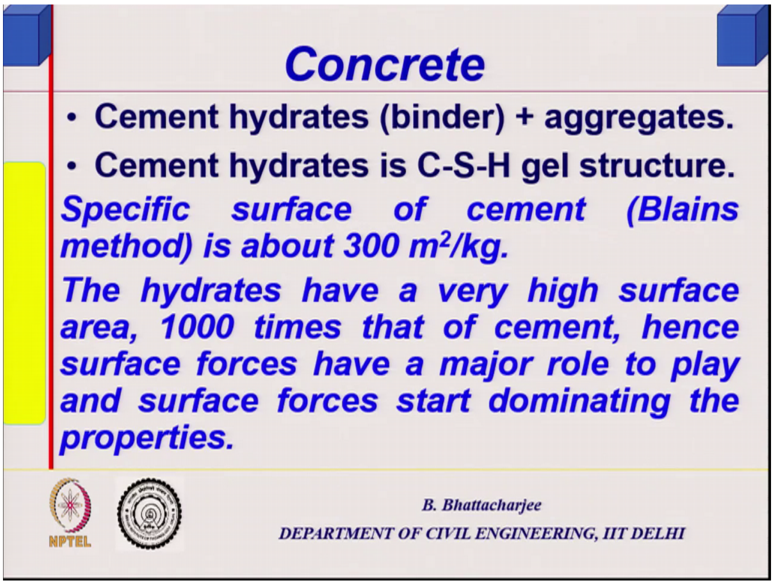
Fire Protection, Services and Maintenance Management of Building

Prof. B. Bhattacharjee
Department of Civil Engineering
Indian Institute of Technology, Delhi

Lecture – 07
Effect of Fire on Construction Materials

So we are looking at, you know if you just recollect from the last class we are looking at Effect of Fire on Materials.

(Refer Slide Time: 00:27)



And then we are looking at concrete and we said that cement hydrates, which is the binding material right which holds which goes into the interstices of aggregate system. It is true for asphaltic material also these are actually particulate system bonded together largely, mechanically chemicals are very little chemicals you know chemical bonding is very little.

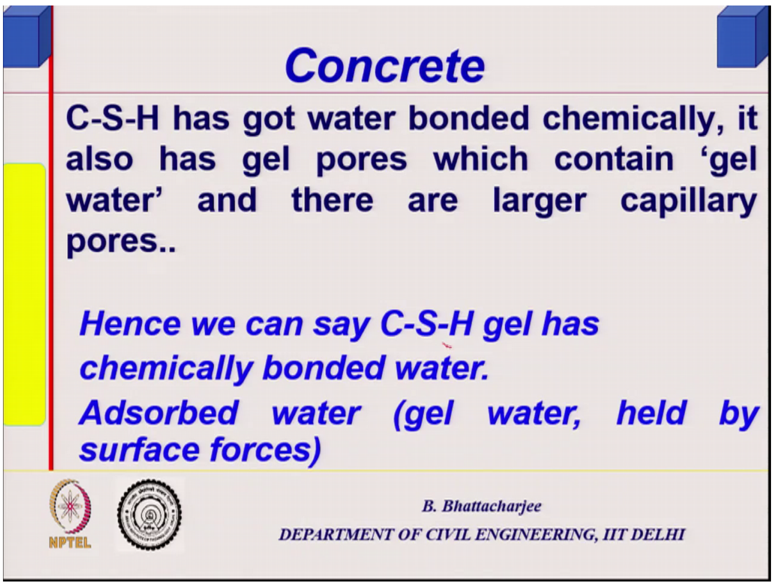
So, inert material you packed them together and interstices it will do some kind of binding material, depending upon the nature of the requirement for example, as for as for you need lot of deformation capability plastic visco, you know say basically viscoelastic material. You want lot of deformation to take place in flexible pavements. Whereas, in case of concrete it is relatively works is rigid, because it is a structural material mainly. Although we can use it in pavement and other places, and essentially it is a binders which are initially in plastic state; in molten or plastic state sort of so that you can mold it.

And then either because of chemical reaction or because of you know this cases in case of cement concrete is chemical reaction, it is solidifies. In case of it is polymers for example, Epoxy concrete then you will have 2 component of the bite resin or something of that kind the monomer system, and there we hardener and it will polymerize to larger molecular weight and solidify.

So, you know and some paints of course, and similar sort of thing there also we have got particulate system and then they evaporate. So, basically essentially this kind of system you have got particularly system bonded together; with some kind of binder. So, the binder is the one that gets affected by fire. Because the inert aggregate system that is actually come from the nature would have formed at very high temperature do not get affected there is hardly any effect on them up to a fire temperature of 1000 degree 1200 degree centigrade or so.

So, as I mentioned in the last class, this is I what I mentioned in the last class that C-S-H is a calcium silicate hydrates, which is the one which has got some capillary pores and filled with water.

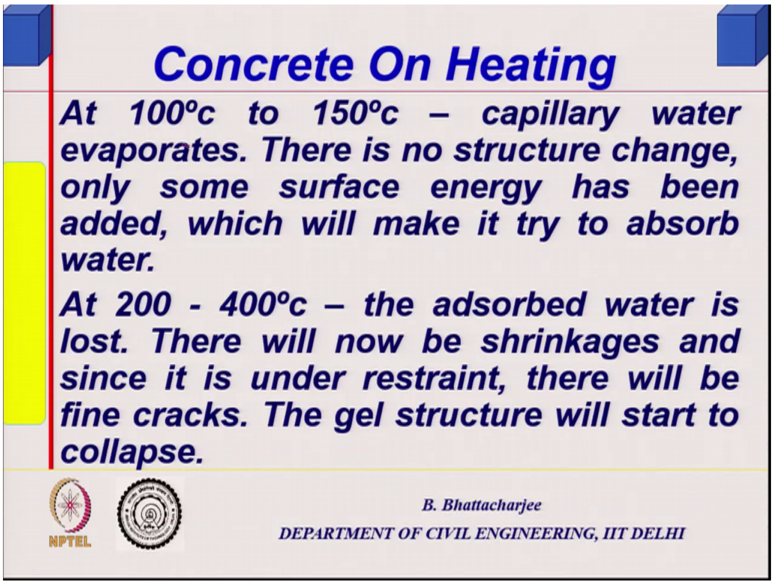
(Refer Slide Time: 02:41)



