Processing Of Non-Metals
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Module - 2
Glass: Properties and Processing
Lecture - 1
Glass: Structure and Properties

A warm welcome to all of you in this lecture on glass structure and properties, today we are going to start module number 2 of our course on processing of non-metals. So, just review what we have already covered in module number 1, we have seen that what are the various type of engineering materials, which are available with the engineers or the products can be made up of different types of materials. So, what are those types of materials that we have seen in in lecture number 1 of module 1. Since, the title of the course is processing of non-metals, so we have seen that what is the distinction between the metals and the non-metals. What are the physical and chemical properties of the metals and the non-metals, in lecture number 2 of module 1.

So, till now we have focused our discussion on the broad spectrum of the manufacturing processes and the broad spectrum of the material. Then try to co related the properties with the applications as well as with the manufacturing ability. That if certain a material has got certain set of properties, how it can be processed? If you remember in case of metals, we have seen that one of the important properties ductility. So, if the metals is ductile it can be easily processed into thin wires.

Similarly, in case of non metals we have seen, that they have got certain set of physical and chemical properties, which are distinct, which are not similar to those of metals. When this distinct is there, the processing techniques or the manufacturing techniques that can be applied for non-metals are different than those of metals. So, with this background we are starting to start mod, other modules of this particular course, though modules would be focusing on the materials, which has the non-metallic properties. Though one of the materials is the glasses so in case of glasses let me first introduce to the module, that what we are going to cover in this particular module. This module has been divided into three lectures or three units. So, we will have three lectures on the glass structure and properties of glass and the processing of glass. So, today's lecture would be focused on the structure and the properties of glass and the remaining two lectures will be focused on the processing. So, the title of the lectures would be glass processing 1 and glass processing 2.

We will see that how or what are the stages of production of glass products or the processing of glass products? So, broadly out line will be provided or a flow chart would be provided a sequential steps would be given, that how the raw materials are melted, how the raw materials are melted first and then they are formed into various shapes like fibers or filaments? They can shape into tubing, they can be shaped into glass wool, they can be shaped into flat glass. Now, depending upon the glass we will have shapes. So, in our lecture number 2 and lecture number 3, we will see that how the glass can be melted?

How the molten glass can be given a particular shape? Now, what is a shape that can be given as a I have already discussed, various shapes can be given, like the flat can be manufactured, glass filament can be manufactured, to the tune of the diameter of 2 micron such fine filaments can be made, glass wool can be made, then we can make a glass tubing, we can make laminated glass, toughened glass. So, different shapes can be given, different properties can be given to the glasses, once we are able to melt it properly. Once we have melted and deformed or formed the glass forming has been done into a definite shape, there may be certain induced stresses in the final products or the final shape that we had produced after forming processes.

So, annealing is done to reduce those stresses. So, all these detail that, what is annealing cycle? What is the annealing point? All these details will be covered in lecture number 2 and lecture number 3 of this module of glass structure properties and processing. But today's lecture would be focused on the glass its structure and the properties. Slightly we will go towards the historical perspective of glasses, then we will see what are the various types of glasses, which are been used in industries these days or in our household these days.

Then we will see the crystalline and the morfers structures, then we will try to understand the what are the specific properties of the glasses? So, with this introduction corelating what we are studying now or what we are discussing now, with that we are already covered in our module number 1 and what we are going to cover in this particular module, we can start the module with the discussion on the glass, its structures and properties. So, let us start the introduction.

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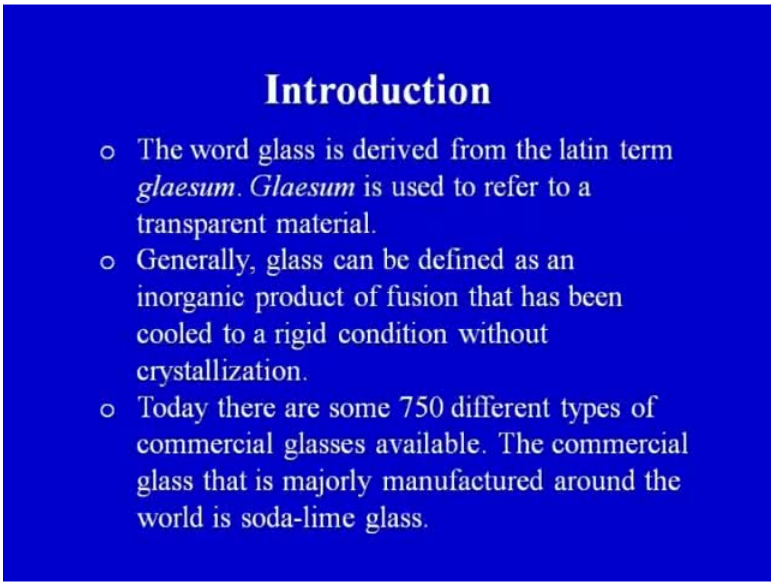

The word glass the historical perspective of glass. On your screen you can see the word glass is derived from the Latin term glaesum or the glaesum is used to refer to a transparent material. So, basically if we see, if we have to explain the meaning of glass to a layman, we can see, say that if it is a transparent material it can be glass. All though certain polymers are also transparent, but generally we say a glass is a transparent material. So, the word glass is derived from the Latin term glaesum and glaesum is used to refer to a transparent material. So, we can say very broad definition of glasses, that it is a transparent material.

Generally glass can be defined as an inorganic product of fusion, that has been cooled to rigid condition without crystallization. So, it means that no crystallization taking place and it has been cooled, means it has become a rigid condition that is it has become a solid. So, from a liquid state it has been cooled to a solid state, without the actual crystallization taking place. So, this transition we will try to understand with a help of the diagram in today’s lecture.

