Basic Construction Materials
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Lecture – 17
Nature of Materials 4 – Part 7

Hi, in this course on basic construction materials, this is the module on the nature of materials. It is the fourth lecture in that module, and we will be looking at inorganic and organic solids.

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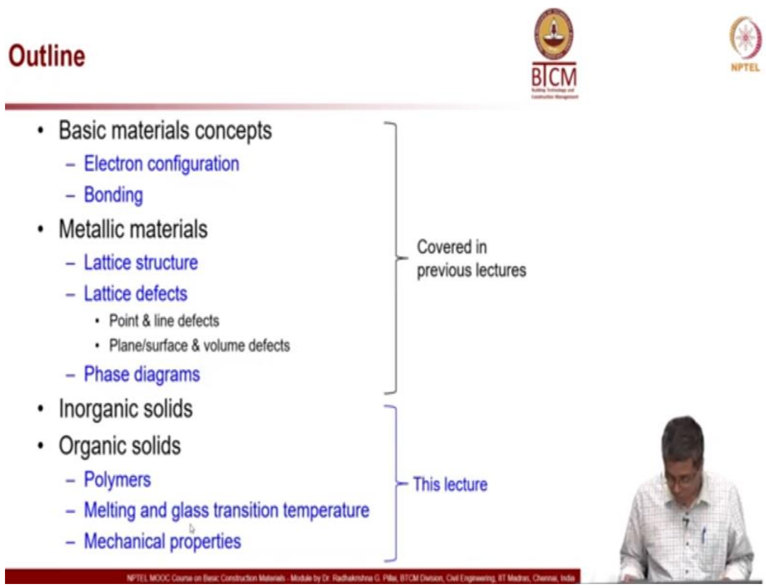

In a previous couple of lectures, we covered in this module the nature of materials. We covered electron configuration, bonding and the lattice structure, and defects in the lattice structure in different dimensions. And then, we talked about the phase diagram. Today in this lecture, we are going to talk about inorganic solids and organic solids.

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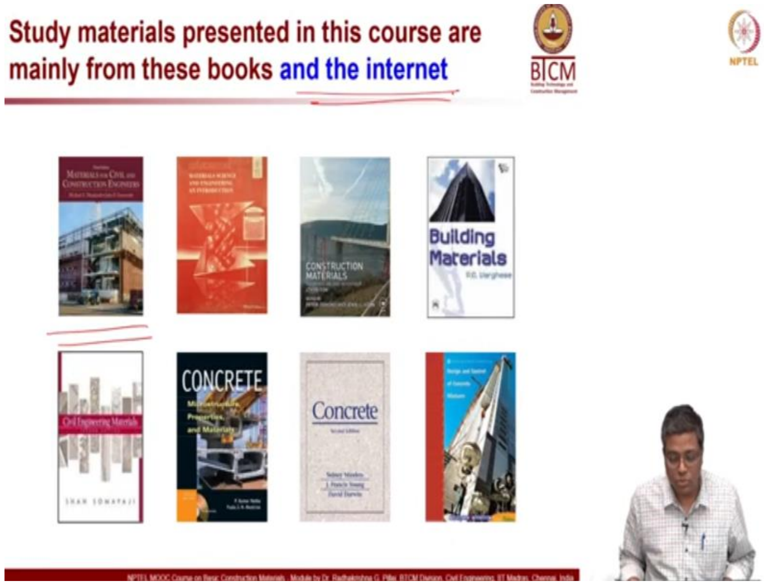

These are the reference books. Today's material is coming from the book by Mamlouk and Zaniewski. Different photographs or sketches from the internet have been used for demonstrating various things.

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Now, inorganic solids are non-metallic elements or a combination of metallic and non-metallic elements. Moreover, they are also known as ceramics, mainly because they have ionic and covalent bonds. These are the two major types of bonds we will see in these materials and different classes. These inorganic solids can be divided into five different classes. The first one is glasses mainly based on silica.

And then the second one is vitreous ceramics, and it is essentially like bricks or pottery, which are essentially clay products. And the third one is cement and concrete, again a multi-phase material with different things present inside as different phases and rocks and minerals. Also, we have some high-performance materials that are artificially made to have specific performance characteristics.

Both in terms of mechanical and in other, it can say thermal characteristics wire resistance so, many other properties we know can be possible, here are some examples shown. Furthermore, they are used for machine tools, and I will show some examples later. Once we know the problem with all these ceramic materials in general, they have poor fracture toughness, and then we handle that problem by doing specific engineering to the product.

That is, for example, if we take cement and concrete. Concrete has a very low toughness, or fracture toughness of plain concrete is relatively low. So, how do we handle that is by putting the steel reinforcement or steel fibers which are good in tensile properties. Then we mix them and make them like composite material. Essentially, our reinforced concrete is a composite material.

So, the steel rebar takes care of the tensile properties required, and the concrete takes care of the compression and also the steel reinforcement, it helps in increasing the toughness as we as compared to a plain concrete system and also we are now fiber reinforced which we discussed earlier different systems are available to increase the toughness.

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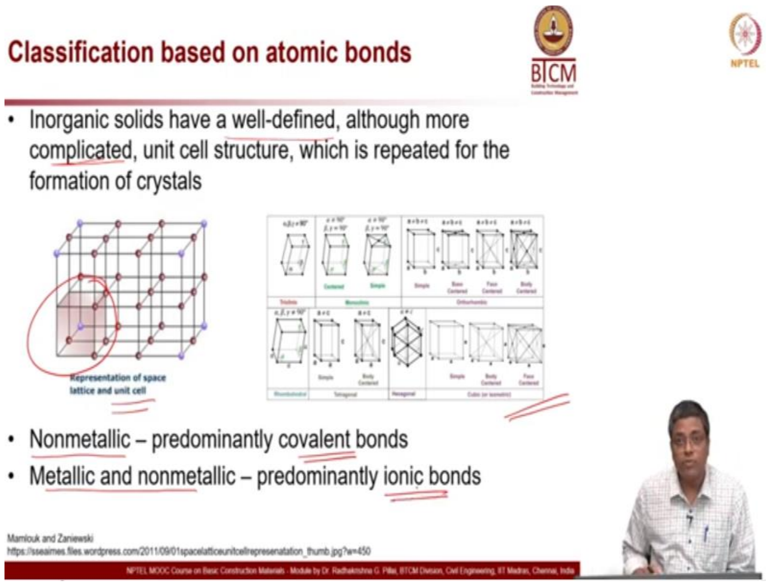

Now, classification of inorganic materials based on atomic bonds. So, they have a well-defined, although more complicated, unit cell structure repeated for the formation of crystals. So, these are just a recap of what we already discussed in the previous lecture. So, we can see this is a unit cell-like here, and these are different types of the unit cell that can be present in various materials. In the case of non-metallic materials, inorganic solids can be fully nonmetallic or a combination of metallic and nonmetallic materials.