And then it has got gel pores as we call it which is actually this in this microstructure of itself of the calcium silicate hydrates. Because they form a gelatinous structure with some you know their layered structure with spaces in between the layer, which we call as gel space and there could be adsorbed water there.

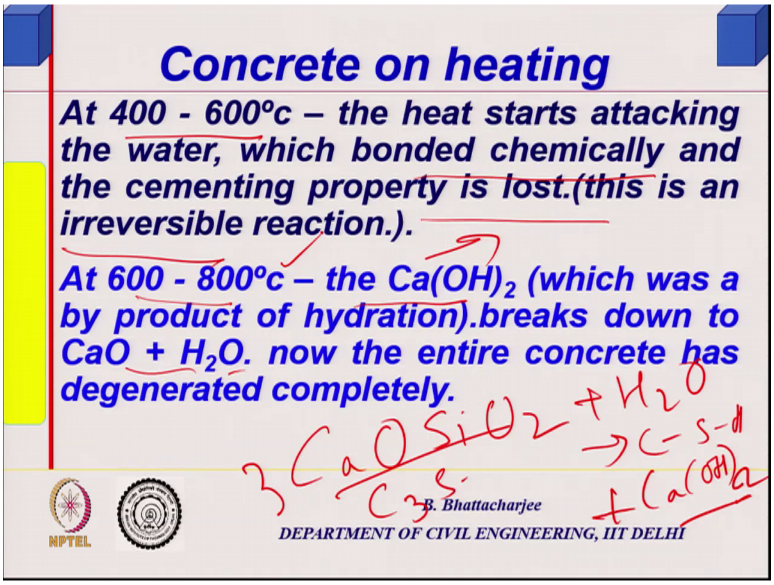
So, as you as you, you know some members H C C S H this part is chemically bonded water of crystallization, this part is chemically bonded water of crystallization all right. And just all are this is adsorbed water and this is there are some capillary water.

(Refer Slide Time: 03:24)



So, that is what I just mentioned in the last class 100 degree centigrade to 150-degree centigrade capillary water will vanish. 200 to 400-degree centigrade adsorbed water will be lost. And this will result in shrinkage and you know cracks etcetera, etcetera due to shrinkage alright.

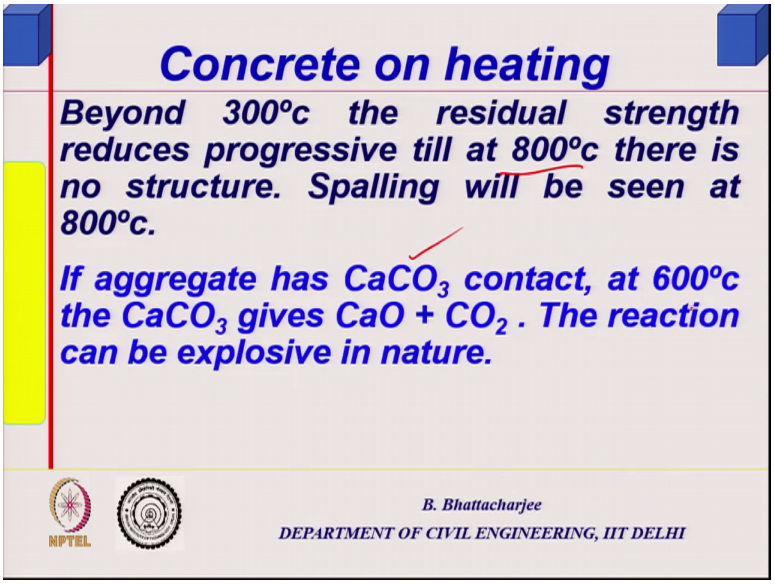
(Refer Slide Time: 03:45)



400 to 600-degree centigrade heat starts attacking the water heat starts attacking the water right? And chemically bonded water goes away causing cementing property to be lost. This process is relatively irreversible very little reversibility is that mostly it is irreversible all right. So, the 600 to 800 degree centigrade the other part because you know reaction of this materials, which is called tri calcium silicate we write it like C 3 S in cement chemistry abbreviate them, when it reacts with water right some amount of water so this would react form C H S gel plus calcium hydroxide.

