Medical Biomaterials

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Lecture - 04
Properties (Mechanical)

Welcome to the course on medical biomaterials. Today we are going to talk about the properties. The mechanical properties a biomaterial should have; it should have lot of mechanical properties depending upon the location of the material.

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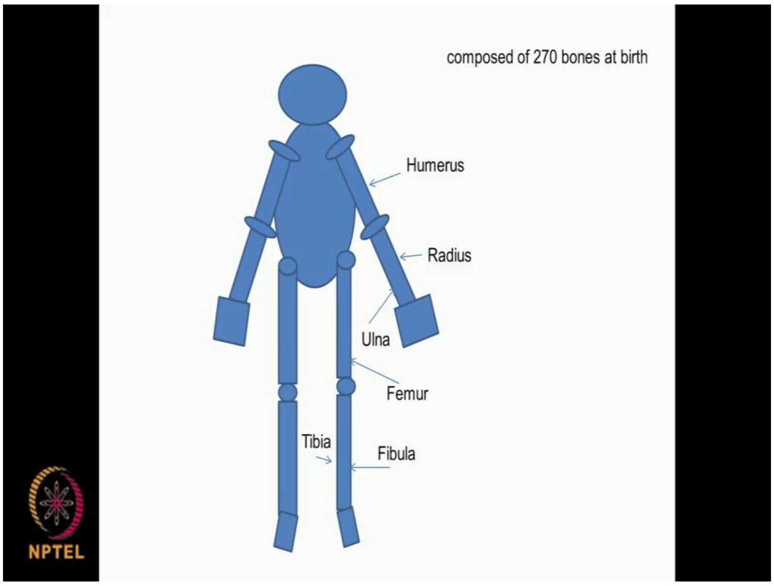

For example, if you look at human body it contains 270 bones at birth and it reduces to 206 bones as you grow older because certain bones get fused. So, the bones for example, if you look at the humerus, if you look at the radius, which is outside if you look at the ulna which is inside the arms, then you have your hand and fingers. Then if you go to the feet you have the femur then lower fibula tibia and then the actual feet. So, there are many bones which undergo quite lot of tension, which undergo quite lot of compression. And an orthopedic surgery replacement of some bone or filling up of some defects. We are going to place biomaterial it could be a metallic biomaterial, it could be a combination of metals and ceramics and so on. These materials should have the desired mechanical properties. So, that is very important.

So, these materials will face either tension depending upon where it is placed material or they may undergo compression depending upon where the biomaterial is placed. So, the biomaterial has to be tested for several mechanical properties, especially materials which are involved in the orthopedic. That is why there are metals used quite a lot in orthopedic situations like stainless steel 3161 titanium then alloys and so on actually. Because these can take up lot of load especially if you look at these parts, here it is going to take up the load of the human being. So, they have to be quite strong.

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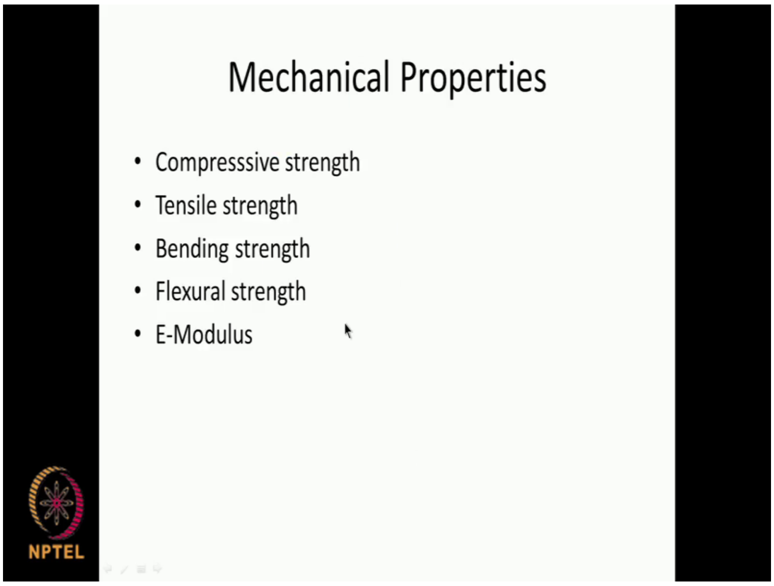

So, what are the mechanical properties compressive? Strength, tensile strength, bending strength, because many times as you know we keep bending our arms our foot and leg and so on. So, the material has to have that particular property, flexural strength again we are flexing some parts. Even if you take the heart valve, diaphragm heart valve it keeps opening closing opening closing so, many thousands of time a day and for a very long period. So, they should have the enough strength then modulus the modulus velas elasticity that is related to the stress and the strain. So, these are the mechanical properties the material has to have it is not that all biomaterials should have this, but especially materials which are involved in orthopedic surgery have to have some of these properties depending up on where it is placed in the human body

