Introduction to Biomaterials
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Module No. # 01
Lecture No. # 15
Important Biometallic Alloys

In this lecture, we will learn about Important Biometallic Alloys. As we see, there are two terms; bio, metallic which means that in realism a certain metallic alloys, which are biocompatible.

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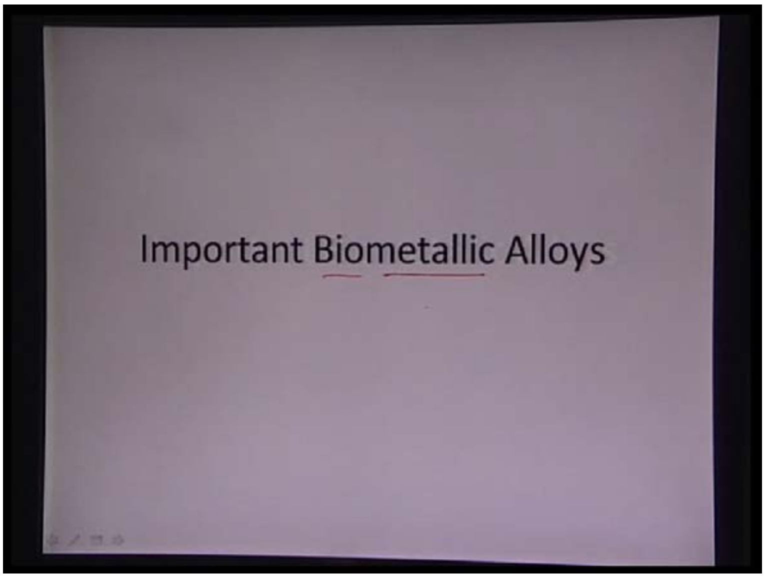

So, in this previous lecture we learn about certain important biometallic alloys, which are utilized for biomedical applications such as, hip implants and other things.

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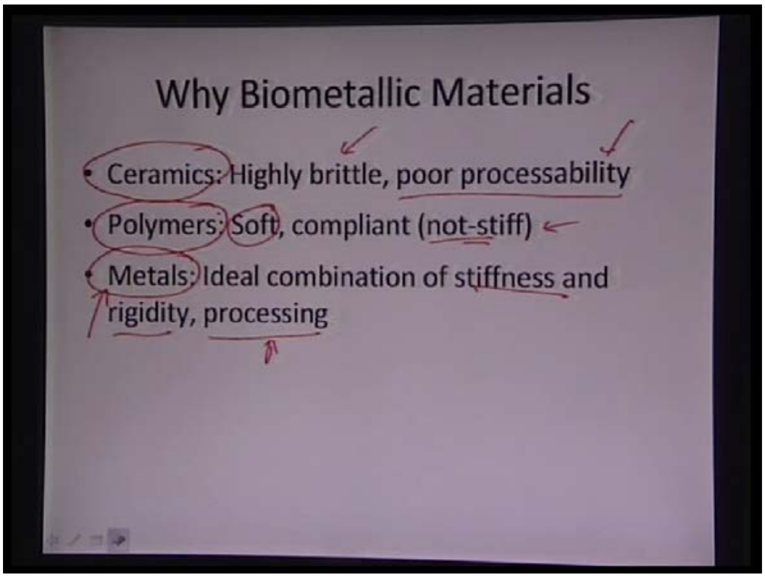

And why, biometallic materials coming to that, there are three classifications of materials, ceramics, polymers, and metals and ceramics they are known for the brittleness and their poor processability, because if you take a ceramic and I am just tend to drop it, it will basically break. And again going to the very high melting points; ceramics are very difficult to process and then coming to polymers; polymers are very soft, but they very highly compliant, so they may not be that stiff, they may not utilize, they may not be so good of kinetic material for providing us skeleton for particular implant. And then, metals they come out as a ideal combination of stiffness and the rigidity with eased processing.

So, overall we seen that, ceramics they are highly brittle though they can be used as skeleton material, but they are very brittle, so they require certain toughness to them and because of their higher melting point, they are also poor processable. And then polymers, they are extremely soft and they cannot really serve as a skeleton material, because of their lower stiffness. And again they have very poor wearing sense as well, but metals come out as winners, because they have ideal combination of stiffness and rigidity in the same time, they can be process very easily.

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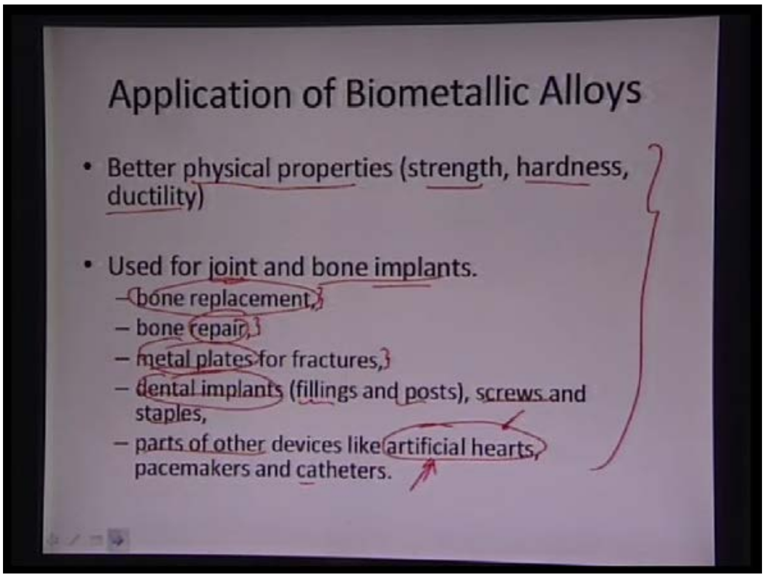

And the application of biometallic alloys, it the basically it is very vast. Why because, they have very good physical properties, very good strength, hardness and ductility, and they are widely used for the joint and bone implants and local use such as, bone replacements, bone repairs, metal plates for fracture like, once we have if we undergo any fracture, you need certain support, so that so that in the mean time, it can provide a supplement to the bone in terms of sharing the load and then, it can also allow the bone to heal with time.