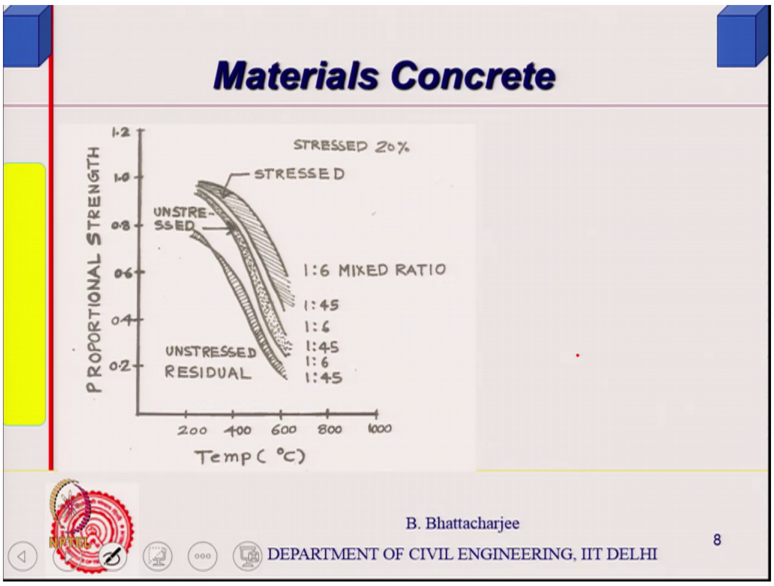
So, calcium hydroxide is also a product of cement reaction. And this breaks down between 600 to 800 degree centigrade. And everything you know breaks down to calcium oxide and H 2 O. Therefore, entire concrete system actually degenerates completely a plate 200 degree centigrade. So, you will see spalling of concrete if it is just chunk of concrete would come down because there is no bond right?

(Refer Slide Time: 05:03)



So strength obviously, beyond 300-degree centigrade residual strength reduces and it goes on reducing till 800 degree centigrade, you will be left with very little. And if the aggregate constant contains calcium carbonate that will get disintegrated around 600 degree centigrade if the aggregate is limestone aggregate and that is what I mentioned.

(Refer Slide Time: 05:23)



So, this is the kind of relationship I mentioned last class, that there is a reduction in strength, there can be 20 percent stressed. And then tested under compression the other case would be you raise the temperature to that particular temperature say 400 degree centigrade, then test it under compression, then you find this strength.

Now, this is the relative strength being talked about one stands for ambient temperature you know strength at ambient temperature. And this is unstressed residual that means you have actually heated it up, cooled it down and then tested it. So, that is the lowest actually, because when you have heated it up; see whenever when you are see there is there is a when you have stressed this particularly it is under compression because we are talking mostly in case of concrete or similar material it will be under compression. And because of heating there will be some amount of expansion.

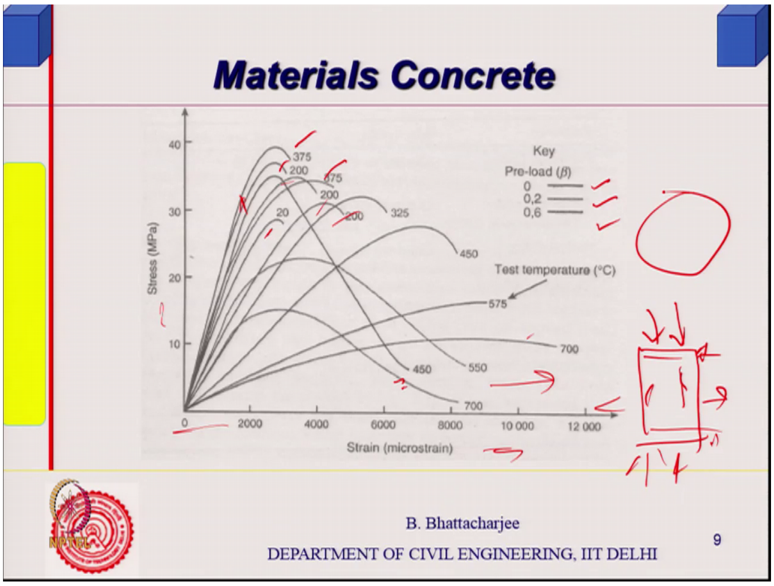
So, some stress might even get relieved you know 20 percent stress you have given then heated it up there will be some stress. So, therefore, you might you might find that this is actually taking higher load. Because you have already pre compressed it then you have heated it up and then testing it from 20 percent to whatever failure. So, there is there is a nullifying effect there will be you know effects are like, first is a mechanical I mean deformation because the load, deformation due to shrinkage there could be expansion. So net effect of all this, you know net effect of all this is what you get the final strength as well as deformation variation.

So, here essentially that is why it shows you higher, when you do not stress this it shows a little bit lower. And it is unstressed residual means unstressed residual means; you have heated it up lot of degeneration has already occurred then you have tested it obviously you get it least and what is this implication, implication is post fire load carrying capacity of the structure.

So, what we see is post fire load carrying capacity of the structure would be much less compared to during fire or similar sort of thing. You know because normally load the dead load would be there an imposed load, which is what we call Quasi static; will not be there all the time because consider a classroom it is not it is not full of all the students all the time. So, that is why it never the working load is much less than the design load.

Design load is that load which will not be exceeded more than 5 percent of the time characteristics load that is what we take and that to, that value we take like consensus of people working load is much, much less really goes to that level it never. So, that is why this 20 percent you know the low is interested.

(Refer Slide Time: 08:25)



Now, if you look at stress strain behavior I think that is what we are looking at; there are 3 cases as you can see 375, 375 and there must be another 375 or only 2 cases being shown here.

If you the issue 1 is 0 another is 20 percent load some cases 60 percent already it is loaded preloaded to 60 percent. So, here you have number of curves say 200 this is not basically this is this is you know pre-loaded to 20 percent possibly. This is preloaded to no preload because that is what we said it is just this comes down. And this might be 60 percent of the strength you have got, which means that we have already done some micro cracking.

Now, if you have done micro cracking heating will not close those cracks, cracks are permanent deformation. Cracks actually you know manifest itself is in form of permanent deformation. And little bit of expansion will hardly cause them to come back fill in that never that is not fully reversible so it never happens that way. So, therefore, this is the thing similarly 700 degree centigrade the cases are 700 degrees centigrade you can see this.

Now, thing is that whether loaded, partially loaded or not loaded; stressed and curved at low temperatures say 20 degree centigrade it is somewhere here. So, you have a modulus of elasticity. Now you heat it up a little bit; then the elastic modulus tend to does not reduce may increase a little bit up to 300 degree centigrade or so even strength it seem to increase.