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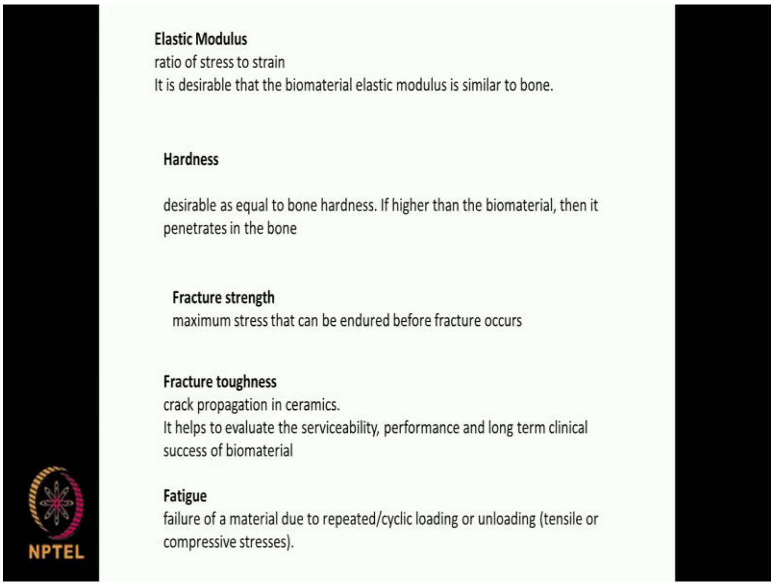

So, elastic modulus what is elastic modulus these ratio of stress to strain the most important. In fact, the most imp difficult challenge is to have a material, which has elastic modulus of that of the bone. Bone has a very low elastic modulus and we do not want very strong material like stainless steel, actually because that has very high elastic modulus. So, then came titanium and now they are looking at other alloys; so that you can keep on reducing the elastic modulus. Whereas, 30 forty years back the general feeling was to have materials which are extremely high in elastic modulus, but they have realized that we should not have such materials, please next to the bone, because the bone elastic modulus and the material elastic modulus would not match. So, most load will go on the material which has very high elastic modulus and that is called stress shielding and the bone will start losing it is strength.

So, there is lot of research now being done looking at materials which have very low elastic modulus. That is why ceramics and some of the oxides are coming into picture. They have compressive strength compressive elastic modulus matching with that of the bone. The next one is hardness. You need to have desirable hardness because bone has certain hardness. So, it should have desirable hardness, but then it should not have too much hardness more than the bone because if I am going to conduct a surgery keeping some materials, next to the bone then it may penetrate the bone. So, it has to match that is very important hardness.

Then comes fracture strength So, what is the maximum stress the material can take up before it actually fractures means breaks. So, that fracture strength is very important fracture toughness what is the difference between strength and toughness. Suppose there is a crack how the crack progresses that is called fracture toughness. And especially this is very relevant in ceramic like material. It he helps to evaluate the serviceability performance and long term clinical success of biomaterial. So, serviceability long term use of the biomaterial. So, fracture strength is when the material fractures, fracture toughness is if there is a crack how it starts propagating.

So, that tells you the toughness of the material. So, these are some of the properties that needs to then you have fatigue, like I said you have this diaphragm heart valve which opens closes opens closes. So, this is called as repeated loading or cyclic loading; so loading unloading loading unloading. So, will it repeated tensile strength may be there, or compressive strength for example, if you see our foot whenever walking each foot undergoes certain compressive force and that is sort of repeated there is a compressive force. And then when we lift the foot the compressive force goes away. Then again when we place the foot on the ground our whole body stands on it. So, there is a compressive force. So, this is called repeated compressive stresses.

So, the material if it is placed in such areas it should be able to take up that that is called fatigue. So, the material may have good tensile strength, but because of the repeated compression, uncompression, compression, uncompression or repeated elongation stopping elongation repeat again elongation the material may fail that is called fatigue.

