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 a prologue or a lecture 0 that you can look at,where I discuss how this course will start and what is the motivation behind the course and a little bit about myself also.

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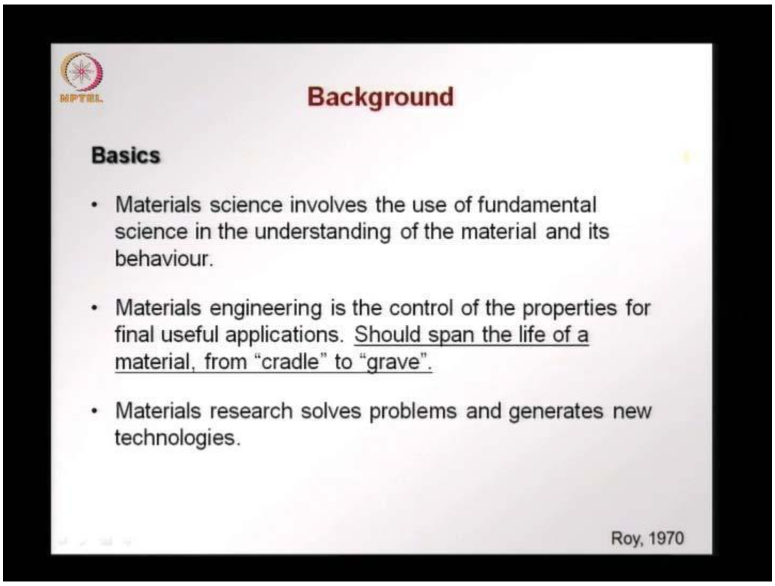

So to start with, when we look at the basics of this course, material science is that which involves the use of fundamentals, fundamental science, in the understanding of the material and its behavior. It is something that we have to know to do more research on different types of materials and to understand how these materials work. Materials engineering is where we control the properties, we develop materials in terms of their final applications, useful applications, this is what we are interested in.And what is underlined hereand what is important to know is that, when we talk about materials inengineering and especially in construction, we should think about the life of the material from the beginning, the fabrication, to demolition or when we don't 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, fabricated, manufactured to when the material is thrown away, demolished, we don't have any use for it any more. Materials research combines material science and engineering basically for two things: to look at how problems that are existing in construction materials can be solved and also to generate new products and new technologies because our demands, that of society, that of the construction sector is always increasing and we have to generate new technologies to answer these demands on the performance requirements.

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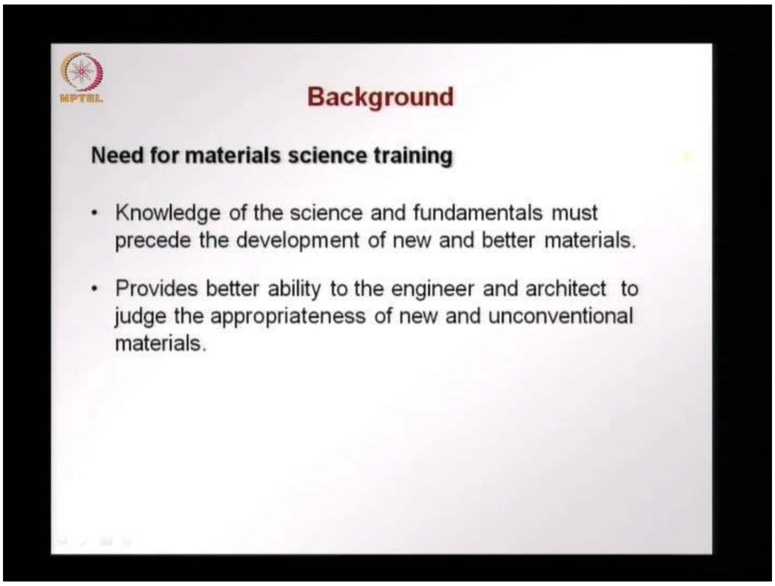

What is the need to learn material science fundamentals in engineering? The knowledge of the science and the fundamentals is always necessary when we have to develop new and better materials and as I said before, society wants us to increase the performance, the construction sectoris looking for better performance and there are problems that have to be solved.And for this, fordeveloping 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 or the architect comes across a new material or an unconventional material, the appropriateness can be better judged.

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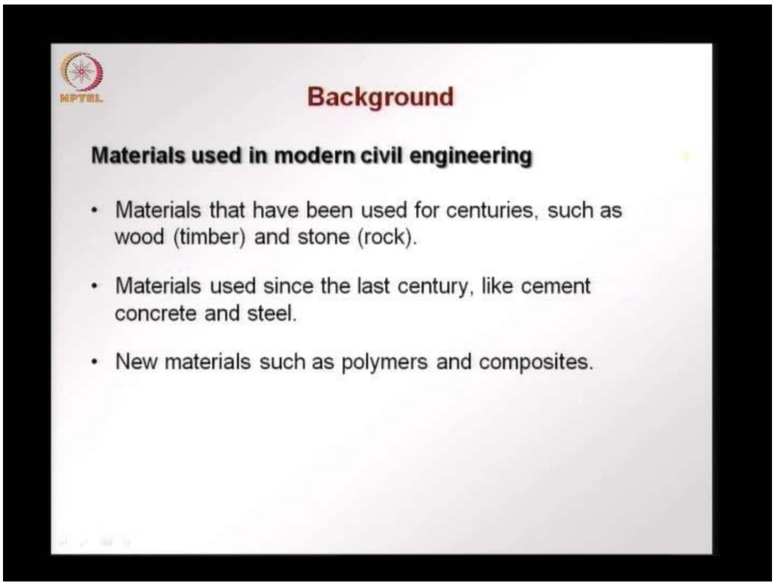

What are the materials that we use in civil engineering? They are not many. We can look at materials that have been used for many many centuries like wood and stone,timber and rock, which probably were the first materials that human beings used when they had to construct something. Then over the last century, we have had cementconcrete 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 composites,'composites' meaning that there are different phases of materials that are combined to give a composite material. They are usually fiber reinforced polymers or polymers with some sort of inclusions. So, all these, in modern civil engineering, are used a lot. And in this course what we'll 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 they do.

