Modern Construction Materials
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Module - 1
Lecture - 1
Part 1 of 2
The Science, Engineering and Technology of Materials
An Introduction - I

This is the first lecture of the course on Modern Construction Materials, and this lecture I will be introducing the course, and telling you why we have to know about the basics behind the science and the technology of construction materials. There is pro log or 0 that you can look at where I discuss how this courses start and what was the motivation behind the course and a little bit about myself also.

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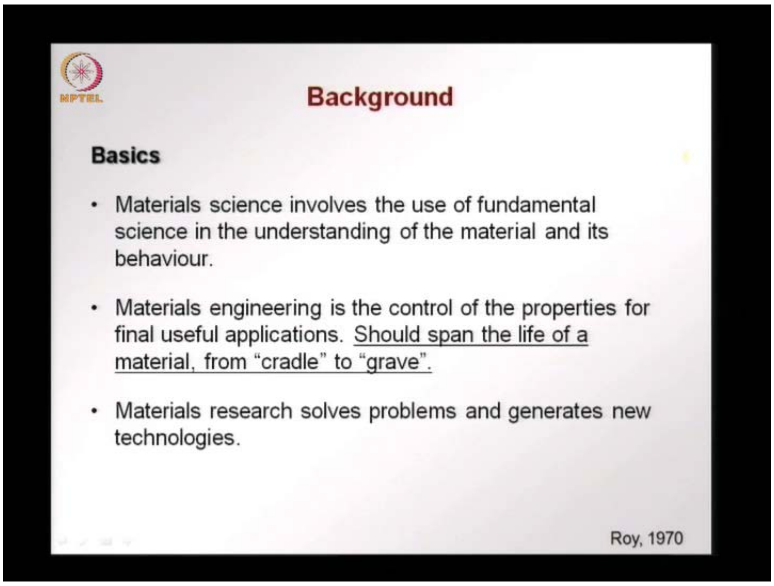

So to start with when the look at the basics of this course material science is that which involves the use of fundamentals fundamental science in the understanding of the material energy behavior it is something that we have to know do more research on different types of materials and to understand how these materials work material engineering is where we control the properties we developed materials in terms of their final applications useful applications this is what we are interested in and what is underlined here and what is a important to know is that when we talk about materials in engineering and especially in construction we should think about the life of the material from the beginning the fabrication to demolition or when we do not have to use the material anymore. So, that is what is called as the cradle-to-grave scenario where we look at the material when it was conceived a fabricated manufactured to when the material is thrown away demolished we do not have any use for at for any more material research combines material science and engineering basically for two things to look at how problems.

That are existing in construction material can be solved and also to degenerate new products and new technologies because or demands that of society's that are construction sector is always increasing and we have to generate new technologies to answer these demands on the performance requirements.

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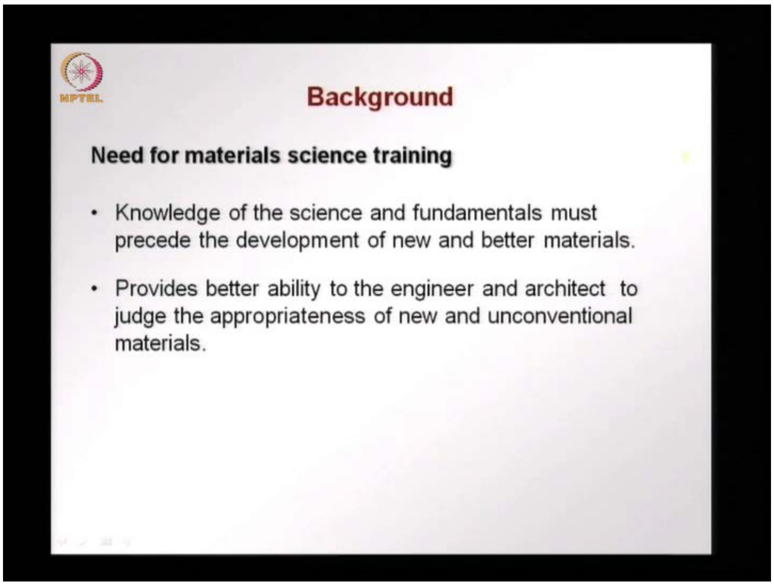

What is the need to learn material signs fundamentals in engineering the knowledge of science and the fundamentals is always necessary when we have to develop new and better materials an I said before society wants us to increase the performance the construction sector is looking for better performance and there are problems that have to be solved and for this for developing new materials we need to understand the science that makes these materials behave the way they are. Secondly, materials science training also helps the engineer and the architect to judge whether a certain material is appropriate for a certain application and this is especially challenging when we talk about new unconventional materials which have not been studied much by the person who is using it. But if the basics of material science are clear when the engineer are the architect comes of across a new material or an unconventional material the appropriate can be better judged what are the materials that we use in civil engineering then not many.

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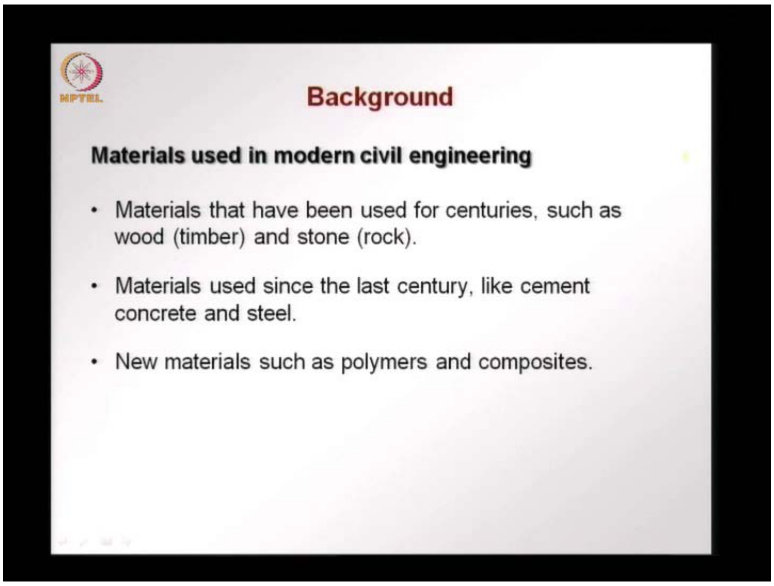

We can look at materials that are been used for many centuries like wood and stone timber and rock which probably where the first material that human beings used when they have two construct something than over the last century we have cement concrete and steel and this is still being used a lot all these materials are being used a lot and what.