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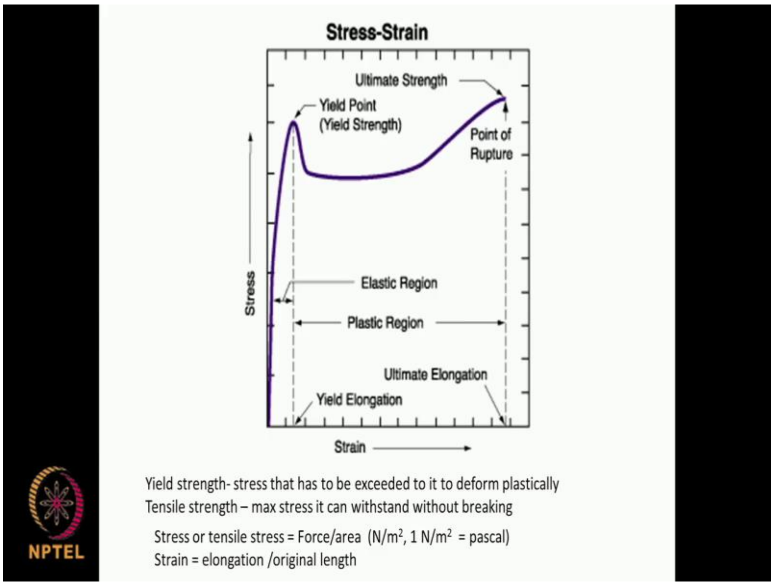

You need to understand this diagram this is called stress strain diagram for the next 1 or 2 classes I am going to talk quite a lot of mechanical engineering .and you will come across stress stain diagrams stress strain modulus compressive stress shear stress creap and so on actually. All these are mechanical terminologies and you need to understand this if you are planning to design material. There is biomaterial which is going to undergo such forces and such exchanges actually

So, what is this stress and what is this strain. So, stress is nothing, but force by area. So, if I am applying a force, suppose I am pulling a rod of certain diameter. Imagine I am pulling a rod of certain diameter or I am compressing a rod of certain diameter, I saw the force that is acting on it divided by the area that gives you stress, you can have tensile stress you can have compressive stress, how is it represented what are the units. It is normally newton per meter square, as you know you must have studied in your school you have the force always representing as newton and area that is y meter square. So, newton per meter square, or one newton per meter square is also called Pascal. So, you will come across these newtons per meter square Pascal, in the next few classes especially when you talk about strength of materials. So, once more tensile stress is force per area. Generally, it is represented as newton per meter square or Pascal. What is strain is elongation divided by original length.

So, if I have say one centimeter rod, I am pulling it because of some force tensile force. So, the rod becomes 1.1 centimeter. So, from one centimeter it has become 1.1 centimeter. Then the strain is it is got elongated by 0.1 centimeter. So, 0.1 divided by original length is 1. So, strain is 0.1 by 1. Please note that strain as no units because you are dividing the elongation by original length. Whereas, stress has some units force by area. So, it is as newton per meter square or it is represented as Pascal do not forget that. So, in this axis we plot stress in this axis we plot strain. So, as I keep increasing the stress; that means, as I keep increasing the force; obviously, the elongation is going to increase. So, my rod gets longer and longer. So, strain also increases like this do you understand, please understand this. This is called elastic region why because once the force is removed the material will come back to it is original length.

So, all materials have elastic region. It is called elastic region understand so, but then you can not keep on extending. So, at some point that is called yield point or yield elongation the material will not be elastic, it will go into a plastic region; that means, if I remove the stress or if I remove the force it is not it is not that the material will come back to it is original, because it has become little bit plastic. So, the first point is elastic and the second point is plastic. So, if I apply more. So, the strain will keep on increasing and then ultimately it will break. The material will break that is called the ultimate strength. So, this is called the yield strength, this is called the ultimate strength yield strength is up to a certain strength the material in the elastic region; that means, if I remove the force material will come back to the original dimension. Whereas, beyond that material will not come back to it is original dimension, but it will not break the breaking is here, that is point of rupture that is called the ultimate strength. So, this is called the plastic region this is called the elastic region.

So, in this elastic region, we can assume this line to be a straight line. So, stress and strain are connected by a linear relationship. Stress is equal to sub slope into strain that is in this region we can consider the whole relationship as a linear. So, slope. So, stress is equal to some slope into strain up to this that is the yield point that is up to the elastic region. So, this is a very important picture. All materials will have some sort of a stress strain diagram. Some of them will not show yield point some of them will different slopes some of them will have different heights and so on. Whether it is a stainless steel or titanium or plastic or ceramic. Everything will have some stress strain diagram and they will vary quite a lot. I am going to show you and once you know the stress strain diagram you can decide which type of material to use depending upon the application.

So, the tensile strength. So, the ultimate strength is here before the material actually breaks. So, the tensile strength if you are talking about is the maximum stress it can withstand without breaking. So, this is the elastic region this is the plastic region. In the elastic region we can assume this line to be a straight line linear. So, stress and strain are connected by a linear relation. So, stress is equal to slope into strain. And another important point is strain has no units because you are dividing elongation by original length whereas, stress has a unit. Because stress is equal to force by area force is represented as newton. So, force by area is newton per meter square one newton per meter square is one Pascal.