This phase transformation that we will see with the help of a diagram, that how we can distinguish between a crystalline solid and a morfers solid, that would be a part of the discussion in today’s lecture. But very briefly we can see, we can say that glass can be defined as an inorganic product of fusion, that has been cooled means it has been that the temperature has been reduced from the liquid to the solid state to a rigid conditions that is a solid condition without crystallization.

Today there are around 750 different types of commercial glasses available. So, we can see glasses all around us. I can just give a view point that, the cameras that are been used that also make use of glasses. Within this particular studio there can be different types of glasses, which are been used for different application. Even the lights that are been used are also using glass, different type of glass. We can seen the tubes that we use in our household, that there we see glass. The cameras are using the glass. Even people use spectacle were the glasses are used.

So, there can be glasses another important applications, sometimes the detectives also use the glasses to take the finger prints. So, sometimes we use a magnifying glass for a particular purpose. There can be different types of glasses, which we see all around in our day to day life. I have just highlighted few application areas of the glasses. We will certainly see in our series of lectures on this particular module or in this particular module we will see what is a tinted glass, what is a laminated glasses, what is self leaning glass, we will see what is a coated glass? So, different categories of glasses also we will see.

So, basically in this particular point that there are about 750 commercial glasses available. I think this is very, very correct, because we see glasses all around us in different forms and shapes. The commercial glass that is majorly manufactured around the world, is the soda-lime glass. So, this is one of the most common types of glass which is manufactured all around the world and which finds substantial applications in our day to day life. So, basically to summarize what we have cover in this particular slide, this gives us the historical perspective and the application spectrum of the glasses.

So, we can just conclude from this slide that glass has been derived, the word glass has been derived from the Latin word which is called glaesum, glaesum means the transparent material. Glass has been cooled or it has been you can say made from a liquid to a solid state without the crystallization taking place. And there are a large varieties of glasses, which are present in our day to day life.

A rough figure has been provided on the slide, that is 750 basically type of glasses are been used. We can further see, note different types of future development in the form and types of glasses, which we will see in near future. Now, what are the batch materials? Now, we have seen that glass it is a transparent material. Now, how are what are the various ingredients that go into the manufacturing of a glass?

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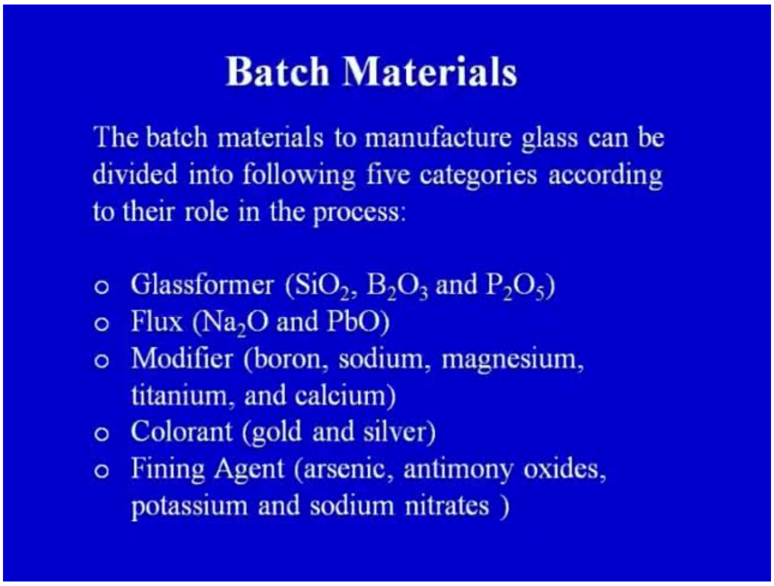

So, batch materials to manufacture glass can be divided into following five categories, according to their role in the process. Now, we have to manufactur one final product that we are calling as glass. Now, this particular glass would be made up of a number of constituents and each constituents will have its one role. For example, we take our body. Our body is one complete entity, but in this complete entity there are so many different organs, there are so many different constituents that are making up the body. We have bones, we have skins, we have muscles.

Similarly, if we take the glass, the general term glass will have so many different constituents and these constituents would be divided into different proportions. In one particular category, we may have more of glass former less of flux, in other category we may have even very less amount of flux more amount of modifier. Sometimes we may use a colour end, we may not use a colour end, sometimes finding agents may be required, may not be required depending upon the processing technique that we are following.

So, basically glass is the common term, but this glass would be made up of different of batch materials, which would be combined in different proportions and then they would be put into a melter. So, we will see that what are the different types of melter, just to give you an over view there are different types of melters, which are use to melt this batch materials. Now, what are this different types of melters? You can have a unit melter, you can have a re cubic type of melter, we can have a electric melter, then we can have a regenerative type of melter.

So, there are different types of melters, which will be used to melt these batch materials. So, first of all we need to understand, that what is the role of the individual constituents that will go into the final processing of the glass? On your screen you can see, the very first point that is the glass former. What are the glass, different types of glass former? That is you can see Si O 2, B 2 O 3 or P 2 O 5, these are sometimes… Silica is the primary constituent or primary glass former, which is used. So, glass former provides or the bulk to which we are adding the additional constitutes to make the glass.

So, glass former is the major bulk, that would result into the formation of the glass. So, glass former different examples are given on your screen and the main purpose of the glass former is to provide the bulk or to provide the basic material, which would result into a glass. Second point on your screen is the flux. Now, what is the role of flux? Flux can be of different types, you can see Na O 2, Pb O. There are different types of fluxes can be used, there can be others also.

The role of flux is to reduce the melting temperature, so in a furnaces we are adding the flux the temperature required to melt the glass former would be reduced. But certainly it will at a cost and the cost would be certain times reduction in the properties of the final glass, that would be manufactured. So, flux although has a advantage, but it has a slight disadvantage also because it affects the properties of the final product. The third important on your screen is the modifier, because once the properties are degraded, we have to slightly improve the property.

