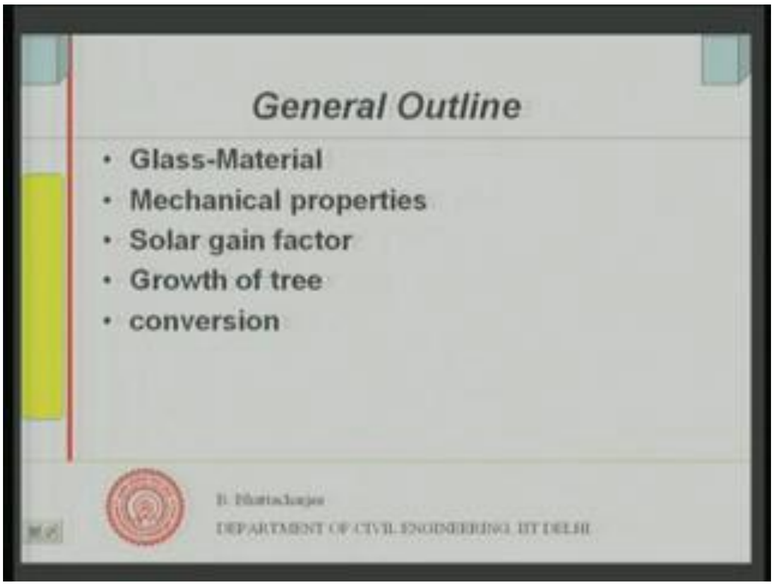
Building Materials and Construction
Prof. Dr. B. Bhattacharjee
Department of Civil Engineering
Indian Institute of Technology, Delhi

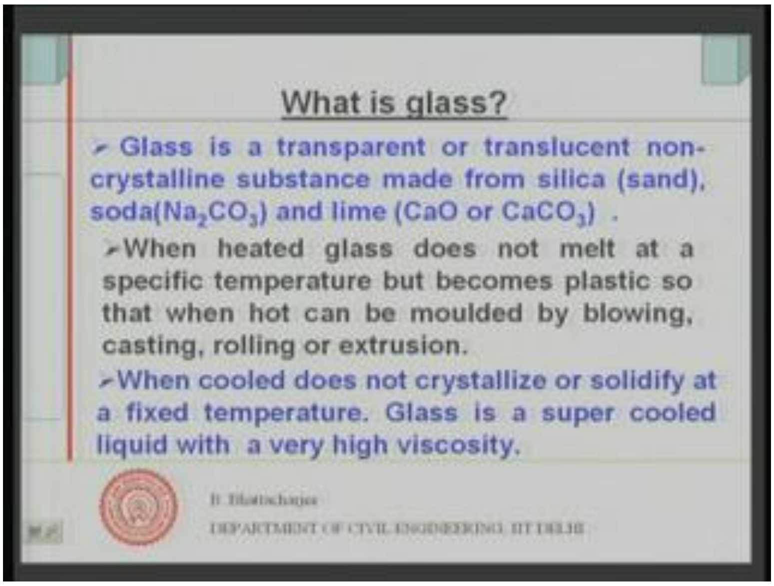
Module - 13
Lecture - 1
Glass and Timber: Glass

(Refer Slide Time: 01:26)



In the thirteenth module of this lecture series; we will be looking into glass and timber. And today we shall mostly look into glass. First as a material, then its mechanical properties. Most important for glass use of glass in building is to is in the facade in the windows as glazing, and therefore we will look into solar gain factor and optical and thermal properties. Then we shall look into introduction of timber. So, we will look into growth of tree and conversion right. So, let us see what is glass?

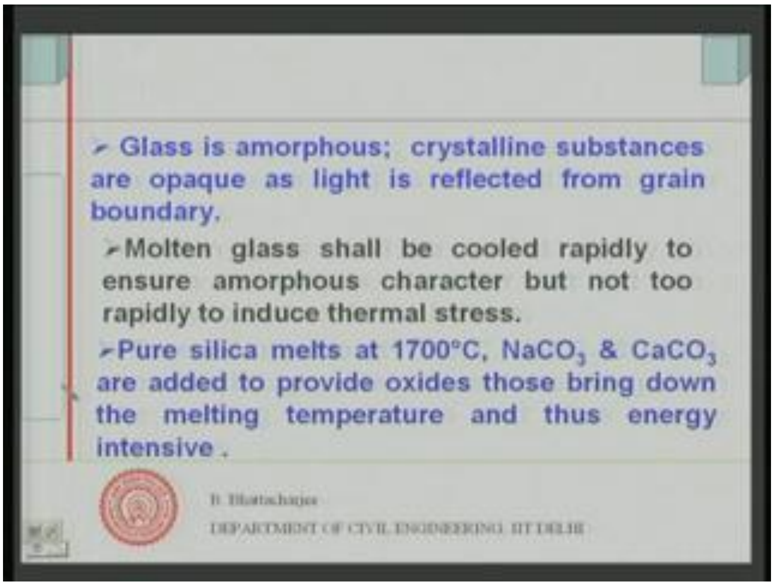
(Refer Slide Time: 02:07)



As you all know glass is a transparent or translucent non crystalline substance, made from silica, that is, sand, soda: sodium carbonate and lime: calcium oxide or calcium carbonate. When heated, glass does not melt; you know it does not melt at specific temperature in fact, it softens. And if you remember your glass blowing laboratory exercises you would know that once it is softened and become plastics, it can be molded by blowing, casting, rolling or extrusion. So, that is a specific property of glass right.

And when cooled it again does not crystallize, it does not form you know it is not a crystalline solid or solidify at a fixed temperature, all crystalline solids actually melts or solidifies at a fixed temperature, whereas glass does not solidify at a fixed temperature. And therefore, it can be thought of as a super cool liquid with very high viscosity, you know it is a liquid with very high viscosity so that, it is not mobile it is like solid. So, it can be thought of as a super cooled liquid with very high viscosity.

(Refer Slide Time: 03:43)



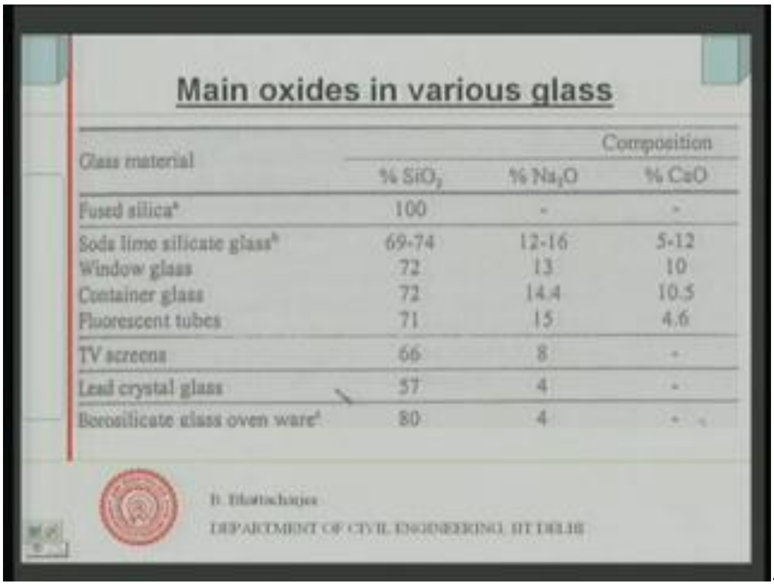
Glass is amorphous and we know that crystalline substances are opaque, you know if you look at the nature of the glass; glass is amorphous and we know that the crystalline substances are crystalline substances are opaque, because light gets reflected from the grain boundaries right. They are very compact and compact structure basically and regular arrangement of atoms. And at the grain boundaries light will get reflected. Therefore, they are all opaque right, whereas glass is not so right.

So, molten glass if you cool it very rapidly, then this amorphous character is ensured. So, its amorphous when it cool it very, very rapidly, if you cool slowly then it will tend to becomes crystalline, have you will have sufficient time to have regular arrangement of the atoms and it tends to crystalline. But if you cool it very rapidly, then it remains as amorphous and that is how it is actually transparent because; amorphous materials can allow light to pass through it.

Now if you cool it too rapidly right, if you must cool it rapidly such that, crystalline crystal formation is not there, but should not cool it too rapidly to induce what is called thermal stresses to induce thermal stresses. Now, you know pure silica melts at 1700 degree centigrade, you know and sodium carbonate and calcium carbonate if we add them to the silica and then try to heat it up, then the melting point of course, reduces down the melting temperature and that is how glass formation takes place.

But in any case basically what contributes; are the sodium carbonate and the calcium sodium oxide and calcium oxide, because we have seen in the glass formation we have finally, will have only oxides Si O 2 sodium oxide, calcium oxide another oxide. So, this carbon dioxide will actually evolve out at certain at certain temperature. And since we have to break this carbon dioxide from both of these compounds, so you have to have lot of energy and therefore, it is an energy intensive material.