So, that is the reason they also require sometimes metals plates and then, there are some dental implants, if they use fillings and posts, they can also be screws and staples in the for the dental implants and they can also form as a parts of other devices such as, in the pacemakers and catheters, they can use for for proper functioning of the heart, while while utilizing this artificial heart. So, artificial heart pacemakers, they utilize metallic biometallic implants to a larger extent.

So, we see that, the biometallic alloys they extend their application for bone replacements, bone repair in terms of supplying the metal plates for supplementing the bone surrounding it, dental implants and as secondary materials such as, a pacemakers and catheters.

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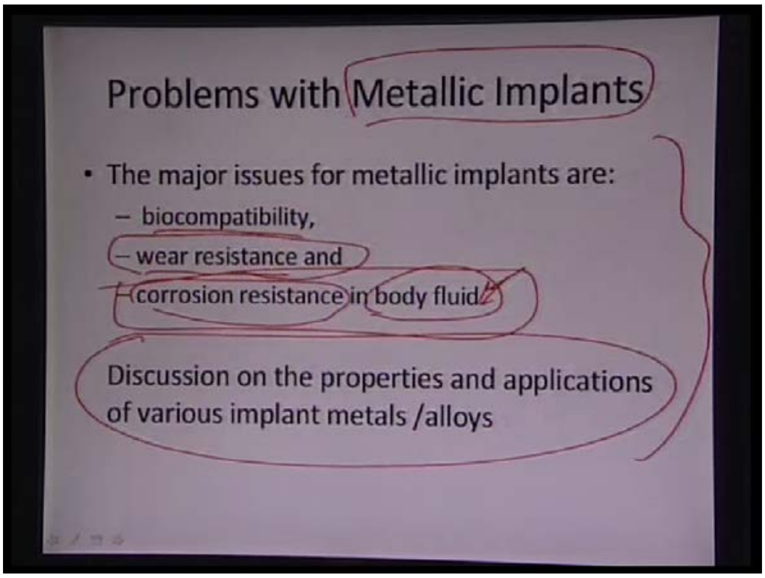

But, what is the problem with the metallic implants? The basic problem with the metallic implants is that, whether the biocompatible or not and secondly, since the metallic they can be very prone to resistance, they will very prone to wear. So, the resistance to wear is very very limited metallic materials, also metallic materials are also known for their higher corrosion; so, they have very poor corrosion resistance and again the body fluid environment is also very unhealthy, because it is very severe, it has very severe conditions with PH varying from very low to very high and then, it should be able to survive that particular PH as well, and with certain contaminants, which are flowing through the body it corrosion becomes very critical problem.

So, the oral problems in metallic materials are: its biocompatibility, its wear resistance and then, its corrosion resistance and we will discuss all these parameters with respect to the application of these implant materials. For overcoming the biocompatibility issue of biocytotoxicity, because if this metallic materials of the, if the the irons are released into the body, it can be very very irritant, it can be even toxic to the material to the body.

So, generally there are some coatings, which are applied on the metallic implants, those can be ceramic coatings with certain porosity; ceramic not only provides a biocompatibility, it also can render much more enhance wear a resistance to it and also much more corrosion resistance in the body fluided environment.

So, that is overall trend that, the implants are basically coated with certain ceramic materials and this particular metal implant will provide the overall structure, overall strength it will serves a overall scaffold, but the biocompatibility, the wear resistance part and the corrosion resistance part will come out basically from the ceramic. So, that is the over all problems with this metallic material and how it has been handle in the current scenario.

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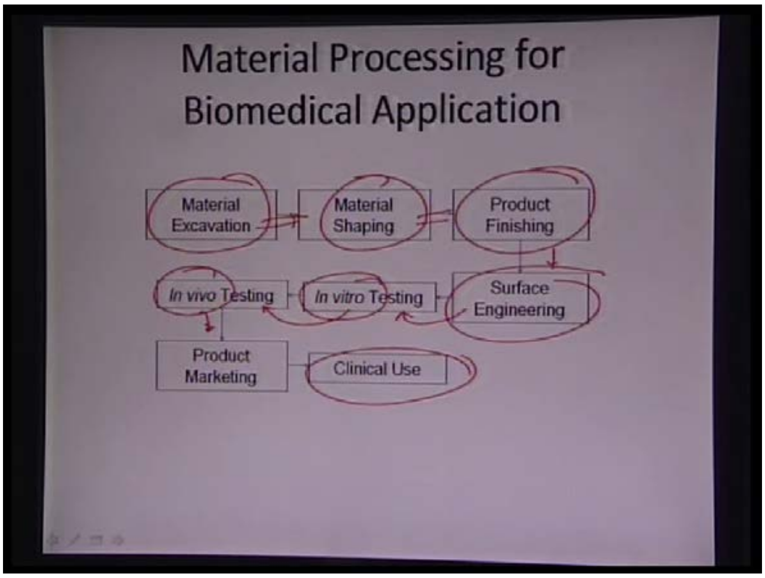

And the overall material processing is very very critical, because we to take accept the metal process it, achieves some something tangible and then, do certain biological testing to be able to use it as a biological implant.

So, the overall process flows like this, material excavation it go then, goes to material shaping to achieve tangible form then, the product finishing to finish it to certain scale and then, do some surface engineering, because we require certain surface treatments, nitriding or any biological coating and then, it has to be tested in vitro and then in vivo; in vitro means outside the body, in vivo means inside the body and then, it has to be marketed in and it has to be marketed after some clinical trails and then, it can be utilized as a biomedical insert. So, that is the overall ball game of utilizing a biocompatible biometallic material.