We are seeing is that new materials which are polymers or polymer based composite's meaning that they are different phases of materials that are combine to create a composite material that usually fiber in forced polymers or polymers with some say sort of inclusions. So, all of these in modern civil engineering are used in this course what we do is look at the fundamentals of materials as such and then try to understand why these materials which are being used often work the way.

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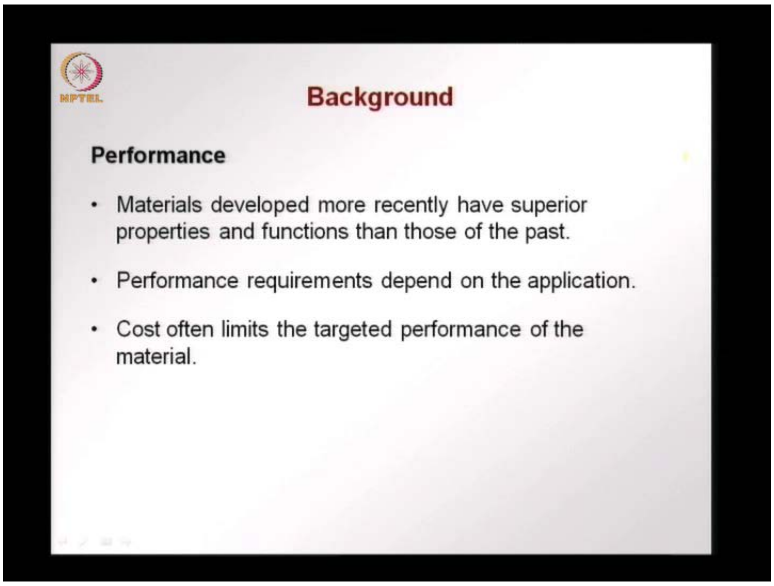

now I mentioned performance before performance is something that we look for in a material materials that have been developed recently are having superior performance better performance and functionality then in the past we always look for improving the performance and in improving the properties that are useful and how they function out the materials function in their use the performance; obviously, depends on the application the requirements of the performance how a materials should perform depends on where we are using that particular material the performance radically changes depending on where we using for example, in a dam concrete as to behave in a very different way than in a payment or in this lab of building cost often limits where you often limits the targeted performance or what we can afford to have as the best performance in a certain application. we may not be able to go for the best performance in all the time in construction materials why is all this necessary why he’s construction material technology important at all for two reasons first we want to understand how a material behaves and that depends on his structures micro structure and nanostructure how the material is put together.

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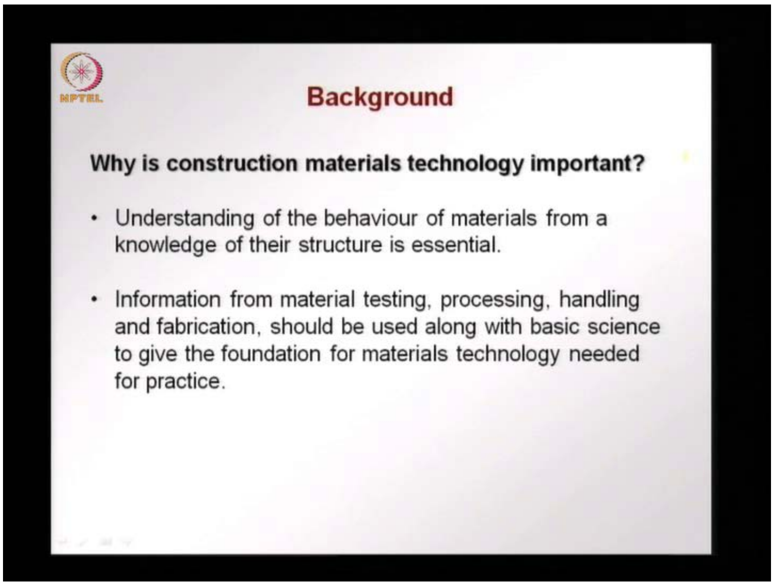

So, understanding the behavior of materials from the knowledge of their structures that is their microstructure is very important. Secondly, material information that comes from testing how the material is processed of manufactured how it is handed along with the basics of science gives us the foundation or the bases for a better materials technology and this is needed for practice because we want to make the material the most appropriate for any application.

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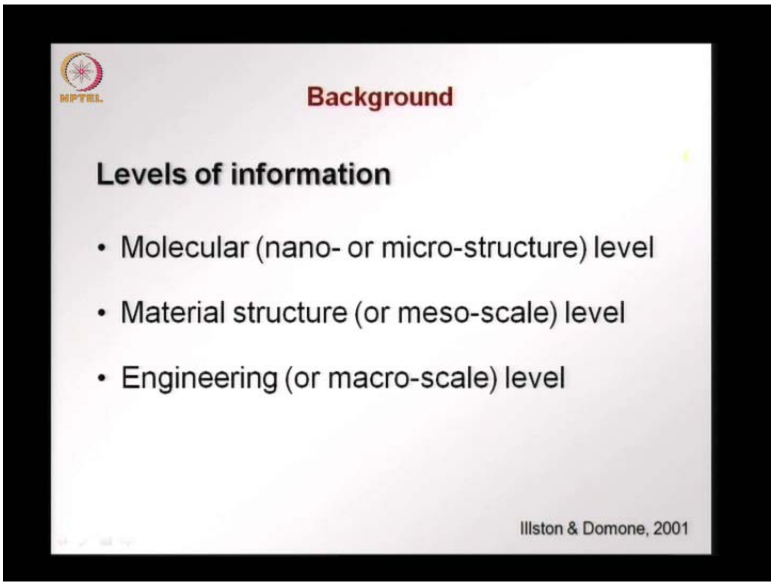

Whatever levels of information that we get about the material we have classified this following lllston and domone in the three levels and the molecule level which is very commonly called as the micro structural level now a day's some people call attached nano structural level, but basically we are looking at structural level, but you need a microscope or some other sophisticated instrument do see how the material is put together that scheme a scale that is higher up often called the measles scale what I have called material structures scale for simplicity is where with you are naked.