(Refer Slide Time: 06:22)



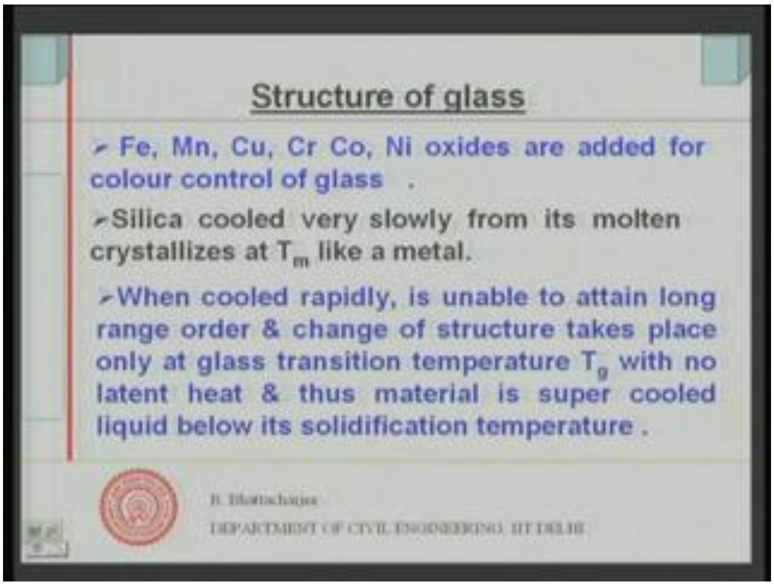
Glass material	Composition		
	% SiO_2	% Na_2O	% CaO
Fused silica[a]	100	-	-
Soda lime silicate glass[b]	69-74	12-16	5-12
Window glass	72	13	10
Container glass	72	14.4	10.5
Fluorescent tubes	71	15	4.6
TV screens	66	8	-
Lead crystal glass	57	4	-
Borosilicate glass oven ware[c]	80	4	-

.

If we look at the main oxides in various glasses there are other minor oxides, but we will only look into the main oxides. We will see in case of pure silica of course, you have got 100 percent pure silica you have got 100 percent pure silica right. But if you look at soda lime glass silicate glass then it will be about 69 to 74 percent silica, 12 to 16 percent of sodium oxide and 5 to 12 percent of calcium oxide. There are several other minor oxides present in this 1 which you have I have just omitted for our purpose to understand, then they are essentially oxides and glasses are essentially oxides.

Window glasses have typically about 72 percent of silica, 13 percent of sodium oxide and 10 percent of calcium oxides. Similarly, fluorescent tubes 71 15 4.6 and TV screens are 66 8 and there are many other oxides; molybdenum chromium oxides and so on and borosilicate glass oven wares are 84, so large amount of silica and other oxides. So, that is what the glass of typical oxide composition of glasses are...

(Refer Slide Time: 07:34)



If we look at structure of glass; first thing to add to color we can add actually iron, manganese, copper, chromium, cobalt, nickel and similar other metal oxides, are added to get color. So, color control can be you can have different colors. For example Fe can give you, can I mean by percentage control of Fe together with the other element, you can get green color or blue color and so on; I mean all of them together. So, oxides by metallic oxides contain the specific oxides that can give selenium oxides etcetera in addition to this would give you specific color. So, color control can be done through this.

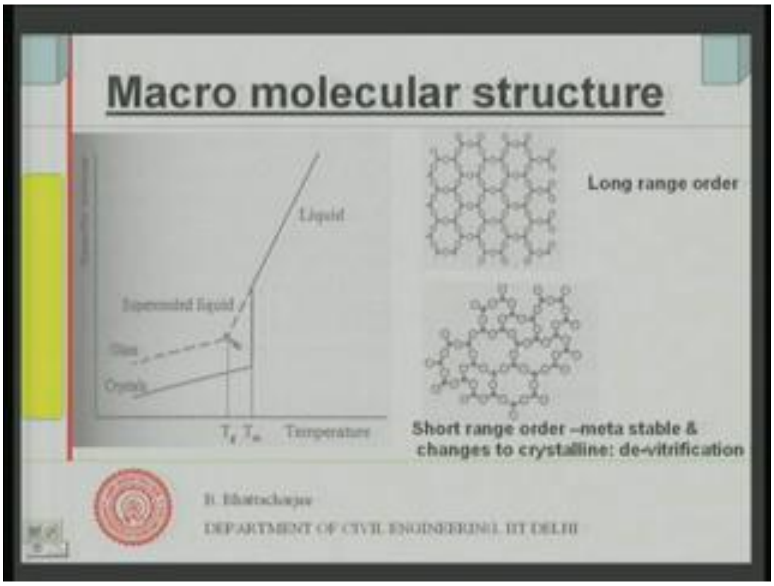
Now, when you cool silica very slowly from its molten state, it crystallizes to gives you a crystal structure let us say at a temperature T m which I call as melting temperature of the glass, melting temperature of the glass like metal like in case of metal right. Then, but if you cool it rapidly it will not be able to actually form for this crystal structure. What is crystal structure, it is actually long ranged ordered molecular you know arrangement. So, this long range ordered it may not be able to actually form if I am cooling it very rapidly right, long range order that may not be available if I am cooling it very rapidly.

So, this change of structure in fact, does not take place at the same temperature, rather takes place at certain lower temperature, as we shall see and that temperature we call as glass transition temperature. We shall see that at it takes place at lower temperature and we will call this as glass transition temperature. We call this as you know it takes place at lower temperature and we call this as glass transition temperature.

So, at this point there is no latent heat evolution and then you can say since it is much below the melting point you know it is actually super cooled. So, when you cool it slowly you know cool it rapidly. If you cool it slowly you will get long range order and it will be crystalline, but if you cool it rapidly, it will actually go below that temperature T m and go to some other temperature, which we will call as glass transition temperature, where it will starts you know hardening and there will be no latent heat evaporation.

Since T g is lower than T m, it is as if it has got super cooled liquid below the solidification temperature. So, it is super cooled liquid below the solidification temperature right. So, right continue with that.

(Refer Slide Time: 10:33)

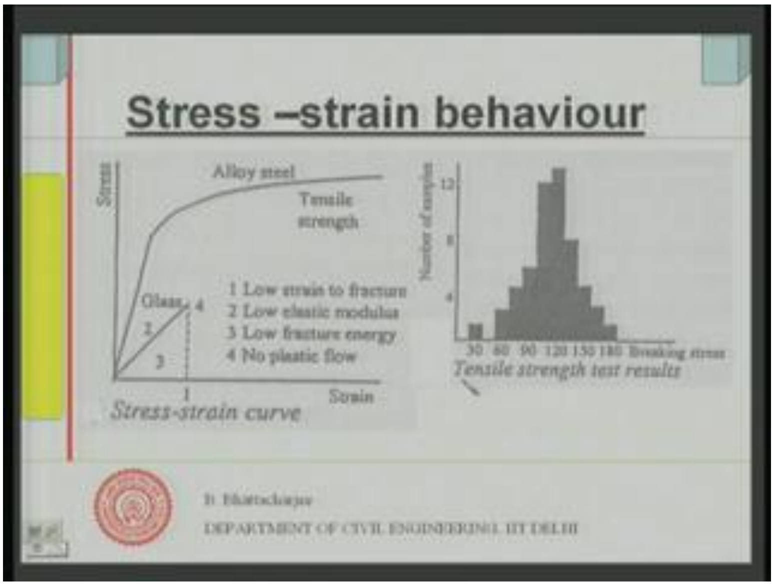


So, if you look at the structure of the glass, it is like this. You see this is the liquid from 1700 degree centigrade as I said and as the liquid I cool, this is the melting temperature, so it should have if I if I cool it slowly at this point it will suddenly become solid and therefore, the specific volume which is on this axis specific volume, this will reduce, so sudden reduction in the specific volume; that is a change of state from or change of phase from liquid to the crystal structure.

But when I cool it rapidly rather not slowly cool it rapidly, actually it goes below this temperature and this temperature is glass transition temperature and the glass formation takes place from there. The structure would look like this; this is the crystalline structure of the long range order, crystalline structure you can see its all orderly the silicon and oxygen molecules I mean oxygen atoms. They are arranged in regular order, it is all orderly, but you see this; this is not as ordered as this 1. So, short range order and therefore, this is meta stable this is not stable crystalline structures are stable; that is what we have seen so far. And this is meta stable and this short range order it is meta stable and it can change in a long range, long term into crystalline structure which we call as de vitrification.

So, this is what is a glassy structure? Where the atoms are not arranged in regular order as you can make it out from here, it is a silicon and oxygen, they are not in same order and this 1 is a regular order which is crystalline structure. So, glass has the glassy structure; that is what it is. And that is how it behaves a super cool liquid, because this temperature you know below the melting temperature. So, you have cooled it below the melting temperature and then it forms a high viscous, high viscosity material or the super cooled liquid which cannot, which does not have mobility like liquid that is why we call it super cooled liquid.

(Refer Slide Time: 12:43)



So, let us see some of the mechanical properties of glass; stress strain behavior. It is important after all even if I use in the windows, then you know what will happen when I am using it in the even in the windows, lets us say then also you know if I am using in the windows it has to withstand the transverse stresses, transverse load locally at least it should not fail, we do not expect glass to take care of the load of the structure. But it must sustain its own load should be able to face the wind loading and so on. And therefore, stress strain behavior is important.

