that is what? We really look earlier as well, that the material which is resorbable in to the body, it should also be compatible, because if I have some toxic material and it is getting resorb it should also be compatible with the body. So, the part which are breaking of they should also have much more compatibility while the breaking of.

So, this is the over combination and this particular combination is not possible, calcium oxide versus Na2O. So, that is what, not practical purpose. So, we have silica certain combination of silica, so and some certain combination of calcium oxide and Na2O to result a bioactive region, and they can also achieve resorbable region we can also achieve a really inert region via particular combination of silica calcium oxide, P2O5 as such out here.

(Refer Slide Time: 22:18)



And there is one. So, apart from that we can the bonding of the bone can also happen certain stages like in stage one we have in the glasses we have alkali extraction from the glasses, once particular material is exposed to some solution. So, in this solution we will get we can generate some hydrogen irons, and that hydrogen irons can combine with alkali irons which are present in a glasses. So, we have some alkali irons, they can get come they can combine with the hydrogen that will lead to the alkali extraction from the glasses, because they will combine with hydrogen to form certain bonding with them. So, that is what will happen? In the first stage that alkali will start getting dissolve it will start forming basically combination with hydrogen ion, and that is how it will remove the alkali ions from the glass.

And second ones the alkali ions is basically removed, it will break the silica structure. So, we all the network we had which was present in the silica, because of the alkali ion that will start deteriorating the silica structure and it will break it. And basically the glass

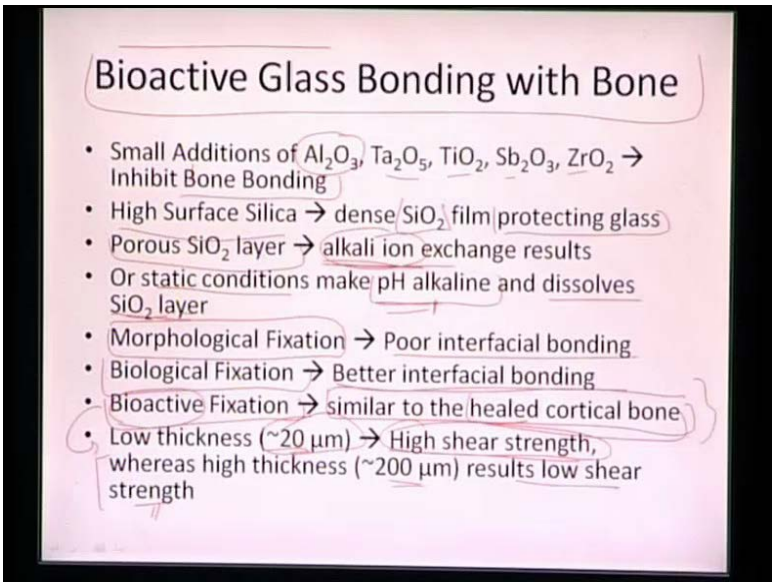
was start dissolving at the interface. So, ones we have solution, once we have a once we have glass, the glass, the alkali will start getting drive by the hydrogen ions, and once we have hydrogen ions it will start dissolving the glass, there is no more alkali ion that is deteriorating or breaking the silica structure. Once silica structure is broke up glass will start dissolving at the interface. So, that is the second stage, and in the third stage what we see that? Silica starts re-polymerizing on a glass surface and that occurs via the condensation of silicon or OH ion silicon SiOH ions that is nothing but silonal. So, again silicon starts getting polymerize on the glass surface, and from that we starts in precipitation of calcium phosphate on the silica-rich layer, and again with the presence of acquires medium we also see crystallization of carbonated hydroxyapatite.

So, that is what we are going to see? That of once the silica oxide is dissolved and gets re-polymerized by the via condensation. And then we see a generation of Ca-P amorphous layer on the silica rich layer, and that basically leads to the crystallization of calcium phosphate to form a carbonated hydroxyapatite. So, from amorphous Ca-P with come back to the carbonated HA, and again here also we need to basically match the mineralization rate. So, that it matches the absorption kinetics, because as soon as the absorption is occurring. So, that has to match with the how carbonated hydroxyapatite is forming.