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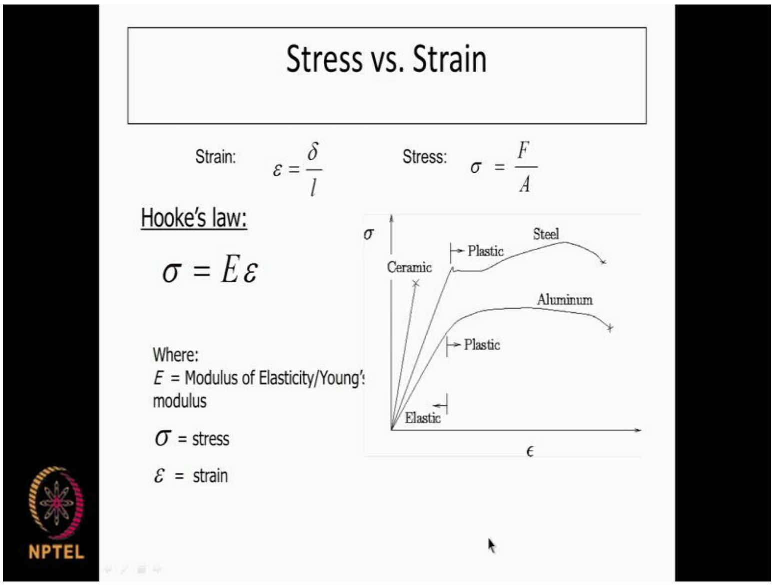

So, this is the mathematical representation epsilon delta is the change in the length or the elongation divided by original length. Stress is sigma force by area and there is something called hooks law sigma is equal to capital E by epsilon.

I told you in the previous graph this is a straight line. So, this is the slope. So, stress and strain are related by that slope. So, that is what this hooks law is about and sigma that is the stress is equal to E into epsilon is your strain here E is called youngs modulus or modulus of elasticity. So, hooks low is valid only in the elastic region please remember that. So, sigma has a unit like I told you in the previous force by area. So, Newton by meter square or it Pascal, Epsilon has no units because you are dividing the elongation by actual length. So, this is dimensionless. So, E will have the units of sigma. So, E will have units of Pascal remember that. So, E is called the elastic modulus of elasticity or youngs modulus. So, different materials are different types of stress strain diagram. So, here we are plotting epsilon here we are plotting sigma. So, if you take steel it goes like this and like this sorry. So, you have the yield point you have the ultimate strength. So, you have the yield point and you have the ultimate strength. Whereas, if you look the elastic region this is the plastic region

If you look at aluminum it looks smoother it does not goes like this, but because if you keep on extending aluminum suddenly after sometime it will become very plastic. You know you can see that it gets extended it extended and when you remove the force. It will not come look at ceramic it goes up and at some stress it just snaps breaks. So, it does not go into your plastic. So, ceramic does not have a plastic region it is elastic only. So, that is a big problem about ceramics. It cannot have very high tensile it will just snap or it will break. So, we do not use ceramic material when it is in there when it is undergoing tension. Generally, most of the orthopedic implants as you see they use steel or they use titanium metals only they use they will not use ceramics or inorganic material because inorganic material will have a stress strain diagram like this they will go up at place some place it will just break it snaps. So, it will not go into the plastic region at all.

So, please look at this stress strain diagram how different the materials are you can see very clearly, the yield stress for steel, but the aluminum quickly changes from elastic to plastics. So, polymers if you take it may the graph may go like this much lower and so on actually.

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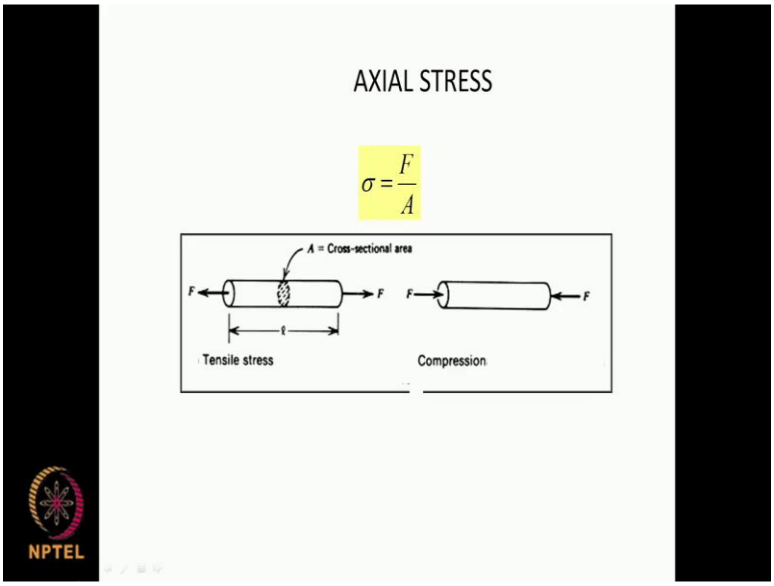

Axial stress is what we call because we are talking about force on either side imagine this is the rod a, is the cross section L is the length. So, corresponding just like tensile we can also have compression especially if you look at foot leg parts because of the weight of the body the material could be under compressive force just like tension you can have compressive forces also taking place into them.