But after that there is sharp fall and deformation capacity tend to increase this is strain micro strain. So, stress versus strain curve is like this. So, as if it is a kind of a ductile behavior it is you know why, because now the as you have heated it up and then let us say loading it lot of cracks have already formed. So, that cracks manifests itself in form of strain right?

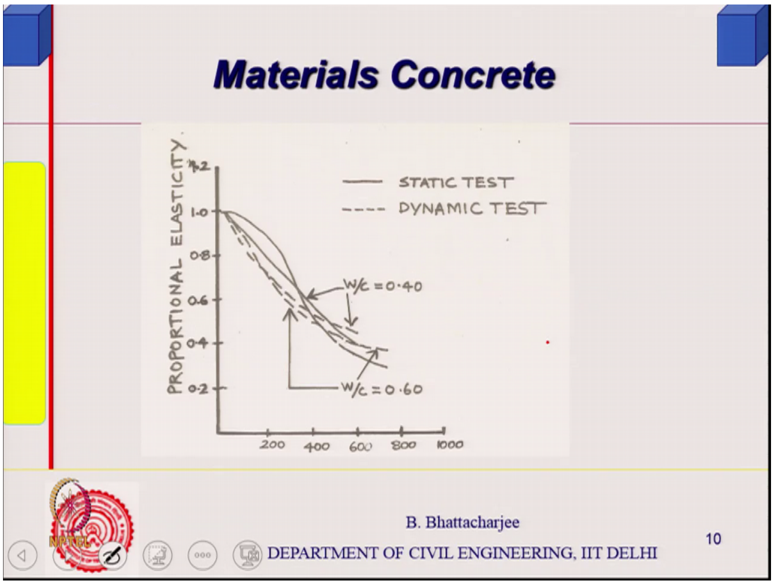
You know lots of cracks you have already formed like tensile cracks would form in a compression cube like this; cube normally when you load like this essentially persons effect causes cracks to form occur like this it bulges out. So, this would have already occurred then you have heated it up. So now, this means the deformation compression deformation because persons effect along this direction there is a compression.

So, when you raise it to 700 degree centigrade there has been already expansion in all direction right? And the failures now the flavor is to start from one of those one of those cracks or whatever has formed, total deformation if you look at it you will find it much larger, but load it can carry is much less, because cracks are already there and if you recollect or may not have studied actually the strength is governed by weakest link.

So, you have already cracks existing in the system, fracture will initiate from those cracks largest cracks in fact; you know (Refer Time: 11:48) theory one can take queue from there. So, it will actually start propagating from large crack, at a critical stress level. And critical stress level is a inversely proportional to square root of the size of the crack. So, you have already crack form larger crack from because you have gone to high temperature.

So, fracture would start at much lower stress level. So, it you know so crack so strength deformation is right, but it cannot withstand anymore, because crack starts propagating easily because already there are some crack surface.

(Refer Slide Time: 12:26)



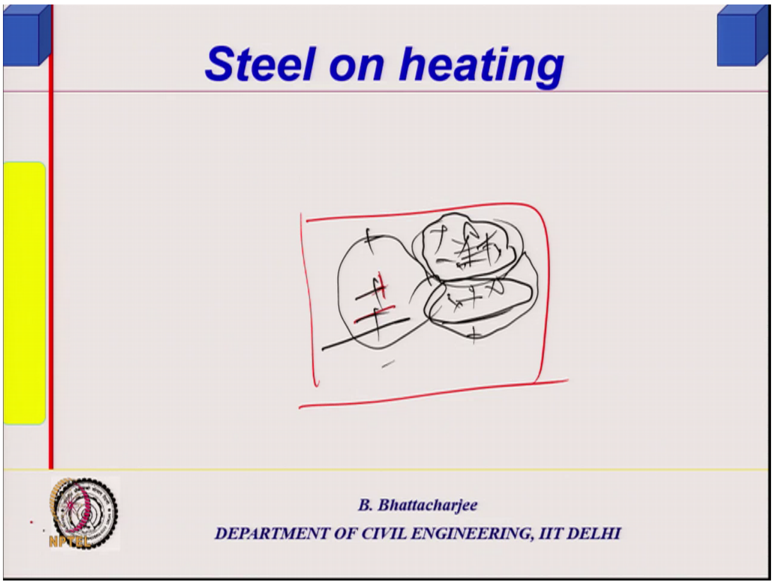
So, that is why you see this kind of behavior and therefore, modulus of elasticity which one would need in design, if somebody is doing a fire design then; you can see that modulus of elasticity relative value it reduces in this manner. Some manner introduces statics tests and dynamics test, what is dynamic test? In dynamic test actually preload it increase the temperature and do it again right?

In a so static test is basically there is you increase the temperature then do a static test only. Dynamic step basically you increase the put the load somewhat load increase the temperature to the required temperature then again do the stress strain behavior. So, this is this you know the both these types of tests have been done with, either case you find the relative elastic modulus tend to come down, whether it is water cement ratio 0.4 or 0.6 they will come down.

So, elastic model you can understand this from previous diagram itself, the stress strain of itself. So, modulus of elasticity will reduce down, strength reduces down while deformation capacity increases, but this theory does not make much of a sense. It can take a lot of deformation, but basically because ductility we relieve from reinforcement, but not from you know concrete is supposed to be a brittle material in that sense.

So, that is how concrete effect of fire on concrete. Strength reduces elastic modulus right and they are all function of temperature we will see that we have some empirical equations available. Let us look at steel now steel or metals they are what are called poly crystalline, metals are poly crystalline, how? Because you will have you know if you look at the say steel its coming from molten phase from molten state.

