Structure, Form, and Architecture: The Synergy

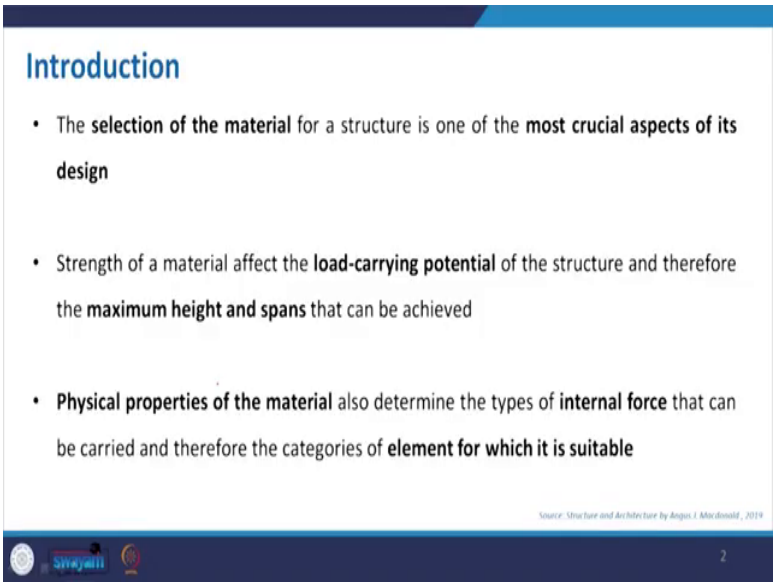
Prof. Shubhajit Sadhukhan
Department of Architecture and Planning
Indian Institute of Technology, Roorkee

Lecture – 15
Structural Materials

Hello, everyone. Welcome back to the online NPTEL course on Structure, Form, and Architecture. So, this lecture we will cover up different Structural Material. This is lecture number 15. So far, whatever we have seen over last lectures so we study about different structural form and also we know the structural property like acting depending on the force applied on it.

How the internal force will behave, like compression or tension or torsion but also that time I mentioned about that it will depend not only with the geometric shape that we select for a structural element, but also the material because, material will have certain properties which will actually give you the hints that whether it is suitable for your structure or not. So, we start today's lecture discussing on structural material.

(Refer Slide Time: 01:23)



So, selection of structural material for a structure is the most crucial aspect for the design because, when we discussed about the elements selection for a structural member then also we talked about the material because, the material based on is you know is the property that the density or the particles how they close to each other or the porosity. So, it depends on that structural material we can achieve some kind of you know stability in the overall arrangement and all.

The strength of material affect the load carrying capacity, no doubt about it. So, whenever a material we use of material having high strength will have high resistance again applied load and it will not collapse easily. So, it will also affect the you know decision on making the span that you can design with that material or the height of the building or height of the structure

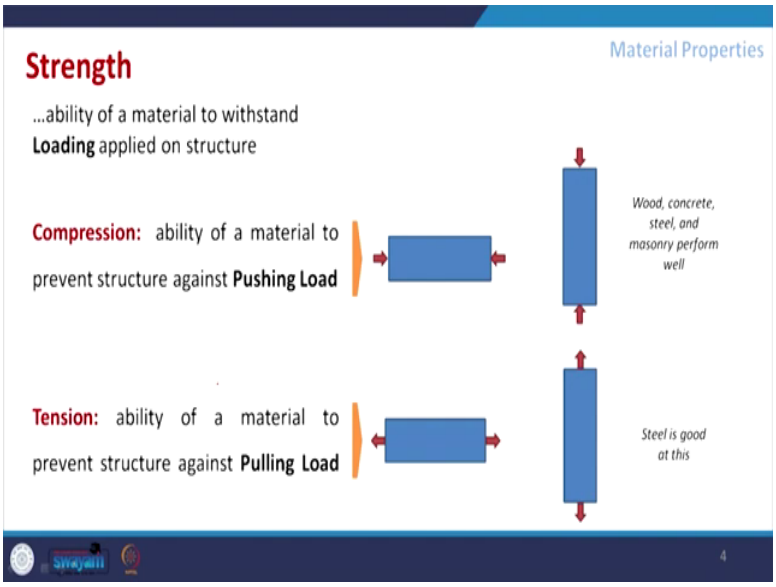
that you can determine based on the material selection. It also says the physical property of the material that determine the internal force and how good it is to act on that.

There are few materials which will help in you know compression, there are few material will come to know which are good for the tensile force. So, we know compression and tension so, based on that here also we will just recap some of the things. And, then basically it will be the one of the crucial part while design structural system for a building.

(Refer Slide Time: 03:07)

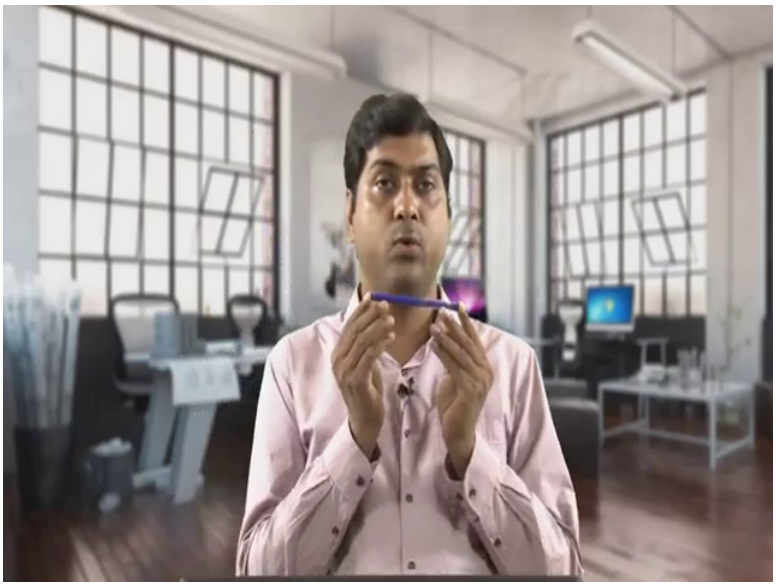
So, basic few properties are the six properties that will look for a building material or the structural material like the strength, then density, then hardness, ductility or the brittleness, elasticity and toughness. So, these are six basic properties of a material we are looking for.

(Refer Slide Time: 03:33)



Let us start with the strength. So, this is basically the ability of a material withstand loading applied on it. What exactly this sentence means? So, strength of a material means it is basically will determine the ability when you apply load on it. It may be tension, it maybe compression, it may be a bending may be torsion, but like to resist again the applied load is determine the strength of the material. So, the compression is another strength where ability of a material to prevent structure against pushing load.