So, absorption of this particular phase or the breaking up of the glass and that thing has to match with the mineralization of how carbonated hydroxide is forming on the surface, and basically what will happen? If we have rapid rate of dissolution of glass; obviously, we will have higher bio resorption.

So, over all process like this we are seeing detonation of glass on the surface, and that is being matched by the crystallization of hydroxyapatite on the surface carbonated hydroxyapatite. So, if you have desolation occurring at much rapid rate it will overall damages structure. So, the structure would not be able to sustain any load, and overall the integrity at the interface will also go back. So, we need to see that at the rate at which the glasses getting resolved, the same rate we are say we should have we should generate the kinetic thread hydroxyapatite, the carbonate hydroxyapatite should start getting precipitated on the silicon surface. So, that is how they should both should match and result bonding with the bones.

(Refer Slide Time: 26:08)



That is what we are able to see for the bioactive glasses. And again the bioactive nature of the glass it can bond with bond, but it has been absorbed that small additions of alumina even less than three percent or tantalum oxide, titanium oxide, antimony and zirconia they enabled bone bonding. Even small aditions of them they serve as, so strong oxides that it does not lead to the bone bonding, because there is no more silica available on the surface, and it does not lead to the bonding with the nearby tissues.

And again once we have very high surface silica, silica or any oxide will form a protecting glass film. Once we have something protecting on a surface, they basically are not compatible with the they do not want to form a bond with anything else. So, we are enough clear does not lead to any bond formations with the cells on a surface.

So, once what happens once you have porous silicon oxide layer that will lead to the alkali ion exchange. Once with the once the layer is enough porous silica that can form basically that can lead to alkali ion exchange with the solution which is present earlier, but again some static conditions they can make pH alkaline, and then that can be dissolved the silica layer, silica layer is a acidic nature. So, any alkaline layer will start basically dissolving it. So, it can happen the other way as well that once we can make pH more acidic it will lead to less resolution of silica oxide, SiO2. So, that is one more problem with that. So, we need to have some conditions which can make pH more alkaline and that will start dissolving the Si O 2 layer, and once Si O 2 layer is much

more porous we can lead to alkaline ion exchange and that is basically nothing but the degradation of the glass, and that will basically lead to the bonding with the bonding of the implant with the bone new bone.

And it can be either morphological fixation, or it can also be biological fixation, or it can also be bioactive fixation. So, once it is only morphological only surface related, we can have very poor interracial bonding. Biological fixation we can have better interfacial bonding, but once we have bioactive fixation it is similar to the healed cortical bone. So, the basically healing is much more assisted by the bioactive fixation, because morphological we only a kind of mechanical bonding, and biological fixation we have much more porosity which is attesting, but in bioactive fixation we also have cells of the surface which is getting degraded, at the same time it has very nice bonding with the newly growing cells.

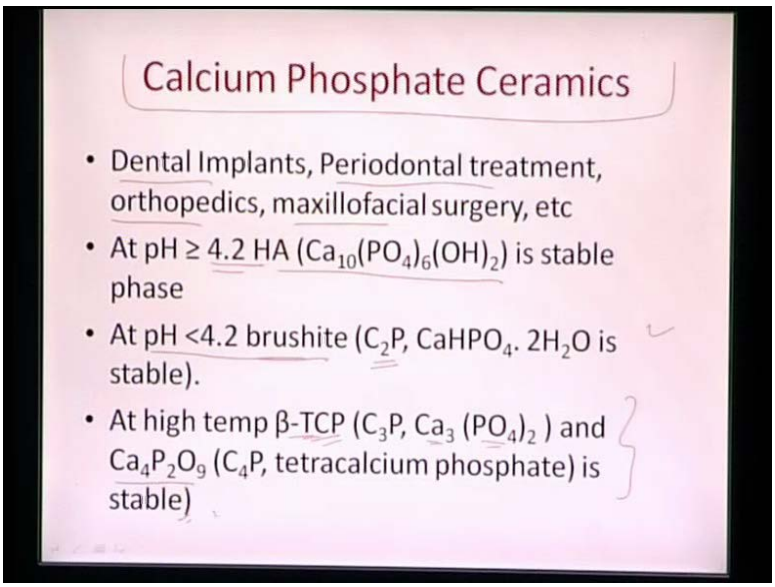
So, that is what is basically initiating the bioactive fixation. It will be very nice that, because we are getting kind of a structure which is similar that of a healed cortical bone. And again the thickness of this bioactive fixation, it is very, very low, because this low thickness can lead to high shear strength, but if we have very high thicknesses such as 2 [macro/micro] micrometers they can result very low shear strength.