(Refer Slide Time: 14:13)



So, what will happen is some sort of dendritic formation of solidification occurs. And it forms some sort of dendrites it is structure, which means; there is something of this kind one solid one crystal another crystal and so on. You know so they form they form they solidify into crystals right, depending upon their arrangement of iron carbon F e c system if you have iron and carbon or any other metal for that matter right, and then you have nickel etcetera, etcetera, whatever you add they form actually kind of crystals, because metals are known to have; say atoms are assumed to be spherical bodies and metals in metals actually they packed with each other in a regular arrangement.

And the space, void space in between those ones should be minimal. What we call; packing density should be a specific value above which the crystal is stable. Packing density means 1 minus the voids in the system packing density is a percentage of solid divided by or total solid divided by volume solid divided by total volume that is packing density. So, they are packed right. And therefore, different sizes of atoms make you know more stable or their properties can be modified for example, Fe alone is soft.

So, you had carbon so F e c system so there are different sort of different sorts of structures is possible, which I have no discuss here, but the point that I want to make you. So, to start with the form somewhere solidification will occur, some point solidification will occur and then it goes on expanding what we call in a dendritic structure form.

So, you will have some sort of growth of this crystal around this initial nucleation point. Then you will another immigration point and they will form. Now orientation of the crystal this is called a grain; the grain is crystals having all having similar orientation and this is another grain. This grain also has got crystalline structure the atoms arranged in regular form, but their orientation could be different than this.

So, finally, you know like all gets filled in. So, you will have number of grains attached to each other with their boundaries right; the boundaries forming, boundaries forming changing crystalline structure from one grain to the other. Now metals are said to be poly crystalline that is why; now this will have all you know although I am saying they should have regular arrangement, but there are defects 1 place somewhere one atom might be missing instead; some other similar atom. For example, sodium lithium belong to the same group.

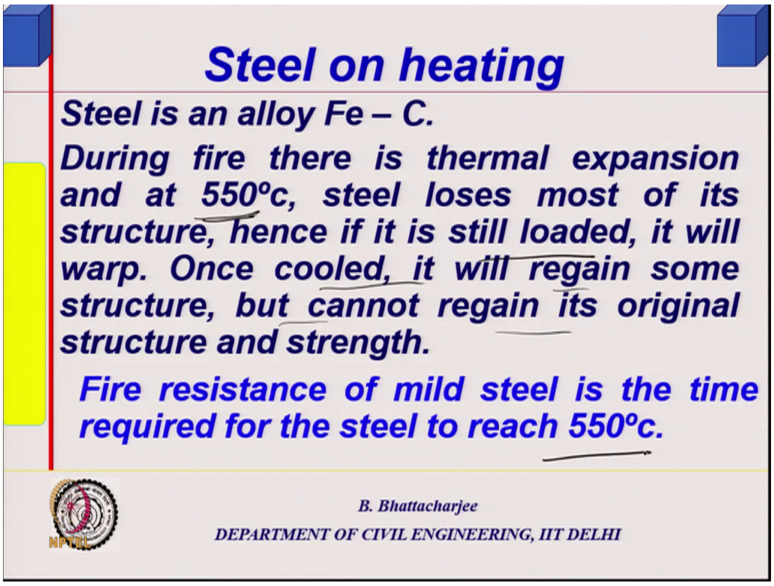
So, if sodium was to come there could be impurity in the material lithium, what I call this sort of thing happens? Actually what happens is you have got atoms and their outer electron forms a kind of a electron cloud cluster of electrons. There nobody you know it is free for all. So, when you apply electric current they can move that is why they are good conductor of electricity heat etcetera.

So now my point is what happens when you supply heat to them. The defects are there in the grain boundaries. Now if you supply heat to a small you know like up to say 200-degree centigrade crystal structure would not change, crystal structure would not seen. You start heating it more there are effect on this grain structure itself, if you heat it up and cool it back you get a new crystalline structure right. Or quench it you might become a totally; for example, you might have heard of thermo mechanically treated steel bars right. There when they come out of the rolling mill you quickly quench them in water cool it or you might have seen blacksmith doing the same thing; he forms actually a hardened layer of what is called martensite.

So, you see if you heat it and cool it in certain rate the properties crystalline structure changes. So, when you heats metals, that is what exactly happens here also up to certain temperature nothing will happen crystalline structure remains same beyond that; it starts affecting the property because drain you know the microstructure starts changing in some manner or rather.

Again this is not a natural material, steel is not a natural material, iron is available not in iron form in nature. So, if you go you know because as I said natural material you have to go to their formation temperature. If it is igneous rock magma still as it cools down from it is molten state at different states different crystalline structure forms so that is what it is

(Refer Slide Time: 19:41)

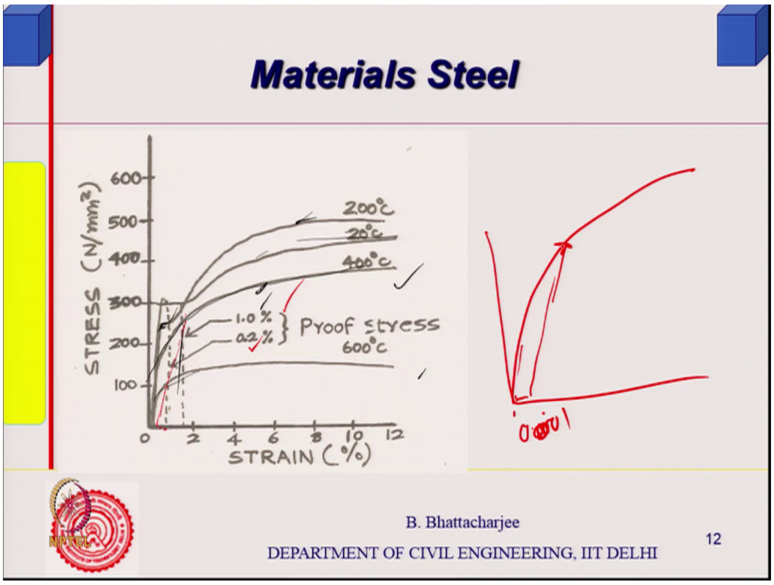


So, steel is an alloy and Fe, Fe and C. There is a thermal expansion up to up to 550 degrees in a thermal expansion, and at 550-degree centigrade steel loses most of it is structure, responsible for strength etcetera, etcetera.