For even if the properties are not getting degraded, we ever focused would be always to improve the properties of the glass that we are manufacturing. Now, this properties can be improved with the addition of certain modifiers. Now, what are the various types of modifiers, which are added to the glass. On your screen you can see, we can use boron, sodium, magnesium, titanium and calcium as the modifiers. So, why a modifier required? To improve the properties of the glass that we are manufacturing.

So, different types of modifiers will have different effect on the final properties of the glass, that would come out of these batch materials. So, till now we have seen that there is a glass former, which provides the basic constituent, then on the top it we add the flux and then a modifier to improve the properties. Finally, two more constituents added, first one is the colorant. The colorant can be gold or silver, in order to impart a colour to the glass and finally, the fining agents. Now, what are the various types of fining agent that can be added?

The different types of fining agent are arsenic, antimony oxides, potassium and sodium nitrates. So, arsenic, antimony oxides, potassium and sodium nitrates, these are some of the fining agents that are added. There can be list of fining agents out of which, we can choose that for a particular category of glass which type of fining agent should be added? Now, what is the role of the fining agent, because we have seen each and every constitute has got a role. Glass former has a role, flux is added for a particular purpose, modifiers are added to improve the properties of the fining glass and then colorant are added to give a different specific colour or different colours to the glasses.

But fining agents are used to improve the quality characteristics to remove the bubbles etc from the glass. So, fining agents are used to improve the quality of the glass. So, if we are able to understand that what is the, what are the raw materials that are going into the manufacturing or the processing of the glass, we would be able to understand the processing techniques in a much better manner. Before we process something, we should know that what are the ingredients of that raw materials, that we are processing in the final shape or in a final product form?

Because we would be seeing in the lecture number 2 and lecture number 3, various processing techniques, which are used for processing these raw materials into the final product. So, before understanding the processing techniques, we need to understand that what are the various types of raw materials that will go into the process, but he proportions may vary. Now, we have seen, on your screen you can see there are five different types of constituents that are the batch materials used in a melter to melt and form the glass.

In the melter the constituents would be melting, the temperature would be high, the constituents would melt and they would form a glass melt and this molten glass would then be formed using any of the technique. Like in case of glass tubing, we will use a mendling case of float glass method at a different technique will be use. So, there are number of techniques, which would we would be covering in the subsequent lecture, but these would be the raw materials. In raw materials on your screen you can see again I am revising because before going to the procession we should know, that which are the raw materials because there only one term would be used that is raw material would be melted.

Raw material is melted and it is in the molten stage the glass is formed into this and this shape, but we should understand when we are looking at the module into quality we should understand that, what are the various types of raw materials that would go into the processing of glass products. So, the various types of raw materials that would go into the final product are the glass former, the flux, the modifier, the colorant and the fining agent. Each one of these has got a specific objective in the final product as well as they will easy ease out the process of manufacturing or the processing of the raw material into the final product. We will come back to these if necessary, while we are discussing lecture number 2 and lecture number 3. Now, what are the types of commercials glasses, which are available?

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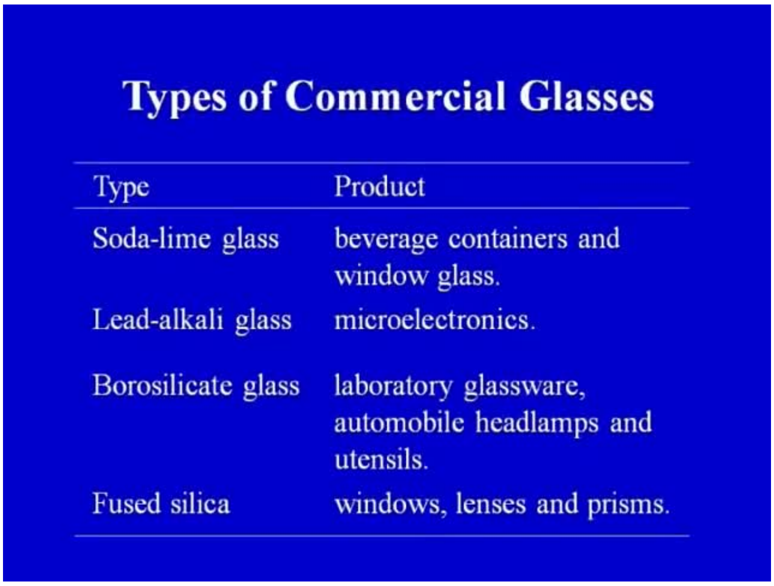

On your screen you can see the type, as we have seen in the slide number one, that soda-lime glass is the most common type of glass, which is manufactured or processed worldwide and has wide applications. So, we can see soda-lime glass and we can see, what are the various types of products that can be made? Now, we have emphasized so much on the previous slide because we should understand that what are the various types of inputs or what are the various types of constituents, which combined together to make a glass.

Now, depending upon the proportions or different we can say fractions or proportions of these raw materials, which are we have seen in the previous slide just again revising glass former, flux, colouring agent, fining agent and the modifiers. We different proportions of these would be combined together to form different types of glasses. Now, what are the various types of glasses on your screen you can see. We can ever soda-lime glass, we can ever lead alkali glass, boron silicate glass and fused silicate glass. So, different types of glasses can be made in there can be other types also.

Different types of glasses are there and each one of these has got certain specific applications. Now, what are the products than can be made with these different types of glasses, which had be made by varying or changing the types of raw materials that go into the making of the glass or the by modifying the proportions of the constitutes that are used to make the glass. These are the types of glasses that are made and now we will see the products. One by one we will try to understand. Point number one, in the type we have soda-lime glass.

