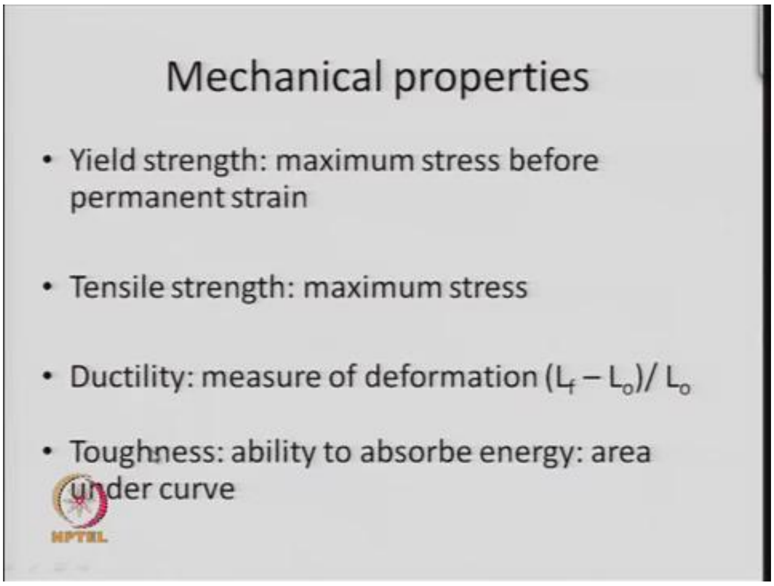
Nano structured Materials-Synthesis, Properties Self Assembly and Applications
Prof. Ashok K Ganguli
Department of Chemistry
Indian Institute of Technology, Delhi

Module - 4
Lecture - 39
Mechanical Properties

Welcome back to this course on Nanostructure Materials, Synthesis, Properties Self Assembly and Applications. Today we are in the 11th lecture of the module 4 and today we will be discussing Mechanical Properties of nanostructure materials. How does the strength of the mechanical strength of a material change, when the particles are decreased in size from normally micron sized range to nano meter size range, what is the change in it is different mechanical properties, so that is the topic of the lecture today. In the previous lectures, we have done many other properties and the previous lecture, we finished the optical properties, so this will be on mechanical properties.

(Refer Slide Time: 01:26)

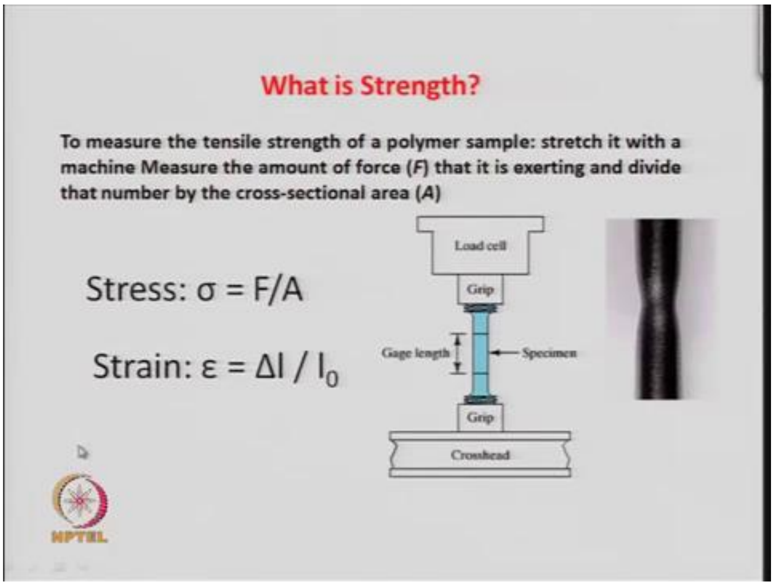


Now, mechanical properties as you see generally we talk about yield strength, which is maximum stress before a permanent strain occurs in the material. So, there are certain very well known terms in mechanical properties, which will also be carried forward to nanomaterials and this terms are yield strength, tensile strength, ductility and toughness. And what they mean are same for micron sized particles as well as nanosized particles.

So, yield strength is the maximum stress that you can give, before the material gets into a permanent strain, that is it cannot regain back it is own self. Tensile strength is the maximum stress, which your applying, that is the tensile strength and ductility measures the change in the deformation. So, if you have an initial length of L 0 and a final length on the application of the stress or deforming force, if the final length is L f.

Then the difference between the two distances lengths divided by the original length gives you ductility, which is how much the material has deformed on the application of a stress, so that is the major of ductility. And then we also talk about toughness that is how much energy a material can absorb, so if want to quantitatively get these numbers, then what you do is...