Now let us see; what is a stress strain behavior of glass. This is the stress strain curve of glass this is the stress strain curve of glass. And compare this with let us say a alloy steel you know which is something like this, alloy steel is something like this. So, tensile strength if you look at it, they have large ductility that is what we have seen, in contrast glass is elastic and low strained up to fracture, very low strained up to fracture. So, it is elastic up to fracture and low strained.

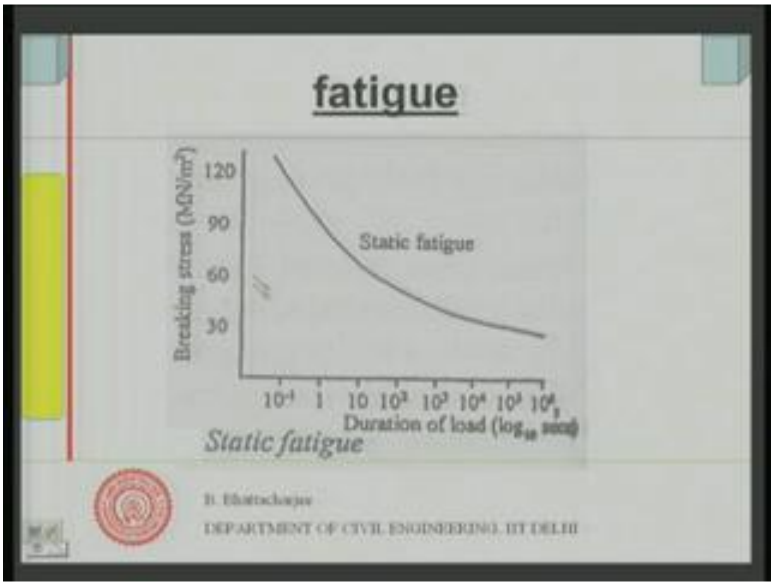
Now modulus of elasticity is much lower than that of this metals you know metals this slope is as you can see, modulus of elasticity which is just divided by the strain is much larger in case of metal, it has got much lower values. Low fracture energy: so area under this curve is also very small, because this strength is relatively small, the deformation is also small, but the modulus of elasticity is low. So, area under this curve is much small compared to something like this, you know which has got very large area. Low fracture energy, low elastic modulus, low strain fracture and no plastic flow there is nothing here.

So, its brittle material no plastic flow and you can understand this from the fact that, since in a crystallized structure you have gained boundaries, whether the dislocation stopped in case of metal. So, grain boundaries do not allow defect to perpetuate from 1 range 1 place to the other, it you know kind of obstruct this perpetuation of defects, which are actually causing the deformation. You know deformations are caused by movement of defects and this would not be allowed by the grain at the grain boundaries, in case of crystalline material, but in case of glassy material this is not the case. And therefore, quickly it fails at low strength low strain and therefore, this sort of property is there.

So, it fails pretty early right. More importantly not only that it fails early, it has got low tensile strength brittle load up you know less ductility, low ductile it is not ductile and also not toughness, no energy can you know it has got low fracture energy. But another important issue is that, the variability of results is very high in this case. Remember we talked about the distribution of strength relative frequency distribution of strength. So, here the same histogram if you try to plot for glass; you can see the strength varies from 30 to 180 MPa, very large results 30 to 180 you know it is a very large strength results, unlike I mean metals unlike metals or even concrete does not show such wide variations. So, variations are very, very large.

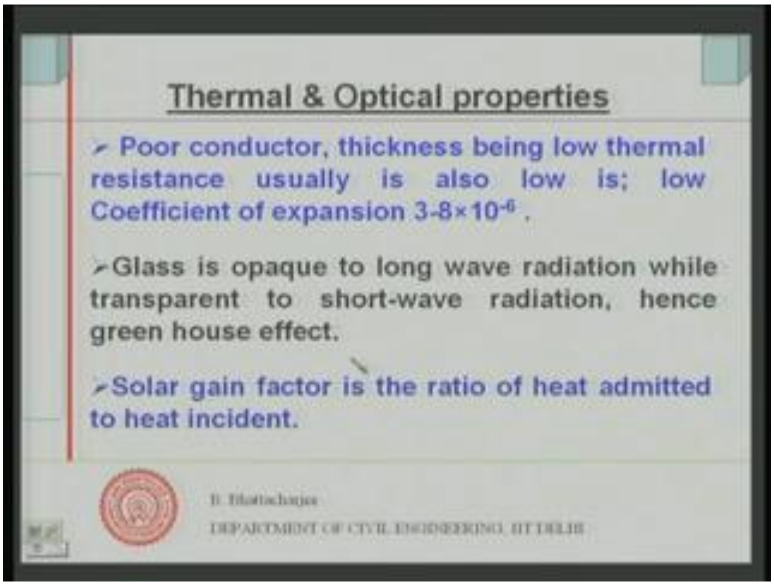
So, variability is also large strength is also large, so mechanically it is not very strong material. So, that purpose of course, we do not use, but definitely use it for the purpose of other purposes like glazing material. That is why mostly in building it is used.

(Refer Slide Time: 16:03)



If we look at its fatigue property, fatigue property is also something like this and order of mega pascal, it does not have of course, the fixed endurance limit as in case of metal right. But 10 to power 6 if you consider, this is how the fatigue behavior is or as SN curve is; SN curve looks like this right So, it is a got a low fatigue strength. So, from mechanical point of view, glass is not a very strong material, but it has got other important properties and that is why we use it as a glazing material in case of building you know windows etcetera.

(Refer Slide Time: 16:56)



Because it has got certain specific good optical properties which we shall see, because we have said that it is a transparent material. Being amorphous it is transparent its transparent or translucent material. So, it allows lights to come in. And let us look into some of these properties. First let us look into thermal properties because if it is put into the building façade, its thermal properties becomes important. Well thermal properties are also important, because it has to withstand the expansion contraction thermal expansion contraction.

So, let us see what about the thermal properties; it is a poor conductor it is understood, because it is an amorphous material and would be a poor conductor, unlike crystalline I mean metals which have which can be good conductor of the both electricity and heat. And it is a poor conductor, so its thermal conductivity is pretty low. But its thickness is usually low, so thermal resistances are not very high, because you use very thin sections of glasses. So, effective thickness you know since they are low resistance, resistance of the glass or window glasses or glazing; that is not very high again. It allows lot of heat to go in heat to go in, because thickness is also low. But its thermal conductivity is low right.

Secondly, its co efficient of expansion if is of this order, which is also low co efficient of expansion is lower compared to let us say steel which is 11 and say somewhat lower thermal co efficient or thermal expansion. And since coefficient of thermal expansion is important from the point of view of it is you know induced stresses under heating and cooling. So, this is what is about thermal expansion.

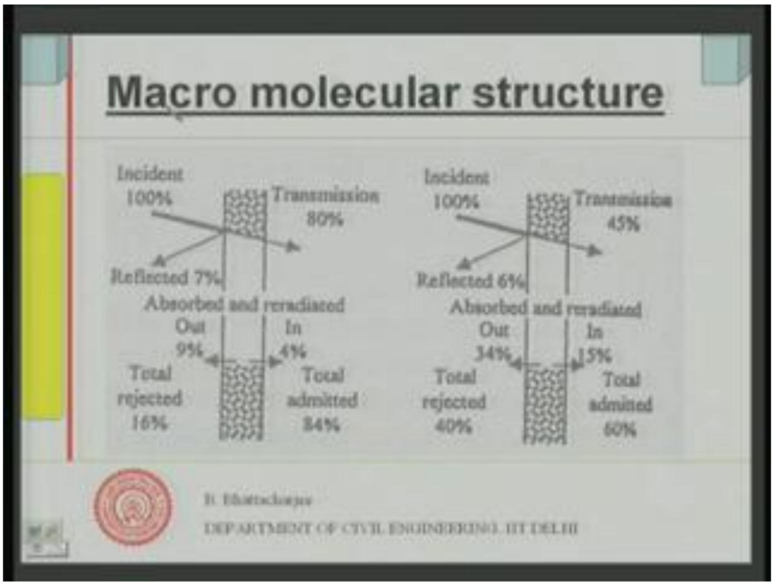
Now it is interestingly, you see we talked about sometime when you talked about walls; we said that you know surface finish we were talking about. We were talking about white wash surfaces and we said that, white wash surfaces have specific property that actually it has got low absorption property to solar radiation, but it has got high long wave emissivity. Now, again let us recall the same thing. The suns radiations is contains large amount of short wave radiation including visible radiation, which you can see, but terrestrial bodies which radiates at much lower temperature something like 20 30 degree centigrade right, they actually radiate long wave radiation. Solar radiation has got lot of short wave radiation. The radiation coming from say earth surface human body or chair table furniture or similar other things; they are long wave radiations.