Eye you can identify heterogeneities and differences in the materials structure for example, if you look at concrete with your naked eye you can see the aggregates you can see the mortared and in the case of say wood or timbre you see the grains you see the fibers and so on. So, this is the material structure level where you see heterogeneities, but you do not going to very fine scale is the molecules and the microstructure the engineering scale is what we use in the design this is when we forget about the heterogeneities we considered the material as such this is the macro scale and we talk about concrete the use it in design have as a isotopic homogenous material even though we understand that they are heterogeneities in the microstructure and in the material structures. So, let us look at each of these levels of the information and see what we get from these levels and how they are useful to us in understanding can be the material behavior. Now in the molecule level we consider the material at the smallest scales we are talking about atoms molecules and aggregations are clusters of molecules.

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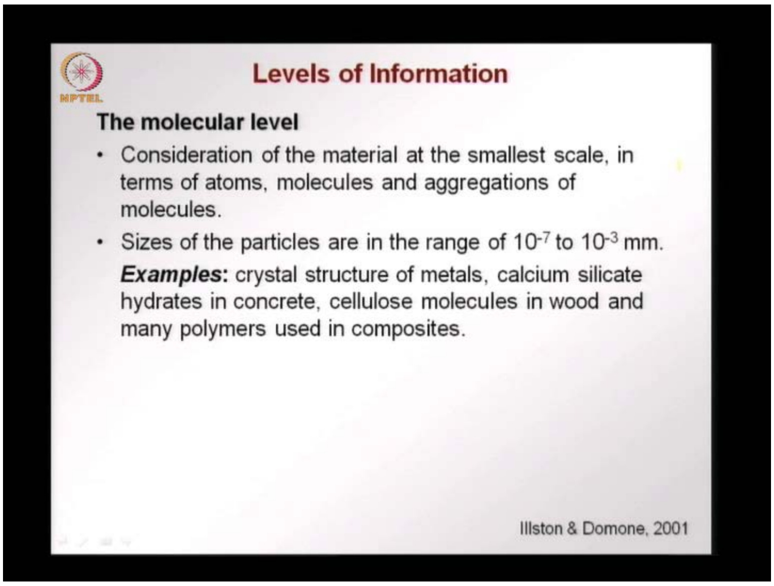

And here in the molecule is scale we are looking at particle in the range of ten to the power of minus seven to ten to power of minus three millimeters. So, you’re; obviously, you need a microscope you need something structure to understand the structure we need science examples of units in the monocular level would be the crystal structure of matters in concrete the calcium silicate hydrate jell particles which are is hundred nanometers in size and in wood and timber we can talk about the cellulose molecules, which make up there fibers in the work and in terms of the composite's again we can talk about the molecule is the sayings of the polymers.

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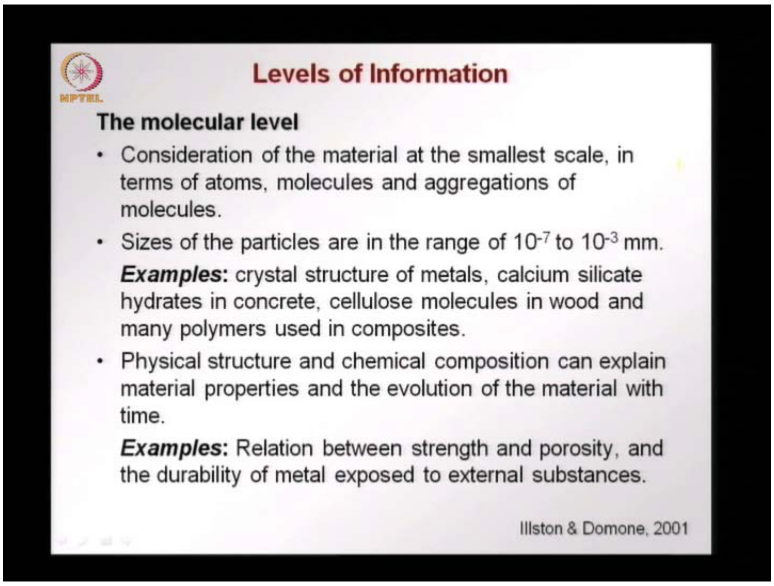

Now why do we need to understands we need to understand this because the physical structure at this scale and the chemical composition gives us an idea of how the material behaves how do we get the material of properties and how this material is evolve with time which is of very high importance when we talked about durable the chemical behavior tells us how durable material, we get ideas about the relations between this strength and the porosity velocities a feature after microstructure.

We generally want materials not to be very poorest because this effects this time and when we understand what happens in the molecular scale he also get a better idea of relation between strength and porosity further as I mentioned durability is a very important in all civil engineering structures you want structures to a lost a long time we want structures to last for several decades if not for centuries and here durability is very important and what governors durability is other chemical aspects the chemical behavior and the information about the chemical behavior comes from the understanding off the molecule.

So, the durability of the Mattel exposed to different chemicals in the exterior can be understood if you understand the molecular level, but then we gone to next higher level the material structure level we now l consider the material as a composite of different phases now what is composite a mixture of different materials each of which retains its character even after yeah mix to get the phases combined to give you the composite's, but each phase as and retains its own characteristics and works together to make them materials behave in a different way call the composite's behavior or the total behavior and this is true for almost all materials that the use in civil engineering understand that they are composite's the scale of the composite's structure.

Now is in the order off one micron to about hundred millimeters and here we can talk about may soon be being the represented by a single break in the material structure level a would cell that makes up the fibrous structure a piece of concrete which would have say aggregates mortared mortar being made-up of cement based and sand and so on. So, these of features that we can identify even with the naked eye we understand that the materials is made up of different phases of component materials have been put together either by fabrication or by the growth of the material structure, how we process the material and how the multi phase responses works out or how the behavior occurs depends on the features in this scale it depends on the shape and size of the particle it does that make up the structure at this level the distribution and the concentration what is often called the dosage of the individual phases in concrete again this would be the size of the aggregates the relative proportions between the aggregate phase and the cement based phase.

So, this influences a lot how we make the material and how the material behavior of the individual phases remain within the composite's are also about simple the state and properties of the individual phases influence the composite's behavior the young's modulus this strength the bond between the phases or important. So, the interface place the probably the most important role in a composite behavior it is often said that the weakest phase in a composite's interface bonding between the different phases is very important to get that ideal or the desired composite behavior and these are things that we can test.