Soda-lime glass as I have discussed, it is one of the most common type of glasses which is used worldwide. So, we can have beverage containers and window glass. So, glass if you ask any child that have you seen glass, a child has one answer yes a glass bottle or a any beverage bottle or a any cool drink bottle. So, that is the one first we can say experience of a child with the glass. Then the glass windows, so glass windows and bottle beverage bottle are the most common type of uses of glass, which we see all around us. So, soda-lime glass is used for manufacturing beverage containers and the window glass.

Second type of glass is the lead alkali glass and this is used in the microelectronics. A little bit sophisticated applications of the types of glass. So, glass the point of putting all these things there, a wide variety of applications have to be emphasized. Just to emphasize that glass is an important engineering material and every engineer should have an idea, that how glass is manufactured and what are the various ingredients that going into a glass manufacturing or glass processing?

So, soda-lime glass very commonly available, lead alkali glass it is used for microelectronic, borosilicate glass many times when we go to the chemistry labs or a lab where the temperature are, temperatures are high that experiments require equipments, which can bear the higher temperature we simply see borosilicate glasses written on some of the containers. So, borosilicate glass is used in laboratory, glassware.

So, where ever using some experiments were the temperatures are higher borosilicate glasses are used. Automobile headlamps and utensils, so borosilicate also finds the applications were slightly higher temperatures are subjected. So, where ever the glass would be subjected to elevated temperature, slightly higher temperature in those cases borosilicate glasses will find lot of applications. Fused silica glasses used for windows, lenses and prisms. So, we have a different category of glass that is a fused silica glass. So, in this particular series of lectures, we cannot into the detail of each and every type of glass, that what are the constituents that will go into this particular glass and how this particular glass can be formed?

But certainly we can just remember few important types of glasses and their applications areas. So, the purpose of showing this particular slide is that we should be able to understand that, if in a laboratory glassware, if on a laboratory scale a particular glass has to be procured as an engineer I should focus on the borosilicate glass. If a glass has to be purchased or procured for the window frames, we should very easily choose the soda-lime glass. So, different types of glasses are there, with different applications. So, just to revise this particular slide there are different types of glasses like the soda-lime glass, lead-alkali glass, borosilicate glass and fused silicate glass and each one of these has got certain specific applications.

Now, coming on to the structure of the glass; till now what we have covered, we have seen that what are the various types of glasses or what are the various types of constitutes or raw materials, that go into glass processing? Then we have seen in one of the slide, what are the various types of glasses, although we have not discussed in detailed, we have only over viewed that different types of glasses.

There also we have taken only four examples and these four examples we have seen, that what are the applications areas? And then we have tried to see that the applications areas not only are very, we can say primitive type of applications like household application, but there are many sophisticated applications also were glass find its application. So, basically the point till now we have covered is that, there are few set of raw materials, which can be converted into a engineering material, which we are calling as glass. This particular glass has got many engineering applications. Now, we will see, what is the structure of the glass?

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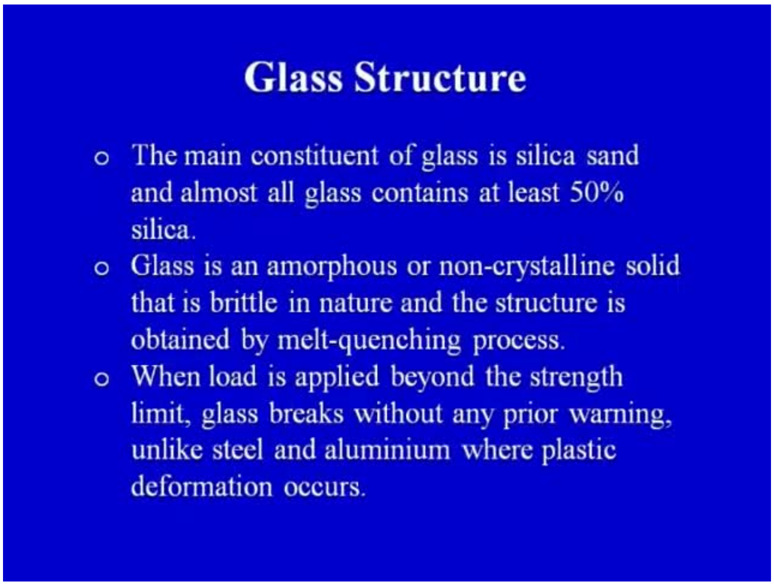

The main constituent of glass is silica sand and almost all glass contains at least 50 percent silica. So, the main constituent of the different types of glasses in a very general form is silica. So, in silica 50 percent silica would be present in different propositions. The basically in totality of 100 percent minimum 50 percent would be silica only. So, glass is an amorphous or non-crystalline solid, that is brittle in nature and the structure is obtained by melt-quenching process.

So, in this particular slide two or three very important points are there which we should try to understand. Sometimes a cross question asked in the examination, one mark question, whether glass is a amorphous crystalline? So, we should remember that glass is amorphous in nature, it is non-crystalline, it is not crystalline. So, first important point regarding the glass structure is, that glass is amorphous nature. Point number two, it is brittle in nature. Now, this brittle characteristics of the glass will certainly pose certain problems in the secondary processing of glass products.

Now, suppose we make a flat glass, there are processes which are used for making flat glass, which we will cover in lecture number 2. Suppose, with the raw materials that we had seen already we are able to make a glass or a glass sheet or a glass plate. I want to make a hole inside this glass plate. So, conventional drilling may not be applicable, why because of the brittle characteristics of the glass. So, when we want to make a hole inside the glass, there may be some other techniques required to make a hole. But conventional techniques may not render themselves applicable for hole making specifically in case of brittle materials.