So, in the case of non-metallic materials, we will predominantly see covalent bonds and inorganic solids with both metallic and non-metallic materials. We will mainly see ionic bonds, just a difference in terms of atomic bonding nature.

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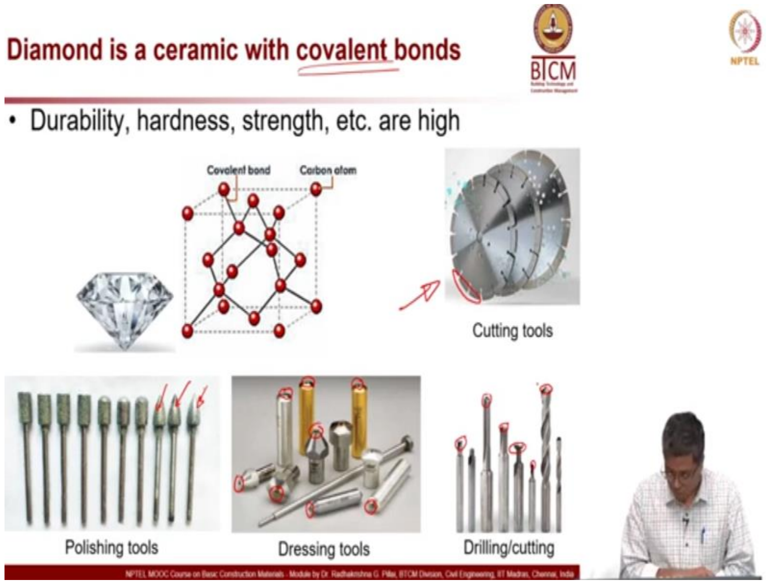

An example of an outstanding ceramic is diamond, and it has covalent bonds like this previous slide. I showed non-metallic means covalent bonds. So, the diamond is an example of that, and we use diamond in construction for cutting as cutting tools, as drilling tools, dressing tools, or polishing tools. So, these are different types of tools that are used even in construction.

So, I want to ensure that this cutting tool we see is not that the entire blade is made out of diamond; we have only a tip of the tool because it is very costly.

Now here we have polishing tools having a diamond coating on this. So, we can see diamond coating; here on the right side drilling and cutting tool, we have diamond-tipped. So, the tools are targeted for that, or some specific points on the tools, where we want the tool to be very hard and at the same time strong, so that we can cut the material, and only there we put the diamond tips, and they are also durability is very good in this case.

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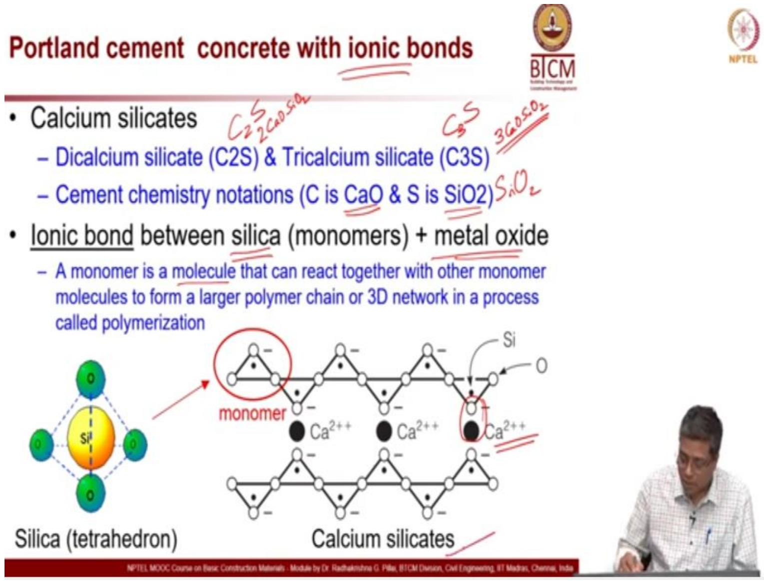

Another example we come across in construction is Portland cement concrete widely used material. It has mainly ionic bonds. So, when we talk about cement or hardened cement. We have two major metal complexes: dicalcium silicate and tricalcium silicate (C_2S and C_3S).
We must know that in cement chemistry, C is not carbon; it is Calcium oxide (lime) (CaO), and notation S is Silicon dioxide (silica)(SiO_2). Dicalcium silicate means 2 CaO and SiO_2, and tricalcium silicate means 3CaO and SiO_2. Now in this ionic bond is formed between the silica and the metal oxide.

So, let us look at what is the role of silica and metal oxide here. So, this is the silica, a typical tetrahedron structure of silica, and on the right side, we can see these white circles over there and that triangle formed with a dot that indicates this is a tetrahedron. Now that is a single element or a monomer. So, these multiple monomers will join together to form a polymer.

A monomer is a molecule that can react together with other monomers to form a larger polymer chain or a 3D network; it is not like the straight line; it could grow in different directions, and this process is called polymerization. So this is what happens, and then there is a bond formed between the calcium here and the metal oxide or calcium oxide and the silica monomer in case of concrete or cement paste.

So, in this region, we will have an ionic bond formation. So, that is a typical portland cement concrete system or portland cement system, to be precise. So, this is calcium silicate.