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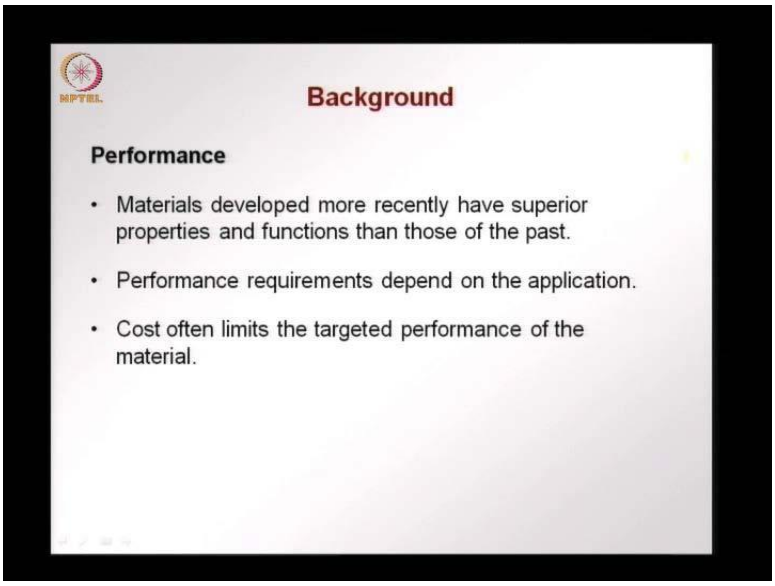

NowI mentionedperformance before.Performance is something that we look for in a material.Materials that have been developed recently are having superior performance, better performance and functionality than in the past. We always look for improving the performance and improving the properties that are useful and how they function, how the materials function in their use. The performance obviously depends on the application. The requirementsof the performance, how a material should perform, depends on where we are using that particular material. The performance radically changes depending on where weuse it. For example in a dam, concretehas to behave in a very different way than in a pavement or in this lab of a building. Cost often limits, very 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 performancein all the cases. In construction materials, why is all this necessary? Why is construction materials technology important at all? For two reasons: first, we want to understand how a material behaves and that depends on its structure,micro structure or nanostructure,how the material is put together.

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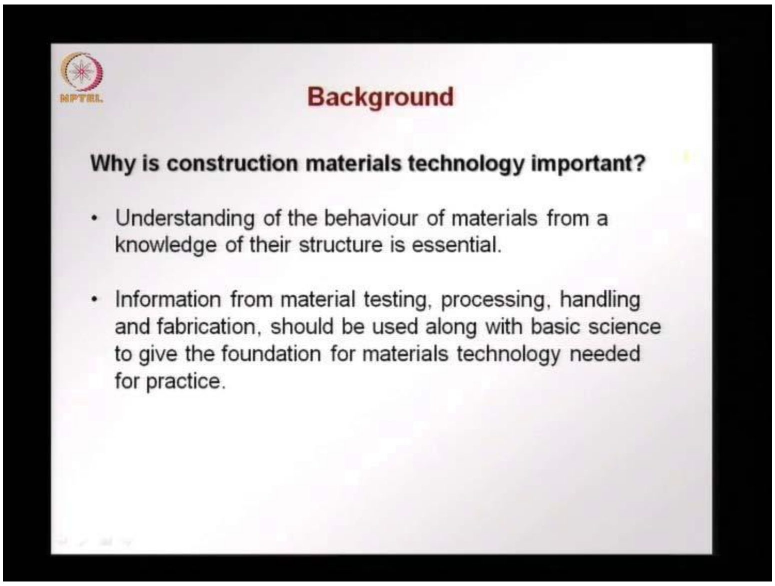

So understanding the behavior of materials from the knowledge of their structure i.e. their microstructure, is very important. Secondly, material information that comes from testing, how the material is processed or manufactured,how it is handled, along with the basics of science, gives us the foundation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

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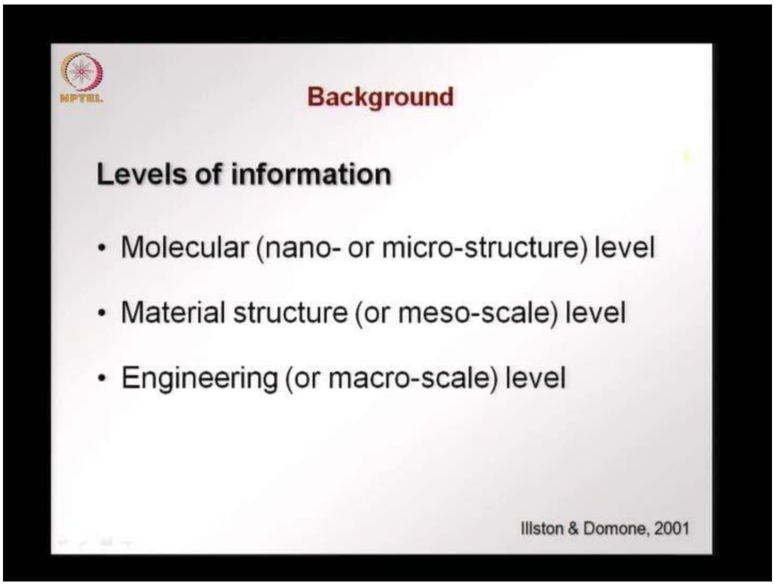