The first step is excavation, generally all all the metals are basically stored as in the form oxide, sulphides and all that as minerals and then, the minerals has to excavated from the earth and then, ore has to be separated; ore is more beneficial form of a mineral, that it has to beneficiated and so that, we can achieve that particular ore we will to refine it, extracted and then make it a useful material.

So, first of all we excavate the mineral from various resources, wherever they wherever they have deposits and the second step is the ore separation and its beneficiation and third thing, once you have achieve the ore basically we refine it to achieve a pure metal. So, we refine it, we do the extractions or the refinement in terms of achieving a pure metal from its ore and then, we optimize a composition, if you are able to achieve only iron then want to get something of iron with chromium and with nickel to get stainless steel, we need to alloyed with chromium and nickel and then, do the secondary processing.

So, this particular also involves some alloy additions. So, now we have a material of stainless steel, this can be utilized for shaping it or doing something else, later on. So, this is the overall process of excavation, we are able to get a pure material form and we are able to alloy it with the required composition. So, that we have a material available for any further use.

And then, second part comes is shaping and once we have obtained a particular material like, we have stainless steel now with us, we need to use we will use that particular form of material, it can be in the form of, it can be utilized by casting or forging or rolling, we need certain tangible shape of material; so it can also be in form of powder. So, we can achieve powder via atomization or we can also crush it to make a powder, we can also certain heat heat treatments and all these processing will lead out to material, one which can utilize for shaping it to a new net shape later on.

So, this particular processing the casting, forging, rolling will yield the material in terms of usable form or in some certain shape, this is billets, this is rods, powders, sheets etcetera. So, first of all, first process was to get a particular material, second process is get in certain usable form such as, billets, rods, powders, sheets or it can be anything else. So, this particular process, shaping utilizes such as, casting, rolling, forging or you may atomization or under going certain heat treatments to be give out some useful form of the material.

And now, what is we are attend this particular material, now we want to refine it further, you want to make it from a, there is actually repetition of powder metallurgy. So, I am sorry about that, but now once we have the material in some usual form, either in powder or in billet or maybe any rod or billet, something we have something visual form.

Now, we can start processing finishing it like in term via machining, we can have CAD CAM design, computer aided design and manufacturing we can again melted and then we can casted as investment casting or fluid powder, we can apply certain pressure and temperature to it, where powder metallurgy out of isostatic pressing via cold isostatic pressing hot compassion.

So, there are certain techniques, which we can utilize to again make it to a near usable shape. So, we have accepted the material, we have got an a particular form of alloy like in terms of stainless steel or it can also be titanium 6 aluminum 4 vanadium after alloying and then, take it to you some first step of getting certain shape out of it, it can be rod, it can be billet. Now, that particular rod or billet has to be finished to achieve a near to the actual usable form. So, we have to perform this finishing step, this is nothing which can be machining, which can be CAD CAM design and manufacturing to a near net shape product or it can also be investment casting and so on.

And saw once we have achieved the particular pre form, now we need to apply certain surface surface enhancement to it, because as I said earlier that, the biometallic materials they are very poor and corrosion, they have very poor wear resistance, they can also be more toxic to the material, if their irons are released. So, there are certain whether the biocompatible or not, that itself can be questioned.

So, we had to grit blasting perform certain surface engineering or surface frequents to it. So, first it can be to enhance the surface area of a particular bio implant and then we can also coated with certain ceramics like, an implant can be coated with hydroxyapatite to give it certain biological biological compatibility. So, we have something called hydroxyapatite, which can be coated on to a biomaterial implants such as, titanium 6 aluminum 4 vanadium or it can also be stainless steel and we will see some part of it like, how what is the stainless steel, how it a good compatible material, but again the coating can also be for hardenings we can do nitriding, carbiding, anything else.

And then we also need sometimes we also need porosity, why because we sometimes it might happen that, we need cells to grow and anchor themselves with the particular implant. So, if the material if the surface is very smooth with no porosity, if it is very dense then, cells may not find enough space to go anchor them. So, apart from biocompatibility, the porosity can also be very important criteria.

The same time the implant has to survive certain wear, because once we are walking you walk millions and millions of steps in throughout of our lifetime and then the particular material has to survive that particular load as well as certain wear because, always the bodies are in respect to each other the surfaces are again interacting with one another. So, the surface has to also be to it has surface also has to be wear resistance and so these are certain criteria out here also it can be it has to be corrosion resistant.

So, biologically compatible should be hard, should be porous, and should be tough. So, these are certain criteria are which really come out from this particular aspect that, the surfacing provides all these properties. So, that the surface properties are enhance to a very large extent. So, for biological compatibility we are coated we can coated with ceramic material, hardening can be hardening toughing can be given with certain secondary agents, which can be alumina, which can be hydroxyapatite, which can be zirconium and then we can we also made to make the the surface little porous. So, cells can anchor to it and also it can also be much it can also be provided with the corrosion resistant coating as well. So, these are the stem which are involve in surfacing to provide much more surface enhanced activity or surface enhanced property to a biometallic material.

Now, comes the quality control that, first of all we have to clean the surface. So, that it is free from any contaminants, then do particular inspection and do quality control to make sure that, the things are within the specifications and if it is a new material then, we also need to do biological testing in vitro; it means outside the body environment then, again in vivo using some, where sacrificing certain animals.

So, this biological testing has to be done in vivo in vitro, in vivo and then it can be marketed and it also trial clinically on patients. So, these are certain aspects to the certain aspects to taking the product to the particular market and being able to use it. So, certain certain things which are required here are cleaning inspection, quality control and cytocompatability, both outside the body and then in the body, in the body it can be it can be done directly on humans.