So, glass is a amorphous in nature, that is one important point we need to understand from this particular highlight, that is there on the slide. Second it is brittle in nature and this brittleness will certainly affect the secondary processing of the glass. Finally, how it is obtained? It is obtained by the melt bunching process. So, melt means high temperature bunching means bringing it down to a lower temperature under specific cooling rate, under pre defined cooling rate, under pre determined cooling rate. So, cooling rate is a very, very important and it dictate the product of glass or the final product that we get out of glass.

So, basically three important points need to be understood, glass is amorphous, it is brittle and it is made by the melt-quenching method. Next point, when load is applied beyond the strength or the limit, strength limit, when the load applied beyond the strength limit, glass breaks without any proper warning. This we will try to understand with the help of a stress strained curve, were we will try to understand that how the glass breaks?

How the failure of the glass takes place under tensile loading? So, that we will try to understand and we will try to compare, that how the glass phase and how are any other metal fails like steels or aluminum. So, we will see how the failure takes place? So, when the load is applied beyond the strength limit, glass breaks without any proper warning or prior warning, unlike steel and aluminum where plastic deformation occurs. So, that third point is important, from the point of application of glass and how it will fail from under specific set of conditions, when the compressive load will be applied or when the tensile load will be applied? Now, on your screen you can see the structure of glass.

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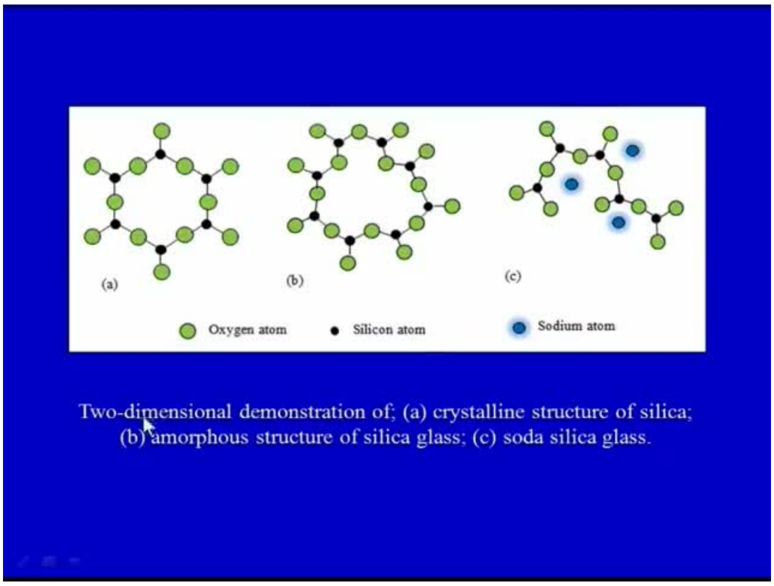

It is two dimensional demonstration of this is a 2 D presentation of a, this is a. Looking at this we can just have an idea that is a very regular pattern or this is the repeating geometric arrangement atoms. You can see, repeating geometric arrangement atoms and therefore, it has a crystalline structure. The structure of silica, this is a oxygen atom, green colour oxygen atom very clearly depicted. Then this black is the silicon atom, it is a silicon atom. So, this is a fairly regular structure, repeating geometric structure or atomic structure or atomic arrangement.

So, whenever it is very, very regular, it is crystalline structure of silica. Then second one it is not very regular, random arrangement amorphous structure of silica glass. Then different types of soda glass is shown, soda silica glass. Here with these blue colours depict the sodium atom, green colour depicts the oxygen atom and black colour circles depicts the silicon atom. So, we can see a crystalline structure of silica. We can see the amorphous structure of silica glass as well as we can see the structure of a soda silica glass.

So, we can see randomly oriented, random orientation or random atomic arrangement. Whereas in case of crystalline silica, we can see it is a repeating geometric arrangement of atoms, repeating geometric arrangement of atoms. So, very clearly distinguishes the structure of a crystalline solid and a amorphous solid. So, amorphous solid will have a different structure and a crystalline will have a different structure. Now, let us try to see the phases transformation of crystalline amorphous solid, because we have seen glasses are amorphous in nature. So, we will try to distinguish between the crystalline solid and the amorphous solid. So, what is given on the slide, let us try to understand.

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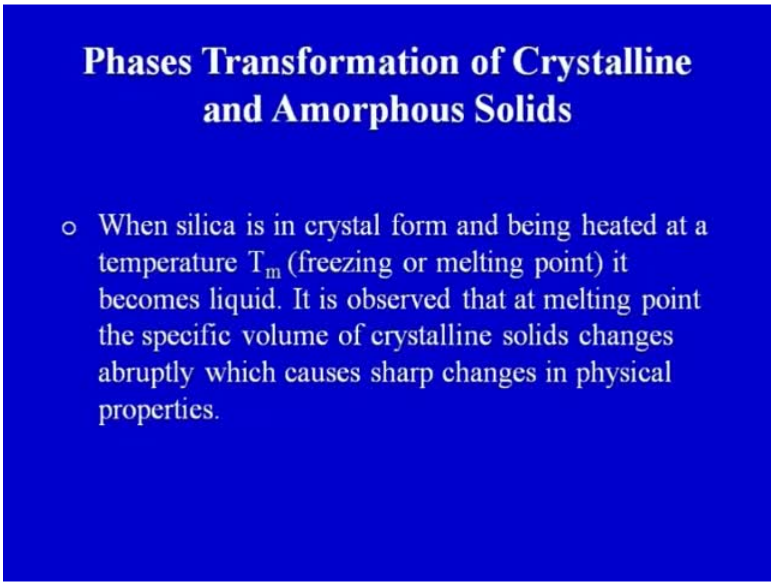

When silica is in the crystal form and being heated at a temperature T m. Now, T m is the freezing or the melting point. So, were why we are focusing on silica, because in case of glasses we have seen silica is the primary constituent or the main constituent, that further result in the processing of glass. One of the key raw materials is silica, when silica is in crystal form and being heated at a temperature T m that is the freezing or the melting point, it becomes liquid.