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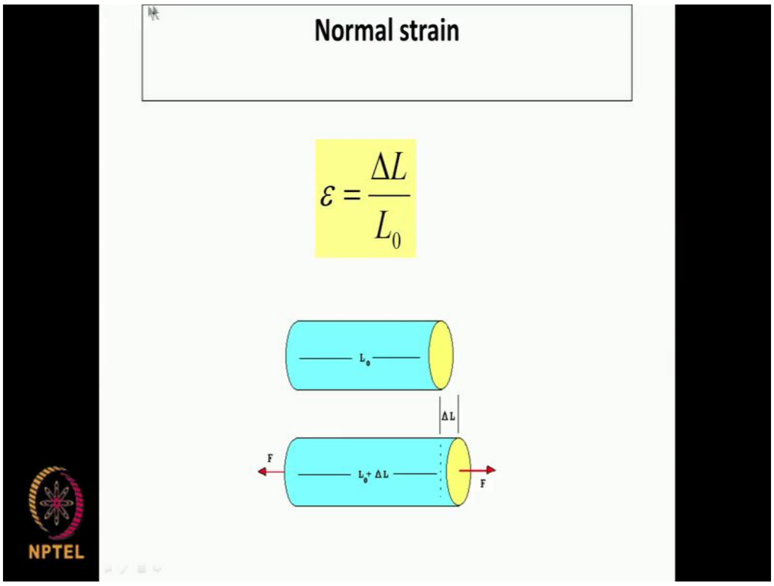

So, the normal strain once more as I said delta L by L naught. We can call L naught could be the original length delta L is the extended length, because I am applying a elongation or delta L is the shortening of the original length because you are applying a compression.

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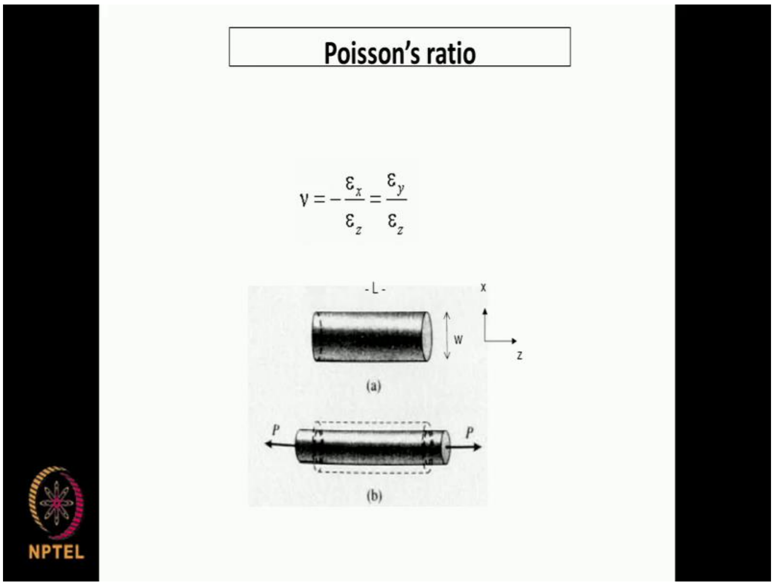

So, epsilon is delta L by L naught epsilon does not have a unit there is something called poisons ratio you need to understand poisons ratio, which is the strain in the x axis x direction strain in the z direction. So, if you have a rod like that, imagine you have a rod like this and a strength L. So, we have z going like this and x going like that. So, when I am pulling that rod the rod may change it is origin, it is length in this direction as well as the rod may come down in that direction, also both are possible right. So, there will be a strain in the L direction as well as there could be a strain in the w direction also. So, if I have a rod I pull it the length may go delta l, but the diameter may go down. So, both can happen that is called poisons ratio that is why you have a negative here because if one direction it elongates in another direction it will get contracted.