So, first of all the first assign is then on animals either it is rats or rabbits, once it is verified then it can go into the market and it can tried clinically as well. So, this is the overall processing cycle of a metallic implant material and then, we saw that the material excavation, it is one of critical features to see where the deposits are, it has to be particularly excavated, it has to be beneficiated, it has to be refined, so that material can be obtained and then it can again alloy to achieve a usable material.

So, we can have a usable material with certain alloy alloys additions to it and then, it goes for material shaping to achieve material in the more usable forms billets, rods and all that and then, this is the first step of product finishing via certain say machining or maybe say, CAD CAM something like that and then, we do some surface engineering, so that we achieve biocompatible bio biometallic material with enhance say, corrosion resistance, enhance biocompatibility, enhance wear resistance and so on.

And these things are very critical because, they decide the life time of a particular implant. So, these things are very very critical that, we have well engineered surface. So, that it can it can it can provide enhance life time of the implant at the same time, which not induced certain toxic effects, which should not be more which should not be wear out so quickly and it should be able to so the purpose of the surgery is not required again and again and that particular implant serves for a little longer life time may be, say of couple more than 40, 50, 60 years. So, that is the overall theme of doing the surface engineering.

And once it has been engineered in vitro testing is required outside the body environment and simulated body fluid then, it in vivo testing within the body of say an animal then, probably marketing it and then trying it clinically, this is the overall cycle of the metallic implant and now it has come with particular usage with all the functional, functional l d for clinical use.

Now, coming to the different biometallic materials we have stainless steel, cobalt chromium, titanium alloys and many others. So, these are three basic alloys, which are used very widely. So, we see that stainless steel, it has very high strength, it is highly economic and it is easy in terms of processing. Steel is one of very common materials and once we alloyed with chromium, nickel it becomes highly usable and it is also very economically available. So, it does not pose much problem in terms of its processing.

So, these are the overall advantages that also have very high strength, but it has also certain disadvantages: it has a poor corrosion resistance, also it has very high modules. So, how do we overcome that, because we do not require very high modulus, why because once a bone is being assisted with something, which is a very high modules then, bone will start thinking oh I do not to I do not have to work it will start desorbing back into the body because, all the load has been taken by the implant and not by the bone.

So, bone will think oh I am insignificant, I do not need to work at all and that bone will basically dissolve. So, we need a support material which will have modules similar to that of a bone. So, that is the disadvantage out here. So, the first disadvantage of poor corrosion resistance is being negated in in cobalt chromium alloys that, it has high strength, but at the same time it is very high corrosion resistance, but again they are also facing the same problem that, they have a very high modules and since this is a very specialty alloy cobalt chromium and both of them are very costly, so that brings the cost part very high.

So, that is the disadvantage that it has very high modules and at the same time it is very very costly. So, we saw that stainless steel, it is good in terms of strength, it is economic, it has easy processing, but it has poor corrosion resistance and very high modules. So, it has been negated by cobalt chromium which is a better corrosion resistance, but it becomes highly costly and while it its modules remains very high.

So, now titanium alloys come and then, they have high resistance, high strength, and high corrosion resistance and they they have low modules. So, again the negative part has been also already undertaken out here, but now titanium alloys they show poor wear resistance, so that is the overall cycle, but either the implant material has it has very poor corrosion resistance or either they have very high modules and once they have very low modules, the problem becomes in terms of handling the wear property of those alloys.

So, this is a very visual cycle that something or else is lacking in the particular material, biometallic material. So, always they require a combination of certain materials and one single material cannot; it cannot take responsibility of all the functionality, which is which is expected out of it. So, that is that makes this biometallic materials very complex in terms of handling it and again the release of metal ion, metal ion it can in use reaction with the body, it can cause irritation in in the body, it can even be toxic when released in the body. So, all these aspects also have to be considered while designing a biometallic material. So, we see that, there are certain materials stainless steel, cobalt chromium, titanium alloys, which can under takes certain responsibility, but at the same time they they also has certain disadvantages either in terms of poor corrosion resistance or in terms of having maybe, say a very high modules or may be having very high wear rate. So, these are all things which need to be balance that, they should have a very very high corrosion resistance; they should have low modules at the same time very low wear resistance, while maintaining high strength mechanical properties and so on.

And also they are released into the body also has to be restricted. So, they are certain parts to it, that that needs to be optimized while designing this particular biometallic materials and this particular case, in this (( )) lecture will concentrate more on the stainless steel and as we we see about them as we go along; there is an another materials as well like like tantalum and tantalum is highly resistant to chemical attack and it shows very very low adversity in terms of biological response, so it is highly cytocompatible and prepare over made porous tantalum sponge kind of material and since it is highly porous, it alloys cells to grow inside and anchor itself, so that basically yields that, tantalum is very good biocompatible material and it can also be very light. So, it can be used since it is a strong material, it can be very light and then it can allow very easy movement of a particular length or any bone bone part.

And again metals have been coated with tantalum and tantalum itself will not degrade and when it is exposed to a body fluid media. So, this tells that tantalum is one of the very stable materials in the bio in the biometallic alloy state and then, it has been very widely used in the clinical applications. So, we see that tantalum is highly resistance to chemical attack. So, it has a very good corrosions resistance, it shows very adverse very little adverse biological response it means it is biological stable, it is not getting affected by the body environment, the same that is not degrading in the body fluid media; it tells that, it is highly release stable and it will not get released into the tantalum as well not get release into the body.

So, tantalum has been widely used in clinical applications from more than 50 years say because, because of its high density it can be utilized as a radio graphic marker, because of high density it will appear little blacker once we are utilizing some radiographic markers and also it it will also being using as material for permanent implantation in bone and since it is anti-ferromagnetic nature, it will not interfere with the magnetic resonance imaging scanning by MRI. So, that is also one of the reason it is also used in the vascular clips.