So, long wave radiation transmittance towards long wave radiation is also important or its of course, in case of surface emissivity is important, but here how much it is being how much of long wave radiation is transmitted through the material; that is important. Now, eventually glass has got an interesting property; it is opaque to long wave radiation while it is transparent to short wave radiation. And you know you would heard of green house effect. So, if you have a glass; it will actually can trap the solar radiation. So, heat can come into inside the you know the glass house inside the glass house and it gets trapped, because once it is inside this radiation hits up the material within that enclosure if it is a glass enclosure is there within that enclosure all the furniture or whatever substances are there they would be heated. And once they are heated, they absorb the solar radiation, they gets heated and then its starts radiating in the long wave radiation.

Now, since glass is opaque to long wave radiation this heat is anyway trapped. So, this can be well utilized in cool countries, from you know to save energy for heating right or cold and sunny like climate London you can use glass very effectively to see that suns radiation is trapped right. So, this is what we know as green house effect; it is opaque to long wave radiation, while it is transparent to short wave radiation. So, this is an important property as far as glazing is concerned.

Now, the property through which you actually define the 2 issues: one it must bring in the light, because we said that building envelope acts as filter, it allows good thing to come in, but undesirable thing it just filters out. Now, from that point of view, the heat gained of the sun glasses are also important, because it is it is usually placed in the envelope of the building. And therefore, heat gained through the glass is also an important issue. And the property through which we measure is you know the parameter or this factor; how much heat it will allow the glass will allow to transmit we call it solar gain factor. Solar gain factor is the ratio of heat admitted to heat incident up on the glass right alright. So, that is what we call as solar gain factor right.

(Refer Slide Time: 22:13)



If we see this solar gain factor, you see this solar gain factor you can see let us say if 100 percent is incident, if 100 percent is incident here at this point right. Some of it will be reflected back and some of it will be transmitted and some amount will be absorbed also. So, some amount will be absorbed also. For example, you know so in this case 100 percent is incident 7 percent is reflected some glass and 80 percent is transmitted. What does it means? 13 percent is absorbed here. Now whatever is absorbed this will be re-radiated in both this direction inside and also outside, you know whatever is absorbed. So, absorbed ones this are re-radiated.

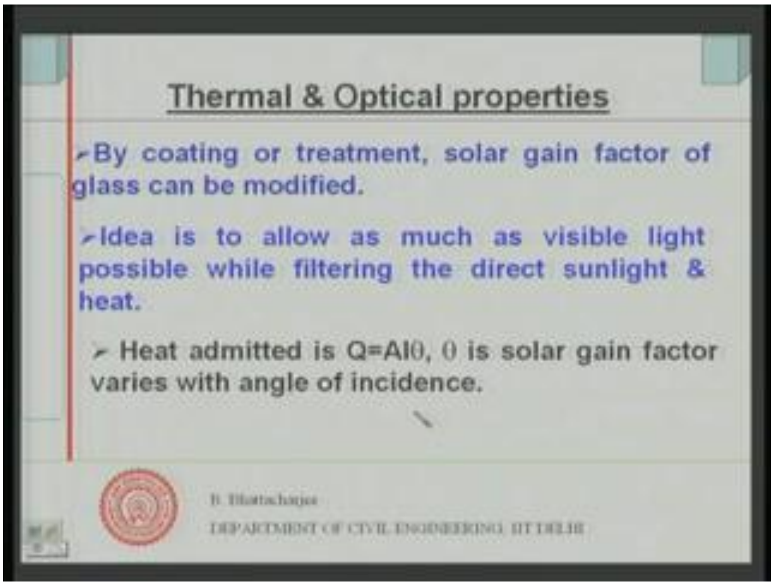
Now, how much is re-radiated; it will depend upon the type of glass depending upon its molecular structure etcetera 4 percent can be 4 percent could can be radiated inside and 9 percent can be radiated in outside .So, in this case how much is going in total is 80 plus 4 84 is going in admitted. So, I call 84 percent is admitted and rejected is 9 plus 7, that is, 16 percent. So, the solar gain factor in this particular case is 84 percent 0.84, solar gain factor will be 0.84 in this specific case.

Similarly for another glass let us say 100 percent is incident 6 percent is reflected out, because there is an interface, reflection takes place from interfaces of 2 material having material having different reflective index, you know interfaces of material having different reflective index. So, here the interface of glass and air 6 percent will be reflected 45 percent is actually transmitted directly, so this is going in. But then 55 45 plus 6 makes it 50 45 plus 6 makes it 51 percent. 49 percent therefore, is absorbed 49 percent is absorbed. And out of 49 percent 35 4 percent is radiated outward, 15 percent is radiated inside, so therefore, makes it 49 34 plus 15.

And therefore, total rejected is 34 plus 6 makes it 40 percent and total admittance is admitted is 15 plus 45 percent is 16 percent. So, it is basically a heat absorbing glass. You can see this is an heat absorbing glass which actually absorbs about 49 percent about half of it nearly it absorbs, whereas this was not an absorbing glass, it was a normal an ordinary glass.

So, an heat absorbing glass if its re radiation is higher on the outer side, now in some cases re radiation may be 50 percent inside and 50 percent outside. In such cases absorbing glass are not really good. For example if it would have absorbed 49 percent about nearly about 25 percent would have been admitted. So, 45 plus 25 would have made it 79 percent admittance or solar gain factor being 70 percent. So, that is what solar gain factor and that has how actually the glass admits energy.

(Refer Slide Time: 25:38)

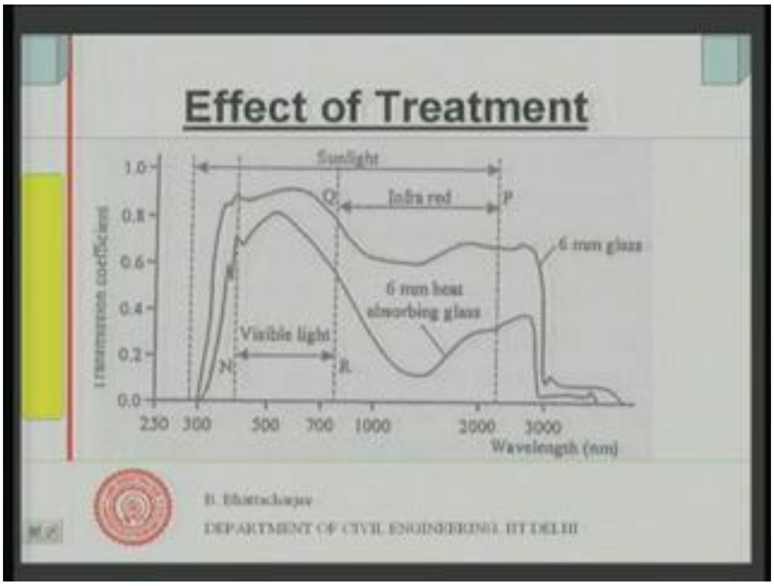


So, continuing with this thermal and optical property we see that solar gain factor is 1 and important issue, which allows us direct transmission or heat to go in. So, we do not want basically, we do not want direct sunlight to go in, less energy should go in it is admittance or its solar gain factor should be lo so that, heat is heat does not go in. But the energy in the visible range it must definitely it should allow to go, because light is wanted natural light is wanted that would make it energy efficient would allow natural light to come in, but not direct sunlight, because which can cause what is known as glare also it will bring in heat.

So, direct sunlight or heat is not wanted, direct sunlight can bring in both heat as well as it can result in glare, but diffused light or visible light as much as possible it should be in it. So, what you do; we can have some coating and treatment to ensure the solar gain factor of glass can be lower or modified to lower values. And then whole idea is that we allow as much as visible light possible, while filtering the direct sunlight and heat. So, we do not want this 2, because they are not useful for our purpose, but we do not definitely want visible light to come in.

And as I told you, total heat admitted can be written like this A into I into theta, where A is the area of the glass, A is the intensity of solar direct solar radiation and theta is the solar gain factor. This can vary with angle of incidence as well. And how we calculate out the solar gain factor; it includes both the direct transmitted value plus also the plus also the re radiated value you know, so both together. We shall see more of it in next slide.

(Refer Slide Time: 27:39)



Now, effect of this treatment if you look at; it let us see this is 6 millimeter, first see what are the x axis, the x axis is wave length this is the wavelength on the x axis. So, this is the total spectrum of solar radiation, actually as you can see and this is transmission coefficient; the direct transmission coefficient. Direct transmission coefficient, it is not solar gain factor we are looking at direct transmission. So, sun's rays you can see where is from 300 nanometer to about 2000 about 2000 2500 nanometer, actually it will be 2200 nanometer.

So, sunlight varies from you know solar radiation which is in this. Now if you look at the a transmission coefficient of suns radiation, out of which actually this is visible range, you know visible range is 376 or something to about 780 or so is the visible range. You know the visible range the colors starting from you know violet to red. So, this is red this side is violet, violet red to you know violet. So, this is the visible range right. So, this side is the all are heat radiation and this side is a long wave radiation. This R this R of course, you know this is only the visible range.