What are the levels of information that we get about the material? We have classified this following lllston andDomone, in three levels: The molecular level, whichis very commonly called as the micro structural level,nowadays some people call it the nano-structural level, but basically we are looking at a structural level where you need a microscope or some other sophisticated instrument to see how the material is put together at that scale. A scale that is higher up, often called the meso scale, what I've called material structures scale for simplicity, is where with your naked eye you can identify heterogeneities and differences in the material structure.For example, if you look at concrete with your naked eye, you can see the aggregates,you can see the mortar and in the case of say wood or timber you see the grains, you see the fibers and so on. So this is the material structure level where you see heterogeneities, but you don't go into very fine scale of the molecules and the microstructure. The engineering scale is what we use in design.This is when we forget about the heterogeneities,we consider the material as such. This is the macro scale.And we talk about concrete,we use it in design as a isotropic homogenous material, even though we understand that there are heterogeneities in the microstructure and in the material structural scale. So, let's look at each of these levels of information and see what we get from these levels and how they are useful to us in understanding the material behaviour. Now in the molecular level, we consider the material at the smallest scale, we are talking about atoms, molecules and aggregations or clusters of molecules.

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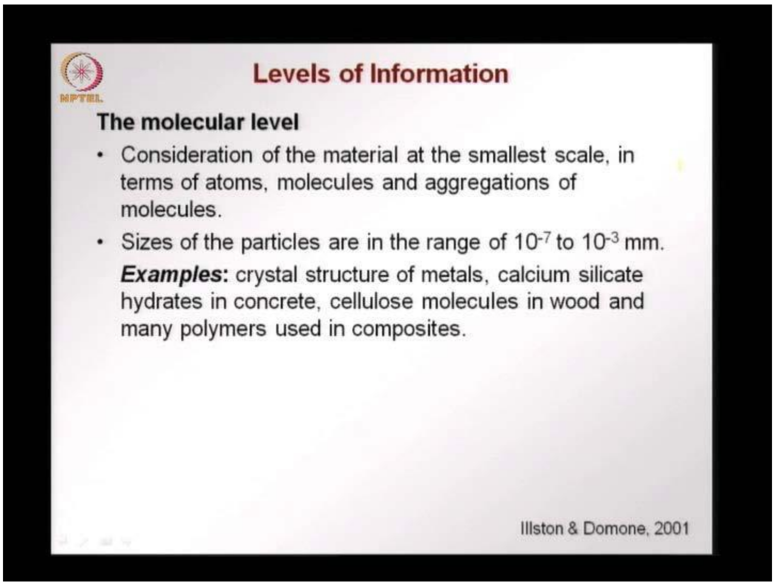

And here in the molecular scale, we are looking at particles in the range of 10^{-7} to 10^{-3}mm. So here obviously, you need a microscope, you need something to look at the structure, to understand the structure we need the science. Examples of units in the molecular level would be the crystal structure of metals, in concrete, the calcium silicate hydrate gel particles which are few 100 nm in size, and in wood and timber we can talk about the cellulose molecules which make up the fibers in the wood. And in terms of the composites again we can talk about the molecules, the chains of the polymers.

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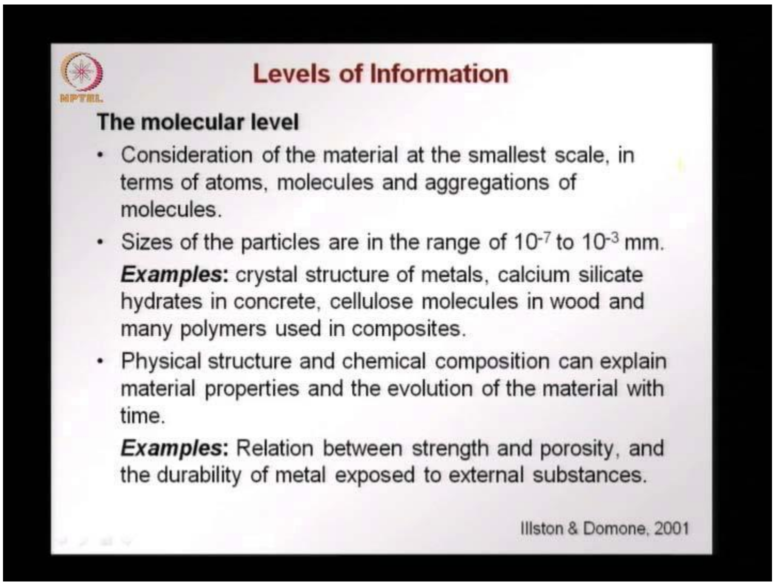

Now why do we need to understand this? We need to understand this because the physical structure at this scale and the chemical composition gives us an idea of how the material behaves, how do we get the material properties, and how this material has evolved with time, which is of very high importance when we talk about durability. The chemical behavior tells us how durable a material would be. We get ideas about the relations between the strength and the porosity. Porosity is a feature of the microstructure. We generally want materials not to be very porous because this affects the strength, and when we understand what happens in the molecular scale, we also get a better idea of the relation between strength and porosity. Further as I mentioned, durability is very very important in all civil engineering structures. We want our structures to last a long time. We want structures to last for several decades if not for centuries. And here, durability is very important and what governs durability are the chemical aspects, the chemical behavior. And the information about the chemical behavior comes from the understanding of the molecular level.So the durability ofa metal exposed to different chemicals in the exterior can be understood if we understand the molecular level well.Then we go no to the next higher level, the material structure level.We now consider the material as a composite of different phases. Now what is a composite? A composite is a mixture of different materials, each of which retains its character even after they are mixed together.The phases combine to give you the composite. But each phase has and retains its own characteristics and works together to make the materials behave in a different way, called the composite behavior or the total behavior. And this is true for almost all materials that we use in civil engineering. We understand that they are composites. The scale of the composite structure now is in the order of 1 micron to about 100 mm. And here, we can talk about masonry being represented by a single brick in the material structure level, awood cell that makes up the fibrous structure, a piece of concrete which would have say aggregates, mortar, mortar being made-up of cement paste and sand, and so on. So these arefeatures that we can identify even with the naked eye, we understand that the material is made up now of different phases or component materials that have been put together either by the fabrication or by the growth of the material structure. How we process the material and how the multi-phase response works out, or how the behavior occurs, depends on the features in this scale. It depends on the shape and size of the particles that make up the structure at this level, the distribution and the concentration or 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 paste phase.