So, high density is good for very good as radiographic markers and its anti-ferromagnetic nature is utilized in the MRI in the vascular clips, it can also it is also used for repair of a cranial defects; also it can be very flexible and for preventing the arterial collapse. So, it is also used as a stent material in the vascular in the arterial collapse for in the arterial regions and again it is used a stents to treat biliary and arteriovenous fistular stenosis. So, it is also good for treating certain an anomalous and also used for fracture repair and for dental application. This is all the wide variety of tantalum just because of its very good cytocompatibility; it is not able to it is highly stable and even in the body fluid environment and because of its high density, it is utilized as a radiographic marker, it is also anti-ferromagnetic in nature, so it is utilized in the vascular clips and it is also utilized for repair of cartilages or arterial collapse as flexible stent, because of high strength, it can well replace all that and for fracture repair and dental applications.

So, this also tells that, tantalum is also one of the very widely used material and there certain other metallic alloys as well, which are utilized in the biomedical industry like nickel and nickel based alloys are used in certain medical treatments and devices; it it is basically it can also present as a contaminant in the fluids for intravenous administration or they can be also released from the surgical implants and other other medical devices.

So, they can also basically enter the body environment and there also, but there also again use for different medical treatments and devices. So, the release can be very irritating like, it can be toxic, it can be irritating to the body. So, it can act as a irritant as well. So, this is though it is utilized in different medical treatments and devices we have to basically check the release of nickel ion into the body under those conditions, so that thing has to be taken care while utilizing nickel.

Magnesium is a very light weight metal and with very high very with beautiful mechanical properties, because its property matched to that of a natural bone. So, it can serve as a very potential biocompatible material, because it is osteoconductive, that is degradable and it can also be load bearing. So, these are three very essential properties of this particular materials; that it is can be osteoconductive, it can be degraded and it is also utilizes it can also bear load. So, that makes it as makes it as structural materials for the body for the body environment and that is the beauty of this alloy magnesium and again aluminum also has been utilized in total hip endoprostheses, which are basically made out of titanium alloys; so titanium 6 aluminum 4 vanadium, also.

And in that, they were regarded as safe and they were considered safe as far as a risk of aluminum release in vivo is concerned, but again others some others studies also have found that it is basically a hazardous agent and it can also get accumulated at certain regimes of say brain, muscle, liver and bone bone. So, there is no consistency in terms of how the aluminum is reacting and how the kind of effects it has producing. So, first of all it has sometimes, if it is embedded in titanium alloy, it is considered safe, but it can also release and get accumulated in say, liver, bone or even muscle. So, that can be little (( )) to the body.

So, we see that nickel and nickel alloys, they are again they are good, but they can also be they can release from either devices or through intravenous administration of some certain drugs. So, their release also has to be kept under check and then magnesium alloys, they are very similar to that of a bone in terms of the properties and then, osteoconductive, the degradable and they were very load bearing implants. So, they can very well utilize as a bio as a biocompatible material.

But, again aluminum is it is little f e that, they do not have direct findings whether it is good or bad and people have found, aluminum can good in certain certain conditions, it can be bad in certain conditions. So, there is still some ambiguity in terms of utilizing aluminum as a biocompatible material. Now, stainless steel is one of economic materials, because in terms of providing strength, but the poor they have little poor corrosion resistance. So, stainless steel basically comprises of iron and then chromium un in the order of 70 to 20 percent, nickel 10 to 17 percent, molybdenum 2 to 4 percent, carbon 0.03 percent and limitations of manganese, prosperous, prosperous sulfur, silicon 2.8 percent.

So, overall the overall protection in the corrosion protection in the stainless steel is given by chromium, because chromium forms a chromium oxide, which is highly impervious in nature. So, this chromium oxide protects the stainless (( )) stainless property to the steel, but the problem with chromium is; it is of a right stabilizer it means b c c structure, so to counter that, we add some nickel to it, nickel becomes f c c or fascinate cubic and it is much more easy and it is very ductile; it is provides f c c phase, so that is the overall strategy of adding certain alloys to the stainless steel. So, we have iron the major content, chromium to provide the corrosion resistance and then, nickel to make to make it (( )) stabilizer and in terms of rendering enhance strength and property to the stainless steel.

So once coming back to that, the prosperous and sulfur also have to they also kept maximum of 0.03 weight percent and again to illuminate, the inclusion and some oxidations oxidation precipitates low vacuum melt can also be utilized to improve the quality of stainless steel and then again this particular has to be cast into some useful shapes for its application.

So, we have the chemical composition also can be very very dominant it can portray a very dominant effect on the on the stainless steel. So, coming back to the again by fact of the alloying elements that, chromium it renders the corrosion resistance to the steel, because it because of the formation of chromium oxide on the surface, which is highly impervious, but the problem with chromium is, it is a ferrite stabilizer and it is much weaker than the austenitic phase.

So, that is the overall theme about using the chromium, limiting the chromium we would want the chromium to be, as much as possible because, it provides the protection effect, but it becomes much weaker, because it forms a ferrite phase which is b c c and therefore, the chromium content then it has to be limited. And to counter a counter that, to make it back into austenite austenite phase we had nickel. So, nickel is do the order of we say 12 to 20 percent to counter and then, make it back to the back to the austenite state. So, that is the over all of philosophy of adding nickel and nickel basically increases the strength of the austenite phase and it is much better than chromium alone.

And again there is one more critical problem with the carbon; carbon has to be very very low, carbon it is a very limited to say around 0.03 percent in stainless steel. So, we have carbon content much less than 0.03 weight percent this happens, because the basic corrosion protection element in the stainless steel is chromium and chromium has very strong tendency to form carbide, so it basically from C r 23 C 6, which is a carbide stem and once this carbide is formed now the overall matrix is divide of chromium to form chromium oxide and since there is no chromium oxide, though overall material will be under attack and it will be very it will have very less corrosion resistance.