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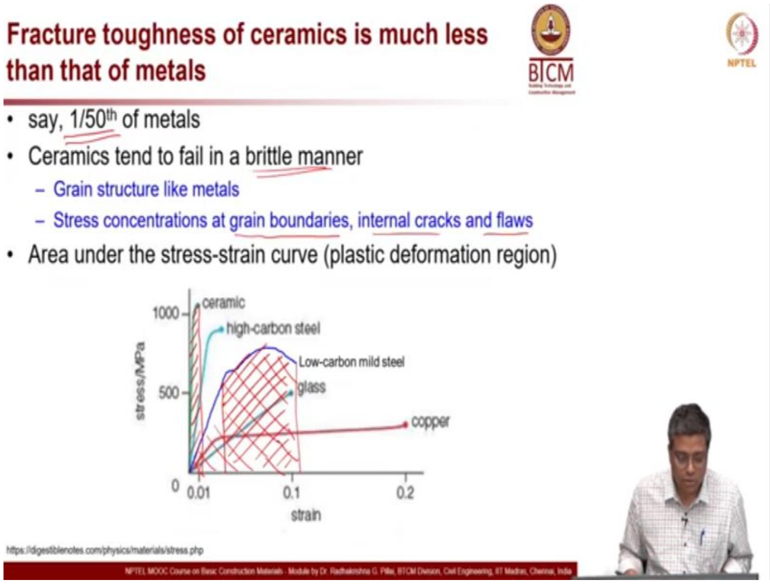

Again, we just discussed the fracture toughness previous to the previous slide, and we know it is much less than that of metals. It could be even 1 / 50th of that of metals. So, it could be very low, very brittle. So, they tend to break in a brittle manner. And like, we have grain structure in metals, we have a similar structure in ceramic materials, and stress concentrations can happen at grain boundaries; also, there could be internal cracks and flows. So, these are the weak locations at which stress concentration can happen and then propagate and then leading to failure or fracture of the material in a brittle manner.

Now, let us look at an example graph here, we can look at this graph, so, this is a ceramic material the first curve, so, we can say this is a vertical line if I draw there, so, I can say this is the area under the curve. For that area under the curve, and if I compare that with, let us say high carbon steel or let us say low carbon steel, I have this area under the curve. If I consider the area in the post elastic region still I have an extensive area, I can say that low carbon mild steel shown there will take much more energy before it can fracture into two pieces. So, the area under the ceramic curve is much less than that below the low carbon mild steel. So, like this, we can take stress-strain curves and then find out the fracture toughness or the energy required to break the material.

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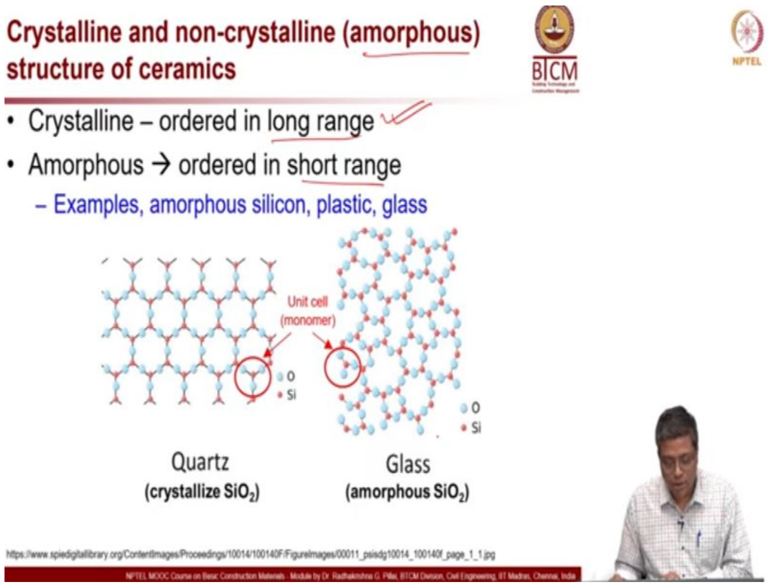

Crystalline and non-crystalline structure, so ceramic materials can generally have two maybe more. We will see the third one later, but in general, we say crystalline and non-crystalline structure. Furthermore, this non-crystalline is also known as amorphous; usually, we will see this word amorphous when we read articles. Now, crystalline when we say they are ordered in a longer range, so look at the first picture.

The first sketch below shows that this entire picture or entire sketch here is well-ordered, whereas I do not see an ordered structure if I look at the right one. So, that is more of an amorphous or a non-crystalline structure. Now, both these we see those two circles red circles over there. So, both these are formed with monomers like this one, and this one, we can see, monomers like the same type of building blocks are still there.

In both these left and right, quartz and glass, we have identical monomers present. However, when they are arranged in, we know, in a larger volume, in the quartz case, we have a very good, very well structured in the long-range means larger volume is in a proper structure or in an ordered manner. Whereas in glass, that orderliness is only for a very short range, it is not for the enter or the larger volume.

So that is what we mean by long-range and short-range, or we can say large volume and small volume. So, here in the second case, it is not well structured, and also, we can call it either non-crystalline or amorphous. Moreover, we will hear this term in many classes in the future, so it is crucial to understand them.

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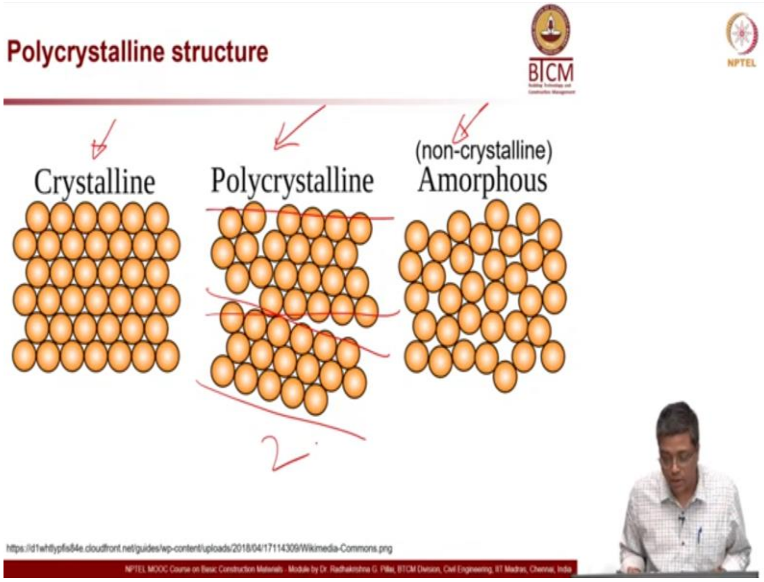

Now, there is also one which is in between these two, which we can call polycrystalline. So, we can see here the crystalline structure. On the right side, we have non-crystalline, and now in the middle, somewhere in between, we have a polycrystalline structure. So, we can see here in this polycrystalline this is one crystal shape, we know, a pattern and this is another one, so, we have two crystal structures shown there. So, polycrystalline.