So this influences a lot how we make the material and how the material behaves.How the individual phases remain within the composite are also important. The state and properties of the individual phases influence the composite behaviour.TheYoung's modulus, he strength, the bond between the phases are important. So the interface plays probably the most important role in a composite behavior. It is often said thatthe weakest phase in a composite is the interface. Bonding between the different phases is very very important to get the ideal or the desired composite behavior and these are things that we can test and we can model.

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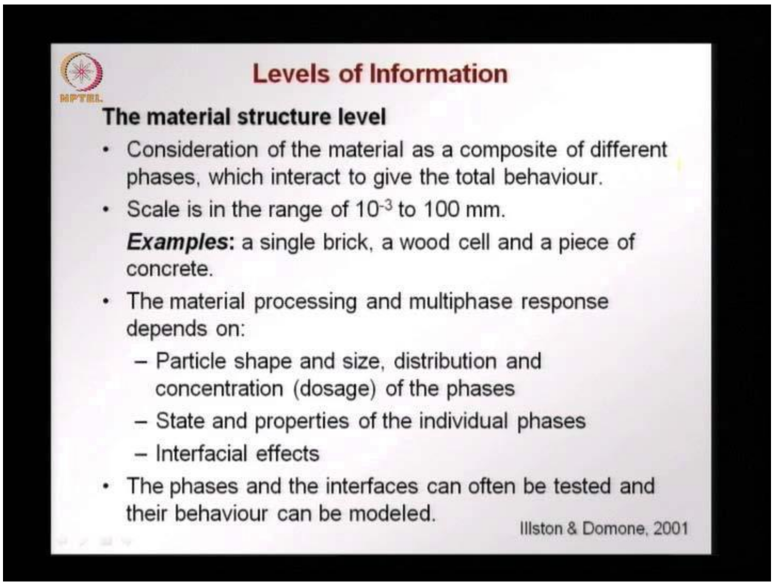

In the material structure level, the phases can still be identified, the interfaces and the phases can be tested and the behaviour can be modeled and these models can help us understand how the structure of the material behaves. Nowwe go onto the next scale, the scale that is used by the designer and where we talk about the total material. Even though we had considered and discussed in the previous two scales thatthe material is made up of many elements, many components, these interact and couldhave different responses, in the engineering level we consider the total material. We normally take the material as homogeneous and continuous.We represent the total behavior with certain parameters and models where 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 as a micron, but could be as large as a metre.And this scale is also important because when we testa material, we are doing it at this scale and therefore, the size of that representative unit which is the minimum volume of the material that represents the entire system is important. We cannot take very smallchunk of the material, test it and believe it gives the properties of the entire material if that chunk of material is too small. We can explain this with this animation.

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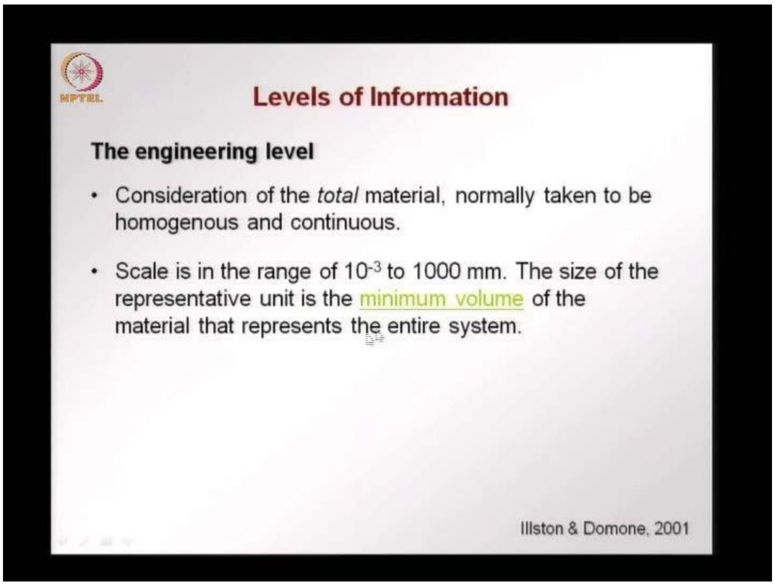

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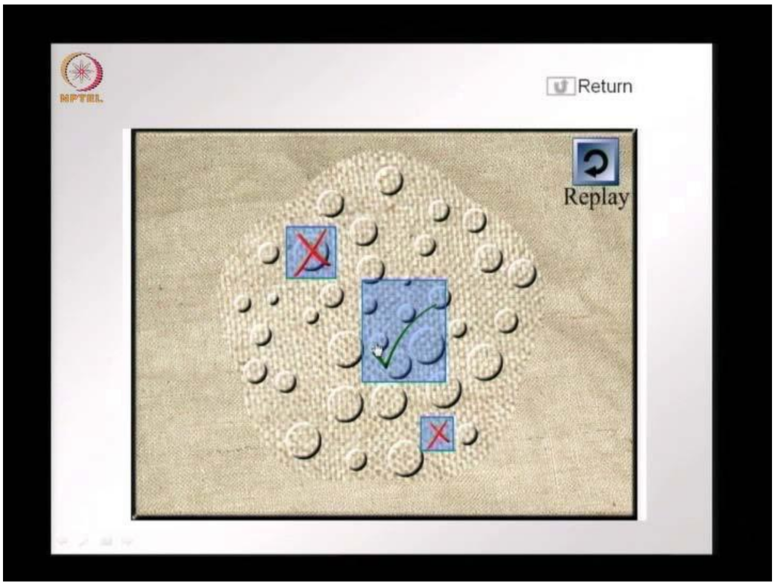

So when we go to this animation, we see that what we have done is, taken an arbitrary material where you have a certain microstructure and you have in this microstructure another phase that is included which is made up of these spheres or disks of different sizes. Now if I were to take a volumethat is this small blue square, you would see that most of this square orthis cube would have only the finer microstructure or will not include any of the larger microstructure. Now if I were to take this square again, I will have one large aggregate phase in it, but I will not have any of the microstructure.

