Materials Science and Engineering

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Lecture -38
Ceramics, Polymers, Composites

Hello friends. Today's lecture will be now we want to look at some other materials which are used in under some engineering applications and these are Ceramics, Polymers and Composites. So, it will be covered in one single lecture though these are very important ones, but metallic materials are the most widely used material and these materials are used in very specific applications.

So, Ceramics are basically compounds between metallic and non metallic elements with interatomic bonds having ionic or covalent character.

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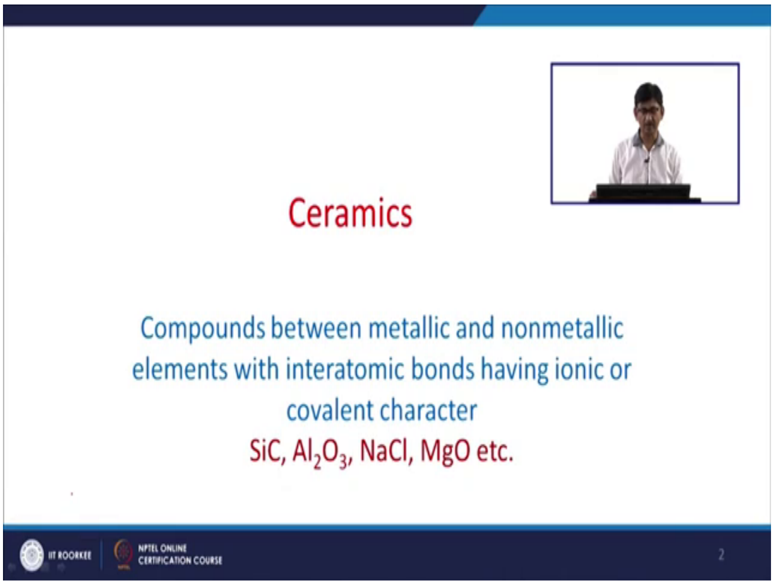

Ceramics

Compounds between metallic and nonmetallic elements with interatomic bonds having ionic or covalent character

SiC, Al_2O_3, NaCl, MgO etc.

So, for example, one of the very important Ceramic material you might have come across is Silicon Carbide. So, in all your Abrasive Paper which you use for doing polishing or you must have seen if any painter is coming to your home and he is rubbing the surface of the wall; may not be they may not be using Silicon Carbide papers, but in the Abrasive papers. Silicon carbide is one of the important ceramic which is used for abrasive application ok.

Another class is Aluminium Oxide Al 2 O 3. Sodium Chloride of course, you must have used this is a cover common salt and Magnesium Oxide. These are some few examples of Ceramic materials. So, in this case you can see that one of the element is is a metal; another element is a non metal and they both combine.

So, either they can have a covalent bond between them or they can have a ionic bond between them. And of course, that is what affects their mechanical property to large extent. So, just to have some idea about their crystal structure ok; so, crystal consists of basically ions located at lattice sides.

So, each lattice side is occupied by one type of ion and crystal should be electrically neutral.

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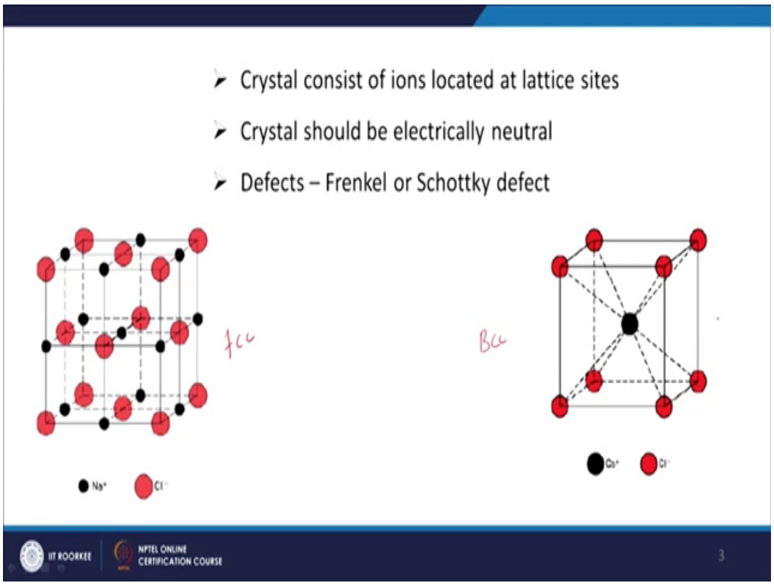

- Crystal consist of ions located at lattice sites
- Crystal should be electrically neutral
- Defects – Frenkel or Schottky defect

So, in totality, if you see for any Ceramic material, the main thing is that electrically it should be neutral ok. So, the number of ions of positive ions and negative ions should be same and that is why you see you must remember when we were discussing defects also the frenk Frankel and Schottky defects in both the cases, we maintained the electrical neutrality in case of defects also ok.

So, it is not like what we see in metallic material where, you just introduce a solute atom or you take out an atom to create a vacancy ok. Here electrical neutrality has to be maintained ok. So, one type of crystal structure here is given for Sodium Chloride and basically, it consist it looks like in an FCC crystal structure.

So, basically these are 2 FCC crystal structures combined together; one which is showing the position of Sodium atom, another which is showing the position of Chlorine atoms or chlorine ions in this case or sodium ions ok. And you can see that for each one have one of the ion there is another ion present to maintain the electric and neutral neutrality here.

So, this is the sodium chloride is based on FCC structure ok; two intervening this FCC structure; one for sodium, one for chlorine ok. And you can put them together to make a sodium chloride crystal. This is for a caesium chloride ok. Another type of structure based on another known crystal structure which is known to us and that is based on BCC system ok. So, you can see one chlorine atom is at the centre of this BCC cell and there are chlorine as caesium atom, chlorine atom at the at the corners ok.