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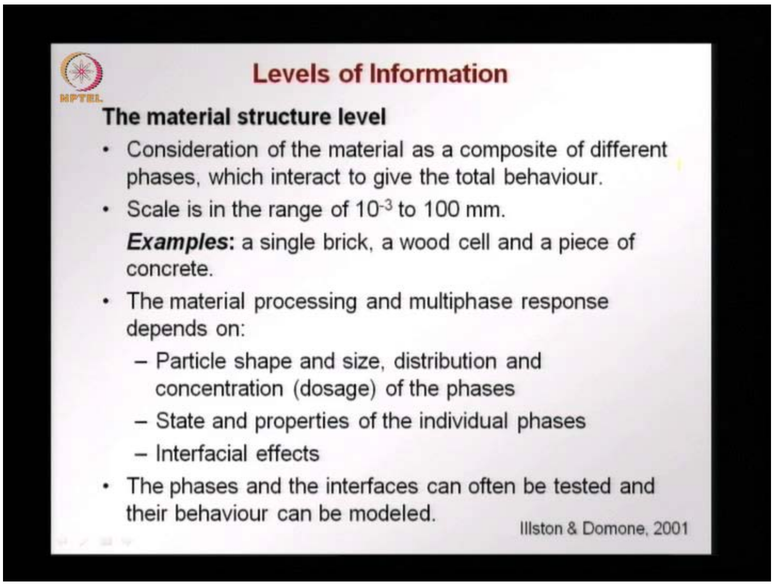

And we can module in the material structure level the phases can still be identified they interfaces and the phases can be tested and the behavior can be modeled and these models can be help us understand how the structures of the material behaviors now we go onto the next scale the scale that is used by the designer's and where we talk about the total material even though we had considered and we had discussed in the previous to scales is that the material is made up of many elements many components these interacts and they could have different responses in the engineering levels we consider the total material we normally take the material as homogeneous and continuous we represent the total behavior with certain parameters and models meant we could use the information coming from the previous scales, but we do not bother much about those components at this level. So, here again we are talking about a scale which would be as small is a micro, but could be as large as a methane and this scale is also important because when we tested material we are doing it at this scale and therefore, the size off that representative unit which is the minimum volume of the material that represent the entire system is important we cannot take very small it is junk of the material test and believed that gives the properties of the of the entire material if that junk of the material is to small we can explain this with this animation.

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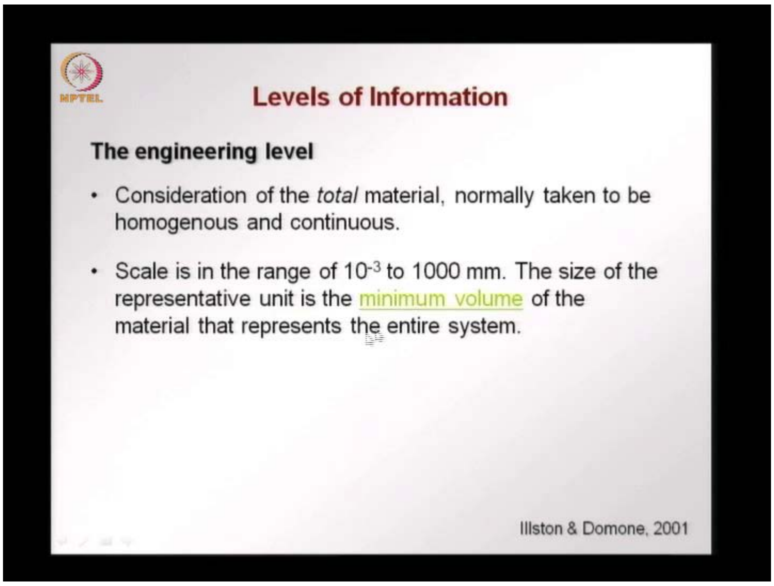

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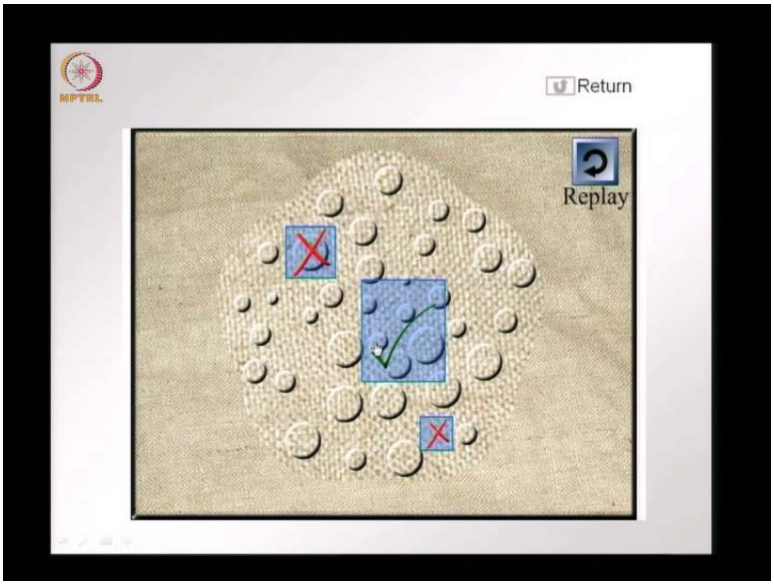

So, when we go to this animation we see that what we have done is taken an arbitrary material when you have a certain microstructure and you have in this microstructure and other phase that is included which is made up of spheres orbits of different sizes now if i get to take her volume that is this small blue square you would see that most of this square is are this cube would have only the final microstructure or will not include any of the larger microstructure, now if i want to take this square again I will have one large aggregate phase in it i, but I will not have any of the microstructure.

So, nether this or this is really representative off the microstructure i have to go for a larger piece of the nineteen the that i have off the final microstructure i have the larger piece of the material where i have enough of the final microstructure and i have the larger phases also include to give me in a representative volume of the material that has to be tested and this has a lot of consequences some people wonder why we use a wonder one hundred and fifty million cube or a cylinder of one hundred fifty millimeter by three hundred millimeter for testing concrete and this comes from these concept of a minimum volume that is needed to represent the materials that we are testing if we were to take concrete cube that is only say five centimeters or three centimeters size, we would not have enough of the cement based the motored and enough of the aggregates on the interfaces to give us representative picture of the material itself.

So, that is why in civil engineering in civil engineering standard in always specify the dimensions of the specimen that has to be tested and this comes from considerations of minimum representative. So, i just scale we can test and we two test and sometimes he must test the material to obtained properties and understand the behavior this testing is done for several reasons initially in development of the material when we make a new material weakening will be proven a material we want to see how would these properties develop if these properties are adequate for the application that we are considered. Secondly, as means of quality.