So neither this nor this is really representative of the microstructure. I have to go for a larger piece of the material where I have enough of the finer microstructure and I have the larger phases also included, to give me a representative volume of the material that has to be tested.And this has a lot of consequences. Some people wonder why we use a150mm cube or a cylinder of 150mmX300mm for testing concrete.And this comes from this concept of a minimum volume that is needed to represent the material that we are testing. If we were to take a concrete cube that is only say5cm or 3cm in size, we would not have enough of the cement paste,the mortar and enough of the aggregates and the interfaces to give us a representative picture of the material itself.

So that is why in civil engineering, in civil engineeringtest standards, we always specify the dimensions of the specimen that has to be tested and this comes from considerations of a minimum representative volume. Soat this scale, we can test and we do tests and sometimes we must test the material to obtain properties and understand the behavior.This testing is done for several reasons. Initially in the development of the material, when we make a new material, when we improve a material, we want to see how these properties develop, if these properties are adequate for the application that we are considering. Secondly, as a means of quality control. Lot of the materials that we use in civil engineering are 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 procure 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 we use this as an input for structural analysis and structural modeling. Models need parameters which have to come from the engineering scale and what do we do with these models? We use these models to simulate the response of a large structure that we are interested in designing or we want to know how this structure is going to behave. It could be an existing structure or a structure to be constructed.

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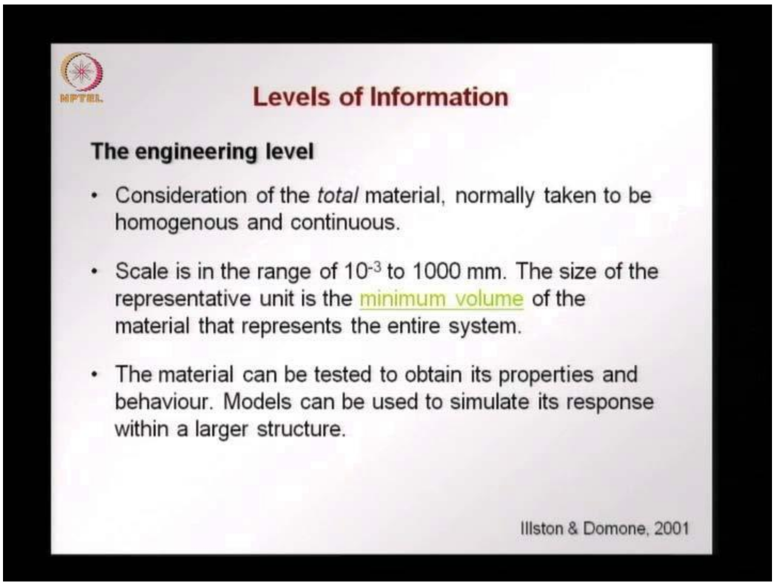

So for all these reasons, we need testing to be done in the engineering level.

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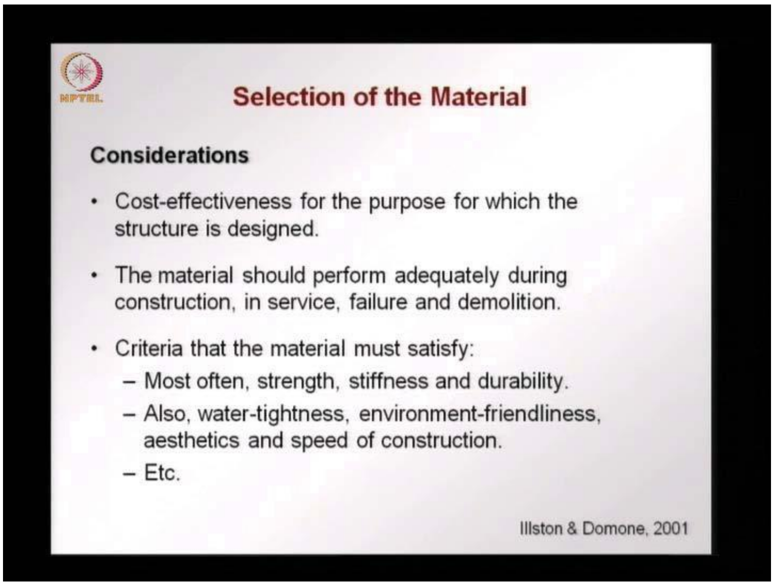

Now we have looked at different aspects that are needed to study a material, what are the considerations for selecting a material.We have many choices in civil engineering as in other engineering fields.How do we go about choosing the material that we will eventually use in a certain application? The best way to characterize the most important considerationis calledas cost effectiveness.It doesn’t mean that we 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 applications. 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 or performance has to consider several aspects .Initially when I started this lecture, I talked about the cradle-to-grave concept and when we put it into the context of a 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 is in 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 or after we don't want to use structure anymore, the application is over, we demolish orwe 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 to thedemolition or the disposal phase. So only when a material is effective in thiscomplete life that it will have in an application, we can think of it as being effective and allthis has to happen at the lowest cost possible for it to be cost-effective. The criteriathat the material should satisfy in a structure, the performance requirements, are most often based on strength.We design,we define materials in terms of their strength and possibly the stiffness or the modulus of elasticity. Implicit to most of these applications is the durability. We want a structure to last for a long time, we want a material to behave well throughout its life or the duration of its application.