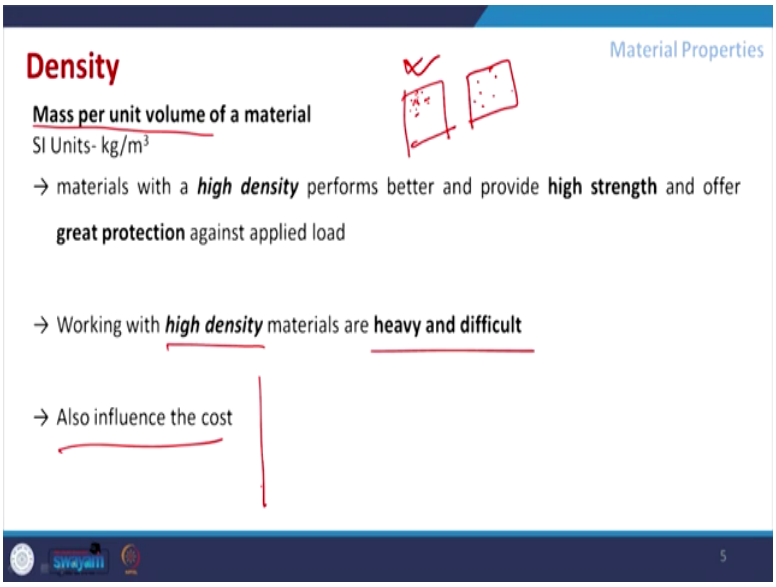
(Refer Slide Time: 04:13)



So, basically when I take this example of the pen so, we try to push them ok. So, I put pressure with my finger to this. So, this pen will try to compress depending on the strength it will have like response to that. And when we go for the tension one so, it is the pulling one. So, push and pull. So, when we try to pull this pen like from taking this particular part away from each other so, that is basically the pulling load applied on it.

So, it will depend on the strength that how it will react, it will resist with that or not. But, definitely depending on a material and it is physical characteristics the limit of the compression like through resist against compression or resist against tension will vary. The next one is basically the material density.

(Refer Slide Time: 05:11)



So, exactly this is to be determined by the mass by the volume. So, it is in SI unit you can say the kg per cubic meter. So, normally if you get a material where you have high density high mass on this like say if I compare the same amount of volume and one is your wood and other is thermocol so, you know the density. And you compare the same volume of steel so, you can easily compare the you know the like the resistance that it can. So, higher the density is the higher performance and higher strength. This is in general and again it will give the great protection.

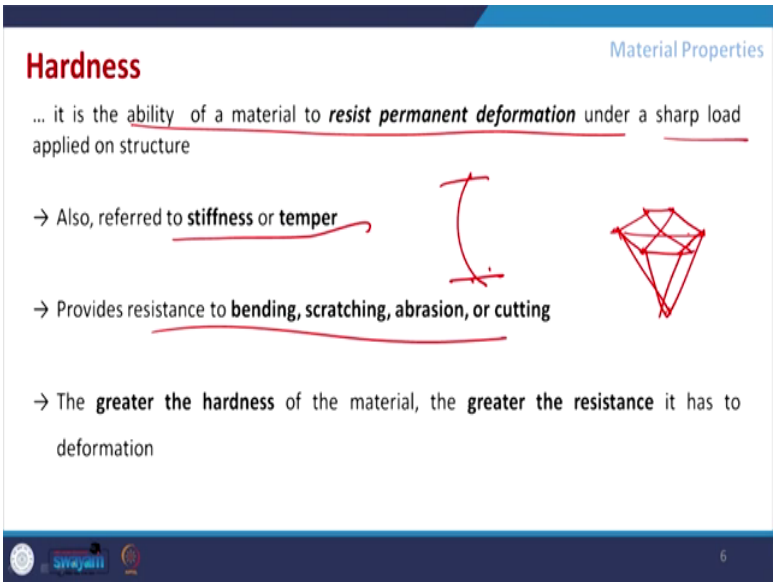
So, if I take 1 cubic meter of thermocol and 1 cubic meter of wood and 1 cubic meter of steel. So, you can get some idea you can all can answer that which one will have higher strength to you know to get withstand with the applied load and the answer is very simple it will be the steel. But, if I compare it with some say take another example the thermocol and like clay block, again clay block will be more and then like that we will determine that based on our

need, based on the load resistance that we require to make our structure we will select the right material that based on the density.

So, density is basically we need to remember this is mass per unit volume. So, if you take the same unit so, when your mass are more and compared to the material the compound is a far away so, you will be selecting the higher density. But, along with that there are problems when you go for higher density so; basically it is very difficult to handle it with. So, it is very easy to work with thermocol. So, normally you know for making models and all we use some lighter material to that. But, at the same time if you want to do it something like wood or maybe some metal so, that you know it will be difficult.

So, in case of the higher density the material weight like in given unit volume so, weight will be more and then hence it will be difficult to work with and that obviously, having impact on the cost. So, whenever you go for that such kind of material cost will going high, but it is again as general statement, but sometimes you may find that the cost of a lightweight material is even more than a heavyweight material, but definitely in that case the lightweight material maybe superior in terms of resisting with the applied load on that particular you know portion of the structure than the heavy material. So, the second property density is another important to select up on the material for that.

(Refer Slide Time: 08:23)



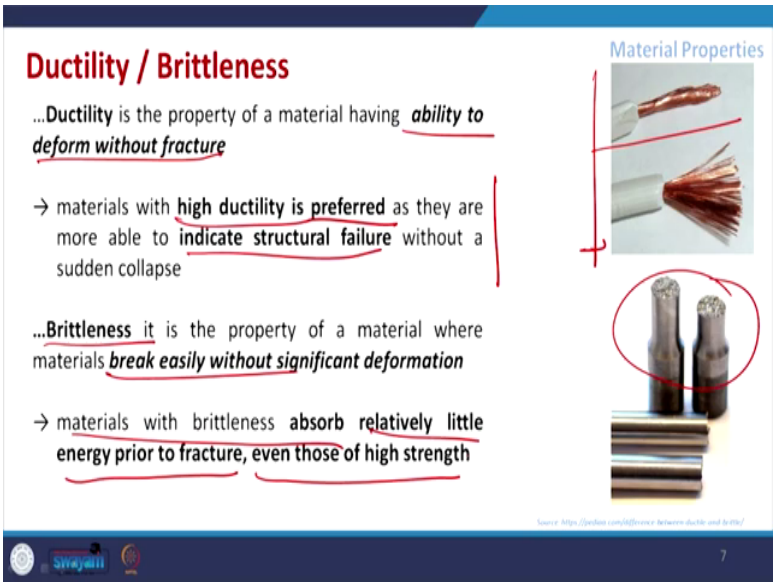
Come to the third property that is the hardness ok. So, this is basically the ability of a material to resistance against the permanent deformation. So, if we say that this again I take this example of the pen I have so, this pen is very hard. Why I am saying that when I apply try to apply the load so, it is not bending with this load, but definitely if I put more pressure then it will go for the deformation. But, the property that is actually resisting this particular force are not going for a deformation is called hardness.

Now, if you take a instead of this pen plastic this made of plastic you take a piece of thermocol maybe look like a pen and then you do this experiment. Then probably you say that hardness is very low. You take wood then they will have something. You take like steel you will get something if you take aluminum compare to steel then you get that steel is you know harder than that aluminum.

So, this is very important that the hardness will resist permanent deformation under a sharp load and also it is related to the stiffness and temper ok. So, in that case what we can say that tempered glass normally we being used smart phone and all, so, it will give the stiffness so that stiffness what we know that due to the stiffness it will prevent the you know even buckling of something. So, deformation to resist.