So, important point to note is, as we have seen melt bunching processer melt bunching method, when silica is in crystal form and being heated at a temperature T m that it is heated to a particular temperature, which we are calling as T m, that is the freezing or the melting point it becomes liquid. So, at that temperature it is liquid. It is observed that at melting point, the specific volume of crystalline solid changes abruptly, which causes sharp change in the physical properties. Now, this is the temperature where it is in the liquid state, but the specific volume will be changing abruptly at this temperature. Temperature is T m that is the freezing or the melting point.

This we will try to understand will the help of a diagram also, but first off all we should understand that once silica is in crystal form, it is crystalline form. Being heated at a temperature T m, that it has been temperature has been increased to T m heated at a temperature T m, it becomes liquid. So, at that particular movement it would be liquid. It is observed that at melting point that this point T m, the specific volume of the crystalline solid changes abruptly. So, if it is a crystalline solid, the specific volume change abruptly, and it will cause a sharp change in the physical properties; so the properties would be different in case of crystalline and amorphous solid.

At this particular temperature, again I am emphasizing that is T m, the crystalline solid would show a abrupt change in the physical properties. The specific volume will decrease sharply. This we will try to understand with the help of a diagram. So, before we go to the diagram, let me first again read what is there on the slide. So, that the things that we are going to discuss in the subsequent slide becomes absolutely clear. When silica is in crystal form and being heated at a temperature T m, at a elevated temperature T m that we are calling as the freezing or the melting point, it becomes liquid.

So, at that particular temperature silica is in liquid form. Next point, it is observed that at melting point at that particular point T m, the specific volume of a crystalline solid when silica is in crystalline form, the specific volume will decrease sharply or solid changes abruptly. The specific volume of crystalline solid changes abruptly, which causes sharp change in the physical properties. So, this is what we are going to see now with the help of a diagram. Whereas in the diagram we have to compare the two, that how amorphous solid will behave and how a crystalline solid behave? So, in case of crystalline solid now the slide has been changed, but I would again emphasized that at a particular temperature T m the specific volume will change abruptly, which will have a sharp effect on the physical properties of the crystalline solid.

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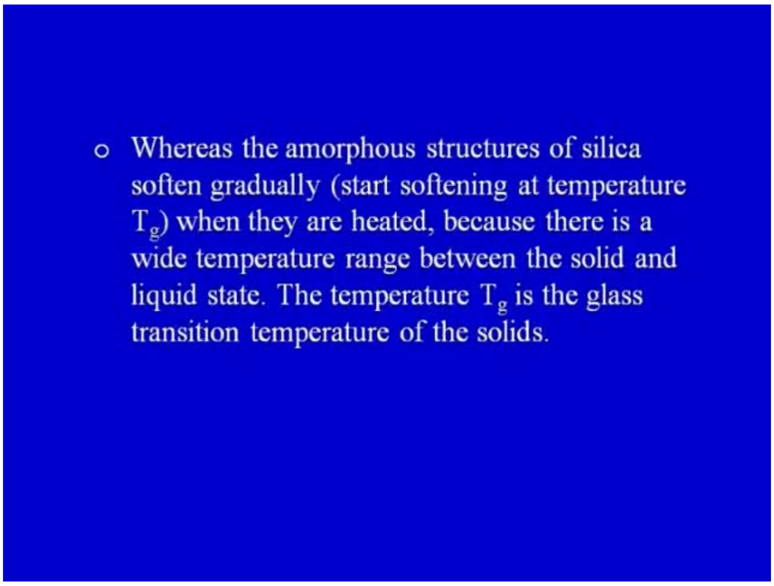

Whereas in case of the amorphous structure of silica, it will soften gradually. The specific volume will now change abruptly, the specific volume will change gradually. It will start softening at a particular temperature T g, when it is heated to a particular temperature. When the silica has been heated to a particular temperature it will slowly try to soften, because there is a wide temperature range between the solid and the liquid state. So, from liquid to solid a wide range of temperature exist. The temperature T g called the glass transition temperature of the solids. So that is T g is a particular temperature or a critical temperature, that is called the glass transition temperature.

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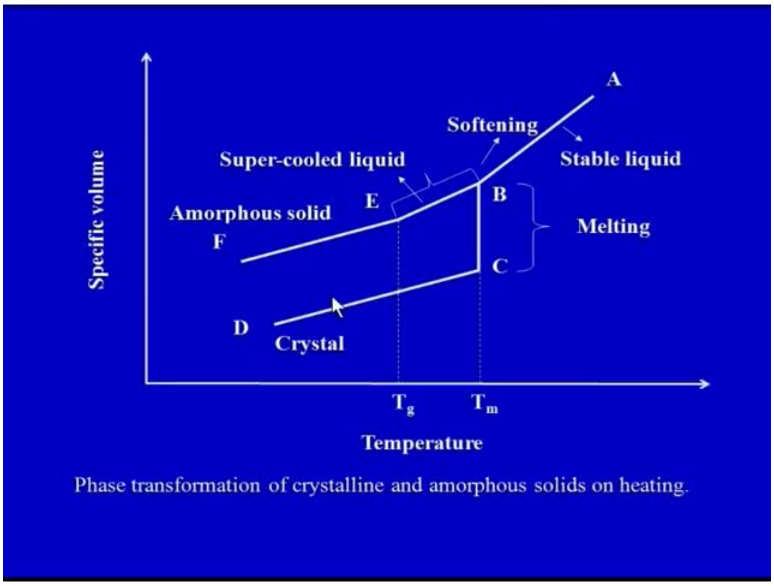

Now, on your screen you can see a diagram. In this particular diagram you can see, on the y axis we have the specific volume on the x axis we have the temperature. Again I am repeating y axis specific volume, x axis temperature. This particular diagram shows the phase transformation of crystalline and amorphous solids on heating from a particular temperature, a temperature is coming down. Here we can see, we have a amorphous solid at a particular temperature and here we have condition A, so this is our temperature T m. That is in the previous slide we have seen there are two critical temperature, one in case of crystalline solid another in case of amorphous solid.