So durability, even though we often do not design for durability, we need to keep durability in mind. This may come from experience, could come from modeling and could come from the fundamental understanding of how a material is going to behave in its environment. So the criteria most often used for choosing a materialin terms of the performance are strength, stiffness and durability. Other than that, depending on certain specific applications, other aspects such as water tightness, aesthetics, speed of construction and nowadays very important is environment friendliness. These are also coming into play. If we have a water tank,we certainly have to worry about the water tightness so that it doesn't leak.This could go for roof slab, it could go for a toilet slab.And when we are talking about aesthetics, any facade element, any decorative element, any architectural element we might choose basically on the reason of aesthetics. Speed of construction is very important and it is becoming more important in India where we are in a hurry to finish projects be it housing projects or infrastructure projects. So, the speed of construction can often help you choose a material. I put in etc, because there are many applications which would require very specific criteria for choosing their materials and this could change, could vary from one application to the other.

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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
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 are commonly used and their properties. This is taken from lllstone and Domone, and in these tables, you will see some important properties and also relative cost. So, if we take the first four which are metals, we see that they have high density.Here the density is given in tonnes or 1000 kg/m^3,stiffness in terms of the young's modulus in GPa,the strength or the limit stress which we have taken basically as the tensile 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 work to fracture or toughness .This is not a very commonly used parameter, but this is very important because it tells us how a material will break or fracture or fail. The higher the work to fracture,means that more energy is dissipated by the material before it actually fails. A Material such as glass which is very brittle will have a very low toughness or work to fracture. Amaterial that is ductile,you see here the range given for metals, it is much higher indicating that the material would fail preferably by yielding rather than fracture.So the material would not break, but yield.Now the last two columns give a relative cost.Here what we have done is kept the other cost relative to the cost of structural steel i.e. structural steel is taken as one and all the costs mentioned for the other materials are 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 that we are using and often, we want a lightweight structure andtherefore, we have to avoid the weight. Density is also important because we buy materials in terms of volume or weight and we pay for it in terms of volume or weight and we need to know the density of the material. Stiffness is important because in most of the service life of a material, the material has not cracked or yielded or failed. It behaves in the elastic regime and the deformations that the material and consequently the structure undergoes depends on the stiffness or the elastic modulus or the Young’s modulus. The strength is obviously very important because the failure, the ultimate limit state of a material and a structure depends on its strength and as Itold you, fracture would define how a crack propagates, how fracture occurs, how rupture occurs andfailure ultimately happens.And when we compare the metals in the top with glass which is very brittle, you see that the density is obviously lower for glass, stiffness is also lower and the toughness or work to fracture is much much lower, indicating or implying what we already know that glass is a very brittle material.

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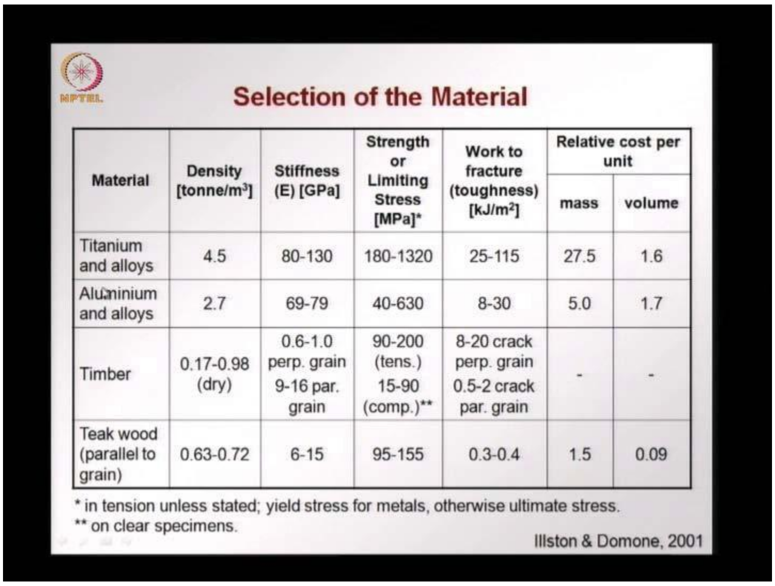

Material	Density [tonne/m³]	Stiffness (E) [GPa]	Strength or Limiting Stress [MPa]*	Work to fracture (toughness) [kJ/m²]	Relative cost per unit	
					mass	volume
Titanium and alloys	4.5	80-130	180-1320	25-115	27.5	1.6
Aluminium and alloys	2.7	69-79	40-630	8-30	5.0	1.7
Timber	0.17-0.98 (dry)	0.6-1.0 perp. 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

Let’s go on. Now you see other metals, less commonly used for structural purposes say titanium and aluminum at the top. Titanium has very high strength compared to the materials that we are discussing here, probably it is at the upper end.It is also having a good toughness, but the cost is very high, almost thirty times the cost of structural steelfor the same unit massi.e. 1 kilogram of titanium could be thirty times more expensive as that of a kilogram of structural steel, aluminum lesser. And in the bottom two rows,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 in GPa.The strength is not as bad as materials such as concrete; it is comparable intension to some metals.The work to fracture and the toughness are good when we comparewith what we saw for silica glass in the earlier slide.A particular type of wood, teak woodthat we use a lot in India is given in the last row. The properties are given in the last row.And what you would see is whenever we talk about timber and wood, we give the properties either parallel to the grain or perpendicular to the grain. This is because timber is not an isotropic material, it an orthotropic material or at best a transversely isotropic material. It has certain properties along the fibers or the grain and another set of properties, which could be different in the plane perpendicular to the grain or the fibres. So, when we talk about the properties of wood and timber we have to specify in which direction we are giving the properties.