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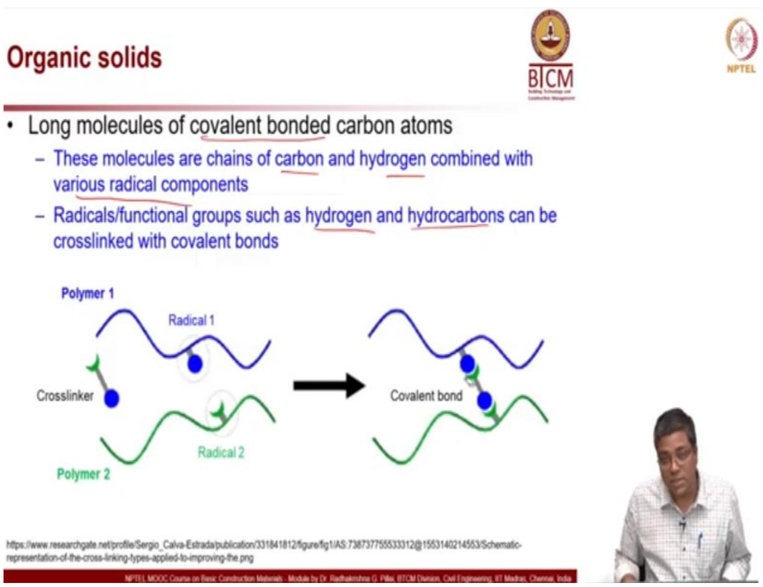

Now, that is about the inorganic solids. Now, we will talk about organic solids. Now, these are long molecules of covalently bonded carbon atoms. And these are chains we know, these molecules are like we can see in the picture at the bottom we have polymer, I am going to call it the blue color and then polymer two which is green color. So, these molecules are chains of carbon and hydrogen combined with various radical or radicals or functional groups.

That is another term, and for example, functional groups such as hydrogen or hydrocarbons can be crosslinked with covalent bonds. Now, we can see here closely. So, I have this blue, this is one polymer chain, and then this green one is another polymer chain. Now, when they are combined, so, we have a covalent bond formed here. So, we have a radical on the radical 1 or radical 2 or functional group 1and 2.

Moreover, that will combine to form a covalent bond, as we see here, in the second case. Now, we can call this also a crosslinker, so these crosslinks change the behavior of the material. So, in the future slides, we will see how vital these crosslinks are, we know, even in some of the advertisements we can hear like, when we talk about paint, crosslinking polymers are used in paint. So, that helps them preventing the cracking of the paint.

So, in the wall surface, we will not see much cracking because they have this crosslinking polymer, which changes their elastic behavior a little bit of we know, there it takes more deformation for that to crack. So, these chains are crosslinking chains. They help in changing the properties of the material itself.

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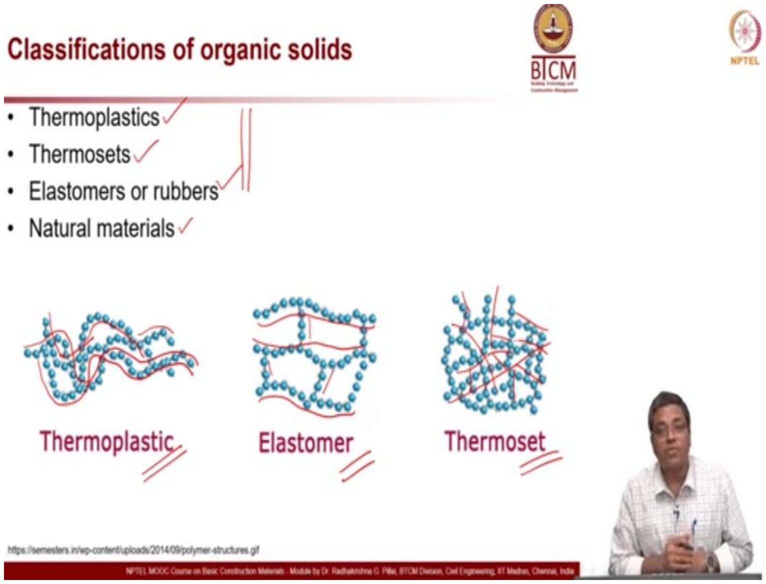

Now, in general, the organic solids can be classified into thermoplastics, thermosets, elastomers or rubbers and natural materials, I am not going to discuss too much detail here, because it is mainly wood or even asphalt for that matter, we can say we know, crude oil in the processing to which level it is processed because it is essentially a naturally available material even though we do have some processing there. So, wood is an excellent example of natural material which we use in construction.

So now, we will discuss these three in the coming slides. So, before we go into the coming slide, let me just briefly explain what the significant difference between these three could be or are so, we can see the thermoplastic we have these different all these we know we can see like 1 chain which goes something like, let me just do it is starting here, it goes like this and then this is1 chain, another chain, if I want to track, could be it comes like this. It goes like this, that is another chain and another chain we can maybe plan this one, this one we can consider us as another, so there are multiple chains in this in the structure.

And they are not connected; that is the main thing to notice there. They are not connected. In the case of elastomer, we can see there is one chain, another chain, and some crosslinking happening in between. However, that is of similar nature material. And now thermoset, we can see there are multiple chains and are crosslinked a lot. So, they are crosslinked. So, this is the significant difference between these 3 class groups of materials thermoplastic, thermoset, and elastomers. Now, we will look a little bit more detail into these.