So, in bioactive fixation we have very low thicknesses of the bonding level which forms. So, it can generate it can take very high shears, that is the advantage with the bioactive glass with a very less inter pressure thicknesses. So, we can see that we have small layers, or small additions of alumina tantalum oxide or zirconia they is tend to form very hig, very thick oxide layer and that basically inhibits the bone bonding, and once we have den silica, again it will also lead to the inhibition of any bone bonding, it because it has a protective layer on its surface. As though once a very thick layer it will it would not lead to any alkali exchange to for that we need to have certain porosity associate with it, or we also or it can also be where increasing the pH or having a alkaline pH.

So, that we can heat away the silica and it should lead certain porosity, and then we can achieve the alkaline exchange and that will basically break the glass. And now, the once we have broken the glass it is nothing but resorption and that thing will lead to bio active fixation and bioactive fixation we have kind of a balance between the material which is growing of and the balance with the and balancing with kind of new material which is

going on its surface. And since, it is getting degraded the cells find it very comfortable to get attached to the this bioglass, and then it can also it also forms a very thin layer inter layer which is around 20 microns, and it has a very high shear strength and that basically leads to very good bonding between the material, which is degraded that is the bioactive glass and then the bone part, the newly growing bone.

(Refer Slide Time: 30:58)

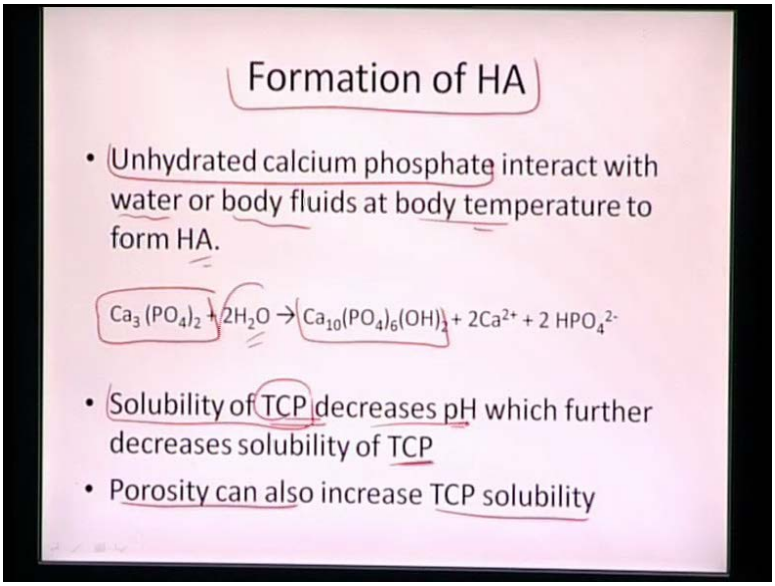


And the bio active part we also are something called the bioactive material we also calcium phosphate ceramics. And again calcium phosphate has been utilize in dental implants, periodontal treatments, orthopedics, maxillofacial surgeries and all that. Again at more than 4.2 pH, we see that hydroxyapatite which is Ca10PO4 whole 6OH twice is stable at less than 4.2, we have brushite; it is called C2P or CaHPO4, 2H2O is stable or at high temperature, we have beta tracalcium phosphate is called Ca3PO4 whole twice is much more stable.

And again at high temperature we also have tetracalcium phosphate, which is Ca4 P2 O9 which is stable at very high temperatures. We can see calcium phosphate has been utilized basically for dental implants or maxillofacial surgery or periodontal treatments, and it more than pH of 4.2 or more alkaline thing we have hydroxyapatite which is more stable. So, once we are able to create some static conditions where we can generate some alkaline pH regions, we will find that hydroxyapatite starts precipitating. So, for that we need to have pH of greater than 4.2, and, but at which lower than 4.2 we have brushite

this C2P or this particular structure is stable, but at high temperatures we have tricalcium phosphate and tetracalcium phosphate which are much more stable.