So, also provide resistant to building bending as you know scratching and also you have this abrasions or cutting. So, take example of say a diamond. So, if you see diamond so, it is very hard to you know make a scratch or even to cut. So, that is a example of the hardness. So, sometimes it may apply to the hardness of the structural material or sometimes it may be the non-structural material, the glass that we look for. Greater the hardness of the material, greater the resistance. So, always we look for a material of higher hardness while selecting it for this kind of you know we need to prevent that permanent deformation.

(Refer Slide Time: 11:21)



Come to the ductility and brittleness they are used side by side. So, we need to know it very carefully so that we can understand the term exactly. So, ductility is a property of a material which is ability to deform without fracture. So, what is fracture? Say, I just try to pull this. So, what will happen, if I put enormous force ok so, what will happen? So, first you will see that there is some deformation, it will not immediately break.

So, you will find that you know the thickness of this particular you know cross section of this pen getting reduced and then after certain time it will actually break. So, that is basically the fracture. But, at the same time if you take a example of a chalk to put the pressure, hardly you will find any deformation it cracks. So, there are materials which are good in this you know producing that they will deform before fracture and that the property is called ductile property or this overall event is your ductility.

So, if you see this image so, this is electrical wire. So, when you just you know try to pull them or just you know to give the deformation. So, it will not really break. So, here this is one example that you can get it. The other one there are materials which are very brittle in nature, say for example, glass. You try to deform it, you put extra force it actually breaks. So, here also these are some of the metal where they are not really giving a sign of the deformation they just break it. So, materials with high ductility is preferred as they are more able to indicate the structural failure, very important.

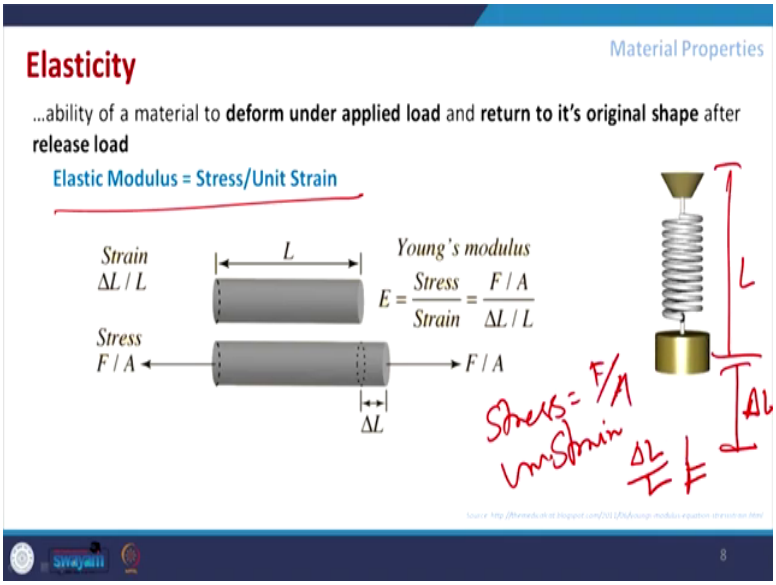
If you make a building; so, building is to protect us, definitely. But, if there is some abnormal behavior due to some faulty design or may be due to some uncertain in activity or maybe there is a huge earthquake. So, there oscillation start and building will try to collapse, but it should give some time, so that we can just go out and put our self in say in a position which alternative we call evacuation. So, they will elongate the evacuation. So, when we use such material having good ductility they will give us the indication that this structure is going to fail. So, it will give some time. So, it is very important features of any structure material that you should use.

The in the other hand the brittleness is the property of a material which can break easily without significant deformation. You take a biscuit you just give pressure, breaks and this is one example like definitely that will not a structural material. But, you know the materials will brittleness basically absorb relatively little energy prior to fracture even those in high strength. So even this material is having high strength because of the high density, but the property is something like that this brittleness so, it has a relation with the temperature deviation also. So, some steel if you like put it in the frozen temperature will be become brittle.

So, we have to see that it is not a particular property of a material that always give me the best result. So, in this case looking at this particular you know metal, this particular cylindrical pipe. So, strength is good, but when you apply this particular thing specially the tension. So, due to that cooling so, it will immediately crack and not give any indication. So, this is something very important. Even the glass it will not really deform and depending on the glass

even we can also you know improve all the ductility and reduce the brittleness so that we can use it as a structural material.

(Refer Slide Time: 15:49)

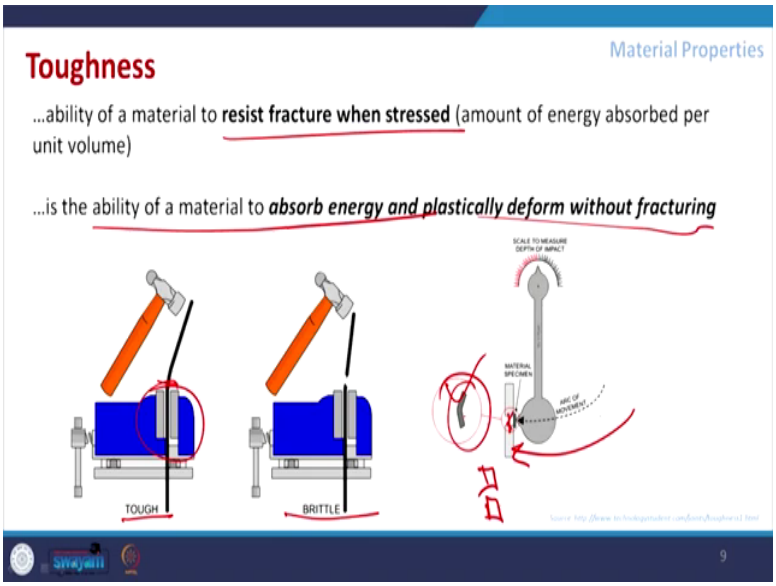


Come to the elasticity that already you explained in some of the property where it is the ability to of a you know of a material which will deform for a applied load and when you release the load it will try to get back its original form. So, if a material can really do the 100 percent you know return back to the original position. So, we can call it is perfectly elastic and where there is no such property (Refer Time: 16:21) also elastic. So, this is basically the concept, but in reality we cannot have such material which is totally like 100 percent elastic.

And, the formula like we use, the elastic modulus which to be calculated by the stress by unit strain. So, stress is force by area and strain unit strain is basically the deformation. And, so in this picture I just want to show you; so, this is the actual length may be L and now after

deformation so, this is delta L. So, strain will be in the unit strain here it is delta L by L and the force applied like if this is the case and the area then force by area is your stress and then the ratio between these will give you the modulus.