In case of crystalline solid we have seen, we have an temperature T m that is the melting point or the freezing point. We have another temperature T g, which is the glass transition temperature. Now, we can see here A to B and C and D, it is crystalline A, B, E and F it is amorphous solid. This is the crystalline solid, this is a curve for that the crystalline solid and this straight curve for the amorphous solid. And this point T g that is the glass transition temperature is falling on the amorphous solid. So, in case of amorphous solid we will have the glass transition temperature. So, we can see in this particular state we have a stable liquid, this particular line and this particular temperature.

On x axis we have the temperature, so at his particular temperature we have a stable liquid, when it is getting when the temperature is reducing, we can see when it reaches the point B. From B that is the melting point, it has a abrupt change in the specific volume. If you see on the screen, there is a abrupt change of the specific volume, which is on the y axis. On y axis we have a specific volume and there is a abrupt change of this specific volume. Then finally, temperature further reduces and we get a crystalline solid. Whereas in case of amorphous solid, initial phase is same and here the softening takes place and finally, we get a amorphous solids.

But certainly there is a distinguishing temperature or the critical temperature, that we call as the glass transition temperature, in case of amorphous solid. So, it is a critical temperature in case of amorphous solids. We just to revise, what we have seen in this particular slide and the previous two slides? How to distinguish between the crystalline and the amorphous solid? So, in case of crystalline solid, we have a very regular structure or a repeating regular arrangement of atoms, whereas in case of amorphous solid we have random arrangement of atoms. That is one important distinction between the amorphous solid and the crystalline solid.

So, in one case we have fairly regularly arrangement, in other case we have a randomly arrangement of atoms, that is first difference. Second difference is that we have a melt, we in case of crystalline solids at the melting point there is the sharp change in the specific volume. Whereas it is the this particular change in the specific volume is very gradual in case of the amorphous solid. In crystalline solid we have a critical temperature that we call as the T m or the melting point, whereas in case of amorphous solid we have a specific temperature which we call as the glass transition temperature. So, with the help of this particular diagram, we see that when the specific changes we get a crystalline solid and abruptly. When it is gradually, we do not get any regular arrangement of atoms and therefore, we get a amorphous solid.

So, we our main aim is to distinguish between the crystalline structure and the amorphous structure, in order to emphasize that glass has got a amorphous structure. Now, we come on to the properties of the glass. We have seen in the previous slide, the structure of the glass. That it has got amorphous structure and we had tried to differentiate between the amorphous structure and the crystalline structure.

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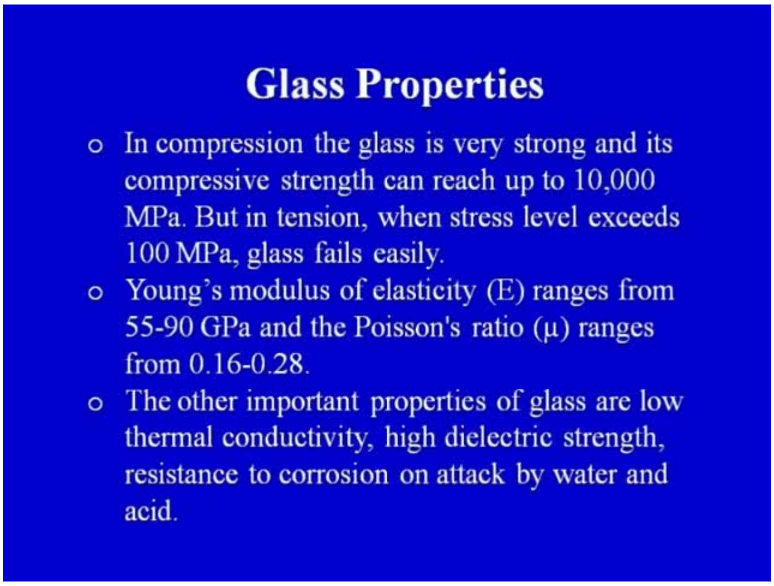

And in case of properties now, we can see that in compression the glass is very strong and its compressive strength reach up to 10,000 MPa or 10,000 mega pascal. But in tension when the stress level exceeds 100 mega pascal glass fails easily. So, these are just the general data, which has been provided. As we see there can be wide variety of glasses which are being used worldwide in different types of applications. We will see some of these types of glasses like the, toughened glass, laminated, the coated glass, the tinted glass.

So, there are wide variety of glasses which are been used, but one important fact which is common for all type of glasses is that the compressive strength of glasses is much better as compare to the tensile stress. So, this just give a order of difference between the compressive and the tensile strength of the glass. We can see the very first point on your slide, in compression the glass is very strong and its compressive strength can reach up to 10,000 mega pascal. But in tension when the stress levels exceed 100 mega pascal glass fails quickly. So, we can conclude from this particular point that for applications where the compressive load is coming on the glass, we can say that a glass can take their load, but in applications where tensile load is acting, we have to exercise question before advocating the use of glasses, glass in those particular application.