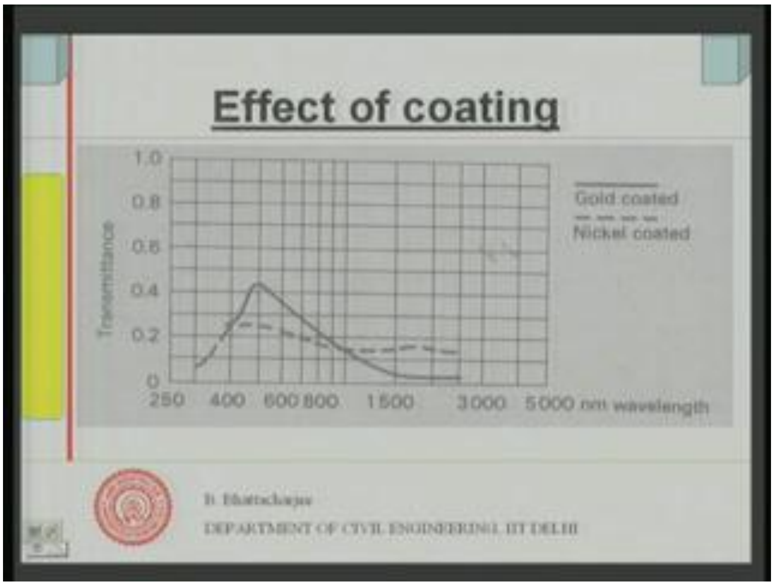
Now if you see the transmittance; in the visible range the transmittance of this is in infrared region as higher wave lengths, larger wavelengths. This is infra red this is red and this is the violet infra red region. And if you go smaller wavelength, then the other

other waves will come in you know electromagnetic waves other electromagnetic spectrum will come in. So, we do not want this to come in actually.

Now if you see normal 6 millimeter absorbing glass, just 6 millimeter glass, then this has got high transmittance here. So, it transmits most of the visible light. But it also transmits a lot of infrared heat radiation. So, this infrared radiations are nothing, but heat radiations you know. So, it actually has got high transmittance value something around 0.6 0.65 etcetera within this range also.

Now, supposing I use 6 millimeter heat absorbing glass it is a treatment basically its heat absorbing glass, which can absorb a lot of heat, it has got high absorb transmittance here some reduction. But in this zone there is some amount of significant amount of reduction right. So, transmittance actually is high here absorbing glass are good it does not absorb it absorbs the heat does not allow it to transmit. But whatever is absorbed a part of it also would actually be re radiated inside. So, admitted would be still high, but still this is a good solution this is a better solution than having ordinary glass.

(Refer Slide Time: 30:28)

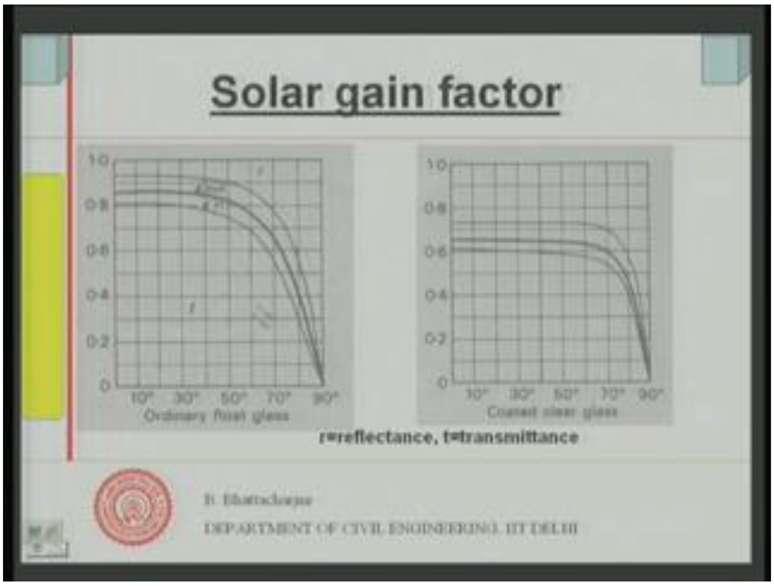


If you see effect of coating; gold coated have got this is again this is the visible range, this is where is the visible range, this is the infrared region gold coated has got high absorptivity here, but very low absorptivity where as at the higher side, nickel coated is something like this. Photochromatic glasses you know which is sensitive to the light, it actually the transmittance varies with the amount of light. So, it is actually photosensitive in a way photochromatic glasses, which will have bromide inside the glass itself and this is its transmissivity is high at lower, you know lower intensity of light and it is low at high intensity of light.

So, it tends to become opaque when light is its very bright with lot of sun shine and when we have less sunshine it is actually its transmissivity is high. So, this is photosensitive sort of an intelligent glass.

But either this coated or such photo chromatic glasses are actually costly they are not very cheap, but they can improve the properties significantly.

(Refer Slide Time: 31:36)

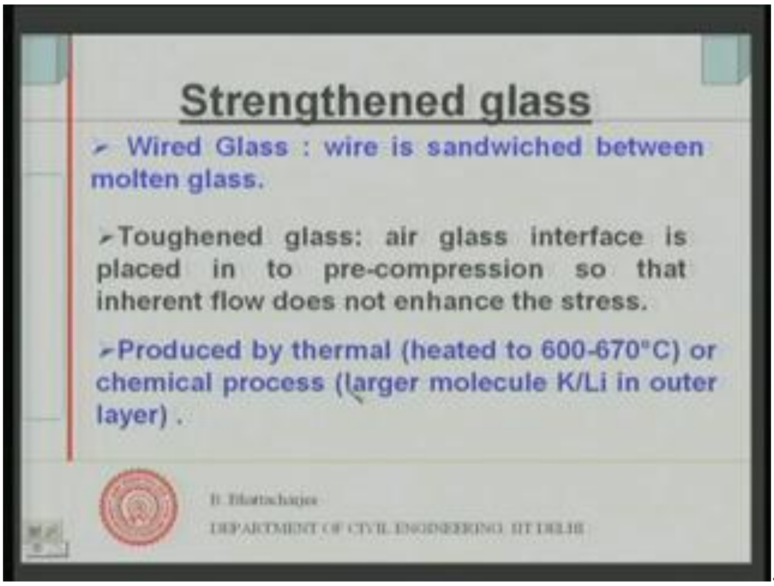


Now we can see the solar gain factor; it varies with the incident angle. This zone is reflectance at see this 0, this is your; that means, its normal you have about reflectivity is about 0.6 or 0.7 in this particular case this is ordinary floor glass and this transmitted amount is this is, this is you know this is absorbed within this range is absorbed within this range is absorbed and this is transmitted. So, t is transmitted t is transmitted r is reflected. So, this height this you know ordinate here, ordinate here this is nothing, but t represents this; t is this, t is this height and r is this height actually this height above this.

So, in any case in this case the r is this much. This amount is nothing, but the absorbed amount, this amount is the absorbed amount and part of it goes out part of it comes out. So, this gives us the solar gain factor this is actually theta. This is theta solar gain factor line is here, solar gain factor line is here right. So, this is solar gain factor and as you can see solar gain factor varies with the angle of the incidence. This is for normal glass ordinary floor glass this is for coated glass the solar gain factor.

So, solar gain factor varies with the angle, but treatment improves the solar gain factor for our usage purpose on the glazing.

(Refer Slide Time: 33:04)



So, this is what was the optical properties of the glass, which are very important from energy efficient building design consideration and also the you know the solar gain factor or energy property related to thermal admittance of heat. That is what or you know heat admission that is what we have checked right.

Let us see how do it strengthen glass because you have said that, glass is first of all it has got low strength, it is brittle, it has got low fracture energy and therefore, we would like to strengthen.

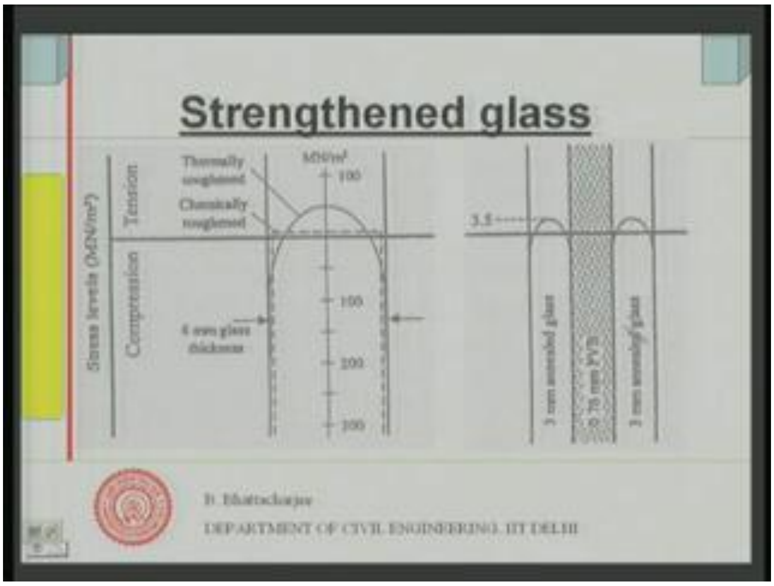
So, we can strengthen the glass in some manners. 1 of the ways of doing it is through wired glass. In this case wire is sandwiched between the molten glass at about 1050 degree centigrade in the molten condition. Actually this wires are is sandwiched between the molten glass. So, that is why you strengthen them so that it cannot splint around. So, if you know when there is a brittle failure takes place the wire does not allow. It is a kind of reinforcement 1 can think in terms of. A kind of laminated reinforcement you know and which will not allow it to actually splinter away toughened glass.