(Refer Slide Time: 17:21)



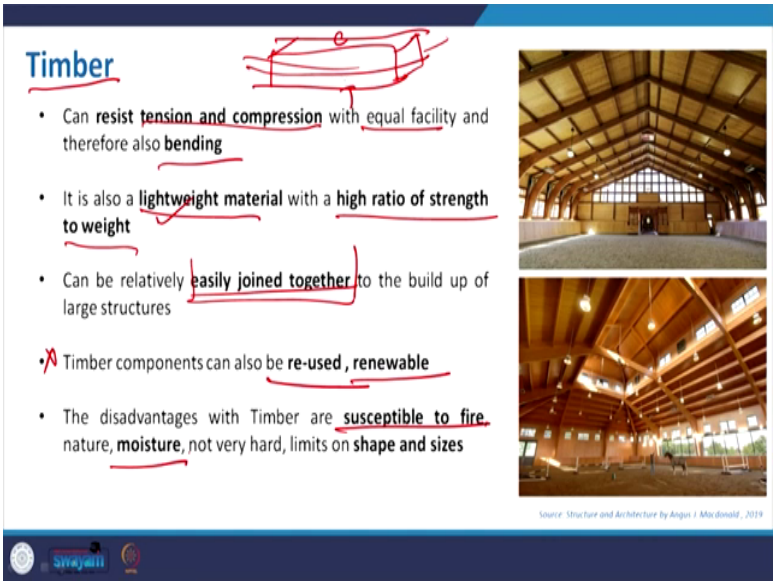
Now, come to the toughness ok. So, we discussed about strength then we discussed about hardness, density and in this case elasticity, now the toughness this is the ability of a material resist fracture when stressed, what exactly it does mean?. So, we let us clear this from this image.

So, in this case this is also the ability of a material to absorb energy and physically deform without fracturing. So, when we compare it to the brittleness, it will absorb less and break immediately. It is just the reverse. So, in this case if you say the building material is tough so, we hammer it. So, we are putting extra pressure and it is anchored at the bottom. So, it is not

really breaking at this particular load and it is giving a deformation bending. So, this is a tough material. When you consider the brittle the moment you put a pressure it will absorb very less energy and then breaks immediately.

So, this is one gif image that I have taken from this website given here. So, this is small piece of the material and there is a you know pendulum kind of movement. So, we put a pressure on this and this is basically the exposer. So, if this particular piece of metal will just come out with this deformations we can say that it is having the good tip you know you know toughness, but if it breaks into pieces and not passing this experiment is not having the toughness. So, this is also important parameter.

(Refer Slide Time: 19:09)



Now, looking at that over the years we have used and even in the prehistoric age and the contemporary architecture we have seen the use of different kind of materials. So, here we will

focus on that, we start with the timber. Timber can resist tension and compression as well with equal facility and does the bending. So, it will act really the wooden baton they can also take this particular you know tension at the bottom if it is a like slab and the compression at the top it is also lightweight material compared to other in that category and high ratio of strength to weight.

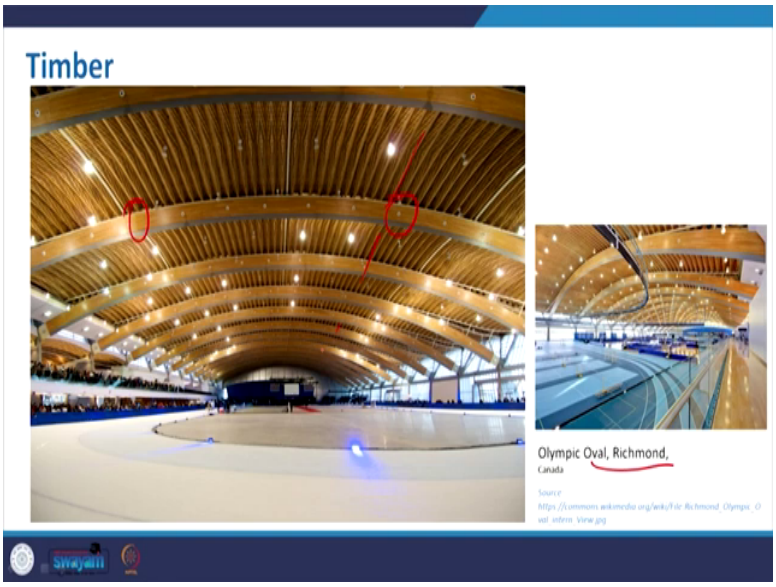
So, whenever you view some material the achieve strength also compared to the weight because whenever you go for material a itself having high self weight so, that will add on to your dead load. So, we want something which will have good strength, good density, good elasticity as well as it will have the lighter in weight so that it can really go with that.

Can be relatively easily joined together because you know like wood are produced from the tree and it has a limitation. So, to create huge structure we need to join multiple such pieces. So, this join is very easy with different kind of you know cross join then ductile joints. So, different carpenter join we can make the structure huge. It need not to be single piece wood structure, but the other important thing is that if timber is used in a proper way or treated way so, it can be reused; a portion of that or maybe like we can go for it like reusing that kind of building material in future in some form or other form. So, it is renewable.

But, the disadvantage with the timber, yes so, it is susceptible to fire. So, it is having that you know tendency so, if something somewhere the fire is main concern and so, lots of accident happened for this particular fire think thing. Recently we have observed some damage due to fire for the wooden structure, some historic structure. Then, also it prone to the moisture if it is not properly seasoned or some treatment or some kind of paint being there.

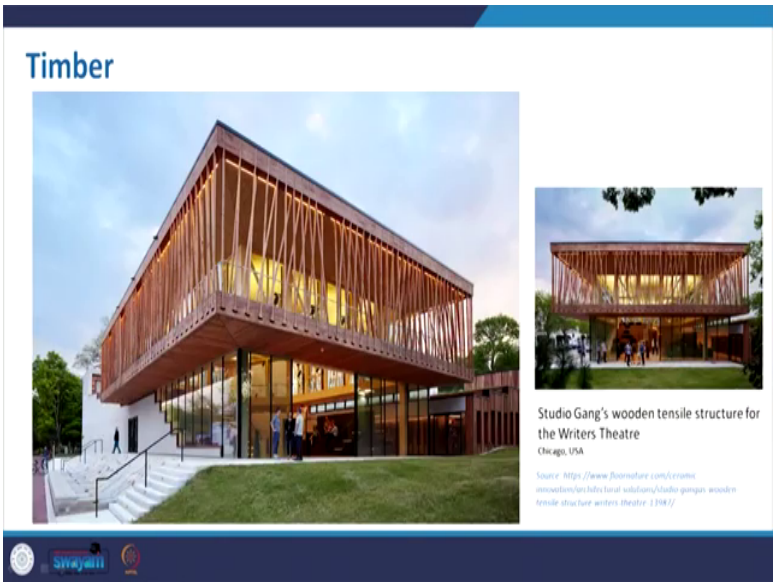
So, along with that also there are problem with the termite attack so, we have to prevent that and now exactly it is not really very hard to extend and so that we cannot really go for multi storey building a complicated structure in that. And, limits on the shape and size that already I mentioned because it is not really available of infinite length or shape, but due to the advantage of easily joined principal so, we can actually make this as per our need.