So, poisons ratio is also important. Because imagine I have a metal implant which is fitted inside the whole, because of tension the implant gets elongated, but it is diameter can shrink. So, there could be a whole created gap created because it is diameter has shrunk. So, if we have a very high poisons ratio you will be in trouble. So, if there is a tension the length gets elongated, but the diameter decreases. So, there is a gap created between these biomaterials and rest of the bone. So, that could be very deleterious you could have infection taking place, and if you have a say for example, adduce you put into that that adduce you break or fail all these can happen if you look at teeth implant they use quite a lot of these titanium screws these titanium screws are nicely fitted into the jaw and if there is a tension on this titanium if it gets elongated, there could be gap created between that jaw and the metal. So, there this gap could lead into accumulation of bacteria and so on actually. So, we need to understand what is the poisons ratio for the material also. So, you will like to have very minimum changes in the dimensions during tension or compression. So, poisons ratio is also very important.

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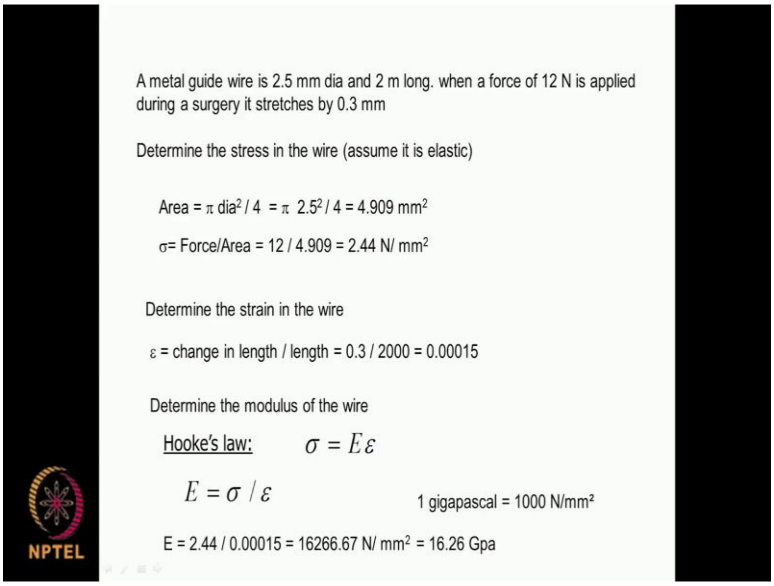

Let us look at the problem problems are very important, because problems give you an idea about the concepts that I am going to discuss. So, we will try to do as many problems also during the course. So, we have a metal guide wire and you must have you must have heard of guide wire these guide wires are used quite a lot. Especially when they place irritral stents inside the body or cardio vascular stents inside the body these guide wires are made of stainless steel or nickel titanium. So, they actually guide the material inside through the artery or through veins. So, that the. So, that the surgeon can place the material at desired place and he or she will be looking at the location using certain visual devices. So, a metal guide wire is 2.5 mm dia and it is 2 meter long, 2 meters means about 6 feet long and a force of 12 newton is applied forces, we I said we will always use term newton during a surgery it stretches by 0.3 mm determine the stress in the wire. So, we are looking at elastic determine the strain in the wire determine the modulus of the wire stress. How do you calculate stress is nothing, but force b area force is given as 12 newton diameter is given here? So, area is pi d square by 4 you must have studied in your school long time back.

So, stress is that area is equal to pi into diameter square by 4 pi into 2.5 square by 4 that comes to 4.9 millimeter square force is 12 divided by 4. So, you get sigma that is stress 2.44 newton per millimeter square strain is elongation divided by original length strain has no units. So, elongation is 0.3 mm and original length is 2 meter. So, 0.3 by 2000 do not forget one meter is equal to thousand millimeters. So, you need to convert that. So, 0.3 divided by 2000 there are no units for strain. So, 0.00015; what is the modulus? Especially if it is in the elastic region the modulus is given by stress by strain simple. So, stress is given here strain is given here. So, we use the hooks law stress is equal to strain into modulus. So, modulus is equal to stress by strain, simple. Now we need to. So, 2.44 divided by point 0 0 0 0 0. So, that is newton per millimeter square. As I said the units of modulus or Youngs modulus will be same as that of force. Now 1000 Newton per millimeter square is one gigapascal. This gigapascal mega Pascal means 10 power 6 Pascal gigapascal means 10 power 9 Pascal.

So, you need to remember all these. So, one gigapascal is thousand. So, if I divide it by 1000 I will get 16.26 gigapascals. So, the modulus is given by 16.26. So, you need to remember this conversion factor also one gigapascal is equal to thousand newton per millimeter square. And one mega Pascal is equal to one newton per millimeter square.