Now, in looking at this unit cell, you might think that there is no you cannot maintain a electrical neutrality here, but if you see the BCC position here is actually can be considered as a sent end position for another crystal. So, if you make another crystal here, these caesium atom can be occupying the or another unit cell where c c a caesium atom ions are occupying the these end positions and then, you can see their chlorine will become the body centred one.

So, these are all interchangeable the centre atom and the body centred position can become a become a corner position for another unit cell which you can make. So, in overall if you see the electrical neutrality will be maintained for the whole crystal.

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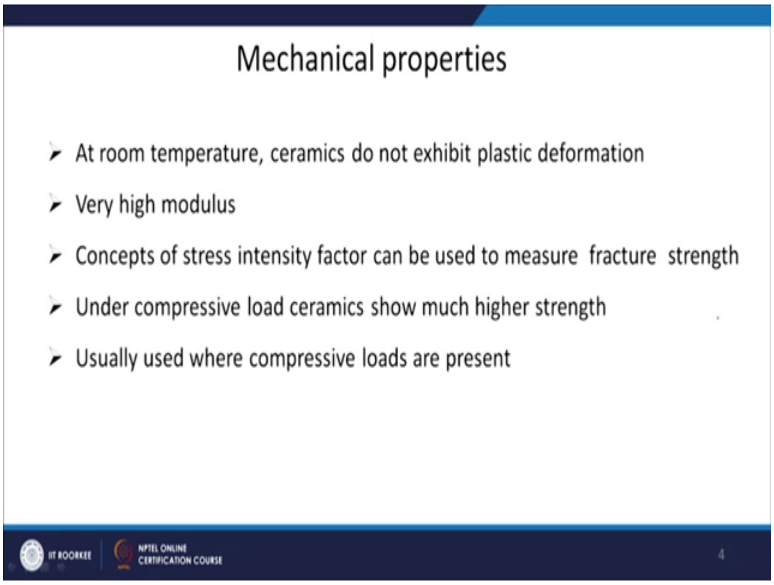

Mechanical properties

- At room temperature, ceramics do not exhibit plastic deformation
- Very high modulus
- Concepts of stress intensity factor can be used to measure fracture strength
- Under compressive load ceramics show much higher strength
- Usually used where compressive loads are present

The mechanical properties: At room temperature ceramic do not exhibit plastic deformation. So, basically they only show the elastic deformation part and then, fracture and main thing is the nature of the bonding; because they have covalent or ionic bonds ok. They the dislocation cannot be introduced here because that will bring an additional ion at the end and that will not be we will not be able to maintain the charge neutrality there ok.

So, the deformation here is not cannot be through dislocation movement and that is why the ceramics usually fail without any plastic deformation. Although they have very high modulus, elastic modulus values are very high for ceramics. The concepts of a stress intensity factor which we discussed when we were discussing fracture can be used to measure fracture strength in the case of ceramics ok.

So, because again, the failure is through because of the defects which are present in the ceramic material and in form of small cracks or any flaws and basically when you apply any stress, they propagate and your material fail under compressive load ceramics.

So, much higher strength they are able to take compressive load very nicely because in the compressive load your cracks do not open up. In fact, you are closing them ok. So, ceramics can be used very nicely under compressive loading condition. So, that is why they are used where compressive loads are present. Measurement of properties ceramics are not subjected to tensile test.

So, the property measure or property evaluation in case of ceramics is not cannot be done through tensile test ok.

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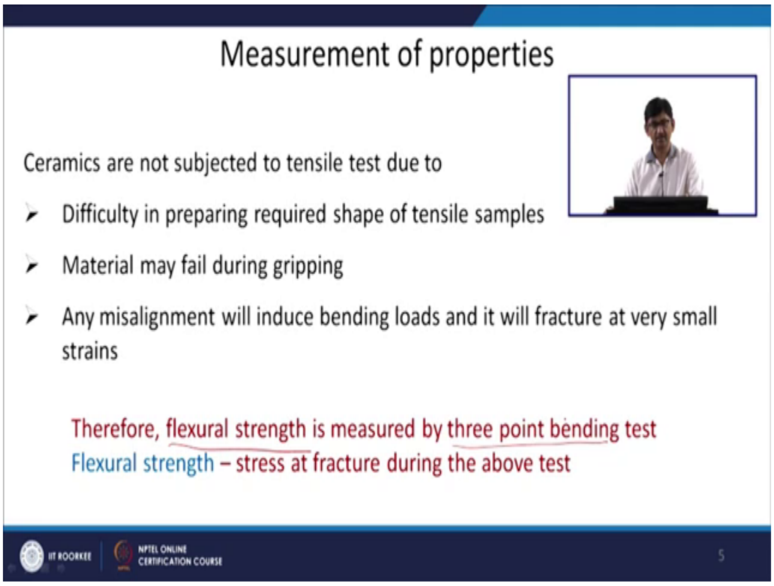

Measurement of properties

Ceramics are not subjected to tensile test due to

- Difficulty in preparing required shape of tensile samples
- Material may fail during gripping
- Any misalignment will induce bending loads and it will fracture at very small strains

Therefore, flexural strength is measured by three point bending test
Flexural strength – stress at fracture during the above test

The reason is first is the difficulty in preparation which is required for to create that shape of the tensile sample which we discussed earlier that what should be the shape of the tensile sample; creating that kind of shape this ceramic is difficult ok. Because you cannot do machining or you cannot do any other forming process to get that shape ok.

So, first thing is how to prepare that kind of sample. The other very important one is because for doing the tensile test we have seen that you have to grip the material and then, you have to extend the material. So, since these are very brittle material; while gripping the stresses which will be imposed on the ceramics that will be enough to break the material into pieces ok.