(Refer Slide Time: 22:31)



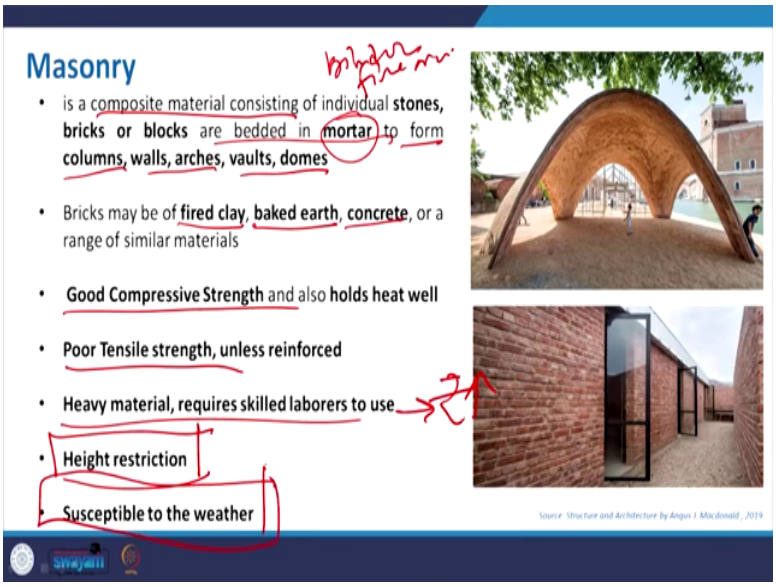
So, this is one example of Olympic an Olympic Indoor Stadium in Canada, so, they have use that you know wooden structure. So, you can find that how you know if you just take a close look or you can search this you know more pictures on this that how nicely they have joined this and these are acting like you know the support like the beam and then you know they used this particular wooden member structure member to create this kind of architecture.

(Refer Slide Time: 23:03)



This is another example of that it is from the example of Chicago where like you know this is again those you know external supports they are being created with the wood. But, the quality of wood depends because in the market there are different variety of wood and again, like there is a controversy like though we have mentioned that it is renewable, reusable, but again it is something like against the nature. So, in order to get that wood we have to cut the tree. So, normally it is not being preferred as building material.

(Refer Slide Time: 23:47)



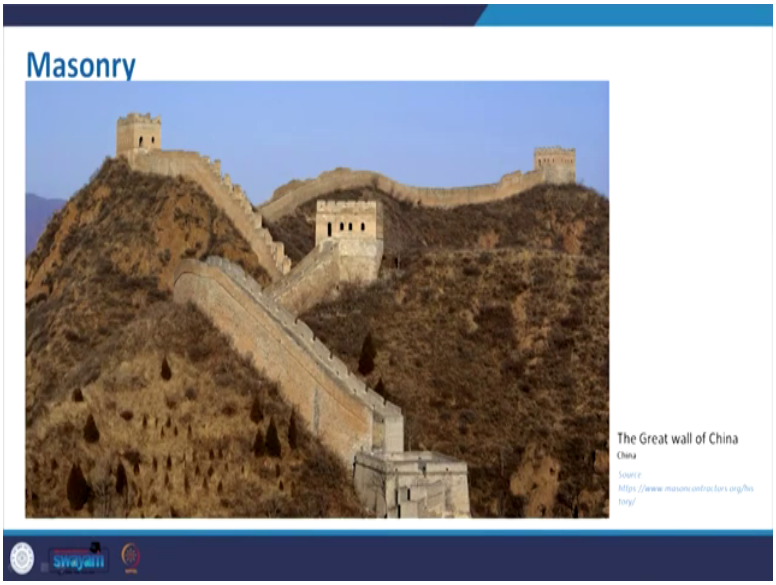
Now, come to the masonry. So, it is basically a composite material consisting of brick or brick like block, it may be of mud or it may be of you know sun dried brick or it may be the burnt brick or the stone and which is bedded in mortar. Now, what is mortar? I guess you have idea, but mortar is a mixture where normally we use some you know binder and then fine aggregate ok. So, binder and fine aggregate means here when you refer it to cement mortar so, it is basically the cement and sand, we add adequate water to make this you know mortar in that.

If it is lime mortar, so lime is actually used in state of cement. Earlier it was there still the cement was not there in the picture. To form the columns walls, arches, vaults, domes and in till the Romanist and other age architecture extensive use of masonry was there. So, bricks as I mentioned it may be baked earth, it maybe the concrete bake. Nowadays we are using it, like

we use the concrete brick or also sometimes we use the compressed brick, the fly ash brick so, as a material.

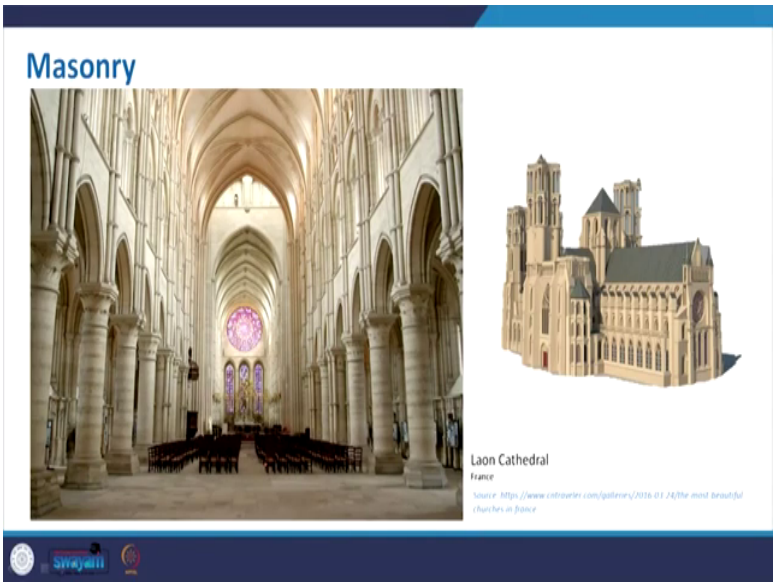
So, it is having good compressive stress, it will resist against the compression, but the problem is with the tension. So, in tension it will actually not really good. So, the way out is to add something more. We will come to that how we can add those. And, again it is heavy material required skilled labor to use and that to you know increase the cost ok. So, it will also increase the cost and here you can see how beautifully they can do it and with masonry without any reinforcement or any other superior structural system there is something the restriction on the height. And, again like if it is not properly plastered or treated it is also expose to the weather that may damage it.

(Refer Slide Time: 26:03)



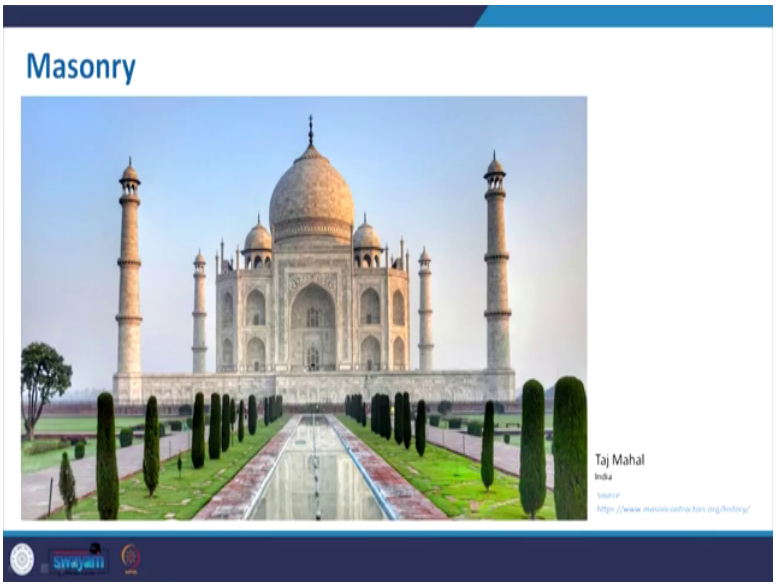
The example is in front of you this is the Great Wall of China. So, which is the masonry work and you know the essence of which the you know this importance of this structure.