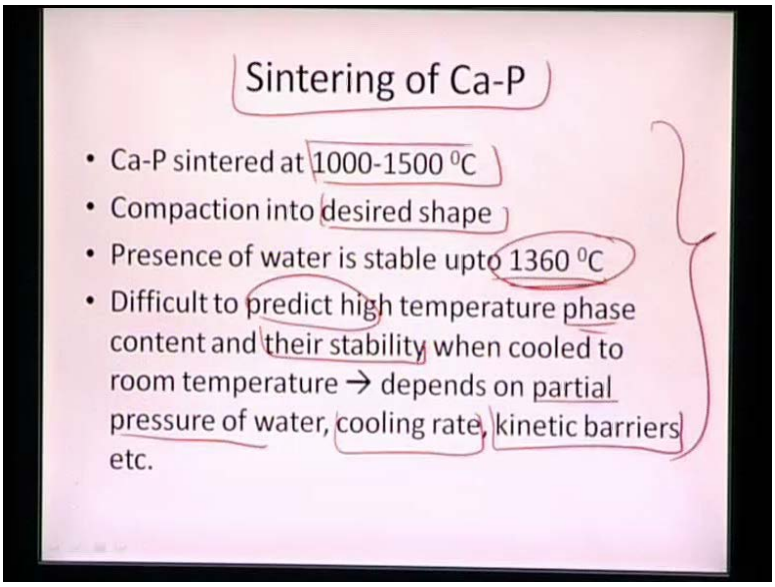
(Refer Slide Time: 32:31)



So, we can see that earlier, we see that we can also form hydroxyapatite. So, we can take even porous corals, and then we can basically try (( )) to form hydroxyapatite. So, we can see unhydrated calcium phosphate, it can interact with water or body fluid, even in body temperature to form hydroxyapatite, we can see some tricalcium phosphate is interacting with water, and it is hydrating into calcium phosphate plus some ions of Ca and HPO4 2 minus, and as we saw earlier that the solubility of tricalcium phosphate decreases with pH. And which can further decrease the solubility formation of TCP. So, we have certain getting generated.

So, once we decreasing the pH, it will start reducing the solubility of TCP. So, we want to make it much more much more alkaline. So, that we want if we want TCP to dissolve in the body we should make the we should generate the condition in which the nature is much more alkali, and that will lead to the more solubility of tricalcium phosphate. And also porosity can also increase the solubility of TCP, because there are no there are more number of interactions sites which can interact with TCP in terms of breaking it down.

(Refer Slide Time: 33:49)

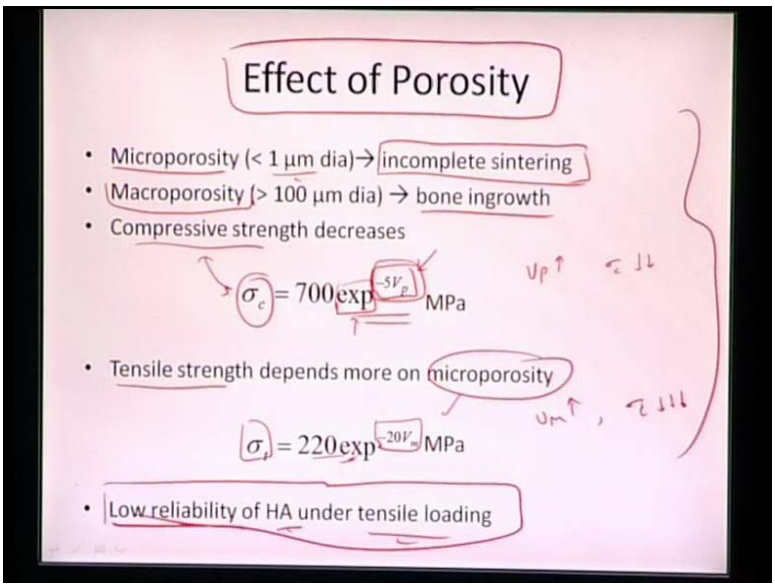


So, we have seen that tricalcium phosphate, it interacted with water to form hydroxyapatite and that is nothing but the dissolution or the solubility of TCP. And again to form a calcium phosphate we need to sinter it to very high temperatures approximately 1000 degree to 1500 degree centigrade.