So, that is not possible. And during the test, if any misalignment is there that is going to impose some bending loads on the sample and it will fracture at very small strains ok; usually point one strain or so. So, that is why tensile tests are not the preferred way to find out the properties of ceramics. What we measure is the flexural strength is measured by a test called three point bending test ok.

And the Flexural strength is the stress at fracture during the this type of tests the three pointing, three point bending test whatever strength you get that is what is we will be calling as flexural strength.

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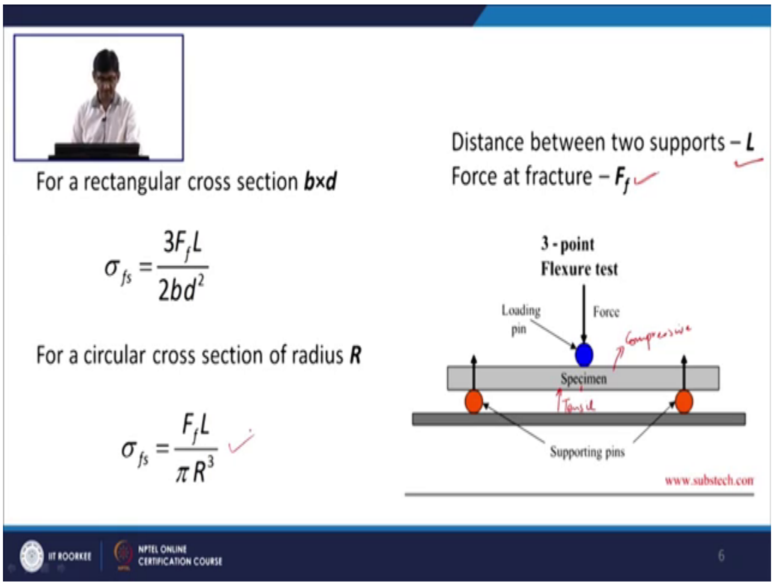

Distance between two supports – L

Force at fracture – F_f

For a rectangular cross section $b \times d$

$$\sigma_{fs} = \frac{3F_f L}{2bd^2}$$

For a circular cross section of radius R

$$\sigma_{fs} = \frac{F_f L}{\pi R^3}$$

And now I will show you that how it is done. So, basically we can take a ceramic simple rod like this and we can simply support it on the 2 supporting pins here and at the centre, we can apply a force F and this type of tests are called 3 - point bending test. Because you are supporting the material at 2 points and at the 3rd point in the middle we are applying the stress ok. So, what will happen? The material will bend under the load.

And if you are applying the force from the top, you will have Tensile stresses here and you will have Compressive stresses here ok. So, when it fractures the crack will propagate from some way it will initiate and start propagating from somewhere here and then it will go through the throughout the sample and we can measure that at what force this happened and that can be used to calculate the stress, it can take ok. So, the distance between the 2 supporting point is the we can say is L. The force which we measured using the load cell at fracture is f, sub f.

For a rectangular cross section having dimension of b by d ok; So, b is thickness and d is width; then, the equation for the flexural strength or the stress at fracture sigma f s will be given by an expression like this. Where, F f is your force at fracture. L is the length between the 2 supporting points and b and d other cross sectional dimension of the material. For a circular cross section of radius R ok, the expression will be slightly different which will be given by the expression given in the second case.

So using these values we will be able to calculate that what is the fractural strength of the material, ceramic material; So, this is what we are going to report in case of Ceramics. Now, next is Polymers what do we mean by polymers? The natural polymer which you must have come across a can be wood is one of the polymer.

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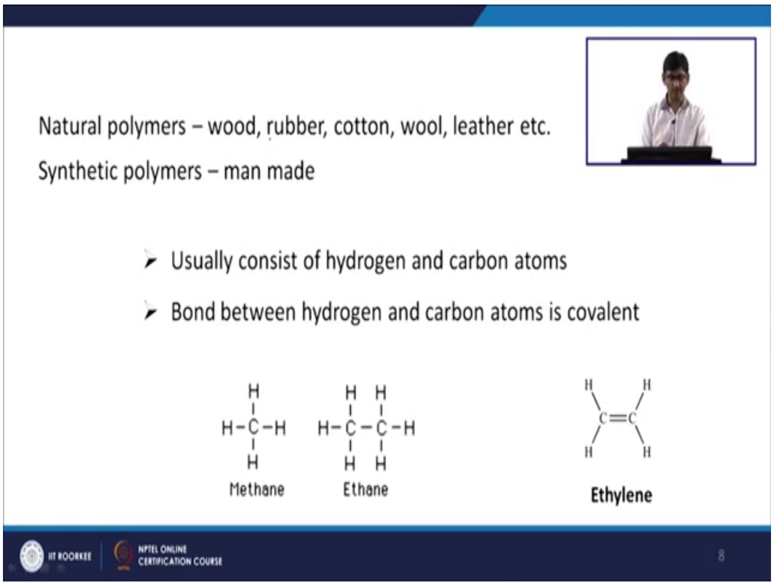

Natural polymers – wood, rubber, cotton, wool, leather etc.

Synthetic polymers – man made

- Usually consist of hydrogen and carbon atoms
- Bond between hydrogen and carbon atoms is covalent

Methane

Ethane

Ethylene

Rubber is another polymer; cotton, wool, leather. So, these are all natural polymers available to the mankind ok. Then, there are synthetic polymers which are made by men for their use and this polymer actually consists of hydrogen and carbon atom. Usually there are some other elements also some other atoms also can be added in the in the molecule ok, but usually they most of the polymer, the main component will be hydrogen and carbon atoms. And the bond between the hydrogen and carbon atom will be a covalent type ok.

So, it will be like this carbon atom is sharing each carbon atom is sharing one electron with each of the hydrogen atom to so that they have a stable configuration. So, in this case it is Methane, when it is sharing with 2 hydrogen atoms. If you combine the 2 carbon atoms and the remaining are shared by the other hydrogen atom; then, it is Ethane ok. If we do not have the 6 hydrogen atom; then, there has to be a double bond between the 2 carbon atoms in that case it is called Ethylene ok.