(Refer Slide Time: 26:19)



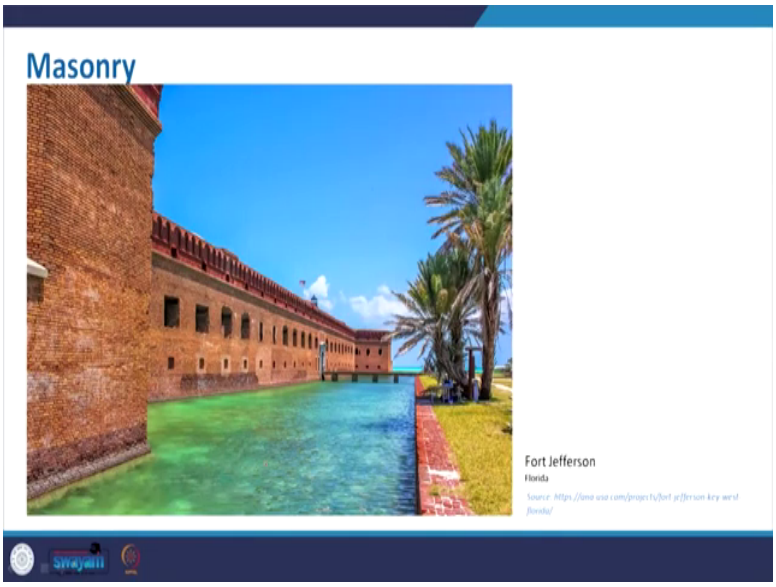
So, come to the other one that is Cathedral, here also it is based on the masonry work. It is from history.

(Refer Slide Time: 26:27)



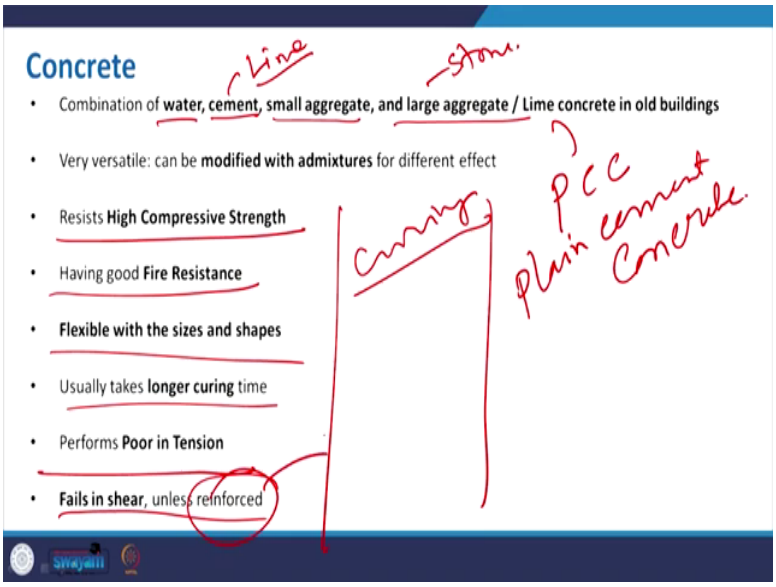
And, again this is something like from India and again it is a masonry work of a stone. So, this is a nice place. So, it been used regularly at that particular time when reinforcement and other thing was not in picture.

(Refer Slide Time: 26:49)



This is another example where you can see that used of the brick as material and then you can see that ok. So, Fort Jefferson that how they have used this masonry work with the your brick and then you know mortar.

(Refer Slide Time: 27:09)



Now, come to the concrete. So, concrete is another invention in the history of building construction and then the overall scenario has changed. So, it is a combination your water, then cement as your you know binder, the this small aggregate or fine aggregate it may be sand. So, you in place of cement we may also use lime. So, earlier they used to get this lime as a material when large aggregate is basically the stone chip of different size. So, that is forming the concrete and we refer it to PCC so, basically plain cement concrete.

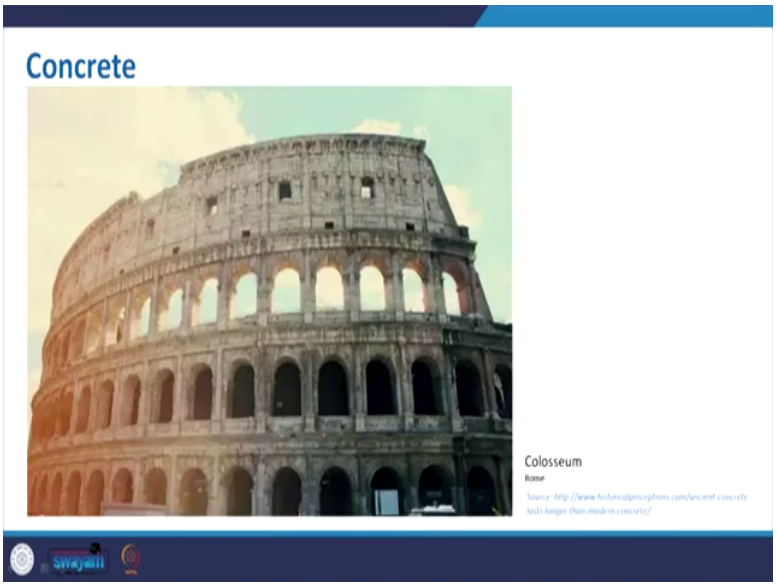
So, in this case there is no reinforcement and it is very versatile as because we are mixing and when it is just mix it is in semi liquid form so, we can give any shapes. So, there is no restriction on the shape and sizes. Then it is also good at high compressive you know stress taking capacity, so good in compression, but poor in tension that similar to the you know masonry work. Then having good fire resistance property that help, that improve also.

Then, flexible with size and shape because of it is can be mold in any form and usually takes longer curing time; this is very important the curing time. So, what is curing time exactly? So, when we make cement with a water so, there is reaction. So, heat generates and all for that you know from the application to it is final setting time when it will able to achieve the strength so, that particular time we need to wet the you know concrete.

So, mostly you if you see that roofing being cast with the concrete and after the next day onwards they spray water or they just you know fill that particular roof with the water so that it will get all the moisture required at that time of you know setting. Then, after it is final setting so, it will not really allow the water. If you do not do that during this particular reaction so, there is lots needs of moisture and it will develop some cracks. So, in our in order to avoid those cracks we have to cure it.