And then they compacted into a desired shape. And again the water which is combining with it is stable up to even 1360 degrees centigrade. So, basically one more problem with the calcium phosphate is that is very difficult to predict the high temperature phase, and what will the content, because we have tricalcium phosphate with tetracalcium phosphate. So, we do not know what will the stability part as well, when they have been cooled the room temperature, and because it is also combining with water. So, it. So, the over all composition is overall phase which is forming at the room temperature after cooling it depends either the partial pressure of water, which is stable up to 1360. And again what is its partial pressure, what is the approximate cooling rate, and at the same time what is the kinetic barriers which are leading to the permission of hydroxyapatite? So, those are certain criteria which needs to be really realize. So, it becomes very difficult to predict what will be the overall phase when's the particular material cool to the room temperature, and because culture phosphate it phosphate it has some sintered 1000 degree to 1500 degree degree centigrade.

And once it has to be compacted, it has to be cool down, and again water is much more stable even up to 13 degrees centigrade. And to make the material we need to cool it down back to the room temperature and depending on its kinetics, depending on the cooling rate, depending on the partial pressure of water. It becomes highly difficult to predict what kind of phases will form and what will be the distribution finally.

(Refer Slide Time: 35:28)



And at the same time we can see the porosity also have drastic effects on the material properties, general micro porosity it has less than one micron, and those results from the incomplete sintering. So, that is the part we once we are sintering it we do not want any micro porosity. So, that will make the material very weak, but at the same time we are requiring macro porosity which is more than 100 micrometer in diameter why, because cells can really go and they can get interrupt, and they can anchor themselves to the implant material.

So, that will assist in terms of the bone growth. But once we have micro porosity it also reiterates the mechanical properties. So, we can see that the total porosity that is given by the Vp part. So, we have the total porosity of Vp that is basically degrading the compressive strength. So, what will be compressive strength we have that is getting degraded by the total porosity. So, it is degraded by the porosity because this term is negative. So, as increase as Vp increases, our sigma c will start decreasing to a large extend, because the dependency is exponential.

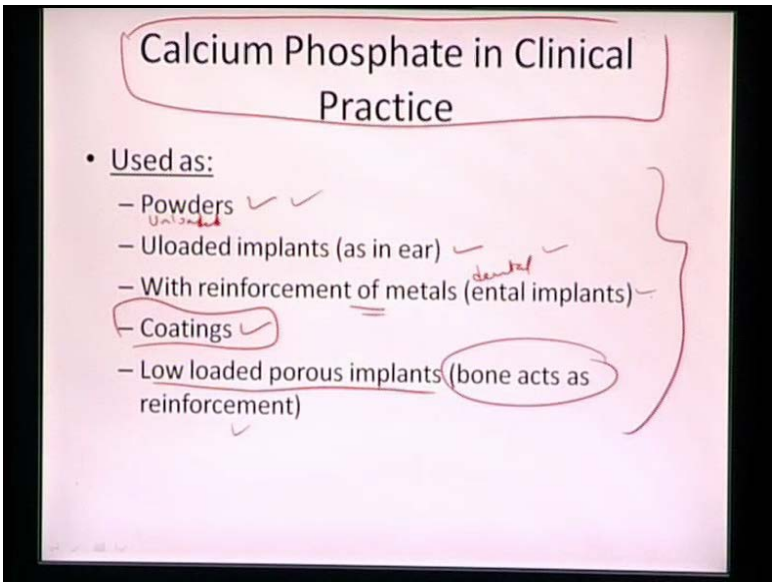
So, that is the overall deal with it that high porosity the compressive strength will decrease exponentially. So, that is the basic problem with it, but what once it comes to the tensile strength it depends more on the micro porosity, and a tensile strength will again decrease exponentially with as soon as the micro porosity starts U m is the micro porosity as it increases, our sigma t of the tensile strength will decrease very drastically, because all the micro porosity consists of a potential crack initialing site.