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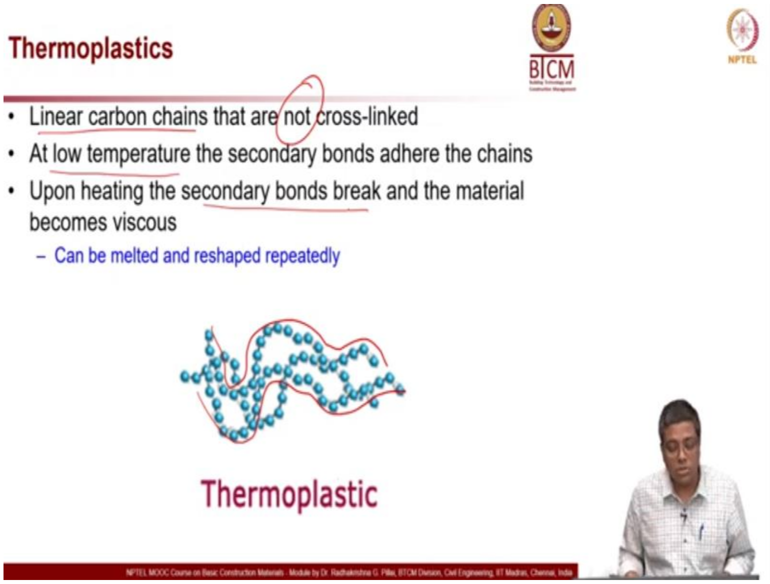

Thermoplastics, as I already mentioned, have linear carbon chains that are not crosslinked. So, it is not crosslinked that is the main thing. So, they are just linear carbon chains; follow on this and maybe another one. I mean, we can try which drawing belongs to which chain, so, anyway, multiple linear carbon chains are not crosslinked. Now, when the temperature is relatively low, the secondary bonds are there, the chains. But upon a bit of heating, what will happen is these secondary bonds can break, and the material becomes viscous they tend to flow, or they starts flowing we know and then so, this is a good thing in we know, when we talk about the reuse of materials, we can use the same thermoplastic material, melted and then reform into a different shape. So, we can reuse it. So, in terms of sustainability, this will be a suitable type of product to use because we can increase the reusability of this material.

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These are some of the examples of thermoplastics, we can see polyethylene. We use a lot of these in various pipes, polypropylene also we use. So, we will see that, we know, many of our construction sites, we will have a lot of these plastic materials being used, these are some of we know, for electrical wiring or we know, some containers for different types of materials which we see in our day to day life, we use all these materials a lot.

Plastic is probably we cannot live without plastic I think today it has reached that level, everywhere we use it but what we have to see is, because they have very high carbon footprint all these materials so, we have to see how to minimize or probably reuse these materials as much as possible. Now, polytetrafluoroethylene is also known as Teflon, which is widely probably known to we.

We know that they have been used for this nonstick cooking ware at home. However, one crucial use which is in terms of construction is that we use for gaskets or sealing, etcetera because they have very good adhesion property and excellent heat resistance that is why it is used for cookware. However, the main thing is low friction and adhesion and so, we know, very widely used for we know making watertight connections etcetera in pipes.

We will see that in the future or whenever we see at the site, etcetera, we will see where Teflon tapes are being used. When we put two pipes together and coupling in between the threading, we will provide that. Another example is polystyrene which is very widely used for molded objects and PVC, and its full name is polyvinyl chloride. Moreover, it is used for water pipeline electrical conduits; I am just citing a couple of examples.

But we will see that we know most of these materials are used in a variety of products and nowadays it is becoming more of a general-purpose plastics, many places we will see different plastic forms, we know even pipes which we see there are other types of products also not only what is shown in this paper in this slide. So, PVC pipes are also some heavy-duty pressure pipes, and on the one on the right side, we can see that thickness is very high.

So, it can also be used for some pressure hoses. Of course, there will be limitations on that. Sometimes we also reinforce the pipes with some fibers embedded inside the pipe's wall. So, there are different applications, and tailor-made products will be there.

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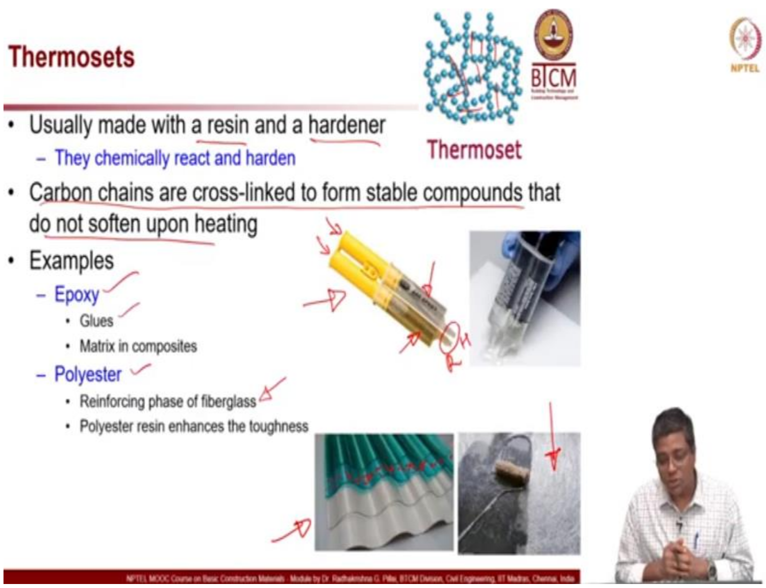

Another set of plastics or thermosets are usually made with resin and hardener. What they do is when they are mixed, they chemically react and then hardens to whatever shape we are putting them in. When I say chemically react, we can see how it is used this we can see maybe before that, I will just explain what they are carbon chains are crosslinked to form stable compounds that do not soften upon heating.

In the case of thermoplastics, we saw that when they get heated, then wer chains are, we know, the secondary bonds are broken. Then it starts flowing, or the viscosity decreases, but in this case, it does not change its viscosity, and these very stable products are formed in the case of thermosets. So, we can see here there are many crosslinks here. So, which are probably very difficult, or they need higher energy levels to break them.

Examples are epoxy and polyester. Epoxy is widely used as glue. This is one example as we can see here, this is a glue which is widely used in construction, we can see there are two tubes connected and what we do is we we know press these two together with our fingers, and it is like a syringe. So, an equal amount of material comes out of the two syringes we see 1 and 2. Thus, an equal amount comes out, and then we mix it. So, one is resin, and the other one is a hardener, and then we mix it very well.