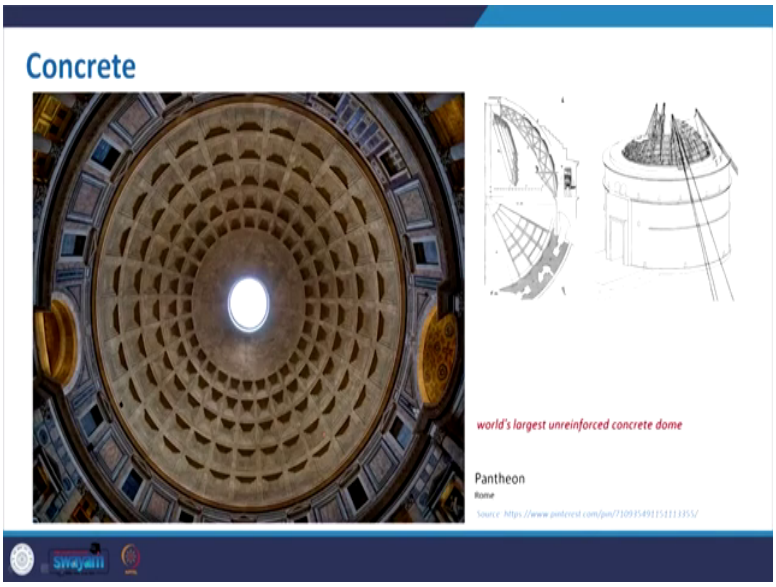
So, curing will take time and unless we just give that time we cannot proceed further. So, that is something we can say a drawback of using concrete as a building material. And, as because it is poor in tension, at the same time it fails in shear unless reinforced. So, we have one way out how we can improve it.

(Refer Slide Time: 30:11)



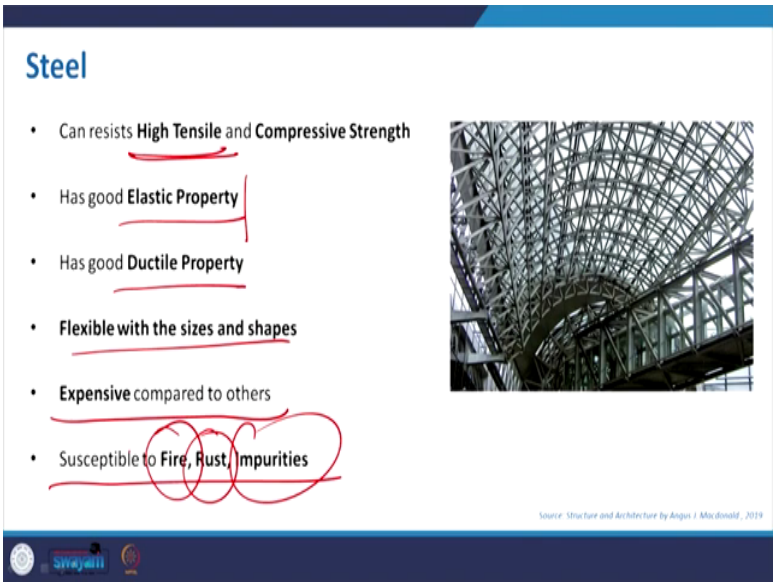
So, this is one example from the Colosseum Rome where this being used in history.

(Refer Slide Time: 30:17)



This is another one the great example again from the Rome, this is the Pantheon. So, the huge dome being constructed with the nice framework, you can able to see that how it being done and then putting the concrete as material. At that time it was not the cement one available so, they made it.

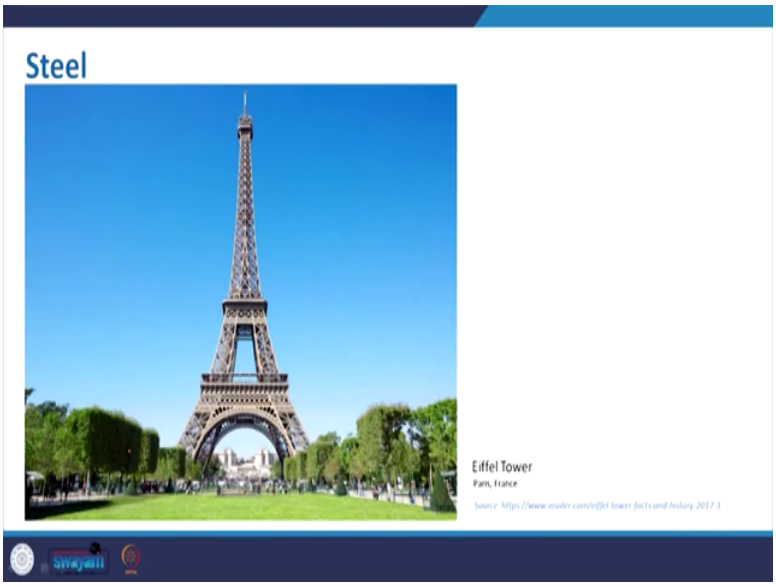
(Refer Slide Time: 30:37)



Now, come to the steel as a material. So, it is having good tensile as well as compression and this tensile property actually help us to come out from different option. So, in this case this also has elastic property that we discuss that it can get its original shapes after releasing the force. Ductile property, which also you know this all these good properties with the steel, and also flexible with the size and shape as because we can prefabricate we can make as per the design. But, it is expensive. So, we are getting so much thing so, somewhere you have to make a trade off. So, it is expensive to others.

But, again the problem is of if it is not properly treated so is the problem of the rust, impurities in these and the fire. So, for higher temperature some explosion or something so, it will be some problem. So, steel as a material is really advanced material, for that we can go high rise we can increase the height.

(Refer Slide Time: 31:51)

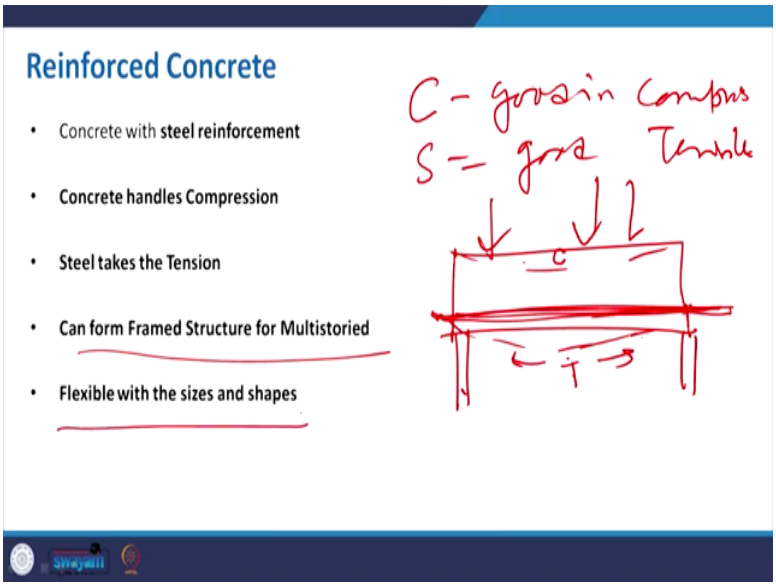


So, one great example and this could be one of the eye opener of you know this kind of you know structure using steel.

(Refer Slide Time: 32:01)

Come to the other one this is again a rib structure where mainly the structure is formed with the steel and then the glass has just to cover it up. So, Eiffel tower and this building in Germany they are the example where steel were used as a material.