So, here you have the density of teak wood. Again,quite low as you would expect for wood.This stiffness is not as high as we would find for titanium and steel, but still it is reasonable,better than polymers which we will be seeing in the next slide. Its strength is much higher than concrete which again we will see in the slide, comparable to the lower end of some metals. The fracture toughness is not very high, 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 volumesince the density is low. What we must keep in mind when we talk about cost is these are just relative numbers.For a certain location at a certain time period, obviously, the cost will vary depending on where we are and when we are going to purchase 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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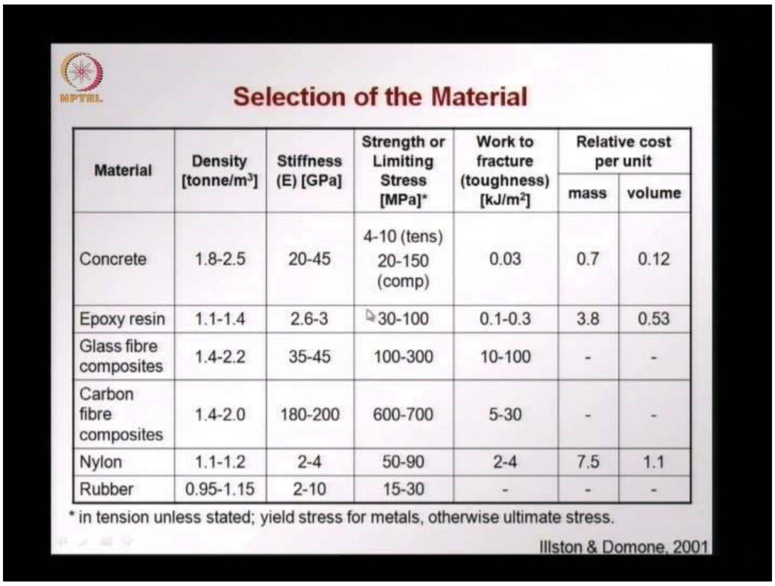

Selection of the Material

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.We see here again the properties that we looked at before, density,stiffness, strength and toughness. The density is in the range of about 2 tonne/m^{3}or2Kg/m. This stiffness is not as high as that we saw for steel, but it is still reasonably high compared to polymers say epoxy resinor a nylon or rubber.It is less than a composite made out of a polymer and carbon fibers. In terms of strength, for concrete asmany brittle materials,we know the tensile strength is very low, almost one tenth or hardly one tenth of the compressive strength. Concrete is used mainly for its high compressive strength and we often ignore the tensile strength of concrete in design.

So we find here that the tensile strength of a concrete would be in the order of four and maybe in very good quality concretes, you can havea 10 Mpa tensile strength,but it would be more in the lower end of the scale. The compressive strength of the concrete can vary, we normally use a range of 20-40 MPa strength and it can go much higher even beyond 100 and 150MPa. The toughness is low compared to the values that we saw earlier for metals and also what we have here for composites and polymers. So, this indicates that concrete, like glass, is a brittle material. It can fail easily, it can crack easily and that is the reason why we reinforce concrete with steel in most of our structural elements. Relative cost, here we have said that it would be much lower in cost that structural steel for the same unit weight. Epoxy and glass fiber reinforced composites and carbon fiber reinforced composites are being used a lot nowadays in repair, retrofitting and in other applications and we have to understand how these materials behave and what we see is that the reinforcement of an epoxy with fibers, be it glass fibers or carbon fibers, improves its stiffness significantly, also increases the strength. And now we are talking about a range which is comparable to what we saw in metals. The fracture toughness may not be always as high as metals but much better than what we have for concrete, for glass or just forunreinforced epoxy resin. So what thesetables have told us is that we have a variety of materials with very 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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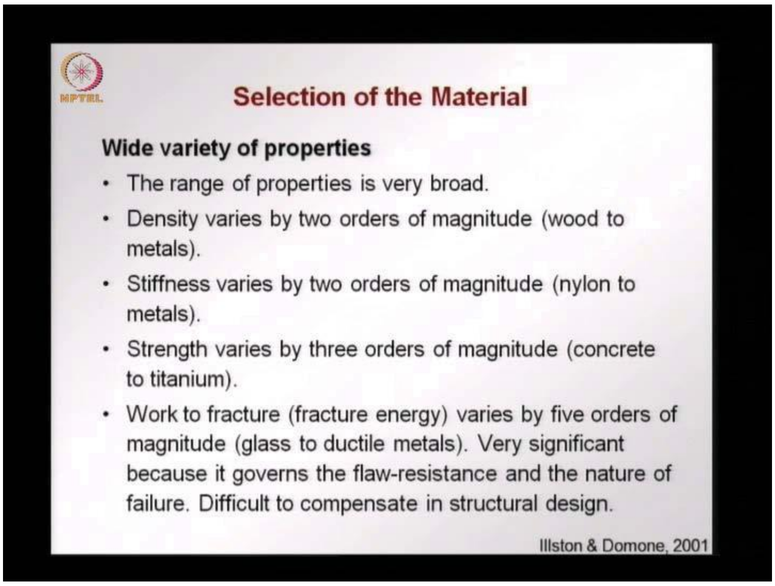

We have seen that there is a wide range or a wide variety of properties. In terms of density, we saw that the densities that we looked at range over two orders of magnitude- wood being the lightest to metals being heavy.The stiffness, the Young's modulus, the modulus of elasticity again varied by two orders of magnitude from very soft very flexible polymers such as nylon to again metals. Strength also varies a lot.We saw concrete intensionis very very weak,it can fail very easily,it can crack very easilyto titanium almost thousand times stronger than concrete. So, all these important properties- density, stiffness and strength varies a lot and again,we have to understand when it would be best to use any of these materials. The last property that we had on the table, work to fracture orfracture energyor fracture toughness varies again by five orders of magnitude, going from glass which is very brittle, we all know glass can break very easily,to ductile metals which do not fracture mostly, but they would yield or shear and fail in a progressive manner, in a plastic manner. So, there is again a wide range and thisfracture energy or fracture toughness, the use of itmay not be very obvious, but it is very important because when the fracture energy,the fracture toughness, work to fracture is low, the material becomes flaw sensitive i.e. even a small defect can lead the material to fail. So, the fracture properties, we will dealwith later, govern the flaw resistance or how the material will behave when it has a flaw and how the nature of failure is governed by this flaw resistance. And this is also difficult to compensate for in design because the defects can occur in a variable manner.We do not always know where the defect is occurring, so that we can deal with in structural design. So, this is something we have to understand and take into account properly.