So that the 50-50 combination part 1 part 2 or Part A Part B like that, they will be mentioned in the products and we mix them and then the as we once we mix it they react and then form a solid, stable compound which cannot be which is very stable and then will not change its properties. So, quickly upon heating and we cannot melt it and regain the shape is also one disadvantage of thermosets.

And these are also used for the reinforcing phase we can see here in fiberglass we can see here some fibers over here they are polyester fibers which are kind of spread and functions like reinforcing material when we talk about fiberglass sheets or even we know car body if we look carefully we will see that there are some fibers in that and that is sometimes fiberglass is used I mean there could be other products also.

However, I am talking about first-generation products used for car body; once the metals people stopped using metals, they started using fiberglass. So, this is one use of fiberglass in construction we use that for different types of sheets. So, in this picture, it may not be evident, but we will have tiny fibers in all these; if we look carefully next time we see a transparent or any roofing material, we might probably see some fibers present inside a composite behavior it gives.

So, fiberglass provides that tensile strength or the toughness which is required, whereas the remaining material usually provides the volume and then makes sure that it has a definite shape also.

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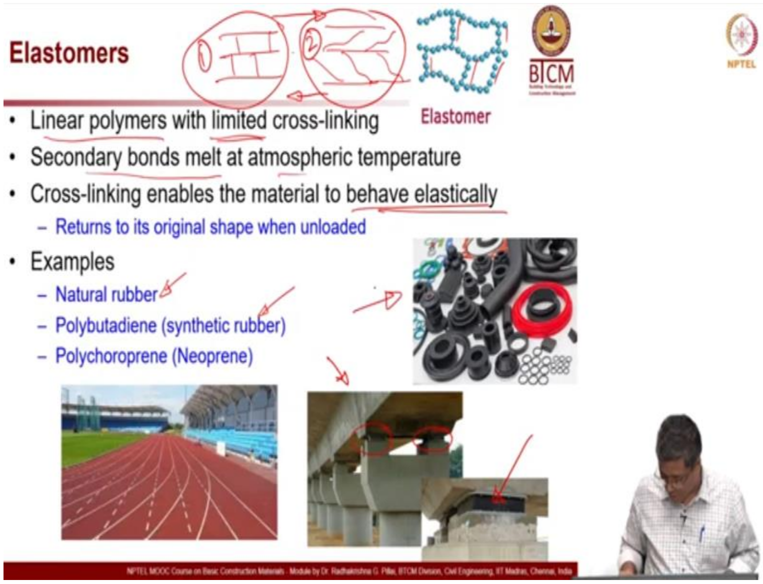

Now another material that again comes in the category of organic solids is Elastomers. Again, these are linear polymers, like the earlier we talked about, we know, this one thermoplastic. In the case of thermoplastics, they did not have crosslinking chains, but here, they do have but are very limited. So, we can see here one here, very limited crosslinking, and now the secondary bonds which are present melt at atmospheric temperature.

And then crosslinking the presence of this limited amount of crosslinking chains enables the material to behave elastically. So, what does it mean when I say it behaves elastically means when I pull, it will try to come back to its original shape when it is removed or unloaded. Now, for example, if I say this particular thing, if I pull here and hear some of these crosslinks, we will realign them cells until it becomes stretched.

And when I remove the load, it will come back again to the original shape. So that is what it means how these chains help in So, I can probably show let us say this is something like this chain is like this, so, I put push this put this force here, then what happens is it kind of becomes something like this. So, this change will rearrange, and when they rearrange, it will elongate, and so, when I apply the force, it will take this shape. When I release the force, it will come back to this original shape.

So, if I am going to call this as first and this is the second case, so, when we apply the load before application of the load, the structure is like in one that is here, when we apply the load, the structure becomes something like this in 2 and then when we release the load, again those cross chains will come back to its original shape which is like in 1. So, we have an elastic behavior; what are the examples for this, we have natural rubber, and then we have synthetic rubber.

Now, we have a lot of sports complexes and many applications where synthetic rubber is used. And then also primary application in construction is when we talk about bridges. Now, there are some changes in that, but there are many bridges where these types of neoprene pads are used. So, we can see this bridge here, so what I am talking about is this point here: the girder on the top of the actual bridge element or the girder is resting on the columns or pillars, so, where they are touching each other.

That is where we provide rubber or these neoprene pads to see this black piece; here is what I am talking about. So, they put this neoprene pad so that there is a proper load transfer happening from or kind of shock absorber. It is not that proper load transfer; we kind of dissipate some of the energy because of this shoe. So that the columns, we know, some of the vibratory load coming from the girders do not get transferred to the column.

So, anyway, they provide good necessary energy dissipation over there and then help the bridge to function the way it needs to function. Furthermore, there are also a lot of other products which are made of these elastomers.

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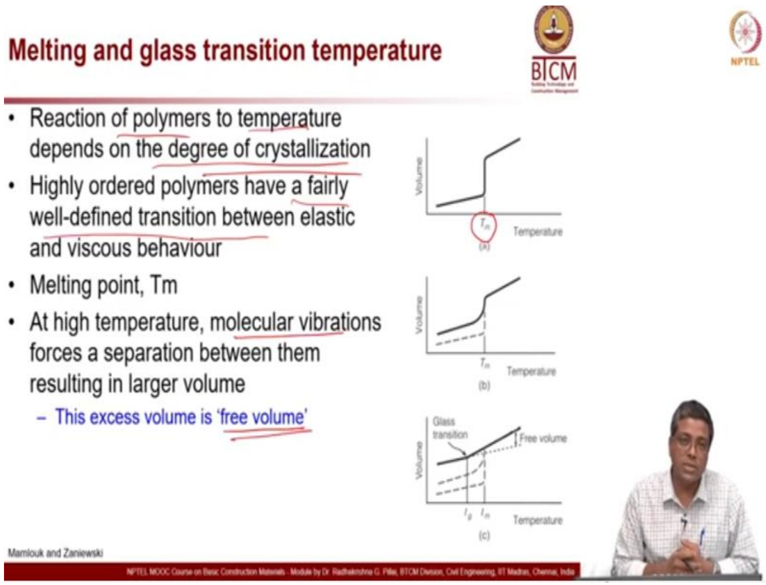

Now, and all these organic salts we have or the solids we are talking about now, ceramic materials we have melting, and glass transition temperatures, two properties I just want to talk about are melting. Let us first look at that. So, in the reaction of polymers to a temperature, we see that when the temperature changes, the crosslink breaks or it moves or it gets elongated, and it behaves the material behaves differently.