So, as soon as we have some tensile strength the propensity to form much more cracking is highly increased once we have micro porosity. So, that those are reasons which will serve as stress and intensity factors of increase in stress intensity factors and that can lead to track formation.

So, that will overall lead to the lower reliability of hydroxyapatite under the tensile loading. That is the problem with porosity part we want the porosity with the same time it is very damaging mechanically. So, biologically we want porosity, but mechanically it is not suited, because it will decrease the tensile strength or even the compressive strength. Compressive strength depends one of the total porosity when tensile strength more depends on the micro porosity, because that is much more potential site for forming new cracks.

So, we can. So, that eventually leads to the low reliability of hydroxypatite and under the tensile loading.

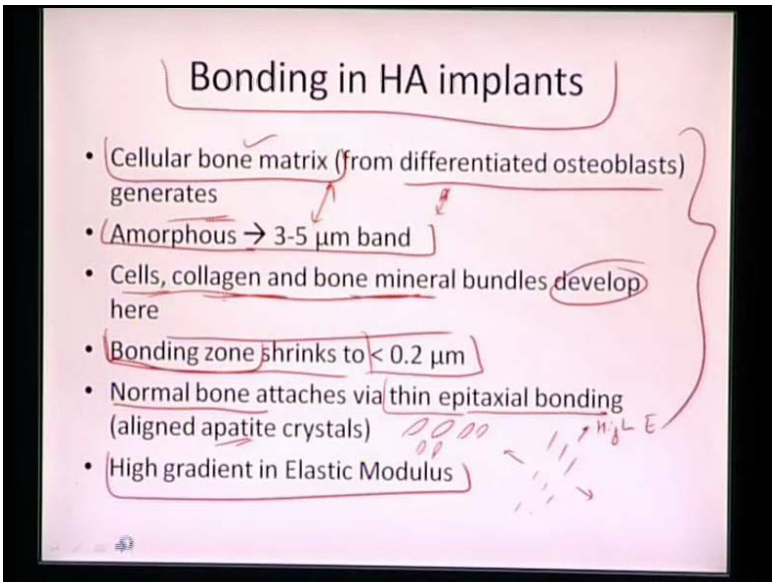
(Refer Slide Time: 37:55)



So, ideally calcium phosphate they when use in clinical practices, they can use as powders, or they can be utilize as unloaded implants that is unloaded implants as such as in ears, because they we do not require, any load or they can also be utilized with reinforcement of metals such as in dental implants. So, we have dental implants we have unloaded implants. And essentially they can also be used in the coatings because when's we have calcium phosphate we want to degrade we can apply them as coatings, because as soon as the new cells they are forming they will start taking place of the older material or the bioactive material, and that is how they will get resorb, calcium phosphate will get resorb.

And then it can serve as a very nice coatings, and they can also use as a low loaded porous implants. So, bone itself will act as reinforcement. So, that those are the several uses of the calcium phosphate that they can utilities either as powders, or unloaded implants, or with reinforcement with the metals, or coatings or loaded porous implants where the bone itself will act as a reinforcement of these particular materials.

(Refer Slide Time: 39:00)



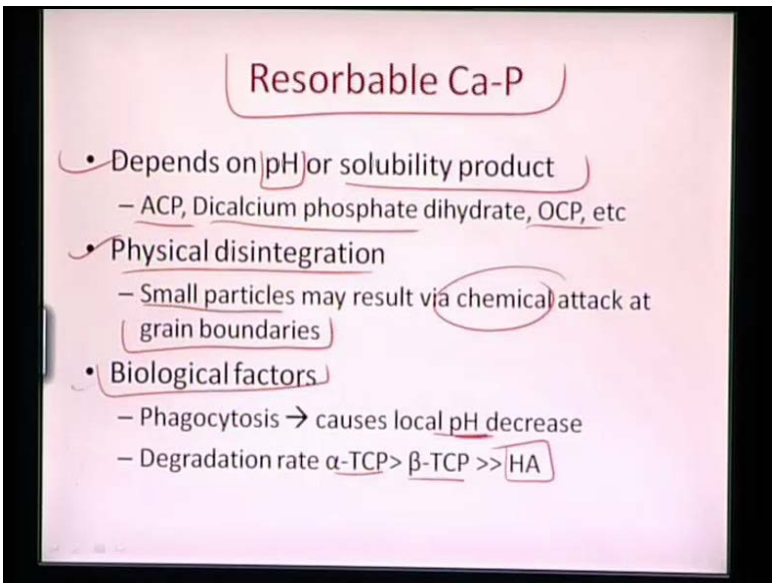
And again what happens in the bonding of with the hydroxyapatite plant is that cellular bone matrix its start generating and it generates where the differentiation of the osteoblast, and it forms amorphous between the cellular bone matrix and it has certain amorphous layer which generates. So, between amorphous and the bone implant region we have certain cells and collagens and bone minerals that start developing in this particular interface.