Now, most of the you know when since we have glass usually are in plate form glass plate and most of its defects come from the fact that, you create any kind of surface defect there the stress increases very fast. You must be knowing that, while cutting glass 1 simply uses then set with a diamond cutter. So, you make a line; that is becomes a weak point there you can break it very easily. So, toughened glasses essentially what is done is; air glass interface is placed in pre-compression. Air and glass interface, because that is where all weaknesses start.

So, if you have interface that is in pre compression you toughen it so that, inherent flow this should be flaw not inherent defect basically. In inherent defect flaw does not enhance the stress. So, any defect at the surface created; there should not enhance the stress. So, you pre compress it so that when some sort of tensile forces comes from outside, it would fast will have to overcome this pre compression and then of course, there it will be stressed. So, toughened glass are based on this principle.

Now, this can be done by thermal treatment or by chemical process. Thermal process pre compression is done actually by heating it to 600 and 670 degree before it starts actually softening out and creating any stresses or cracks in the system. So, this compressed you know all defects are first removed and then compressed. And then, chemical process by allowing larger molecules; for example, potassium instead of lithium in outer layer of the glass, by this kind of chemical or thermal treatment 1 can toughened this glass right 1 can use of course, laminated glass which we shall look just in a moments time.

(Refer Slide Time: 36:22)

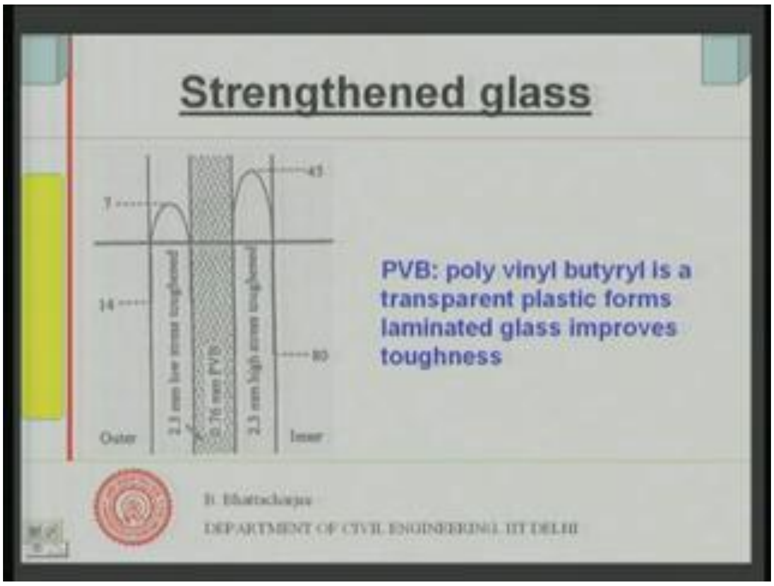


For example this is what a toughened glass will look like. Now this is the thickness of the glass, this is the thickness of the glass, this is the thickness of the glass right. And if I look at the stresses right at this point; this is compressive stress along this direction and tensile stresses. So, this is the thickness of the glass, here it is all compression if it thermally toughened. If it is thermally toughened at the boundary it is pre compressed to about let us say 75 MPa, because this is 100 MPa 200 MPa. So, this is about 75 MPa both the surfaces; this is surface of the glass this is surface of the glass and you get actually pre compression here.

And its stress diagram is somewhat parabolic. Now inside we have got inside you can have tension. So, in case of small tensions 50 MPa etcetera and surface is actually pre compressed right. Chemically toughened glass will have pre compression here, pre compression here over this length and this is the small tension here. So, pre compression here and that can be very very large, very very large surface compression, but most of it is under very small contentions chemically, because here you have put molecules which are large you know the atoms which are larger in size and they change the structure and make it actually a kind of pre compression.

In case of laminated glass, we will discuss this of course, about this lamination a little bit later on transparent lamination. So, in case of laminated glass, same kind of toughening can be done by the thermal process like this is about 3.5 MPa and this is pre compression this is pre compression and this layer is also pre compressed. So, strengthen of glass by thermally and chemically is possible.

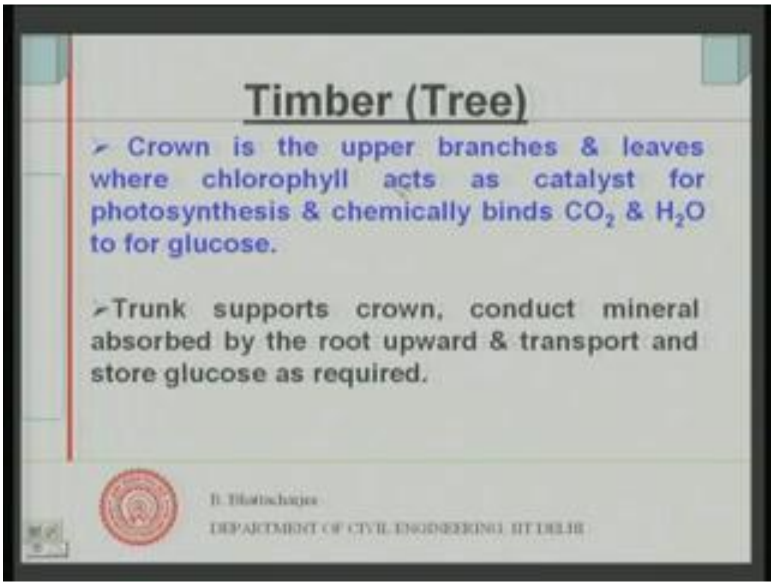
(Refer Slide Time: 38:09)



Now this is the same thing, it can have different sort of pre compression or you know surface pre compression could be different. For example in this 1 it is much higher compared to this. So, surface is compressed and inside is tension. So, it is compressed up to 80 MPa, here whereas inside it is 45. Tension is this inside tension is 45 MPa, here it is 14 MPa is compression, 7 MPa is tension and this 2 3 millimeter 2 to 2.3 millimeter low stress toughened glass and 2 3 millimeter high stress toughened glass.

So, in case of laminated ones, you can have in fact, different pre compression or toughening extent of toughening can be different. The inner 1 could be toughened more compared to the outer 1 depending upon the situation. Now, this trans you know laminated glass laminated glass to improve the toughness is something like this; this will have a inside core and the leaves are the glass leaves, even we have seen in the previous case also the similar ones. This is 2.3 millimeter this about 0.76 millimeter polyvinyl butyryl is a transparent material. So, this material 0.76 millimeter 1 can use in plastic and this plastic is transparent and therefore, it can be used to improve the toughness of the glass. So, what it will do; actually any failure of this 1 it is toughened on both sides plus any failure of this 1 actually splintering will not be allowed. So, it is actually in a way reinforced and strengthened right to take further load.

(Refer Slide Time: 40:00)



So, that is the idea about glasses and we have understood that even if you know in buildings of course, we do not use much of this toughened glasses strengthened glasses not much. But our main interest lies in glazing window glazing, where the optical and the thermal properties are important right and you can have single glazing or double glazing with in special cases double glazing with in special cases double glazing with vacuum inside so that there is no heat transfer its completely insulated, for you know window purposes for in the case of use in the widows right.

So, basic thing is that glass should allow light to come in, but should not allow heat to actually penetrate alright.

So, let us look into now timber introduce timber to you and which we will discuss their usage some of the usage in details in the next lecture of this module. Now timber comes from tree. Timber is basically processed it comes from tree. So, let us look at tree the growth of the tree. Timber is the process you know it is a material comes from natural source that is tree, of course the use of timber is getting restricted, because from the environmental concern, because deforestation has resultant in several resulted in several environmental problems.

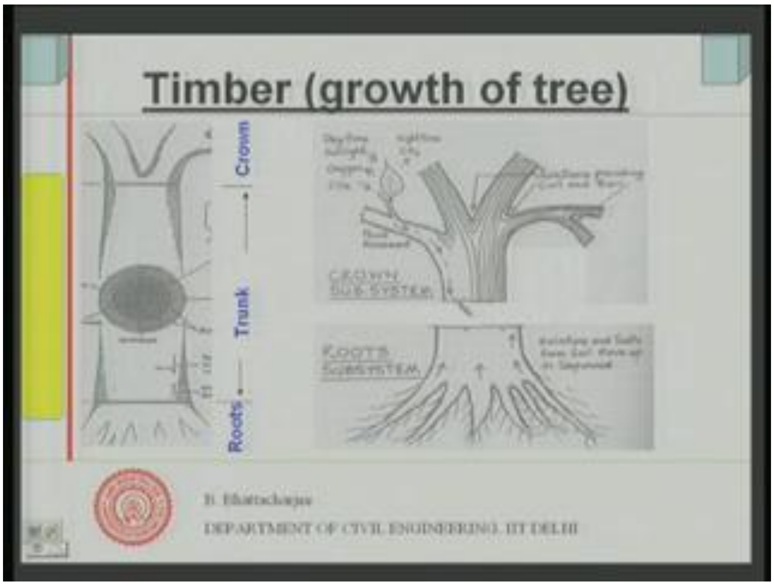
Therefore use of timber is getting restricted especially timber directly. However, process timber still continues to be used to certain extent in construction and buildings and therefore, for example, you must be aware of plywood being used as shuttering material in concrete construction or use their usage in doors and window frames these are very common. So, therefore, we will discuss some of them right now.