So, we see that with the that the over all theme of having low common content is to avoid the formation of C r 23 C 6 carbide and this carbide basically forms on the grain boundaries and its sensitization as a material; what does meant by sensitization is that, we had certain grains and then, this chromium basically combines with carbon to form precipitates. So, this blank dot which I am I am drawing here this is nothing but, precipitate and then, the interior of the grain, it becomes devoid of chromium.

So, we have chromium rich regions, which are nothing but, the grains out here and the interior of it, it gets devoid of chromium. Now, this particular region the interior of the particular grain is now much more prone to corrosion. And now we are grained that, we have high chromium and then, we have low chromium and that basically is called sensitization, where one will act as a cathode and one will act as a anode, so that interior of the material can follow the local galvanic cell and it can be basically E tau, the core of the grain; now, we have one region which is very rich in chromium, which is C r 23 C 6 and now the interior has been devoid of chromium and this can really form a disbalance region or this is called sensitization of a steel. So, that is what basically deteriorates the corrosion properties of stainless steel. So, that is the reason we want to keep a minimum content of carbon and stainless steel.

So, basically we can reduce the corrosion damage to the steel. So, overall we want to keep a low low carbon content to avoid the formation of chromium carbide and this basically it avoids the precipitation at the grain boundary and this basically is avoiding the sensitization of steel or the formation of carbide at the grain boundary and which in turn overall reduces the corrosion damage to the stainless steel.

That is the philosophy of keeping the carbon content very low and again the microstructure is also well defined by ASTM standards that ASTM specifications state that; we should have a desirable single phase austenite. So, achieve a single phase austenite we must add some nickel to it.

And it basically says, no ferrite b c c or carbide phase it means keep the carbon content less than 0.03 weight percent, so that there is no formation of carbide and chromium is available for imparting the corrosion resistance by a formation of chromium oxide layer. So, basically to do that we have chromium and then, it is being counteracted by it basically forms f c c phase and that thing to in to counteract that, we add nickel to achieve a f c c phase. So, this is overall strategy of this particular thing of maintaining the microstructure. At the same time the steel has to be free from sulphide stringers or any oxide inclusions, so there has to be a clean steel making or we use low vacuum technique low vacuum melt that we basically avoid the formation of any oxides we keep the sulphur sulphur content less than 0.03, phosphorous content also less than 0.03, so that the sulphide stringers can be avoided into the particular steel.

So, once you have clean steel, the properties will automatically enhanced because, there are no lamellas of stringer or lamellas of stringers of sulphide, which will form certain boundaries and those boundaries are generally weak and then, they lead to failure or may be enhanced corrosion as well.

So, by achieving clean steel we can have much more uniform phase as well and that will basically reduce the pitting corrosion and also it will avoid any interaction of or form a formation of interfaces between metal and inclusion. So, the overall theme of this particular microstructure or controlling the microstructure is at any f c c phase; it is single phase austenite, avoiding formation of any carbide, so that we can retain the corrosion resistance of a material, no ferritic phase and only austenite phase.

So, that the mechanical properties are superior, it should be free from sulphide stringers; we need to avoid the unclean steel making, because the sulphide stringers they lead to reduce the strength as well as, they can also form a metal inclusion interfaces and it can again induce certain corrosion to it. So, the pitting corrosion can be well assisted by this particular this particular stringers also it will become a material as well. So, this is the overall strategy of controlling the microstructure.

Now, the grain size of the microstructure is recommended by ASTM again. So, ASTM of size 6 or finer it means grain size of 100 micro micrometers or less is recommended for the 316 L, it is the 316 type low carbon stainless steel and the grain size is can be calculated from N is equal to 2 to the power n minus 1, where capital N is a number of grains, which are counted in 1 in square at 100 x magnification and small n is nothing but, the ASTM grain size, which should be number 6 or smaller it means ASTM grain size number 6 or more.

The grain size for the microstructure is recommended by the ASTM for 316 stainless steel which recommends that, the ASTM grain size should be number 6 or finer it means that, the grain size of stainless steel should be 100 microns or less or in terms of ASTM number, the grain size should be number 6 or more.

So, the grain size can be calculated via this particular formula that N is equal to 2 to the power of small n minus 1, where capital N is a number of grains, which are count in an area of 1 in square at a magnification of 100 x and the small n is nothing but, the ASTM grain size, which should be number 6 or more, so that the number of N the number of grains counted in the region can be much more or much finer. So, we see that of particular microstructure will show you will show us particular grain pattern and at the grains and if these grains there much finer or they much finer and less than 100 microns it means the grain sizes number 6 or more.

So, we we we attain certain macron bar say this say this one certain number and these grains are finer than or lesser than 100 microns then, we have attained the ASTM number 6 of grain size. So, that is what we are able to see from this particular recommendation that, we the grain should be very very fine, so that the mechanical properties are very good and then, it should be totally homogenous, it should be free from any inclusions any any inclusions or any carbides and any oxides and it should be it should have very homogenous structure and as per ASTM recommendation N is equal to 2 to the power n minus 1, so this n is nothing but the grain size.

So, number of grains in a 1 inch area square, so 2 to the power 6 minus 1, it is equal 2 to the power 5, so many numbers of grain should be visible in a 100 x magnification in an area of 1 inch square for ASTM number 6. So, that is well how the ASTM grain size is calculated for stainless steel and as the grain grains they get refine and the grains also need to the very very uniform, because once the grains are more uniform, then only the properties can very very uniform throughout the matrix. So, we have to avoid the secondary inclusions or any carbide, which can generate into the particular matrix.