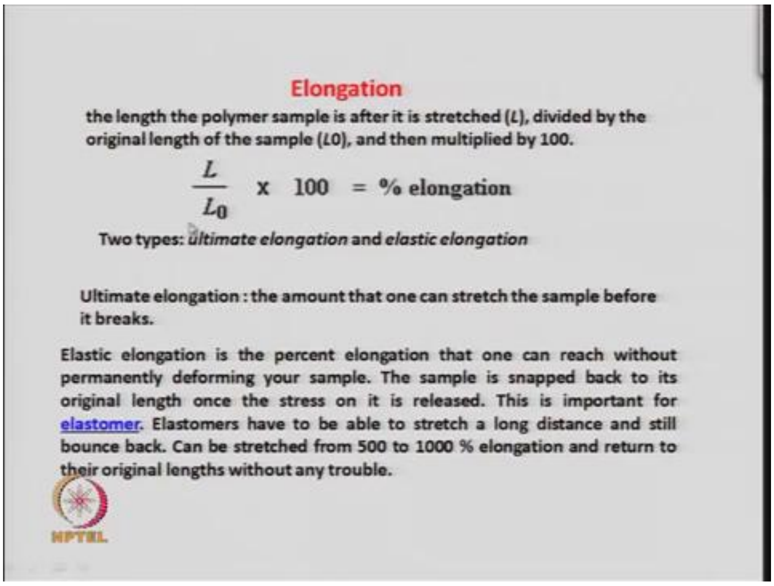
(Refer Slide Time: 03:30)



You have to measure these stress and strain, etcetera, so how do you major the tensile strength for example, you have a polymer and you stretch it with the machine and then major the force F that it is exerting. And if you know the cross sectional area then F the force divided by the area will give the stress and strain is as we defined just before is the deformation length delta l divided by the initial length l naught, that gives you the strain.

And that can be measure by a device like this, where you have the specimen in between two chambers, which one is called the load cell where you put the weights. And the other end is kind of fixed and you measure the deformation when you apply a certain load, by that you can major stress and strain.

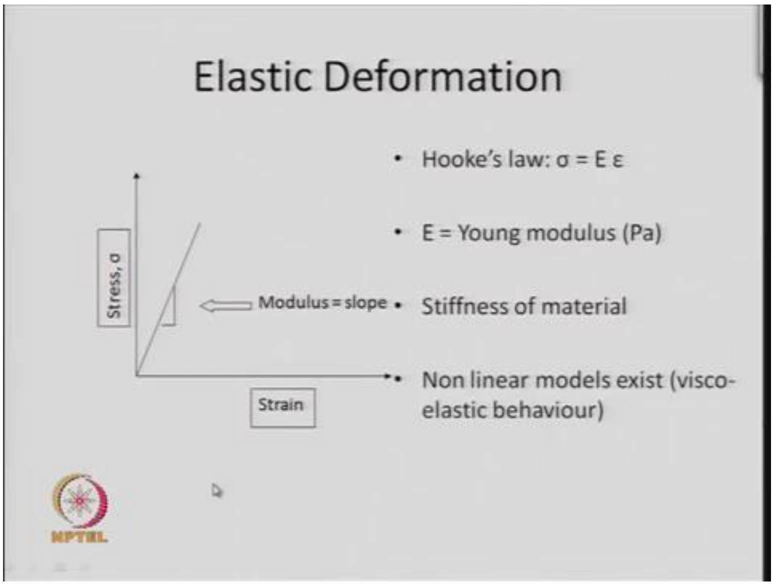
(Refer Slide Time: 04:34)



And this percentage elongation is also what we measure which is given by the length, by the initial length multiplied by 100. So, instead of strain which is given as ratio you may also define it, in terms of percentage elongation, where you multiply the final length divided by the original length into 100. So, you can have two types of elongations, the ultimate elongation and the elastic elongation, the ultimate elongation is that amount that one can stretch the sample before it breaks.

And the elastic elongation is the percentage elongation that you can achieve without permanently deforming the sample, so how much you can elongate such that, it goes back to it is original cell that is the elastic elongation. And ultimate elongation is beyond which the polymer or that material will break, so in many cases these are called elastomers, where it is able to stretch for a very long distance and still can come back. So, it has a very high elastic elongation can be around 500 to 1000 percent elongation and then return to their original lengths.