Because the tensile strength or the stresses in tensile loading are entirely different from the stresses that are there. So, in case of compression strength, so when we have a high compression strength, we can say that yes glass can be used. When whereever tensile load is coming on glass, we can advocate that no, we can go for any other engineering material which has got good tensile strength. So, very briefly again we can say that in compression the glass is good in tension the glass is not good. So, in tension, we can see the order of difference between the compressive strength and the tensile strength.

Second point Young's modules of elasticity ranges from 55 to 90 giga pascal and the Poisson's ratio ranges from 0.16 to 0.28. So, we can see that wide range of we can say Poisson's ratios is there and wide range of modules of elasticity is there. Why, because there are wide range of variety of glasses which are available. The last point in this particular is slide on glass properties is, the other important properties of glass. Why we are discussing these properties, because when we are going to form the glass in to a different shapes, we need to address these properties.

Once we know that yes these are the properties which are there in glass, we can select the process accordingly and we can manipulate the process accordingly. So, the other important properties of glass are low thermal conductivity. So, they can be used for these types of application also, high dielectric strength, resistance to corrosion on attack by water and acid. So, which is one important application that is resistance to corrosion on attack by water and acid. So, wherever the changes that the galvanic corrosion or the other types of corrosion may takes place, there we can advocate the use of glass.

So, the summary of this particular slide of glass properties is, that glass is good in compression, poor in tension. The Young's modulus has a wide range from 55 to 90 giga pascal. The Poisson's ratio has a ratio range from 0.16 to 0.28. The other properties are low thermal connectivity, high dielectric strength and resistance to corrosion on attack by acid and water. So, these are few properties that the glass possess. On your screen you can see a very simple representation of the stress and behavior of steel and glass.

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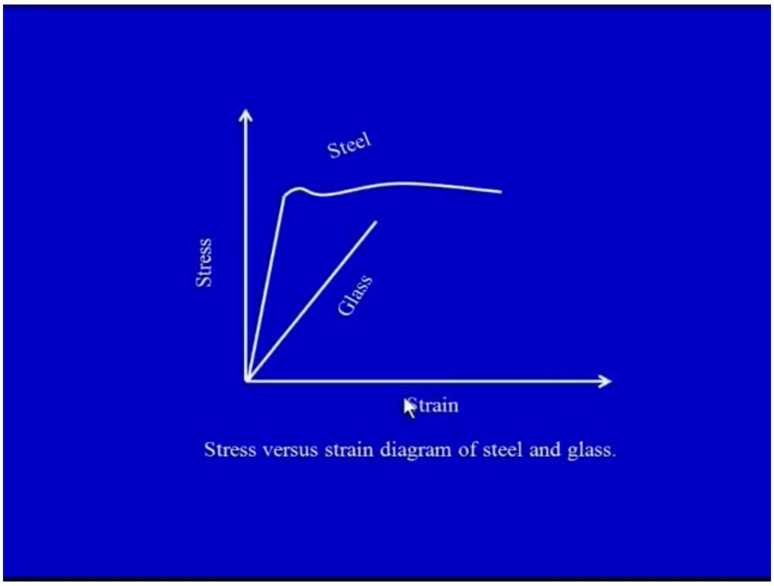

Where, so here we can see that there is no abrupt failure in case of steel. There can be necking that may take place, may be the steel will elongate the cross sectional area will slightly reduce. When we are applying the tensile load after, we can say some passage of time, the final catastrophic failure or a final abrupt failure would take place. But before the failure certain amount of deformation would be noted. So, the strain would be there that is change in length to a original length.

There would be some change in length as compare to the original length, before the actual tensile takes place. But in glass we can see that the failure is taking place abruptly, there is no plastic deformation that takes place, which already has when indicated that glass is brittle in nature. So, this particular slide that is a stressed stained behavior clearly indicate that the behavior of glass is different from the conventional metals, that are used for various engineering application. This will dictate the use of glass in particular application and would also dictate the processing techniques that we are going to use for the manufacture or processing of glass.

So with this we come to the end of our lecture number 1 in module 2, in which we have seen the basic aspects of glasses. If you remember, we started with discussing with the what are the various types of raw materials, that is the various constituents of raw materials, which are used for processing of glass. We have seen that there are broadly five categories. Category number one is the glass former, then we have flux, then we have third point that is the modifier, fourth point are the colorant and the fifth points are the fining agents.

We have seen that all five these got certain specific objects in the batch material or in, they act as the constituents in the raw material for the processing of glass. Then we have seen that, what is the structure of glass? How the crystalline structure different from the amorphous structure? We have tried to understand that there are two important temperatures, in case of a amorphous solid it is an glass transition temperature and in case of crystalline solid we had seen that at the temperature that is T m or the melting point, there is a sharp change in the specific volume, which it results in the sharp change in the physical properties.

So, basically we have tried to understand the difference between the amorphous and the crystalline structure, glass although has a amorphous structure. And finally, we have seen some important properties of glass, that it is good in compression, it is poor in tension. We have seen the range of Young's modulus of elasticity of glass, we have seen the range of Poisson's ratio for the glasses. We have seen that glass has good we can say corrosion resistance to water and different types of acid. And finally, we have seen the load we can say stress strain curve for metal and glass.

We have seen in case of metals like steel plastic deformation takes place, but in case of glass we have a brittle structure, when it is loaded in the tensile conditions. So, next we will see in lecture number 2 and lecture number 3, that is glass processing 1 and glass processing 2, we will try to understand the various processes, which are used for converting these raw materials or these amorphous solid that we had seen in today's class into usable products. Like flat glass, glass fiber or filament, glass wool, tubing and toughened glass or laminated glass. Finally, we will see that these products or that these shape which are produced from the basic raw materials that we have seen today that they are un yield in order to make them usable under different situations. So, with this we come to the end of lecture number 1 of module 2 in our course on processing of non-metals.

Thank you.