So, the reaction of all these polymers to temperature depends on the degree of crystallization and how well the crystal structure is. That will influence the relationship between temperature and the behavior of the polymers. Now, highly ordered polymers have a reasonably well-defined transition between elastic and viscous behavior. If I look here, we can see this graph A where I am talking about melting point Tm.

So, we can see that when it reaches here very well defined melting point. Now, this is a case with a highly ordered polymer melting point, and we can very clearly see that at this particular point, the volume increases that means significantly, the material starts melting, and when it starts melting means what happens is when the temperature increases, there are molecule vibrations. Because of those vibrations, they tend to get separated, creating some volume between, or we know, they tend to get separated and occupy a larger volume. Now, what is this larger volume that is what we are calling free volume?

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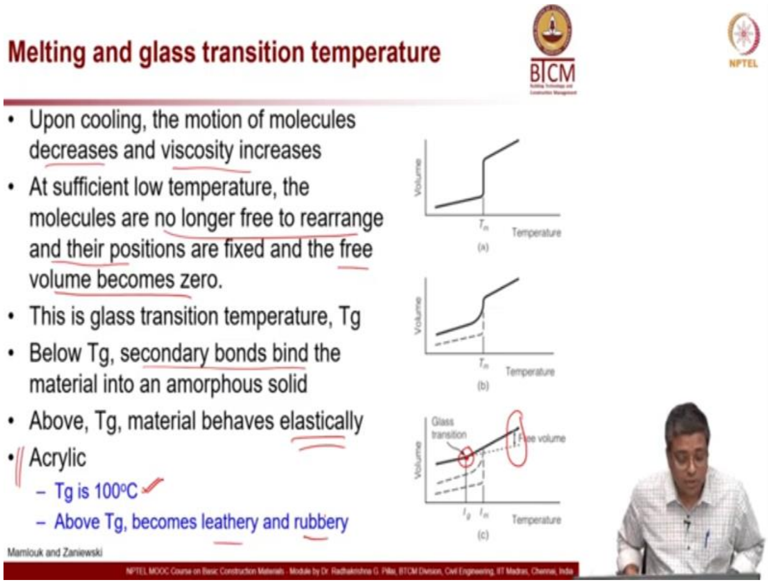

Now, let us go to the next slide whereupon cooling what happened, which was about the melting point. Upon cooling, the motion of the molecules decreases, and the viscosity increases, or the material becomes more and more difficult for the material to continue to flow. So, the viscosity increases. So, we are going backward direction now. At some sufficiently low temperatures, the molecules are no longer free to rearrange.

And their positions are fixed, and when their positions are fixed. There is no further volumetric expansion or volume change possible, so we can call free volume becomes 0, so here, this is the free volume it is; we can look at that drawing at the bottom right so that free volume becomes 0. Furthermore, that temperature is what we call glass transition temperature. So, I am talking about this point here. So, at this point, the free volume is 0.

Now, below the glass transition temperature, the secondary bonds bind to the materials together and become an amorphous solid. Now, above the glass transition temperature, the material behaves in an elastic manner. So, it also depends on what types of bonds are present. For example, acrylic is the Plexiglass or the glass-like transparent sheet which we use in construction. We might have seen it is not glass, but most of it is; we call it acrylic.

And it is a transparent sheet, widely used in construction where we do not want glass, but at the same time, we want transparency. Now, is glass transition temperature is 100 degrees Celsius and above the glass transition temperature. So, if we take that sheet and then start heating it, after about 100 degrees Celsius, we will see that the material starts to flow. It becomes leathery or rubbery starts to flow, and then its properties can change; even the mechanical properties will change.

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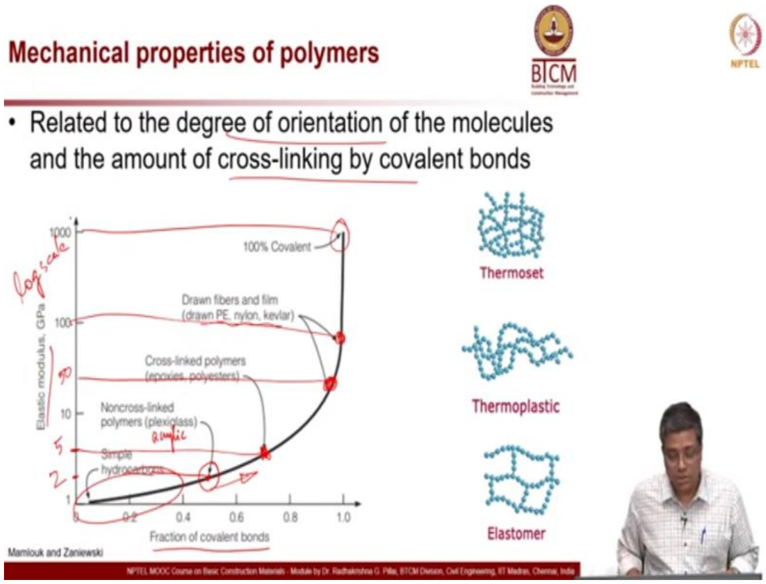

So, I will show how the mechanical properties of various polymers change. And they are dependent on the degree of orientation of the molecules or the crystal structure. And the amounts of crosslinking both these are influencing the mechanical properties of the polymers. Here is an example graph or graph which kind of compares various materials and their elastic models. So, we can look at a fraction of covalent bonds, or how much of all the bonds present, how much is the covalent bonds.

So, we can see, as we have very little covalent bonds, the modulus is very little. The bottom left corner region is what I am talking about as the amount of covalent bond increases, or the fraction of the covalent bond increases, and the modulus increases. So, for example, the Plexiglass or the acrylic, which we just talked about acrylic; we just talked about the modulus is somewhere here, so I can say this is log scale.

So, we should note that the lower modulus is somewhat here, so maybe about 2 or 3, let us say 2 or 3. If I take crosslink polymer or epoxy materials that are thermoset plastics, I can probably see that this is about here, maybe 6 or 7, something like that, or this, this will be about 5, I think. Now, if I look at the other type of manufactured products, very high-performance material, then I see like, we know, it goes even this, this could be about 50 in the log scale.