So, we need to have more uniform grain size as well and again the fine grains will enhance the mechanical yield stress. So, we this is basically given by a particular equation, sigma y is equal to sigma i with an inverse relationship with the grain size. So, we see there is some frictional stress, yield stress is depend on the frictional stress, but plus some parameter which is dependent on the propagation of this particular propagation parameter, which can allow the slip slips to occur through the grain boundaries and d, it is inversely proportional to the square root of d, sigma y is proportional to 1 by under root d and as soon as the grains grain size is getting reduced, the overall yield stress is required will basically keep on increasing.

So, that is what we once we have the grain size very very fine, the extreme number more than 6, then we will have the grain size very very low and as the grain size was getting lower and lower, the overall yield strength will keep increasing and it means increase in the yield stress or the enhanced mechanical property of a specified steel.

So, that is what the overall advantage of achieving a final final grain structure and grain refinement can be achieved, where certain techniques such as, rapid solidification, we can also do certain cold working, which will break the grain size, we can do a rapid annealing and then, it could also we can also do some sort of a heat treatment or recrystallization; recrystallize the particular grains to achieve even finer grain structure and usually 30 percent cold work is done, which is which is done to an enhance the yield strength, enhance the ultimate tensile strength and also enhance the fatigue strength and this cold work is doing nothing but, breaking the grain size and refining the grains.

So, we achieve a grain size of very very fine nature and as we understood later, that the yield strength is dependant on the under root of the grain size. So, this particular dependence enhances the yield strength and the ultimate tensile strength and basically we will have if we have a particular microstructure; it should be very fine in the transverse direction.

So, we will see very very fine grains in a particular material and this grains are much lesser than 100 microns. So, this is as per specialization for ASTM that, we have grain sizes very very uniform of lesser than 100 microns and that is what we will see and under service this grow grains will undergo some plastic deformation and at plastic deformation can also be given by a cold working or 30 percent cold work and again we can also see certain slip lines.

So, if we had certain grains we will see certain slip lines which we generate (( )) which will which will, which are basically allowing this slip to occur, it is basically following slip in this direction and and this can also has certain slips something like this to allow slip in this direction as well and they can be different alignments of slip in different this is different grains, which will allow slippage in certain direction.

So, those slips are accommodated by certain slip lines, which are predominated in the material itself and again the grain size also has to be much finer. So, that. So, that this location can get piled up at certain locations and it will basically enhance the strength. So, this particular module arises from the piling up of the dislocations within a certain grain; the grain size is very very small, then many dislocations have to be accommodated within the certain region and then grain themselves we can slide down and final grains can therefore, result better yield strength as well as, better ductility to the material.

And once the grains are undergoing plastic deformation, we starts seeing some basically some tuning or some slip lines, which will basically we present in the microstructure. So, we are seeing very fine microstructure in a transverse direction direction and after plastic deformation we see much breakage of the those bigger grains into very fine grains and that things that thing is (( )) by the plastic deformation and we also see certain slip lines.

Seeing the mechanical properties, how they depended on the basically heat treatment which is given to the material we see that, we have certain specification for a stainless steel in this case we have little higher content of sulphur and phosphorous and they basically for yield to formation of some sulphide stringers and that is, if you see that the yield strength is around 221 megapascal, tensile strength of around 483 megapascal and fatigue strength in a certain range, but as soon as we go about a better purity steel, which as low sulphide content and even lower carbon content.

So, now we can see that, the yield strength has increased to by certain time by, maybe to the order of the 50 percent, tensile strength is also increased an even, the fatigue strength is approximately similar. So, this thing is arise as arising because, now we have remove the sulphide stringers and we also have reduce the formation of precipitate or the carbides out there, but as soon as we cold forged, we can see that there is drastic enhancement in the yield strength; it has gone from 221 to 331 to 792 megapascal. So, these three have the similar composition and from 331 increase into 792 and tensile strength is gone from 586 to 930. So, this drastic improvement is achieved even, where 30 percent cold one and then fatigue strength as improved in this particular case from 240 to around 310 to 448 megapascal.

One thing to remember is the E or the young's modulus is remaining similar or same for all, all of them because the whole young's modulus does not does not depend on the treatment on the how the material has been heat treated it is totally it is totally dependent on the overall material property.

So, totally how the bonding is really occurring between iron basically iron, chromium, nickel and all those. So, the modulus is totally compositional property and then we have seen, similar young's modulus for all of them, but as we go from 30 percent cold forging to a very high level of cold forging. We can see further enhancement in the yield strength, there is gone from 700 to 1213 megapascal, tensile strength as gone to order of gigapascals 1.3 gigapascal and even the fatigue strength has gone up drastically.

So, you can see, what is the effect of this particular treatment in terms of deciding the mechanical properties of stainless steel, so that is the overall strategy of basically designing and providing certain heat treatment or some mechanical treatment in terms of such as, annealing or cold forging to enhance the mechanical property via several times.

So, a part from the grain structure, this part is also very important and how the cold working work is, works is like cold working it can automatically be generated as well like with the with the service time of a particular say, bone implant screw and we see much elongated grains or texturing in the stainless steel.

So, if we are rolling the particular material of a cold working a particular material, we can as grains we start aligning in one direction and then, we basically elongated. So, this is what, we will observe in the texturing or the elongation part of the cold work stainless steel. So, we will see that the grains are elongated along the rolling direction or the form direction we can see the elongation of grains and it will be much larger and that, that is actually giving also (( )) texturing of the stainless steel, but if you try to see longitudinal section; longitudinal this is nothing but, the texturing part along the longitudinal section, but if you see a perpendicular to that longitudinal axis or the transverse axis we will see that the grains are again equiaxed; we will see that equiaxed grains, which were probably less than 100 microns as per ASTM specifications.