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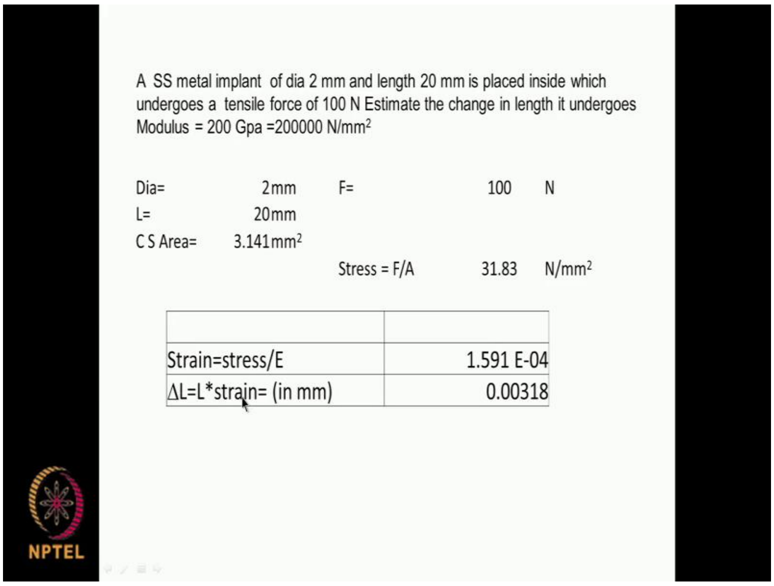

Let us look at another problem. A stainless steel metal implant of diameter 2 millimeter and length 20 meter is placed inside which undergoes a tensile force of 10 newton. Estimate the change in length it undergoes modulus is 200 gigapascals. As I said in the previous slide one gigapascal is 1000 newton per millimeter square. So, 200 means multiply by 1000. So, many newton per millimeter square. So, the force is given, diameter is given force by area will give you the stress the modulus is given. So, from there we can calculate strain, original length is 20 millimeter. So, from there we can calculate what is a change in length that is delta L understood.

So, diameter is 2 millimeter length is 20 millimeter. So, cross sectional area pi d square by 4. So, pi into 2 square into pi 4 2 square is 4. So, pi square by 4 4 and 4 gets canceled. So, cross sectional area is 3.14 millimeter square. So, please remember we need to maintain the units very correctly. Force is equal to force is equal to there is a mistake here. So, it is not 10 newton will assume it has hundred newton force is equal to 100 newton. So, so stress is equal to force by areas. So, 100 divided by 300 divided by 3 will be 301.8 3 newton per mm square, we use the same units. So, stress is equal to modulus into strain. So, stress divided by modulus will give me the strain stress divided by modulus will may give me the strain 31.83 divided by 2, 00,000 stress is 31.83 modulus is 200000. So, 200 gigapascal is to 200000. So, that comes to 1.59 10 power minus 4.

Now, elongation delta L is equal to L in length original length into strain. So, strain is this original strength is 20 mm, multiplied by 20 this will be in millimeter because the original length is in 20 millimeter understand this problem. So, the diameter is given length is given. So, force is hundred newton cross sectional area is pi d square by 4 stress is equal to force by area 31.83 newton per millimeter square. Strain is equal to stress by modulus 200 gigapascal which is 200000 newton per millimeter square strain is equal to stress by E. So, 31.83 divided by 200000. So, this comes to 1.59 10 power minus 4 there is no units. So, far because stress and modulus have same units then delta L that is the elongation is given by length into strain is this original length is 20. So, you multiply this by 20 it becomes 0.00318.

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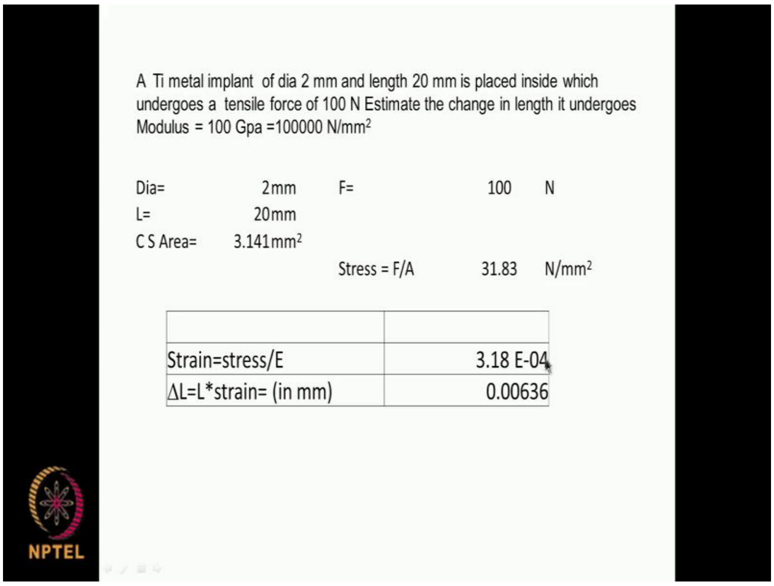