Timber is basically the source of timber is basically the tree. So, let us see what the tree is, its growth, crown it has got 3 parts as we shall see now. Crown is the upper branches and leaves where chlorophyll acts as catalyst for photosynthesis and chemically binds carbon dioxide and water to form glucose. So, tree has got 3 parts as we shall see in the next diagram, it has got 3 parts: 1 is the crown, next is the trunk and bottom is the roots. Timber comes from the tree, so we are trying to look at the growth of the tree, how its structure is. Of course, 1 can go into details of the structures in molecular level and so on which we will not be doing in this particular course, but we will try to see from the point of view of usage in construction.

First look into the tree, structure of the tree itself and then some of the usage that would be there. So, it has got 3 parts as we shall see it in the next diagram. Crown is the top part which actually has got upper branches and leaves. And the purpose of the leaves is to it has got chlorophyll, which acts as catalyst and you know that photosynthesis takes place it can in presence of sunlight, it acts as catalyst and chemically binds carbon dioxide and water to form glucose.

Trunk is the next level which supports the crown and conducts mineral absorbed by the root. The root absorbs mineral from the ground and transport it upward the trunk transport it upward and also stores and transport the glucose generated by the upper crown, generate in the crown by the leaves transport and store it as required as required. Now the point is this part is also where you get seed. So, reproduction of the tree is possible from the crown part. This supports the crown and root supports the whole system.

(Refer Slide Time: 44:16)

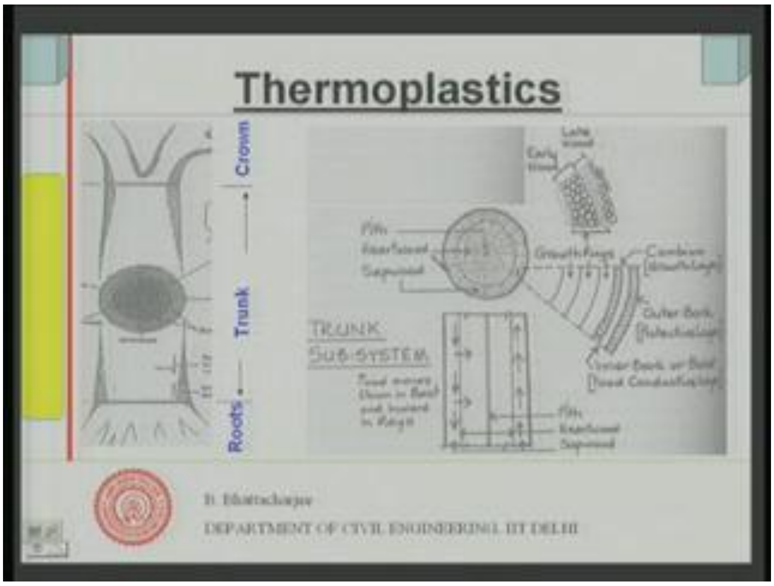


So, that diagrammatically it looks like this; the roots, the trunk and the crown, roots the trunk and the crown. Just look at the roots now what does root do; moisture salt from the soil move upward, you know root sub system moisture and salts from the soil move upward. So, that is what root does, it gives you a firm foundation of the tree, it does not it will not allow tree to actually fall down, supports it totally and also collects minerals and salts minerals and moisture from the ground, which it requires for it growth and transport it upward.

The crown on the other hand has got leaves and what it does; in presence of sunlight during the day time it absorbs carbon dioxide from the atmosphere and then converge this carbon dioxide in presence of the moisture that has gone up in presence of that it converts it to glucose. And that is the fundamental way how actually is energy is absorbed you know in the solar energy is absorbed in the solar energy is actually absorbed first to the living being right. And then of course, the other animals or other living beings actually consumes this. So, this energy is then transmitted to the other living being, when 1 consumes this right. So, this is what it is.

So, from here the food movement the glucose movement will take place downward, glucose movement takes you know takes place in downward. In the night time of course, this carbon dioxide is emitted out of this. Now, this junctions from our structural point of view junctions providing curl and bark. So, these are the junctions right, this junctions like this sort of curly grain structure they come from here, curly grain structure come from this also right.

(Refer Slide Time: 46:18)



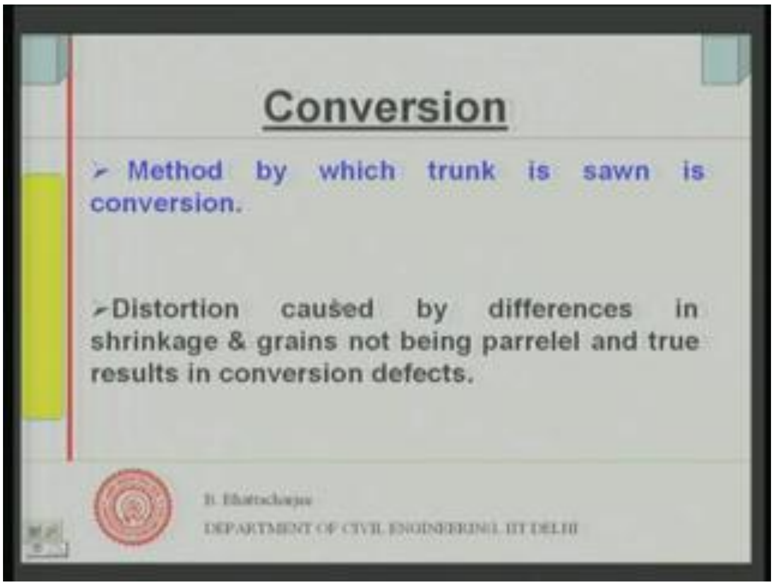
Let u see the most important from structural point of view which is a trunk. Now the trunk sub system looks like this; it has what is known as center a pith, this is called pith center you have a pith center you have the pith. Then you have got this portion this portion are known as sap wood, sap wood is there in the perfidy. The inner in between in between the pith and the sap wood we have heart wood. So, this is the heart wood. And what does sap wood do; sap wood actually carry the minerals and moisture from the roots upward to the crown and also transports the glucose downwards right and transmit it inside into the tree.

So, purpose of the sap wood is to you know transport the food right through the blast inner and also inward as rays right. So, if you look at the cross section, that is, this portion of the trunk of the tree, this will give us idea trunk even similar ideas are there in the branches also, because this is want is used is used mostly for making timbers right. Well, early wood structure would be like this later wood structure will be like this. Now tree grows radially outward from the center as it you know as it goes it goes radially outward from the center. So, growth of rings takes place, growth ring takes place. This is 1 growth ring the other growth rings and so on.

The outer periphery outer bark which is a protective layer, there is a protective layer ultra layer bark and then this is there is a cambium between this inner bark or bast, food conductive this is a food conductive their inner bark or bast which is food conductive here and then you have cambium growth layer this is actually the growth layer as the growth layer as the growth is taking place. So, food is moving inside and the growth would take place and it will increase in its dimension, the dimension will increase. So, that is how its increases takes place ring wise, ring wise increase takes place right radially outward. And therefore, from here you know growth rings from here the outer peripheral 1 is again the sap wood as you have seen through which essentially. So, this is the this is the sap wood somewhere, through which the food movement takes place and the heart wood is already grown rings, heart wood is already grown rings. And you can see pith is of course, at the right at the center.

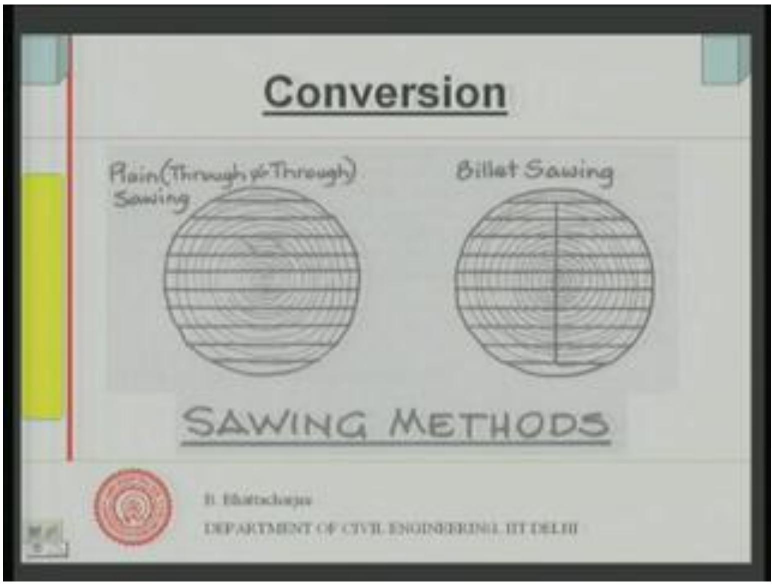
And you can of course, see the structure; the initial wood structure would be early wood will be something like this and late after sufficient growth it will be something, growth structure will be something like this. So, that is what it is. That was the growth of the trees.