So, you can have different types of molecules which can be used to make a polymer by having different type of bonds between the carbon and hydrogen atoms. So, if you see the molecule of a polymer, these are called Macromolecules because they are very long chained molecules ok.

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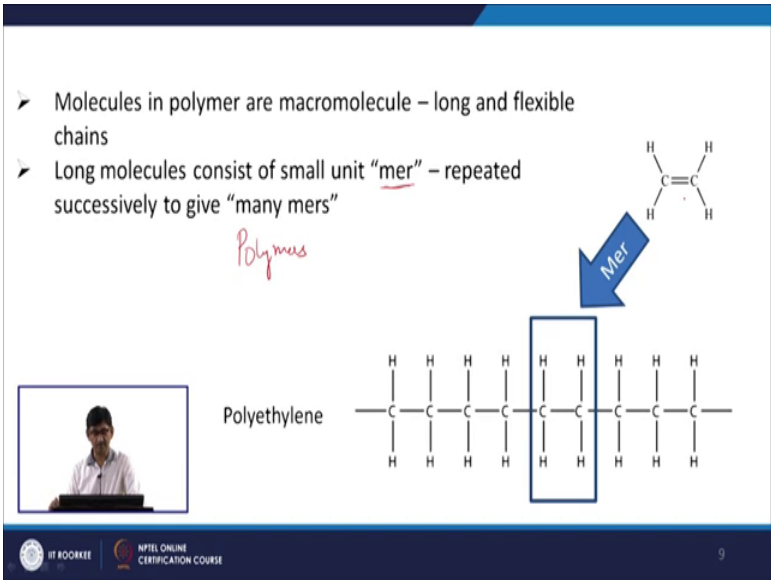

- Molecules in polymer are macromolecule – long and flexible chains
- Long molecules consist of small unit "mer" – repeated successively to give "many mers"

Polymers

So, one molecule may consist of very large number of atoms and it may be in like a chain form ok. So, molecules in polymer are macromolecules which are basically long and flexible chains and these long molecules consist of a small unit called "mer" ok. So, one small unit can be shown here which is basically Ethylene molecule; So, this is the "mer" and the 2 carbon atoms and 2 hydrogen atom attached to each carbon atom ok. So, this is one single unit which can be repeated. So, one unit is shown here ok, this can be now repeated again and again.

To make a big chain of more of these small molecules can make a big molecule. So, these are repeated successively to give many mers and that is why these are called Polymers ok; number large number poly means more large number. So, these are many mers which can be termed as Polymers ok.

So, this is a very popular Polymer Polyethylene ok. So, one ethylene can be combined together to create a long chain of molecule. The chain shape and structure if you want to see chains are not straight, but in zigzag shape ok. So, a chain can be like this also.

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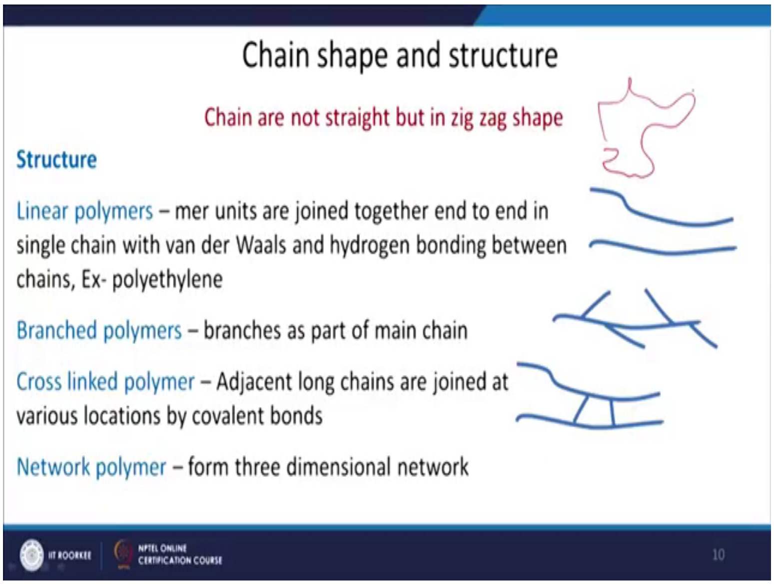

Chain shape and structure

Chain are not straight but in zig zag shape

Structure

Linear polymers – mer units are joined together end to end in single chain with van der Waals and hydrogen bonding between chains, Ex- polyethylene

Branched polymers – branches as part of main chain

Cross linked polymer – Adjacent long chains are joined at various locations by covalent bonds

Network polymer – form three dimensional network

May be something like this ok; very long chain and basically all these small molecules keep attaching to each other and you can make a very long chain like that ok. So, these are not straight chains, but may be arranged in a very zigzag fashion in the molecule, in the overall structure. So, we can define the structure according to this ok. So, linear polymers are basically mer units are joined together end to end in single chain with wonder wall forces and hydrogen bonding between chains example, Polyethylene.

So, basically in this case you have this long chains of macromolecules and there may be between the carbon atoms and the hydrogen atoms ok, there can be some van der Waals forces can be there or hydrogen bonding can be there between the 2 big molecules ok. So, you have 2 chains and between the 2 chains, there can be some kind of forces can be there ok. These are either van der Waals forces and or hydrogen bonding and in both cases we know that these forces are very weak ok.

So, you it is not going to hold it very strongly, you can have some relative movement between the chains ok. So, these are not very strong forces, but they can keep the molecules kind of together by having a small force acting on them. Another kind of polymers can be Branched polymers ok. In this case, you can have small branches coming out of the main big chain ok. So, these are called Branch polymers.