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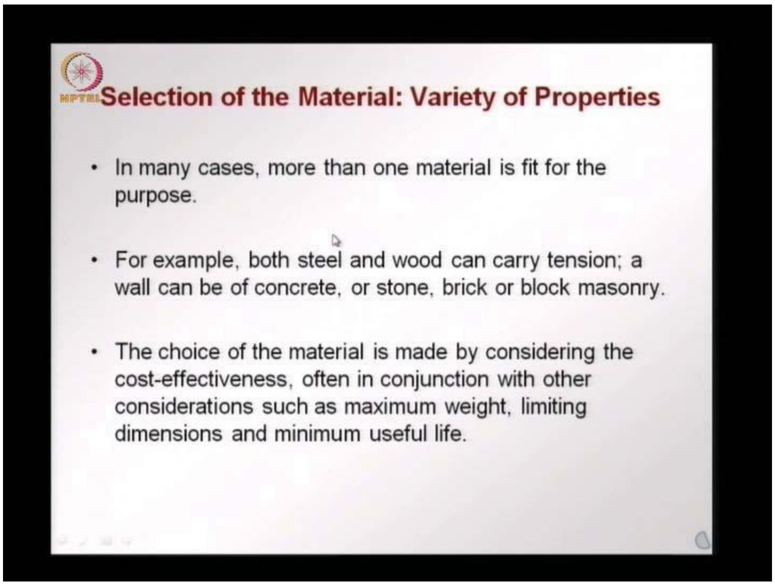

So, in the selection of materials, we find that more than one material is fit for a certain purpose. For example, when we talk about a tensile element,both steel and wood can carry tension well. We saw that the tensile strength of wood is quite good, may be not reaching the value of steel, but quite high. That is the 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 very often intension. When we're talking about a wall- a partition or an exterior wall, we can make it out of concrete or more often with masonry be it brick masonry, block masonry or stone. So we have again a range of choices that we can use for 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 do we pay for it. So the effectiveness comes in conjunction with,together with consideration such asmaximum weight, limiting dimensions and useful life.

In the next part of this lecture, what we will look at is we will take an example of a simple beam and we will see how different materials would behave in the same application, where we will look at how to take into account the density, the stiffness and the strength for optimizing the choice of the material.

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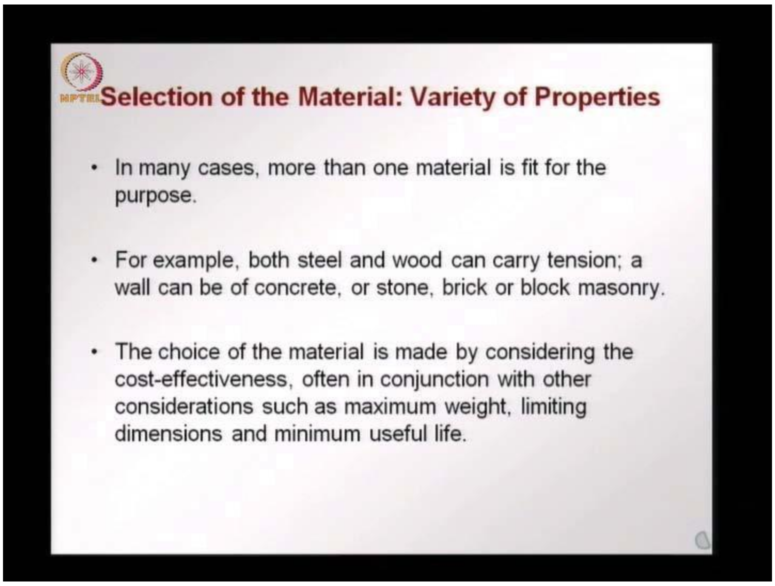

Other thanthatin an application, we might have to look at the maximum weight that the structure can have, what is the size of the element because if you have a very bulky element you are using up thespace inside a building or a structure.And as I mentioned several times already, thedurability or the life is very very important.We have to look at the useful life of the structure.

So in summary, we have looked at the reason why 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 meso scale. Each scale gives us different information that we would need for developing a new material, for solving problems in existing material and understanding whether a material is most appropriate for a certain application.And we've looked at the range of properties that are there in the materialsthat we normally dealwith. We looked at metals which are heavy, have high density but also have very high stiffness and highstrength and also high work to fracture or fracture toughness or fracture energy.

So metals generally behave well in structural applications. Concrete, on the other handhas a low tensile strength and that is the reason why we have to reinforce concrete with steel when we use it in structural applications with reinforced concrete. We also looked at other materials like glass which is very brittle. We looked at polymers like epoxies, nylons, rubbers which have very low weight, but also very low stiffness and possibly lowstrength also. But these materials, polymers can also be reinforced with fibers to give much higher stiffness and strength, almost comparable to those of metals.

So, we'll continueon these concepts in the next lecture where we'll start with an example of beam as I said before. And we will see how to optimize the choice of the material for that. And we will also look at other properties like variability which comes into play in the material selection.

Thank you.