So, have certain region between amorphous and the bone cellular bone matrix so, that region starts developing some cells collagen and bone minerals. And then it starts shrinking the bone bonding. And this bonding zone shrinks down to the around 0.2 micro meter. So, we have all the cells collagen bone mineral they start developing, they start cooling those things together and that basically leads to the bonding zone shrinking to less than 0.2 micrometers, and normal bone will start then attaching itself via thin epitaxial bonding, and it will have some aligned hydroxyapatite or the apatite crystals which are nicely aligned in the natural bone.

And that alignment basically leads to the high gradient in the elastic modulus. So, in wind direction where we have all the apatite crystals align we get very high modulus, and that is the reason it will have very poor modulus as the perpendicular direction. So, overall we can see hydroxyapatite, we can see that cellular bone matrix will generate once the osteoblast starts differentiating it forms certain amorphous region, and in that

particular amorphous in this particular interface we have cells collagen and bone minerals they start to develop and, because of that it starts shrinking to less than 0.2 micro microns. And now, that brings the bone closer and it basically starts forming epitaxial bonding which are nothing but the aligned apatite crystals to lead to a very high elastic modulus.

(Refer Slide Time: 40:56)



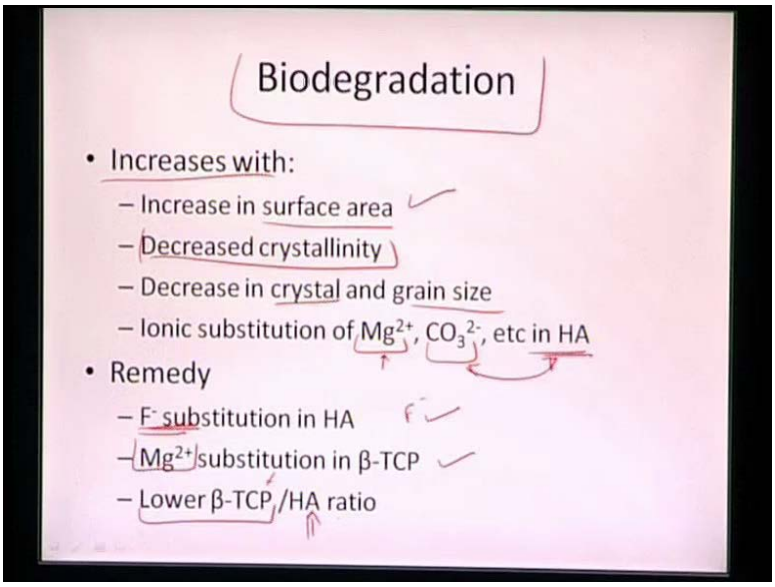
Again the resorbable calcium phosphate we saw that it depends on pH, as soon as pH is much higher. We start much more solubility starting much more solubility of calcium phosphate. So, it also depends on the pH or the solubility product, and it can also amorphous calcium phosphate, di-calcium phosphate, or even octacalcium phosphate. And it can also be a physical disintegration, because what happens is there are small particles they get attack chemically, and those particular chemical activity occurs more at the grain boundary. So, this small particles they basically results, because of chemical attack, and those particular particles they start going at the grain boundaries, or anywhere else and they start disintegrating the material physically, and there can also be some biological factors.