Control lot of the that we use in civil engineering on not made by the person who is building your final structure or the owner of the structure it is made by a third-party and when you the procured the material we want to know what the properties of the material are. So, that we find out whether the material that is being delivered is what we have really asked for. So, this is quality control and this depends on a lot of testing again in the engineering scale thirdly why we need material behavior to be understood properties to be characterized is that views this as an input for structural analysis and structural model models need parameters which have to come from the engineering scale and what do we do with these models we use-based models to simulate the responsible as a large that we are interested in designing are we want to know how this structure is going to behave if he could be an existing structure or structure to be constructed.

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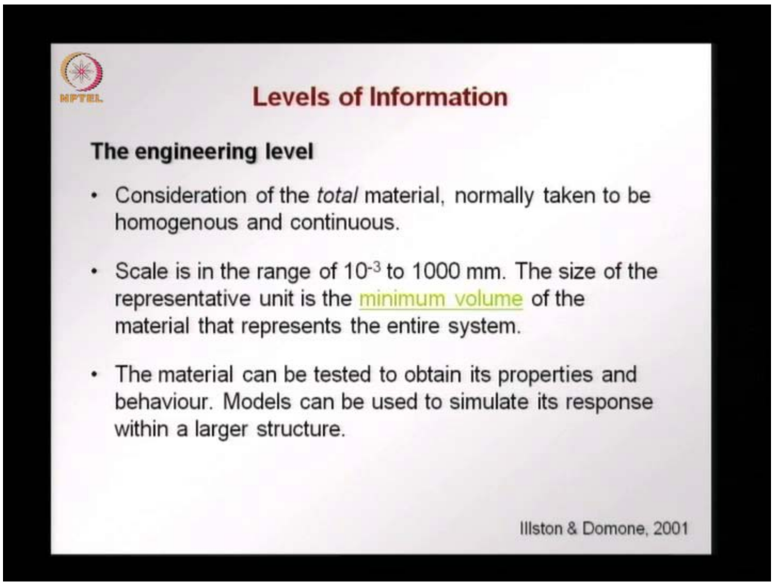

So, for all of these reasons we need testing to be done in the engineering level now we look that different aspects that are needed to study a material what other considerations for selecting a material we have many choices in civil engineering has another engineering fees how do we go about choosing a material that we eventually use in certain application the best way to characterize the most important consideration is call it cost effectiveness it does not mean that the use the cheapest material, but we use the most cost effective material effectiveness is thought of in terms of the performance of the structure in the desired applicants. So, we look at how effective the material is going to be in the application that we are considering and that for the lowest-cost possible and this effectiveness of performance has to consider several aspects initially when I started this lecture i talked about the cradle-to-grave concept and when we put into the context also civil engineering application we are talking about the phase which is during construction manufacturing processing of the material the actual building of the structure that we want the phase that isn't service where we are using the material or the structure how the structure will fail or how the material will fail and after it fails after.

We do not want to use structure anymore the applications is over we demolish what we have to dispose the material. So, we should think about the cost-effectiveness considering the whole cycle ranging from the construction period or the construction phase, but to the demolishing the disposal phase. So, only when a material is effective in this complete life that it will have in an application we can think of it being effective and or this has to happen at the lowest cost possible for it to be cost-effective the criteria material should satisfied in a structures the performance requirements or most often based on strength we design we defined materials is in terms of their strength and possibly the stiffness or the models of the elasticity implicit to most of these applications is the durable we want the structure to lost for a long time we want to a material to behave well throughout the life for the duration off its application.

So, durability even though we often do not designed for durability we need to keep durability in mind this may come from a experience could come from modeling and could come from the fundamental understanding of how a material going to behave in its environment. So, the criteria most often used for choosing a material in terms of the performance or strength stiffness and durability other than that depending on certain.

Specific applications other aspects of this what the tightness is it takes speed of construction and now a days it is very important is environment friendliness these adults are coming into play if we have water tank they certainly have to worry about the water tightness of the does not leak this could go for roof slab it could go for a slab and when we are talking about is the ticks element any basode elements any decorative element any architecture element you may choose basically reason off these tickets speed of concept is very important and it is becoming more important in India where we have we are in a hurry to finish projects these housing projects on infrastructure projects. So, the speed of construction can often help you choose a material i put in etcetera because there are many applications which would require very specific criteria for choosing their material and this could change could vary from one application to the others.

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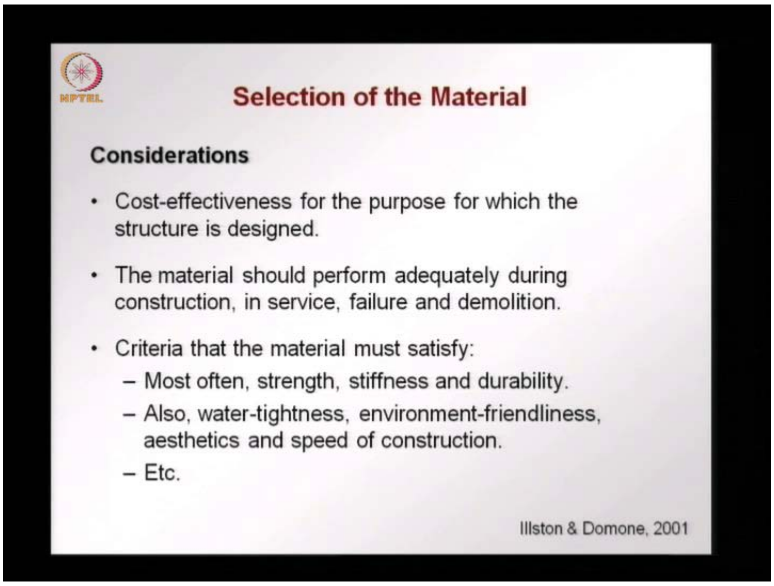

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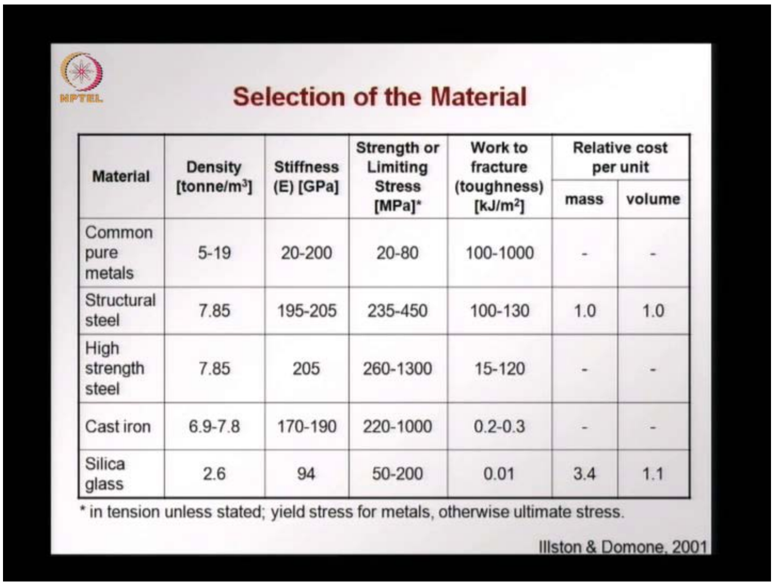