So, the length has increased by 0.00318 understand millimeters. Now look at the same similar situation, but the modulus has changed. So, originally I used stainless steel metal implant now I am using a titanium metal implant titanium has lower modulus hundred gigapascal. Otherwise it is the same 2 millimeter diameter and 20 millimeters is the length it undergoes 100 newton oh sorry, it this also undergoes 100 newtons per meter square sorry 100 newtons tensile force. So, in the previous one it is a stainless steel implant with a modulus of 200 gigapascal here, here in this particular case it is titanium implant with the modulus of hundred gigapascal. So, what is the change in length same way we have the diameter is 2 mm length is 20 mm cross sectional area is pi d square by 4 3.1 force is equal to 100 newton. So, stress is equal to force by area. So, hundred divided by 3.1. So, 31.83 newton per millimeter square then strain is given by stress by modulus sorry stress by modulus. So, 31.83 here the modulus is hundred thousand in the previous case it is 2 thousand. So, we get 31.8 into 10 power 4 increase in length is equal to original length into strain.

Original length is 20 mm. So, the increase is 0.00636 mm. Then what is that when I use a stainless steel implant which is got a modulus of 200 gigapascal. Applying same if you have the same diameter same length same force, I got 0.003 approximately. And when I use a titanium plant which has got 100 as it is a modulus of elasticity for youngs modulus that increase in length is 0.0063. So, it has it gets elongated much more then the previous one.

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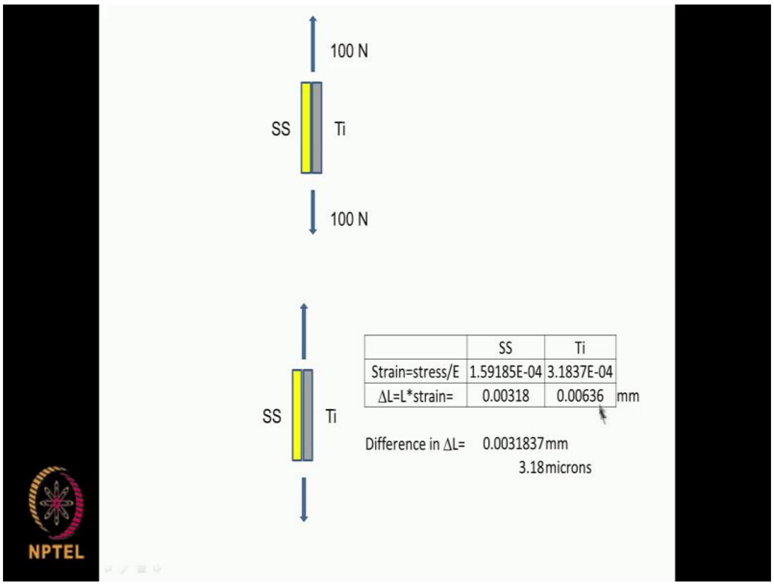

So you think it is not a problem, but it is actually a problem. Imagine I have a biomaterial designed which has got a stainless steel and titanium. So, it is a biomaterial which contains stainless steel and titanium, I keep it inside the human body and it is undergoing say a tension of say 100 newton. It is going undergoing a tension of 100 newton, but it is a mixed biomaterial which has got both stainless steel and titanium together. So, one of them will undergo 0.003 mm elongation another one will undergo 0 0 6 elongation. You are in big trouble right stainless steel will undergo 0.003 elongation because it has got higher modulus 200 whereas, gigapascal whereas, titanium has 100 gigapascal axis modulus. So, it will undergo 0.00636.

So, there is a difference in which these 2 may materials will elongate, although this is a single biomaterial which contains both these. So this difference is 0.003. So, subtract this are almost 3.1 8 microns. So, if I have a biomaterial which is made up of a small rod of stainless steel and a rod of titanium and I place it say suppose I fuse it on the top here and the top here, and I place it inside the body and that particular material is undergoing a tension. Although the tension is constant titanium will get elongated slightly more than the stainless steel. And this difference could be 3 microns. So, this biomaterial is in big trouble. So, the most important lesson from this is when I am having using different materials and prepare a biomaterial. If the modulus does not match and if the material is undergoing a tension, each of these materials may have different elongation. This can happen in compression also each of the material will have different compression or elongation.

So, the whole biomaterial could fail. So, there has to be a match of the tensile properties especially, if they face these type of axial stress strains or axial stresses or axial compressions. If they are not going to face this type of mechanical forces, then it does not matter, but if they are going to be placed inside for example, in the human body and it is facing a compressive force or a tensile force, and I have different materials the modulus of has to be modulus of elasticity or the youngs modulus, has to be same. Otherwise their elongations may differ and so one material may have a slightly longer elongation than the other and this may lead into the failure of the entire material. So, we shall continue more on these mechanical properties in the next class also.

Thank you very much.