(Refer Slide Time: 49:15)



Now we have something called conversion; method by which actually trunk is sawn is called conversion. You have got 2 you have the trunk and you have to cut it into pieces, you have got it to cut into pieces in order to cut it into pieces in order to make timber out of it usually planks batons planks or batons. So, method by which trunk is sawn is called conversion right. There can be some sort of distortion cost by differences in shrinkage, because the moisture is an important criteria as a far as timber is concerned as we shall see, because its moisture content is very important and that is as you dry of it can shrink. So, if there is differential shrinkages; grains not being also grains are parallel they are not true parallel to your cutting direction. Therefore, side some certain defects can come from conversion.

(Refer Slide Time: 50:19)

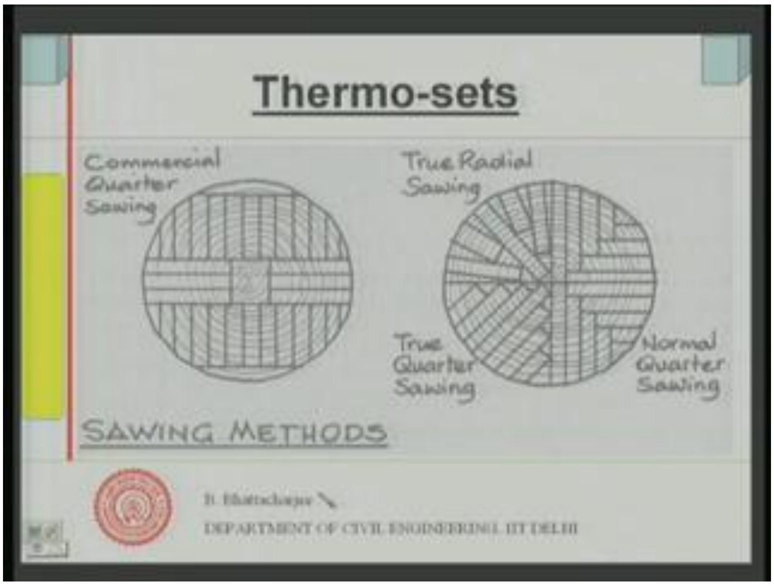


So, let us see what is what do you mean by conversion. Now you can saw them like this; pieces likes this you know these are plain through and through sawing this is called and this is called plain through and through sawing. And the properties that you will get would depend upon how you have actually sawn, depends upon conversion, because as you can see as we shall see further that, you know the material wise, it is actually cellulose fibers embedded in lignin, timber would be cellulose fiber embedded in lignin. Now the fibers actually extend along vertical direction, so therefore, the properties along vertical direction and in the horizontal, because its growth was in the horizontal direction.

So, the properties along this horizontal direction radially outward direction and properties along the vertical direction; they are on likely to be same. So, therefore, timber is essentially an isotropic, it is not isotropic, it would not have same sort of properties in both the direction, it is an isotropic. Therefore, how you cut it is an important, its behavior or its properties that you get depends upon how you cut it.

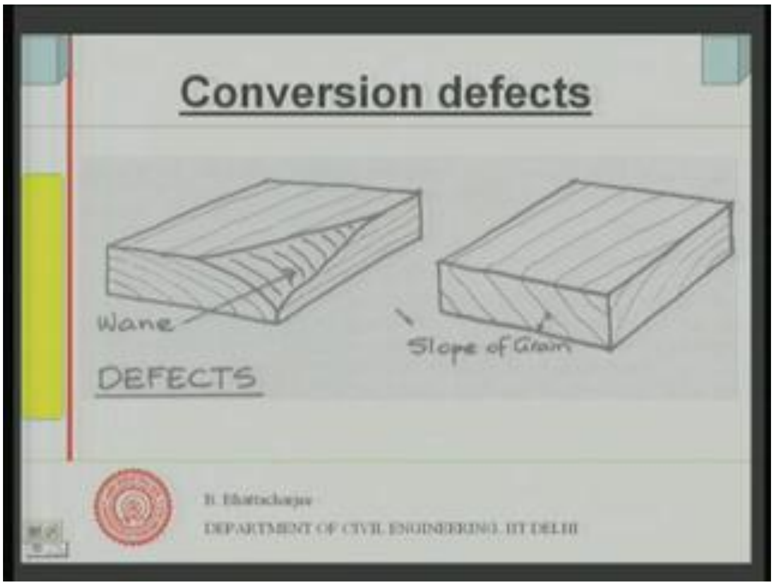
So, 1 ways to cut is cut through and through plain, billet sawing would look something like this, you have cut actually it is like this and then pieces are brought in here right, pieces are brought in from here. And once you have removed the bark this you know this useful planks could be obtained in this manner. So, this is called conversion, this is called conversion right, this is called conversion.

(Refer Slide Time: 51:55)



And this is also part of actually conversion this part of conversion its part of conversion. So, commercial quarter sawing this is called commercial quarter sawing. So, what you do; you leave this portion central portion cut pieces like this and cut here. So, there will be certain amount of and pieces like this. Then through radial sawing so this is true quarter sawing something like this, this is radial sawing, this is quarter sawing, this is normal quarter sawing something of sort of this processes. And there will be certain amount of wastages, depending upon the way actually you have way you have gone for the conversion right, way 1 has gone for the conversion.

(Refer Slide Time: 52:45)

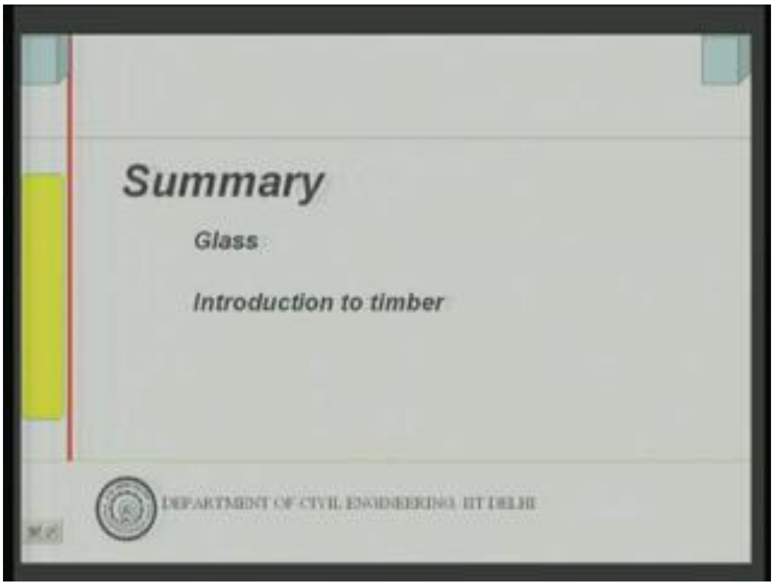


Now, conversion can result in defect formation, conversion can result in defect formation, because we said the grains are not always parallel to your direction of you know they are not all parallel lines. Some places they will be parallel, there can be other kind of defects also present. So, what happens is you have this sort of from after conversion you might find that, because you have chosen the kind of conversion, you might find there is what is called wane. Or slope of the grain not being actually it should have been something like this it should have been something like this rather, the grains are something you know it is it is not parallel, slope of the grain being different than the slope of the grain being different then what you know there is a sloped grain.

So, it should have been basically no slope vertically and here also and this is again not same; here you might find slight slightly higher, somewhere else you might find slightly different. And this defects can give you reduction in the strength or properties as desired. So, conversion is the process of sawing. And depending upon from the conversion process chosen, properties differ sometimes it can give rise to defects right. And the planks are thus obtained from planks or batons whatever it is; they are obtained from this kind of conversion process right.

So, what we have looked into?

(Refer Slide Time: 54:14)



We have looked into basically; as far as timber is concerned we have essentially looked into the growth of tree today. And also we have looked in to conversion now. From the growth of tree we have understood the trunk is the most useful portion from the point of view of timber. And we have also understood conversion, you know which is the method depends upon and it is a method of sawing actually; how you saw it and how you obtain that way.

Now, since it is a natural material there will be several kind of defects present in it and therefore, its properties many times may not be desirable; this is 1 issue. Second issue in process of just using it naturally as it is; there are lot of wastages, because of this conversion process and we do not use every material together. However process wood process timber, it would process them in a right manner, use them in a judicious way in materials like ply woods, particle boards and so on, which we will discuss in the next class. And they can be used more efficiently and many of this defects which are present are you know which are present; they can be you can take care of them in a more efficient way.

One thing is to be understood unlike most of the material that we have discussed so far, timber is anisotropic its property along the direction the grain and perpendicular to the grain direction they differ. They are not same direction, you know their properties along the direction of the grain and perpendicular to the direction of the grain; they are not same. So, let us summarize to this discussion; we have actually discussed about glass and their properties and you know that it is the most important glazing materials and we have introduced timber.

Next class we will look into little bit on to the material or molecular structure of the glass I mean of timber and then followed by its uses in industrial timber products like; particle boards, like ply woods etcetera, where you can use it structurally. I think with that we can conclude our discussion today.

Thank you.