Material	Density [tonne/m³]	Stiffness (E) [GPa]	Strength or Limiting Stress [MPa]*	Work to fracture (toughness) [kJ/m²]	Relative cost per unit	
					mass	volume
Common pure metals	5-19	20-200	20-80	100-1000	-	-
Structural steel	7.85	195-205	235-450	100-130	1.0	1.0
High strength steel	7.85	205	260-1300	15-120	-	-
Cast iron	6.9-7.8	170-190	220-1000	0.2-0.3	-	-
Silica glass	2.6	94	50-200	0.01	3.4	1.1

* in tension unless stated; yield stress for metals, otherwise ultimate stress.

Illston & Domone, 2001

Now, we have a table of some materials that the commonly used and their properties this is taken from lllstone and domone, and in this tables you will see some important properties and also relative cost. So, if we take the first four which are metal we see that they have highly density that here the density is given in tones or thousands kilo grams for meter cube stiffness in terms of the young's mode list in gegapascals the strength of the limit stress which a which we have taken basically as the tinsel strength in terms of metals this would be the yield strength and otherwise it is the ultimate stress.

So, that would be the fourth column the fifth column is worked a fracture or toughness this is not a very commonly used parameter, but this is very important because it is tells us how a material will break all fracture all failed the higher the work to fracture means that more energy is dissipated by the material before it actually fails material such as glass which is very brittle will have a very low toughness or work to fracture material deduct is ductile you see here the range given for metals it is much higher indicating that the material would failed preferably by yielding rather than fracture.

So, the material would not break, but yield now the last two columns give relative cost here what we have done is kept the other cost relative to the cost of structural steel d that structural steel is it is taken as one of our and order all the all the costs mentioned for the other materials divided by a certain cost for the structural steel. So, density is important because the weight of the structure depends on the density of the materials of that we are using and often we want a lightweight structure and therefore, we have to avoid the weight density is also important, because we by materials is in terms of volume are weight and we pay for a in terms of volume and weight and we need to know the density after material stiffness is important because in most of the services life of material the material has not cracked or yielded or failed it behaves in the elastic regime and the deformations material and consequently the structure under goes depends on the stiffness or the elastic mode lest of the young models the strength is; obviously, very important because the failure the ultimate unit state of material honest structures depends on its strength and i said told you fracture would defined how cracked propagates how fractured occurs how ruptures occurs and failure ultimately happens and then be compared the metals in the top with glass which is very brittle you see that the densities; obviously, lower glass stiffness is also lower.

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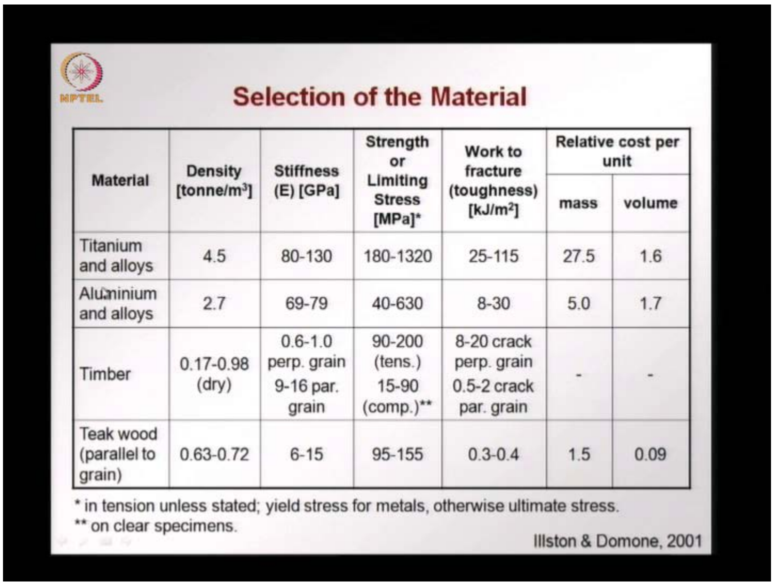

Selection of the Material

Material	Density [tonne/m³]	Stiffness (E) [GPa]	Strength or Limiting Stress [MPa]*	Work to fracture (toughness) [kJ/m²]	Relative cost per unit	
					mass	volume
Titanium and alloys	4.5	80-130	180-1320	25-115	27.5	1.6
Aluminium and alloys	2.7	69-79	40-630	8-30	5.0	1.7
Timber	0.17-0.98 (dry)	0.6-1.0 perp. grain 9-16 par. grain	90-200 (tens.) 15-90 (comp.)**	8-20 crack perp. grain 0.5-2 crack par. grain	-	-
Teak wood (parallel to grain)	0.63-0.72	6-15	95-155	0.3-0.4	1.5	0.09

* in tension unless stated; yield stress for metals, otherwise ultimate stress.
** on clear specimens.

Illston & Domone, 2001

And that toughness and worked do fracture is much low indicating what implying what we already know that glasses is very brittle material let us go on now you see other metals less commonly used for structural purposes set a tie tanium and aluminum at the top by tie tanium is very high strength compared to the materials that we are discussing here probably at the upper end it is also having a good toughness, but the cost is very high almost thirty times the cost of structural steel is to the same unit mass that is one kilogram of tie tanium could be thirty times more expansive as that of a kilogram of structural steel aluminum less at in bottom two rose we have general properties of timber the density as we know for timber would be much lower than for metals the stiffness is also not always very high this value is an gegapascals the strength is not as bad as materials such as concrete it is comparable intention to some metals then worked to fracture and that toughness good when be compared with what we saw for silica glass in the earliest life the a particular type of wood tick wood that use a lot in India is given in the last row the properties of given in the last role and what you would see is whenever is talk about timber and wood we give the properties either parallel to the grain perpendicular to the grain this is because timber is not an isotropic material it an author topic or at based on transversely isotropic material there certain properties along the fibers or the grain and another set of properties which could be different in the grain perpendicular to the grain or the fibrous. So, when we talk about the properties of wood and timber we have to specify in which direction we are giving the problems.