Then, you can have Cross linked polymers. In this case, now the 2 big chains are kind of connected with each other with cross linking ok. So, these cross linking's are there ok. So, adjacent long chains are joined at various location by covalent bonds.

So and then there can be a Network Polymer which forms a 3 dimensional network. So, you can see that as we are going from this simple type of arrangement to a Branch type and then to Cross linking type and to Network polymers, you can understand that the strength of the polymer will increase in this way ok; because it will be more difficult for you to deform the polymeric chains during when you are applying any stress ok.

Now, if you want to see in terms of crystallinity that whether there is any crystalline nature is there for polymers ok, the polymers can be divided into 3 types ok. An Amorphous polymer means there is no long range arrangement of atoms like what we see in metals that atoms are arranged in a very nice fashion according to the their crystal structure.

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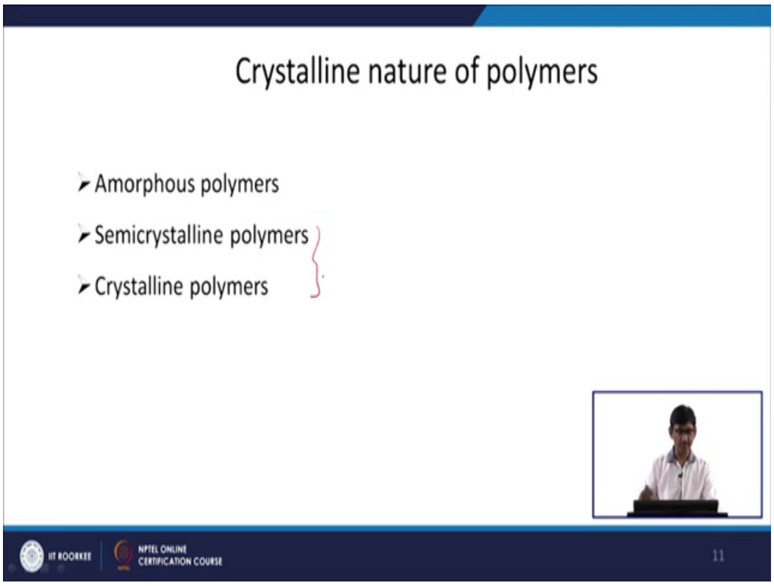

Crystalline nature of polymers

- Amorphous polymers
- Semicrystalline polymers
- Crystalline polymers

In case of Amorphous polymers, there will not be any arrangement of atoms ok. Then, there can be Semicrystalline or Crystalline polymers ok. In this case the atoms are arranged in a in a particular manner ok, you can have a repeated arrangement of atoms and you can do some exordia analysis to find out the crystallinity in the polymers. So, it is possible to have a crystalline nature of polymer; that means, the there will be some repeated arrangement of atoms in the in the polymer.

Now, coming to Stress - strain curves of polymers ok.

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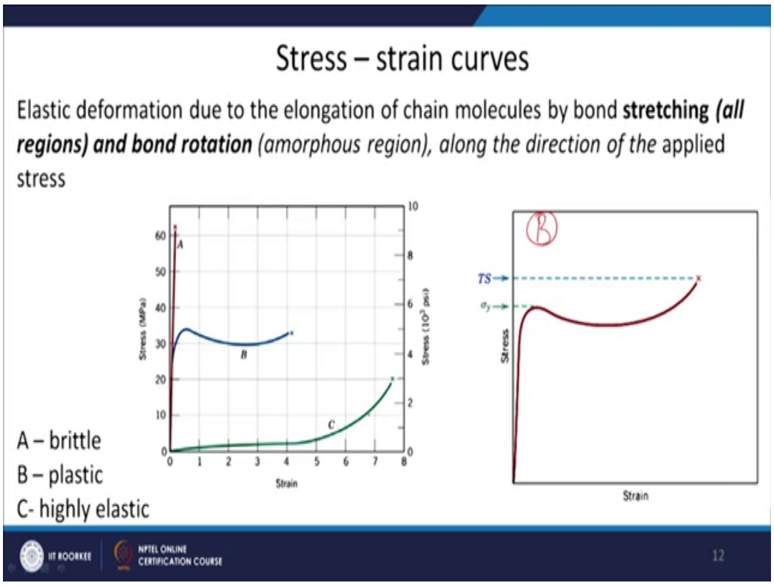

Stress – strain curves

Elastic deformation due to the elongation of chain molecules by bond **stretching *(all regions) and bond rotation*** *(amorphous region), along the direction of the* applied stress

A – brittle

B – plastic

C- highly elastic

The elastic deformation due to elongation of chain molecules by bond stretching and bond rotation, along the direction of the applied stress; So, the elastic deformation part if you see in the in the polymers ok, it is due to the bond stretching and bond rotation along the direction of the applied stress. So, in this case also the bond stretching will be there between the 2 atoms ok. Then, there can be 3 types of polymers are shown here ok. The polymer A; A is a brittle material polymer ok.

So, you can see that only the elastic part is there and then, the fracture took place. Then, there can be a plastic one which will which we which is shown here also. So, this is the B type here. So, it shows the elastic part here ok. Then, you have the yielding of the polymer and then, you have the plastic deformation and maximum stress at which the polymer will fracture.

So, this is a typical polymeric Stress - strain curve, for a polymer which shows plastic deformation. Then, for one which is shows very highly elastic deformation ok, you will not see this yield stress and then, the plastic part, but it will start deforming and you can see that the Young's the modulus is very small for this kind of polymers ok. So, it start deforming. So, very high strain is there without any corresponding increase in the stress ok.

And when the all the chains are kind of stretched, then you start seeing some deformation in the in the plastic, it also may not be plastic here; it will be still in the elastic range and then, it will fracture at this point ok. So, this is how the typical stress strain curves will be there for different types of polymers ok.