So, if it is loaded it starts warping you know it will warp. Once cooled it will regain some structure, but cannot regain the original structure and strength. So, up to 200 degree centigrade again steel nothing happens to steel, but beyond this 200 degree centigrade we find properties anymore. Now one simple way of handling steel is you assume that the moment the structure which 550 degree centigrade, it will warp hinge formation will occur here and there and it will collapse possibly.

So, we assume that if steel has it is 550 degree centigrade it is no good at all this is very simple one, this is extremely simple way of looking at it.

(Refer Slide Time: 20:42)



So, stress strain behavior of steel mild steel for example, people have seen. So, you have up to 200 degree centigrade you know 200 degree centigrade you have something of this kind 20 degree centigrade, 200-degree centigrade yield strength comes down a little bit, but ultimate strength somewhat increases, but this is this you know it is ultimate strength somewhat increases.

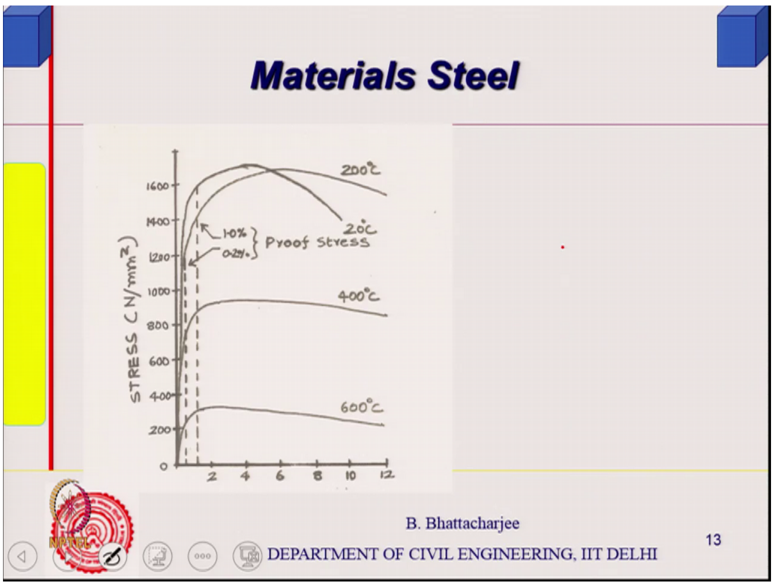
In other words, we can say up to 200-degree centigrade strength reduction is very minimal. As you go further this sharp yield point starts vanishing, you know this one 20 degree centigrade you had something of this kind this starts vanishing and it becomes something like this. 400 degree centigrade something straight away is something like this and upper yield point and lower yield point they have worn 600 degree centigrades something like this.

So, their property starts changing because while at 200 degree centigrade there will be expansion occurring, the you know the crystal possibly would have tend to move from away from each other. And this location should move accordingly they might go to the grain boundaries, but still you know like pulling for if you to if you have to pull it further load it further then it will resist more, but beyond 400 degree centigrade or 600 degrees this is what the way varies.

So, in such situation you take proof stress, proof stress is what you draw a parallel line you know you draw line parallel, you draw a line parallel right? You draw a line parallel line to this curve at 1 0 0 1 percent. So, 1 percent or 0.2 percent proof stress you start looking at they reduce down significantly. Remember wherever you have a stress strain diagram of steel is like this right, what do you do? You see you take proof stress for instead of taking yield stress you take useful strength as proof stress simple case.

So, what you do? You take 0.0 1 percent means 0.001. You know 1 percent I mean 1 1 percent would be 0.01, 0.01. So, you take strain as 0.01 and draw a line parallel to this wherever it touches there is a proof stress that is not use in steel design or RCC design. For with you know with let us say bars where you do not have sharpened point.

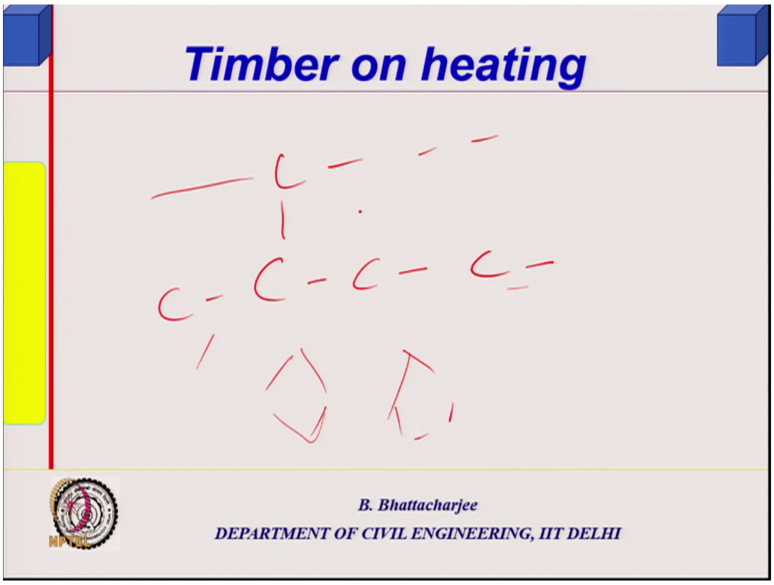
(Refer Slide Time: 23:15)



So, this is for high strength steel, this for high strength steel same behavior up to 200 degree centigrade there is not much of a problem, but beyond 200 degree centigrade 600 or 400 degree centigrade you find that strength reduces significant. Elastic modulus also would behave in the same manner. If you see this elastic modulus you know initially elastic modulus is by and large same, but beyond that actually some of them elastic modulus also gets affected a little bit.