So, they will remain as such in the transverse direction, but the longitudinal longitudinal direction you can see much more elongation along the work direction. So, that if it has been rolled then, we see much more texturing along this direction or the grains has elongated along horizontally, but the transverse part will have still equiaxed grains.

So, that is that in that part actually is being shown by this particular screws scheme of microstructure development, how the microstructure will develop for the screw as we roll it, so it will show some elongation elongation along the roll direction or some texturing and whereas, the transverse section will remain as such.

And coming to the corrosion property of stainless steel; it is again one of the very critical parts of utilizing the stainless steel as body implants that, a corrosion behavior of duplex steel found to be very good and again it is the super ferritic steel is also very good as compared to the 316 stainless steel and it is also been suggested by group of sivakumar that, super ferritic and duplex stainless steel can be adopted as the implant material, because of their high pitting and crevice corrosion resistance.

So, a once we start avoiding the sulphur and phosphorous, it can basically enhance the corrosion pitting resistance, so that it can avoid the formation of certain stringers and then it can reduce the inclusions and metal surface context. So, that is the reason it can lead to enhance crevice corrosion resistance and once we have a duplex steel or once we have a super ferritic steel and again once we alloying the stainless steel with certain alloying additions chromium, nickel, molly and all that basically it it can also lead to certain allergic and carcinogenic effects So, this part also we had to kept under check keep under check that, we are protecting the particular material and it has not really corrosion prone and it may not lead to certain alloy certain ion release into the body.

So, though chromium is you know (( )) chromium is again said to be carcinogenic and then, chromium it provides a protection, where formation of C r 2 O 3, but it basically becomes it becomes a ferritic stabilizer. So, it forms the b c c structure, to counteract that we are added nickel and again to enhance certain mechanical certain certain properties of steel we are producing (( )) addition of molly silicon, which can react with oxygen and basically make the steel very much pure.

So, again those are again ferritic stabilizer as well. So, to counteract that we extra start add nickel and as soon as we start increasing the alloy, alloy concentration basically that can be very deleterious as it may lead to more chances of ion release into the body and it can be highly allergic, because those those ions get accumulated at a certain locations they might cause irritation, they can be more allergic or can going be carcinogenic.

So, we have to keep this particular thing under check and super ferritic steel or duplex steel can be used as a body implant material and again he has been observed that, in the case of stainless steel some infected plated fractures have been studied by a group of Hierholzer and they found that, the absolute concentration of ions as well as the nickel chromium ratio in the fatigue regions with where basically it has affected the the affected regions they are basically they are richer in nickel by chromium ratio and they are richer in ions.

So, that as that the affected at the infected areas are basically rich in a nickel chromium or ions, so this tells that these are the culprits of causing the allergy reactions. So, that is what we are able to see that, corrosion has to be very much kept under control and because that causes allergy and that thing is resulting out of some alloys, ions and the nickel chromium and that thing is again found in near the in infected areas.

So, that really tells that this ions are really have to kept under control and then, we can improve the corrosion resistance of a particular bio implant material and basically it will come out to the overall thing that for initially we require beneficiation the excavation of a particular material to form a to achieve a basically pure element and then do certain alloying addition, alloying additions to achieve a usable material, which whose composition as which can we which we can utilize, which is much more biocompatible.

And then that particular material is basically fabricated via certain processing rounds, casting, casting rolling, forging to achieve some usable form such as, billets, sheets and so on. And once we achieve that, then we do certain machining to it to provide a certain usable shape. Once you attain a certain shape you want to give it certain coating, so that the surface properties can be enhanced.

So, we basically utilize coatings of nitrides and all that for improve wear resistance, some coatings of hydroxyapatite for better wear and for better wear resistance or rendering much more biocompatibility to it and then we also, these are the overall parts which we can really give as a surface treatment and then, it has to go under quality control and then, some clinical trials and as well as, before that we do also do some animal studies in vivo, in vitro to basically comment on the overall biocompatibility and a usability of that particular implant for clinical trials and from there on, we realize that, there are certain materials, stainless steel, cobalt chromium alloys, titanium alloys, tantalum alloys, nickel alloys, magnesium, aluminum alloys.

And we saw that, how they overall usability is and this lecture we concentrated more on the stainless steel part of what is the importance of the alloys such as, chromium to impart much more corrosion resistance to it and other other other elements such as, molybdenum, silicon which are again used for keeping the check on the inclusions and we have to keep sulphur phosphorous lower in at very low content less than less than 0.03, 0.01 per weight percent to avoid the formation of lamellas and since our chromium and again molybdenum and silicon are more ferrite form of and we have to make it much more austenite, austenitic in nature, so for that we add much more nickel. So, nickel is added in the order of 12 to 20 percent to make it again make it from ferrite to austenite and austenite is much stronger in nature.

So, that is how we saw that, how the transition occurs from ferrite to austenite and then austenite is much more required form for the biomedical implant and then we also realize that, there is some restriction in terms of grain size because, finer grain size will render a much more or better enhanced mechanical properties in terms of yield strength, tensile strength, fatigue strength and again we saw that, it also has to undergo certain forging or some sort of treatment it can be thermal, it can be mechanical. So, that a grains can be reformed to a much larger extent in (( )) with parameters, mechanical parameters we can alter the overall mechanical properties of the material.

It can be either annealing, it can be cold forging and so on and then we also looked up on the overall corrosion behavior that a duplex stainless steel or super ferritic stainless steel are much better in terms of providing the corrosion resistance, but again the concentration of alloy, ions or chromium nickel can be found more in the affected areas or the infected areas, which which are again cause be more allergic, which can again be carcinogen. So, we have to keep a check on that as well and that, that is how the stainless steel can be used as a much more biocompatible and as a biometallic implant material, so basically we will end our lecture here, thanks a lot.