Now, we will come to the Composite materials. So, we are not dealing in a lot of details of these mechanical properties of these materials ok; just trying to get introduce you to different types of material that what how they behave, what is their structure and they have of course, in engineering application also they have uses now in different components.

Then there can be another class of material which is called Composite materials. So, in this basically you have two or more chemically different constituents combined microscopically to enhance properties ok.

So, in this case we add or we combine two different material which are chemically very different to each other and these are microscopically combined in a way that they, you can easily see that where the one constituent is there, where the other constituent is there. So, in the sense it is not very you cannot compare this with the alloys; where, you have precipitates or maybe some other phase ok.

Those are microscopically at the microscopic level you have in (Refer Time: 22:30) reactions to make those alloys ok; where is in composites, there are there are no in (Refer Time: 22:37) reaction we kind of add two different constituents microscopically means you can which you can easily manipulate and then, you make a composite of two different constituents ok.

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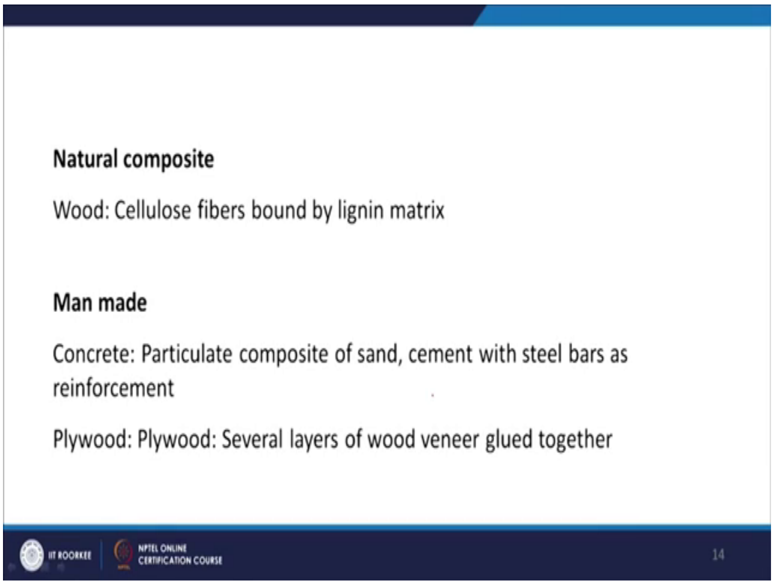

Natural composite

Wood: Cellulose fibers bound by lignin matrix

Man made

Concrete: Particulate composite of sand, cement with steel bars as reinforcement

Plywood: Plywood: Several layers of wood veneer glued together

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Some of the examples, Natural Composites, if you want to see one is wood which contains the Cellulose fibers bounded by lignin matrix.

So you have two different constituents are there and they are coming together to make wood ok. Man made, Concrete can be a very good example to understand ok. So, at one level you have a particulate composite of sand and cement ok, we are mixing them together cement is a separate constituents, sand is a separate constituent. So, it can be a particulate composite.

The other way of looking at it is when you make any column or beam ok, you add this mixture of cement and sand and you also have reinforcements in form of steel ok. So, this is now a composite of kind of fibre composite can be you can look at look at like fibre composite that a steel bar is there and around that you have cement and sand mixture ok. A Plywood is a very good example of composite ok; several layer of wood veneer is glued together. So, if you see a Plywood, if you cut it you will see there are individual layers of wood which is pasted together.

So, by making a composite like this, you can increase the strength of the wood and it these are very high strength material and that is why they are used in where lot of different application is a structural material also ok. So, Plywood is a very good example of composite.

Similarly, the RCC the reinforced concrete is a very good example of composite and that how the composite materials can be made. So, primarily composite consists of matrix as you can see in terms of wood that Plywood which we were discussing or and the concrete which you are discussing ok. So, it could will contain a matrix and then, it will contain a contain a reinforcement ok.

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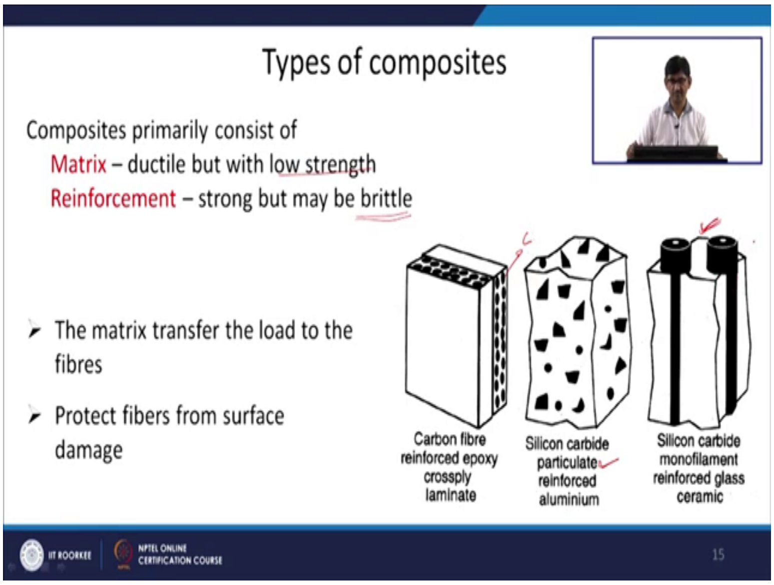

Types of composites

Composites primarily consist of

- Matrix – ductile but with low strength
- Reinforcement – strong but may be brittle

- The matrix transfer the load to the fibres
- Protect fibers from surface damage

So, the matrix is usually if you take metals or polymers ok, it will be ductile ok, but has low strength because the problem with the matrix is that though it is a ductile, but it has low strength. So, composite the idea of making composite is that you can combine the properties of two different material together to get enhanced property in the composites.