We have some empirical equations and we will look at them, let us look at the material behavior first. What about timber; what is timber? Timber is essentially cellulose fibers, embedded in lignin. You may call it as natural composite, natural composite cellular cellulose fiber embedded in lignin sorry. So, what in on heating on heating they show behavior of charring.

(Refer Slide Time: 24:28)



Now, little bit of see the polymers are or any other you know, like you can have long chain polymer right? So, you can have even I mean something like this hexagonal rings etcetera repeating itself long chain polymer, long chain polymers. So, fibers are usually long chain polymers. Now this once they are usually thermoplastics, means what? When you heat them up they will slide over each other each chain will slide over each other. So, a point comes when they start softening, when you heat up the slide over each other and they start softening.

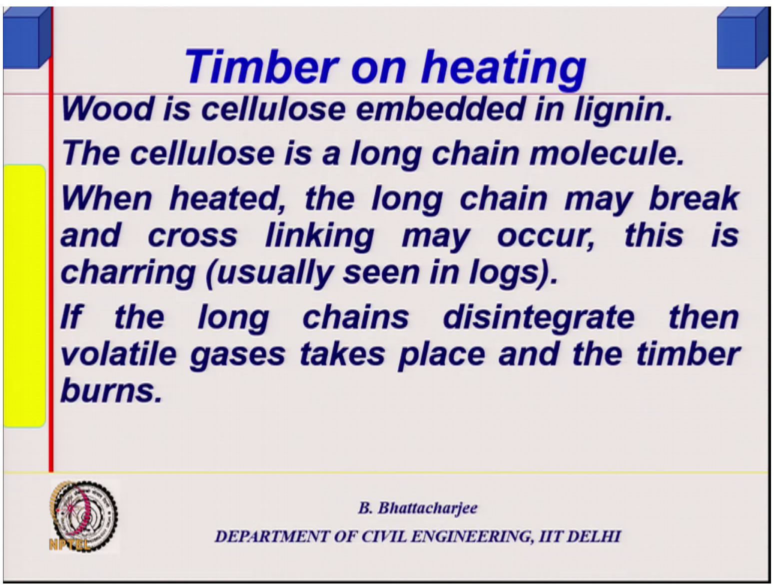
So, that there is a, they and you cool it again they can get into the same material. So, you can remould it these are called thermoplastics. Now supposing I have got 2 dimensional structure instead 2 dimensional structure, then now sliding is not possible and if it is 3 dimensional structure sliding will further not be possible.

So, you have complex 3 dimensional structures, such slidings do not occur they are called thermosets. You can heat them up then, but molecule will break pyrolysis would broken they will burn. You know they will actually and we still heat it to the ignition temperature smaller molecules will come and they can react with oxygen combustion process.

So, timber cellulose fiber I said they are long chain, when you heat them up some of those chains will break down in between and at lower temperature they break down, and they form actually cross linked structure. In other words, they tend to become 2 d or 3 d structure from a 1 dimensional. Chart product is actually not the wood it is no longer just cellular got say it is a thermosets type of behavior you will have cross linked structure it does not burn so easily it is insulation call it is good.

So, log if you have you can see that it is core hardly gets burned you have charring product at the periphery, at the surface. And this chart product they do not allow it to pass through them they are relatively insulating and they are burning rate you know they now breaking them becomes a little bit more difficult right? So, they do not soften only you can disintegrate them at higher temperature.

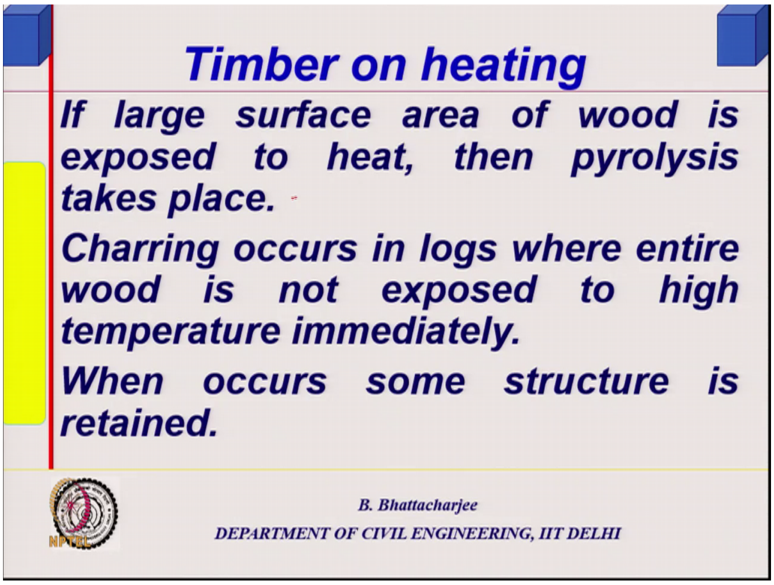
(Refer Slide Time: 26:59)



So, timber this is one thing timber shows charring. So, wood is cellulose embedded in lignin. The cellulose is a long chain molecule when heated the long chain may break and cross linking may occur this is charring. Usually you will see them in logs. So, if long chains disintegrate then volatile gases takes you know would come out and timber then burns.