So, you have you have the density of tick wood again the quite low as you would expect for wood this stiffness is not has high finally, as the word fine for tie tanium steel, but still it is reasonable better then polymers which will seeing the next slide in strength is much higher than concrete that we will again see in the slide comparable to the lower to end of some metal the fracture toughness is not very highly it can fail in a brittle manner and the cost in terms of mass is about fifty percent approximately more than steel and in terms of volumes since the density is low it is quite know what we must keep in mind when we talk about cost the these are just relative numbers a for certain location in at a certain time period; obviously, the cost will vary depending on where we are and when we are going to put is these materials quantities and so on. So, this should not be taken as absolute values, but more of an indicative relative cost of different materials.

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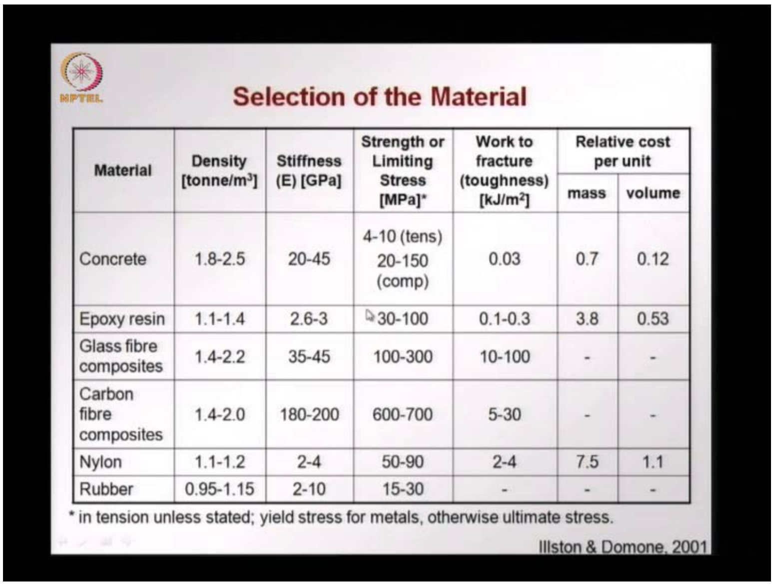

Selection of the Material

Material	Density [tonne/m³]	Stiffness (E) [GPa]	Strength or Limiting Stress [MPa]*	Work to fracture (toughness) [kJ/m²]	Relative cost per unit	
					mass	volume
Concrete	1.8-2.5	20-45	4-10 (tens) 20-150 (comp)	0.03	0.7	0.12
Epoxy resin	1.1-1.4	2.6-3	30-100	0.1-0.3	3.8	0.53
Glass fibre composites	1.4-2.2	35-45	100-300	10-100	-	-
Carbon fibre composites	1.4-2.0	180-200	600-700	5-30	-	-
Nylon	1.1-1.2	2-4	50-90	2-4	7.5	1.1
Rubber	0.95-1.15	2-10	15-30	-	-	-

* in tension unless stated; yield stress for metals, otherwise ultimate stress.

Illston & Domone, 2001

Now we go on to third set of materials concrete being one of them that we see in this table concrete as you would know is one of the most popular construction materials will be see here again the properties that we looked at before densities stiffness strength and toughness the density is in the range of about two tones of meter cube at two kilograms per meter this stiffness is not as high is that we saw for steel, but it is still reasonably high compared to polymers one of us can at oxygen lysine rubber it is less than composite made out of a polymer and carbon fibers in terms of strength for concrete as many brittle materials know the tensile strength is very low almost one tenth or horridly one tenth of the compressive strength concrete is used mainly for its high compressive strength and the often ignored that tensile strength of concrete in design.

So, we find here that the tensile strength of concrete would be in the order of four and maybe in very good quality concretes you can have ten mega paschal tensile strength, but would be more in the lower end of the scale the compressive strength of the concrete can vary we normally use range of that twenty two forty by the mega paschal strength and you can go much higher even beyond hundreds and hundreds and fifty mega paschal the toughness is low compared to the values that we saw earlier for metals and also what we have here for composite's and polymers should just indicates that concrete like glass is a brittle material it can fail easily it can crack easily and that is the reason by we reinforce concrete with steel in most of us structured layer relative cost here we have said that it would be say much lower in cost and in structural steel for the same unite weight epoxy and glass fiber reinforce composite's and carbon fiber reinforced composites are being used a lot now a days in repair retrofitting in other applications.

And we have to understand, how these materials behaved and what we see is that the reinforcement often epoxy with fibers it glass fibers and carbon fibers improves this stiffness significantly also increases this strength. And they are now talking about a range which is comparable to what we saw in metals the fracture toughness may not be always as high as metals as much better then what we have for concrete for glass or just the and reinforced epoxy. So, what will stable have told us is that we have a variety of materials with very different properties, and we have to see how to optimize the choice of the material for a certain application. And this will depend on the knowledge of how the material behaves; obviously, its properties and a very good knowledge of what we expect in certain application.

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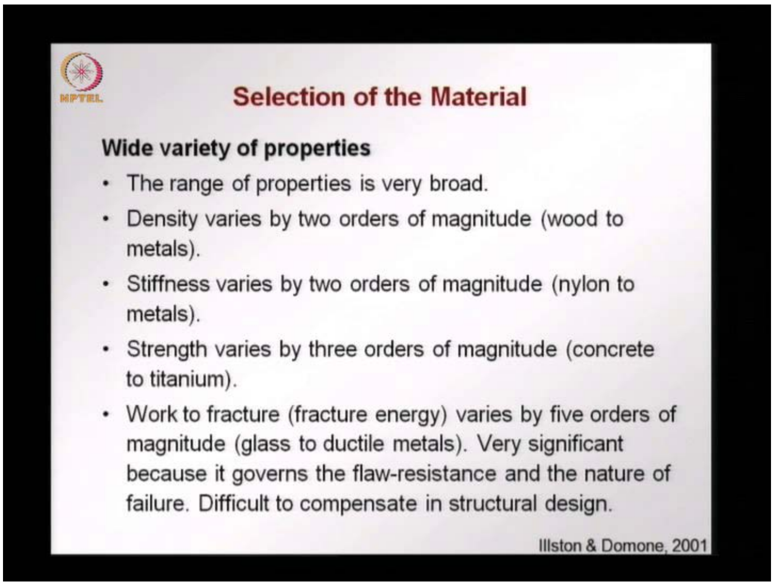

We have seen that there is wide range or a wide variety of properties in terms of density we saw that the densities that he looked at range over to orders of magnitude would being the lightest to metals being heavy this stiffness the young's modules the modules of the velocity again vary high two order of magnitude throng from vary soft very flexible polymer such as nylon to gain metals strength also varies a lot we saw concrete intention it is very weak it can fail very easily it can crack easily to tie tanium almost thousand times stronger than concrete. So, all of these important properties density stiffness strength varies a lot.