(Refer Slide Time: 32:21)

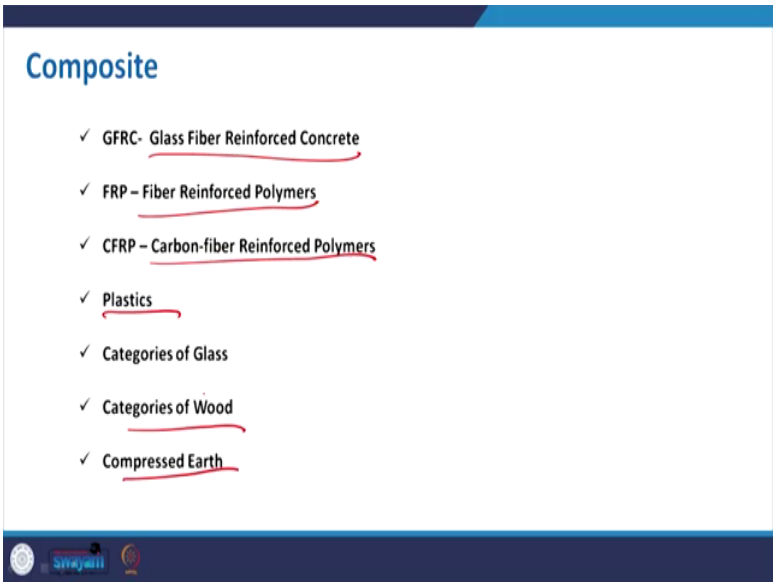


Now, the reinforce concrete is basically we take the advantage of concrete that is concrete is good in compression and steel is good in tension. So, we take the advantage between a like what are the advantages of individual one and group them together. So, if you take a concrete block and you put the pressure on top, these are the supports it will try to bend very easily. So, tension developed at the bottom like when you bend it so, first no you know tension will developed at the bottom because you can see like the fibers they can go away from each other and the top 10 compression. So, compression can be well taken by the concrete.

And, then if you add the reinforcement at the bottom ok. So, this will well take care of the tension so, your structure will maintain the static equilibrium. And, can form the frame structure for the multistoried being used flexible with size and shape as both the material can be used in any form any shape.

So, this is a nice example of our reinforced concrete structure, the shell structure being used similar kind of structure being used in Sydney Opera House. This is another auditorium from Spain, there also the shell structure the reinforcement reinforced concrete being used as a structure material. So, we can do wonders with this reinforced concrete as a material where we can use both.

(Refer Slide Time: 34:15)



Apart from that there are composite material which are now people looking for the lightweight material to be used. So, instead of you know the increasing dead load with the steel so, glass fiber reinforced, then other kind of fiber, reinforced polymer being used then plastic as a material then carbon fiber as a material. So, many such different composite material can also be used in this but, depending on the property where we use and looking at the six properties

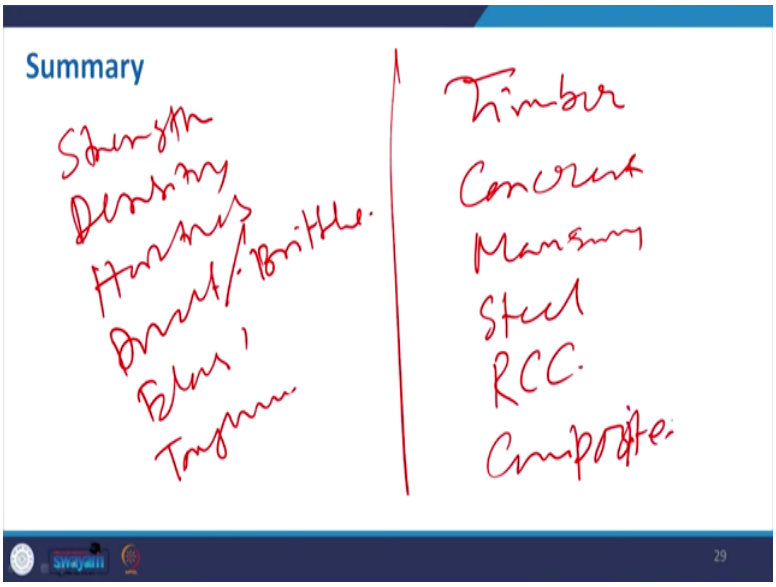
of this you know ductility, elasticity, hardness, toughness, then your strength, density. So, we will pick up which one to be picked up.

Now, for the wood, so, it may be a raw wood, it may be a processed wood, it may be a medium density fiber. So, depending on our expectation and the you know purpose we will use it.

(Refer Slide Time: 35:01)

So, these are some examples in random examples where GFRC is used then carbon fiber is used which will really give the you know resistance of the axial strain, prevent the you know collapse in shearing. Compressed earth can also make the structure not the high rise, but it can solve which will reduce the cost and also make it very sustainable.

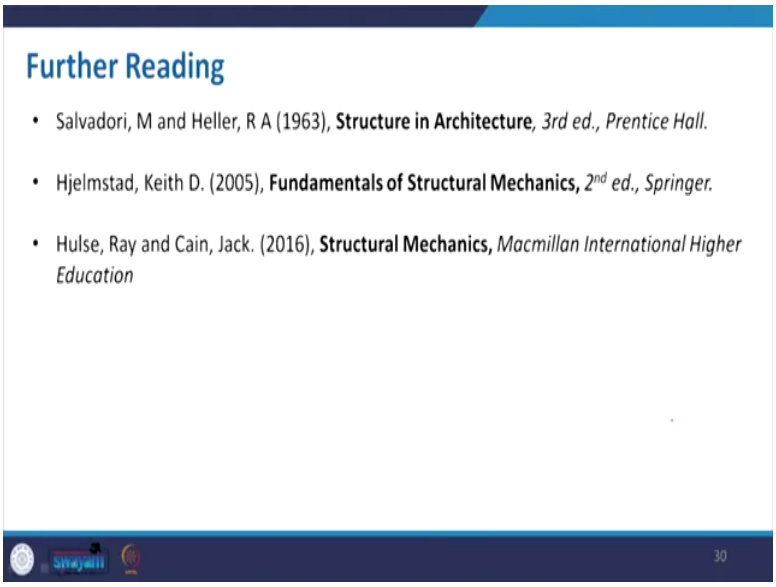
(Refer Slide Time: 35:19)



So, overall today's lecture so, what we found that to select a material is very important thing and we have to look for your strength, then you have density, then you have hardness, then you have ductility, then elasticity and then you have the tough you know toughness of the material. So, ductility or the brittleness is another property looking into that we also discuss the timber, we used concrete, we used the brick or stone masonry, we used the steel as a material, and then RCC – reinforced cement concrete together, then we also discussed about some advance or you know lightweight composite material.

So, with that we will see and time to time when we discuss various form or various type of structural you know construction so, we also link it with this material. So, this is one of the very important lecture that we discussed today.

(Refer Slide Time: 36:29)



And, for further reading you can refer to the books I have mentioned. And, next followed up lecture will be the structural typology. So, we will again discuss that in the next lecture, lecture number 16 and for that till that time I again thank you to take part in this particular course.

Thank you.