So, reinforcement can be in this case can be a strong reinforcement, but it will have a problem that it can it will be a brittle; it may have a brittle nature, though it may be strong, but it may brittle nature. So, you are combining two different set of properties here; one has a ductile nature, another has a brittle nature.

It has a lower strength this these have high strength ok. So, by combining when we have the composite, it will give you a properties which will be combination of these both and it can give you much better mechanical properties.

So, there can be different type of composites ok. For example, this one is a Carbon fibre reinforced epoxy crossply laminate ok. So, you can see that these are the carbon fibers and they are arranged in a crossply manner. So, in one case the carbon fibre is in this direction, in another ply and next play the carbon fibre is in this direction.

So, these are crossply type of laminate and carbon is there for reinforcement of the matrix ok. Similarly, there can be another type of composite which is called a particular composite ok. Particulate means the reinforcement is in form of particles.

So, these are silicon carbide particles and aluminium is reinforced with that. So, aluminium is a soft material, we know that it has a lower strength; although very good ductility. So, we are adding this silicon carbide particles in aluminium to increase the strength of the composite.

Then there can be this type of monofilament reinforced glass ceramics ok. So, Silicon Carbide monofilaments are there in the in the matrix to give to reinforce it. So, there can be different types of ceramics possible ok. This long fibers, may be short fibers or may be particulate ok.

So, in when we are going to discuss about mechanical property of ceramics, we will be concentrating on this long fibre which are one of the most important composites that what will be the, how you can find out the strength and modulus properties of a composite by knowing the individual properties of the matrix and the fibre. So, to find out that you can use Rule of mixtures.

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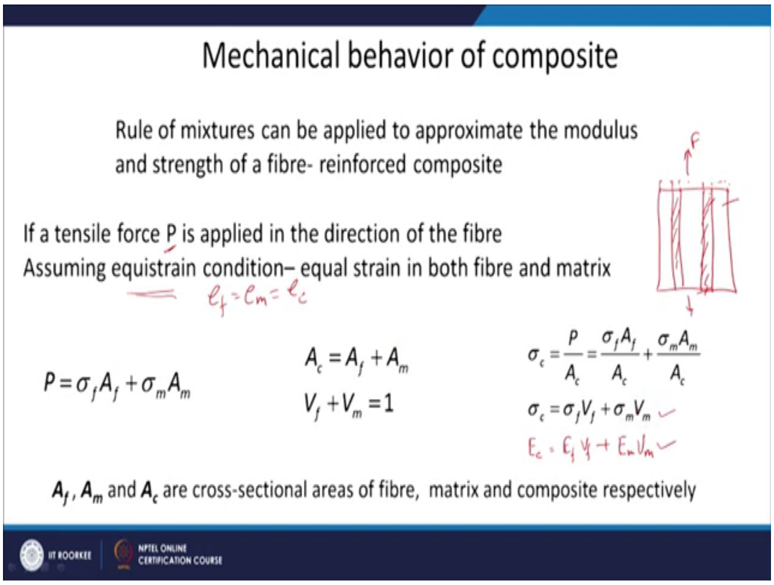

Mechanical behavior of composite

Rule of mixtures can be applied to approximate the modulus and strength of a fibre- reinforced composite

If a tensile force P is applied in the direction of the fibre
Assuming equistrain condition– equal strain in both fibre and matrix

$e_f = e_m = e_c$

$$P = \sigma_f A_f + \sigma_m A_m$$

$$A_c = A_f + A_m$$

$$V_f + V_m = 1$$

$$\sigma_c = \frac{P}{A_c} = \frac{\sigma_f A_f}{A_c} + \frac{\sigma_m A_m}{A_c}$$

$$\sigma_c = \sigma_f V_f + \sigma_m V_m$$

$$E_c = E_f V_f + E_m V_m$$

A_f, A_m and A_c are cross-sectional areas of fibre, matrix and composite respectively

The Rule of mixtures can be applied to approximate the modulus and strength of a fibre-reinforced composite. So, if a tensile force of P is applied in the direction of the fibre. So, if fibres are arranged in this manner along vertically for example, then if I am applying the stress in the vertical direction ok, if I assume that equestrian condition is going to be there equestrian means when I am applying the force.

So suppose, this is your matrix and in this I have fibers like this that say I put some hedged and up I am applying the stress here ok. So, some force I am applying let us say. So, when these are going to deform ok.

So, if there is any in there are no defects between the between the or there is no introduction of defect between the fibre and the matrix and you have a very good bonding of fibre and matrix; what will happen? Both have to deform simultaneously ok. So, after some time suppose, it deform to this much dimension ok. So, it gets elongated in this direction, then the strain in both the matrix and the fibre will be has to be same ok; If I am applying stress like this.

So, this is a condition called equistrain condition. So, in both the constituents the strain is same ok. So, basically what we are trying to say here is that strain in f the fibre is equal to strain in the m which is matrix and that is the strain in the Composite. So, all the three cases the strain is going to be same; if that is so, then I can use a Rule of mixture kind of condition here that the force P can be divided between the fibre and the matrix in this form.

So, sigma f is the force stress acting in the fibre, if I multiplied by the area of the fibre. That will give me the force of in the fibre and similarly, this is the stress in the matrix this is the area of the matrix if I multiply by that then, I will get the force in the matrix. So, when we are saying that this equistrain condition will be there ok. So, force will be divided between the matrix and the fibre according to their area that whatever area they have ok. So, force will be divided between that constituents ok.

So, I can write an equation like this to express the force total force on the system. Now, A c the area of the composite will be basically area of the fibre plus area of the matrix and in terms of volume fraction if you want to see, I can say that the volume fraction of fibre plus volume fraction of the matrix will be equal to 1; 1 means it will be the total volume. So, in terms of fraction if you want to see, it will be equal to 1. So, I can express this stress system here, if I divide P by the area of the composite, then I will get the stress on the composite.