And again we have to understand when it would be best to use of these materials the last property that he had on the table worked the fracture of the energy of fracture toughness varies again by five orders of magnitude going from glass which is very brittle you all know that glass can break very easily to ductile metals which do not fracture mostly, but they would yield or shear and fail in a progressive a manner in a plastic manner. So, there is again a wide range and this fracture energy a factor toughness the use of that may not be very obvious, but it is very important because when the fracture energy the fracture of toughness worked to fracture is low the material becomes flow sensitive that is even a small defect can leave the material to fell. So, the fracture properties.

Will deal with latter govern the flow resistance of how the material will behave when it as a flow and how the nature of failure is governed by this flow resistance and this is also difficult to compensate for in design because the defects from occur the variable manner he do not always know where the defect is occurring. So, that we can deal with structural design. So, this is something we have to understand and take into account properly.

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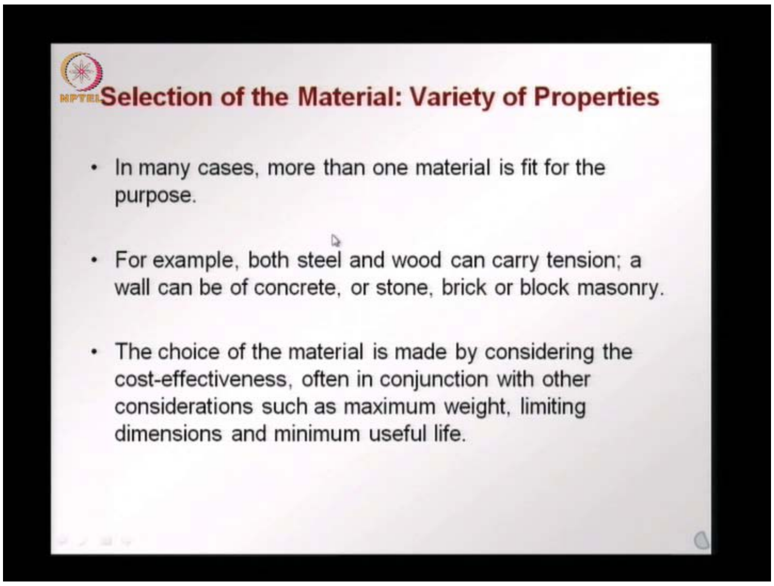

So, in this selection of materials we find that more than one material is fit for a certain purpose for example, when we talk about a tensile element both steel and wood you can carry intension well we saw that the tensile strength of wood is quite good may be not reaching the value of steel, but it is quite high that is reason why in traditional structures we see a lot off ties tensile elements in trusses made.

Out of wood and steel as we know is used in often intention when you're talking about the wall a partition on an exterior wall we can make it on the concrete or more often with masonry break masonry be blocked masonry or stone. So, we have again range of choices that we can use for the making masonry and as we saw before the choice of the material is made by considering cost-effectiveness where we look at how the performance of the material will be and how much to be. So, the effectiveness comes in conjunction with together with consideration such as maximum weight limiting dimensions and a useful life in next part of this lecture what we look at is will take on example of as simple being and we will see how different materials would behave in the same application where we look at how to take into account the density this stiffness and the strength for optimizing the choice of the material other that in an application.

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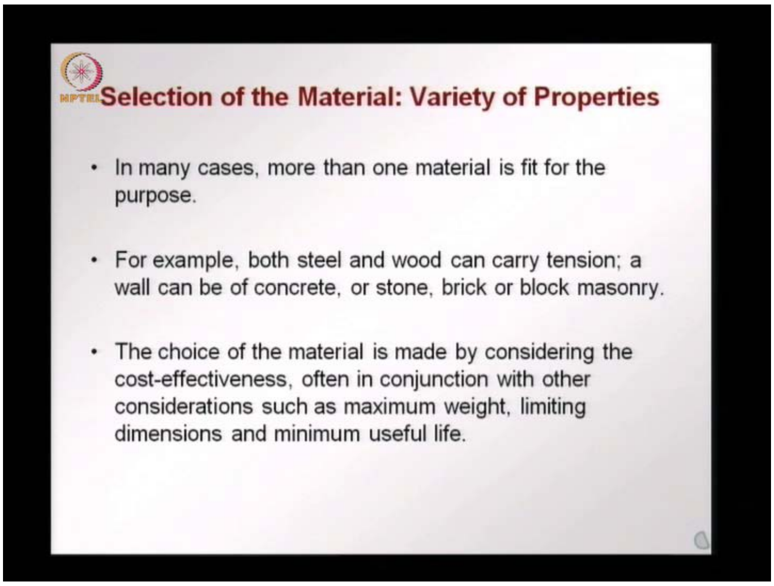

We might have to look at the maximum weight that the structure can have what is the size of the element because if you have a very bulky element you aren't using up this piece insight a building or structure and i mentioned several times already the durability other life is very important we have to look at the use full life of structure. So, in summary we have looked at the reason by we have to understand material science concepts why we have to get information from different scales of the material going from the micro structural scale to the engineering scale passing through the maze a scale the is scale gives us different information that we would need for developing a in her new material for solving problems in existing material and understanding weather a material is most appropriate for a certain application and we've looked at the range of properties that are there in material is that the normally deed the looked at metals which are heavy have high-density, but also have very high stiffness and high-strength and also high worker fracture affected toughness affected.

So, metals generally behave well in structural applications concrete on the other hand has and low tensile strength and that is the reason why we have to reinforced concrete with steel when we use it in structural applications with reinforced concrete we also look at other materials glass which is very brittle we looked at polymers like a proxies nylon robber which have very low weight, but also very low stiffness and possibly go strength also, but these materials polymers can also be reinforced with fibers to give much higher stiffness and strength almost comparable who those off metals. So, we will continuous on these concepts in the next lecture well will start with an example of being a I said before and will see how to optimize the choice of the material for that and we also look at other properties like variability which comes into play in the material selection.

Thank you.