So, we have either dependence on the pH, or detonation from the (( )) particles, or the debris particles there can also be some biological factors. Such as phagocytes that causes a local decrease in the pH, and again also depends on the kind of material which is

present such as degradation of alpha TCP is much more than degradation of beta TCP which is even higher that of a hydroxyapatite.

So, the resorption of the bioactive calcium phosphate depends either on pH, or the solubility products which are present out there, and generation of particles in can also lead to the mechanical degradation of the calcium phosphate. They can also be some biological factors such as phagocytosis can also cause a local decrease in the pH, and that will basically reduce the solubility of tri-calcium phosphate or again in the same time if we have more of TCP, alpha TCP, beta TCP then they have much more degradation then that of a pure hydroxyapatite those are also certain concerns. And again this biodegradation it increases with increases in surface area, because more the surface area more there is interaction of this particular material with the surrounding environment.

(Refer Slide Time: 42:43)



And there is much more loss either in terms of corrosion, in terms of particles interaction, or in terms of even contact with the nearby flowing media, or it can also biodegradation can also increase, decreased crystalline, because once we have crystalline there are much more crystalline regions which can serve as a strong reinforcing regions. So, once we have lower crystalline that can also lead to the degradation of the material.

Again once we have decrease in the crystal and the grain size that can also lead to the biodegradation. And again once we have ionic substitution of magnesium 2 plus or CO3 plus etcetera in the hydroxyapatite that can also lead to the biodegradeation degradation. That is nothing but the breaking of the of the glass, and then but that part basically combines with hydroxyapatite and basically it starts increase increasing the degradation of hydroxyapatite. Because it can leach away the ions from hydroxyapatite and it can go away as something else.

So, what will we can do is we can stabilize OH in the hydroxyapatite via some fluoride substitution. Fluoride ion substitution it can also be induced in hydroxyapatite that will lead to the increase, decrease in the biodegradation. We can also allow magnesium 2 plus substitution in the beta-tricalcium phosphate for it is for remove for reducing it is biodegradation, or we can also have lower beta TCP ratio by HA ratio, because beta TCP has much higher degradation rate.

So, once we start increasing the hydroxyapatite content that will overall reduce the biodegradation to the certain concerns whether increase in the surface area, or ones we have ionic substitution of magnesium 2 plus, or CO3 2 minus in hydroxyapatite. There is nothing but taking the ions away from the hydroxyapatite. So, that leads to very high biodegradation also once we have lower crystallinity, we do not have enough well of crystal sites to lead to stabilize the particular structure. So, that we can avoid by inducing much more of f minus or np 2 plus, substitution in pcp or even having a hydroxyapatite ratio.

So, overall we can see that we have certain materials which can be highly inert which is aluminum oxide, or zirconium, or zirconia. So, aluminum oxide has shown to be very nice material, because that has very high wear resistance. So, fracture strength, compression strength at the same time it has very low wear resistance, very low wear of the material. So, in that particular manner aluminum oxide is very good.

Then comes to the overall material which can be highly active, or they can be highly porous and those, because of porosity it can also start reducing the mechanical properties. So, porous materials are generally utilizes coatings in the body implant material, and later on we also have some something call bioactive material, and they can start forming performing bond with the particular newly growing cells, and that happens

that we have particular combination of silica Na2 Na2O and either also CO. So, that overall combination leads to a very good bioactive material.

And that happens that we have breakage of the breakage of the alkali metals with the with the hydrogen ion, and then we have re repulsion of silica on that and then over that hydroxyapatite we have mineralization of hydroxyapatite and then that leads to the overall bonding, and that bonding is leads to a very fine film, and that has very shear strength, because it is approximated 20 microns. And that is how it leads to much stronger bonding with the bone then we also have resorbable calcium phosphate, and that depends directly on the pH or the overall chemical composition. In case we have tri-calcium phosphate that can dissolve at much faster extent.

So, we can also see how the pH? How the solubility or how the physical factors of the biological factors can induce the dissolution of this calcium phosphate and so, eventually we can choose the particular material which is to according to over needs in terms of having a very good property, it can bioactive it can be bio-resorbable property, it can be an inert property of inert material property. So, how we can design it? In terms of achieving implant materials, which is very high life, at the same time it can serve the purpose with enhance cyto-compatibility. Thank you.