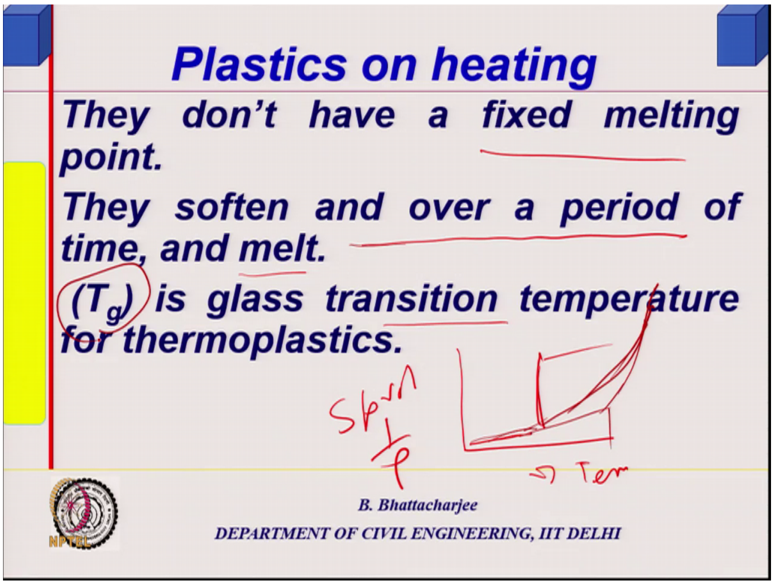
So, you have to break those chains at higher temperatures. So, you can see that timber you know it has it log form. If it is small pieces form, then charring would not occur because surface area is very large now and heat would be reached everywhere in almost all parts of the wood crib or root pieces they will actually all get disintegrated simultaneously. You know, but in a log surface get charred before heat can enter inside and that is why this is this sort of behavior.

(Refer Slide Time: 27:53)



So, if large surface area of wood is exposed to heat then pyrolysis takes place that is what it is. So, charring occurs in logs where entire wood is not exposed to high temperature immediately when occur some structure is retained.

(Refer Slide Time: 28:07)



So, that structure is retained actually, then plastics; they do not have fixed melting point as I said thermoplastics right? I already mentioned them. So, thermoplastics often over a period of time and melt and we call something like glass transition temperature.

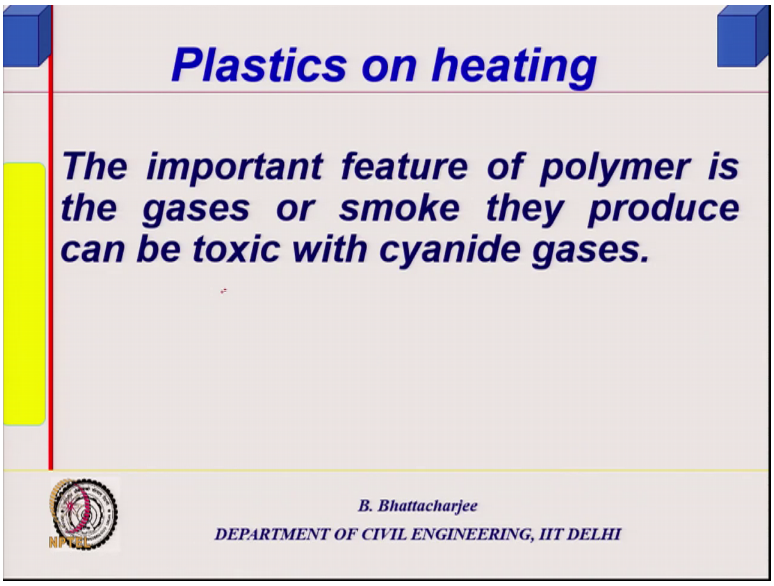
Now, what is it? Actually is something like this, if you see the specific volume which is nothing but 1 by density right, as a function of temperature right as a function temperature. So, solid they will expand density will reduce. Now in case of material where you have got sharp melting point what will happen; suddenly they will become liquid you know suddenly they will become liquid like ice you know, but then here the ice of course, the volume of water is, volume of water is less.

Ice densities you know it is less therefore, it occupies more, but many other materials the liquid occupies the more volume or you know different volume. So, it is a sharp change well in plastic it is not so, in plastic it is not so plastic it will be something like this, then it might change like this often and then it goes like this. So, plastic softens because the slide molecule slide and then this temperature we call as glass transition temperature.

So T g, now my point is I am not really going to the material sense of it the issue is T g of plus thermoplastics is usually 70 80 90 100 140 200 degrees you know it is very low. So, there many plastics thermoplastics will start softening while thermo sets will start disintegrating at their ignition temperature. So, your Epoxy or Epoxy concrete or similar sort of thing or you know many times you apply Epoxy repair material.

Now, one has to be careful, you have got to give some protection to it. So, that if you are done that kind of repair in a building in future it should not be vulnerable to fire. Because they can withstand much lower temperature than normal concrete, cement hydrates can really withstand better temperature epoxy may not.

(Refer Slide Time: 30:32)



So, the important feature of polymer is this, but other important feature of this material is that; many of these plastics which are used for example, your chairs and tables if you have a plastic wrapping on them. And if they burn they generate lot of toxic gases generate lot of toxic gases right?

So, the smoke they produce they can be that can be fatal or dangerous to health. So, some of them even produce the cyanide gases, because nitrogen would be there, carbon is very much there, hydrogen is there. So, they can produce H C N or cyanide gases react with something. So, the risk of poisoning is more from kind of thing, right. So, this is the materials on heating. Let us see a little bit with the structure, just after this.