So, we see from 5, and it is about ten times increase from here to here; now, it is not only 50 we have also very high about 100 this could be close to 100. Now, when we have a 100% covalent bond, we have very high modulus for concrete; for example, we have very high elastic, I mean concrete also depends on what type of concrete we talk about, but if we have or 100% covalent bond is diamond, we have very high modulus for the diamond.

So, it depends on different materials. So, these bonds do play a role in influencing the mechanical and other properties of various materials. So, they have a considerable role in designing our structures and making sure we understand those behaviors at the microstructure level. So, we will design and incorporate those in our civil engineering design and then ensure that our structures stand safe.

That is service life, and we talked about many of these in the earlier lectures; service life sustainability, all these words were introduced to us. So, please read all those concepts, it is essential in today's world for us to incorporate these concepts in all the designs which we talk about, not all the structures which we design should not only last for the initial few years or something, but it should last for a long time.

So, we have to decide what that design life is, and then when we choose a particular material, is that going to give us the long life we desire for the structure. For example, I did not talk about it earlier but let me just tell we most of the plastics which we talk about, if it is used for external or exterior environment, where sunlight is going to hit the material directly, we have to think about the UV radiation, whether this plastic will degrade in a short period.

So, that is very important for us to think about when we use plastics; if it is going to be covered, then it might be it might last longer, but if we are going to use it for the exterior environment, where it is directly hit by sunlight etcetera, we will see that we know, if it is not UV resistant, they will become brittle very fast. It may not be suitable for the structure.

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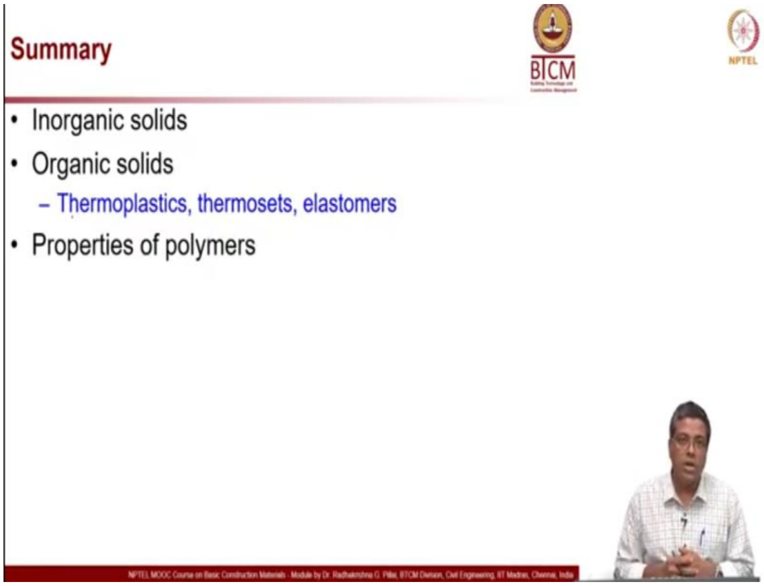

To summarize, we talked about inorganic solids, organic solids in which we talked about thermoplastic, thermosets, and elastomers. And also, towards the end, we talked about the properties of polymers, how very briefly how the bond can influence the properties, and how it is related to the temperature of the system's ambient temperature. With that, we will close this session.

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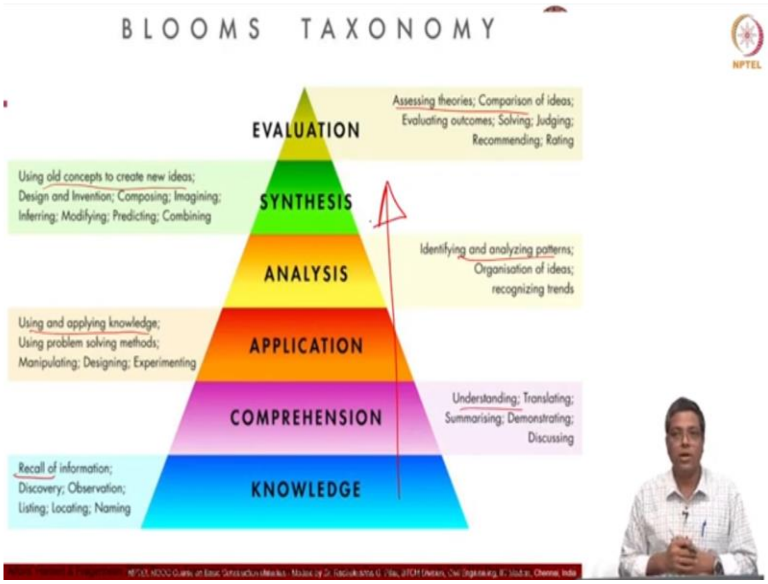

But before we close, I just wanted to tell we there is something called Bloom's taxonomy. So, these are we can read about it, it is not part of the syllabus as such but I thought it is good for some of we may be interested in to becoming teachers or we know, it will help in how to set question papers etcetera.

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So, this is a way of distinguishing the fundamental questions within the education system. So, we can look at this table all these words, which we see in various questions in the exams. And in our class, we also will try to use what we know, which helps us identify the depth of knowledge a particular student has. So, for example, if we use these kinds of words in the question, that kind of checks whether the students remember something.

And if we have in a compute something convert different discuss all these word estimate this checks, whether they understand the concepts or not, the third one is to check whether they can apply a particular concept or not. And then fourth is analyze, then evaluate, then create new knowledge or insights, categorize of creating something, so, this we can I do not want to talk to detail, we can look at all these words and then we can see how to use these words in wer question paper, especially, we know, if we see them as we go towards the right that is more and more difficult, difficulty level kind of increases.

This is shown in the triangle over here where we can see. The first one recalls, we know just memory checking. And then the second one understands all that then, the third one is using and applying knowledge identification, identifying and analyzing patterns using all concepts to create new ideas. And then finally assessing theory all this is for evaluation. So, as we go up, it becomes more and more difficult. So, I just wanted to introduce this concept called Bloom's taxonomy. We can Google on this and learn about this also if especially if somebody is interested in becoming a teacher in future, thank you.