So, it will be sigma c equal to P by area of the composite which is equal to as equation suggests here sigma f A f upon area of the composite plus sigma m into m upon area of the composite. Now, the area of the fibre divided by area of the composite ok, if you remember again our the one of the lecture where we were discussing about quantitative (Refer Time: 32:30) metallographic that the volume fraction whatever you get in the air in terms of area fraction can be considered as the volume fraction from statistical analysis.

So, area of fibre divided by total area of the composite will give me the fraction in area and that I can say that it will be also as fraction in volume ok. So, this will be now sigma f into f by A c will be written as V f here and m by A c will be written as V m here. So, this is volume fraction of matrix. This is volume fraction of fibres ok. So, I can write a simple Rule of mixture kind of equation like this to get the stress of the stress in the composite.

You can in fact, write for the modulus also; modulus of the composite will be equal to modulus of the fibre into volume fraction of the fibre plus modulus of the matrix into the volume fraction of the matrix ok. So, I can write it for modulus also as I am writing for stress to get what will be the modulus of the composite ok. So, these two equations we have to kind of remember by using rule of mixture.

So, depending upon what is the volume fraction of fibre, it will have that much contribution to the total composite stress or strength and similarly, what is the volume fraction of matrix that will be contribute to the total strength of the composite. Now, if you want to see the Stress - strain curve in terms of composites ok.

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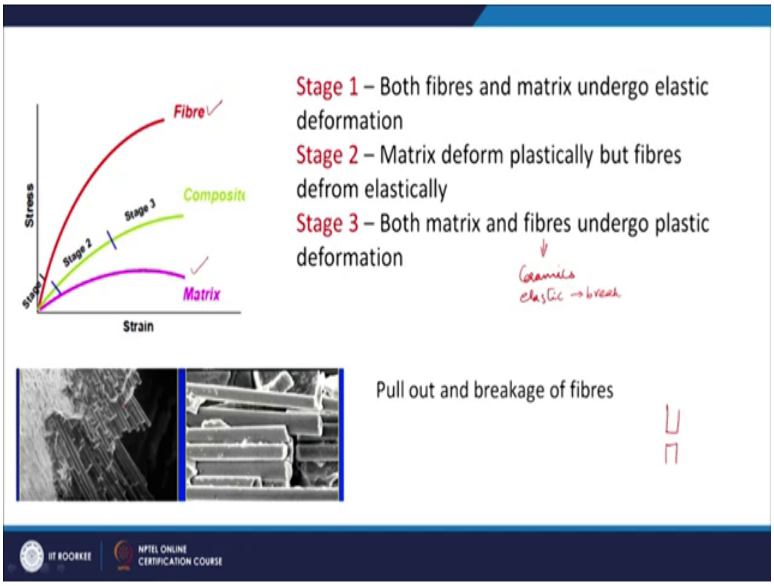

Stage 1 – Both fibres and matrix undergo elastic deformation

Stage 2 – Matrix deform plastically but fibres defrom elastically

Stage 3 – Both matrix and fibres undergo plastic deformation

↓
Ceramics
elastic → break

Pull out and breakage of fibres

So, for example, for a matrix is the stress-strain curve is like this which is having lower strength and lower modulus and so on. The fibre is very stiff it has higher modulus higher strength and so on. But have lower ductility. So, we can have a composite of these two to get strength in between the modulus of in between the two ok. So, we get a good compromise of property between the two, the matrix and the fiber.

So, if you see the deformation of the composite, it can be divided into 3 stages. So, in Stage 1- Both fibre and matrix undergo elastic deformation up to this point. Stage 2 - Matrix deform plastically but fibres deform elastically ok. And Stage 3 - Both matrix and fibre undergo plastic deformation.

So, if the fibre is not does not exhibit any plastic deformation for example, the fibre is made of ceramics, just for an example; it does not show any plastic deformation then, the whole deformation throughout the deformation of the composite. This will show only the elastic deformation whereas, the material is showing the plastic deformation and we know that it is it will show the elastic deformation and then, it will break though the matrix will keep on deforming plastically.

So, when it breaks the crack will propagate through the improve the ceramic, but because these fibers are surrounded by the matrix, the ductile matrix this crack will not go beyond the matrix and in the matrix the crack will be blunted ok. It will it will not be it will not remain as sharp. So, by doing this kind of making a composite what we are doing is that the if any because of defect any one fibre breaks also, the crack is not propagating throughout the material.

If the whole material is of ceramic, what will happen a if crack start propagating, it will propagate throughout the volume of the ceramic and the whole material will fracture. By making a composite what we are doing is if any one fibre breaks because of any defect in that ok, the crack will be limited only to that fibre; only that fibre will break and it will not the crack will not propagate beyond that fibre because around that fibre there is a ductile matrix.

So, if you keep on deforming the material and all the fibers will keep on breaking and the remaining material will deform plastically, what you will see it after the after the deformation if you do the analysis of the fracture sample. You can see that these fibers are broken in a brittle manner with a faceted kind of fracture in which the material is divided in two part and there is a planar fracture here and it the matrix a the fibre has pulled out ok.

So, material is deform is a has been deform plastically and is been there is a deep bonding between the fibre and the matrix. How can the fibre are pulled out? You can see here also that fibre are pulled out of the out of the matrix. So, they deform elastically and then, the fact the it fractured whereas, the matrix deform plastically and later on there will has to be deep bonding between the matrix and the party and the fibre ok.

So, with that we have covered one class of materials that is Ceramics, Polymer and Composites and Ceramics are one of the very important ingredient of any composite ok. Lot of composites are made using Ceramics and Polymers also because they do not have very good strength, they are usually strengthened by adding some kind of fibers or any other reinforcing material to increase their strength. So, using this class of material, you can make another type of material which is Composite and that is very useful for engineering application ok.

So, Thank you.