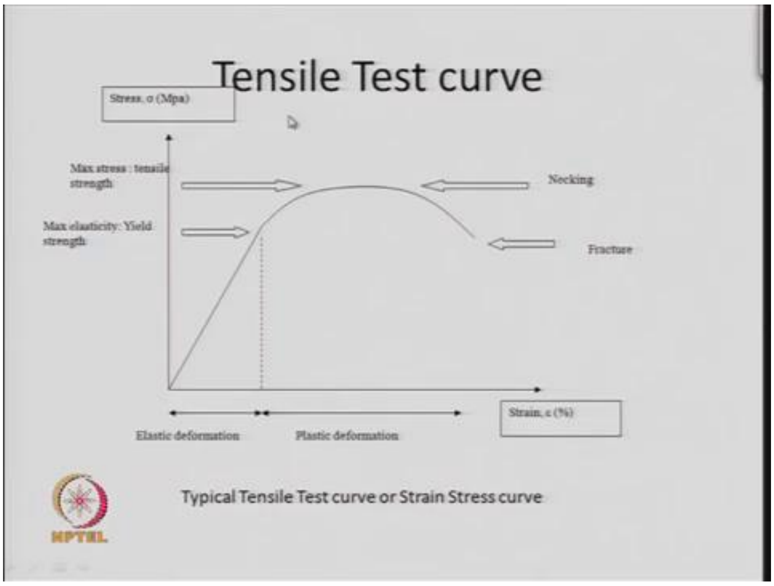
(Refer Slide Time: 06:03)



Now, normally we plot for any elastic deformation, you plot the stress verses strain and since it is elastic, it is normally liners, so there will be a straight line between the stress and the strain. And this slop of this stress strain plot will give you the modulus and this is given by Hooke's law that, this linear portion which is called the elastic deformation follows Hooke's law, where the stress is proportional to strain.

And this constant of proportionality is called the young's modulus and that has this units of Pascal's, and from here you can also measure what is called the stiffness of the material. And if it bends beyond a particular stress, if you keep on increasing the stress and the strain and you loose the linearity, then you go into what is called the non-linear region and that is not define by Hooke's law. Only the linear part of the stress strain curve is defined by the Hooke's law and that part is called the elastic deformation.

(Refer Slide Time: 07:25)

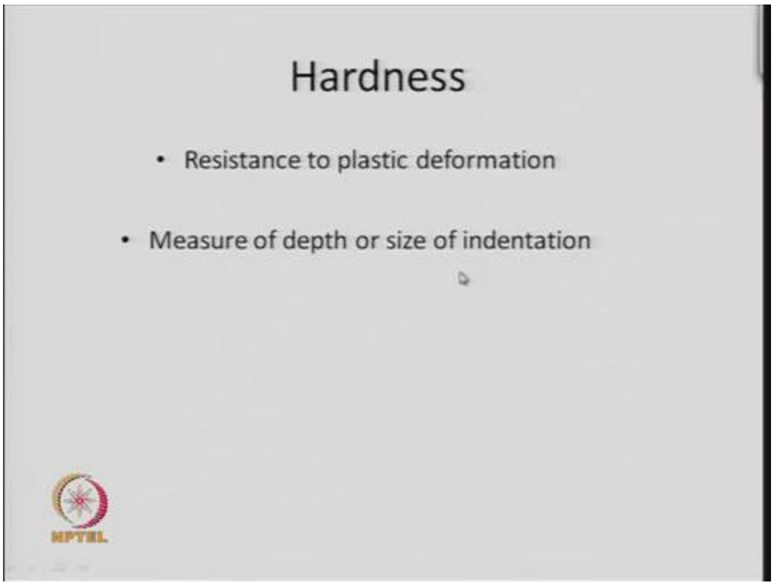


Now, in the tensile test curve you can get a maximum elasticity is what you get in the linear portion and then the curve become non-linear, so this point here is this is the region where you have the elastic deformation. So, this access the x access plots the strain and till this value of strain you have an elastic deformation, where the yield strength the stress is directly proportional to the strain and this point is called the yield strength, because beyond this it is no more linear.

And the maximum stress is that is a achieve before the stress again tends to go back, this value of the maximum stress is called the tensile strength and beyond a certain point it breaks and so that point is called the fracture point. So, this is different regions of the tensile test curve denotes the mechanical properties of a material, so what is the region of elastic deformation if the region is large, for example if you have a linear plot till this value, then the strain is linear up till this.

So, depending on the linearity you have the elastic deformation and that you can extend depending on the type of material you have, beyond the elastic part where it becomes non-linear is called the plastic deformation. So, the strain can be elastic or plastic and that depends on whether you are in the linear zone or in the non-linear zone in the tensile test curve; so this is a typical tensile test curve or a strain stress curve for a material.

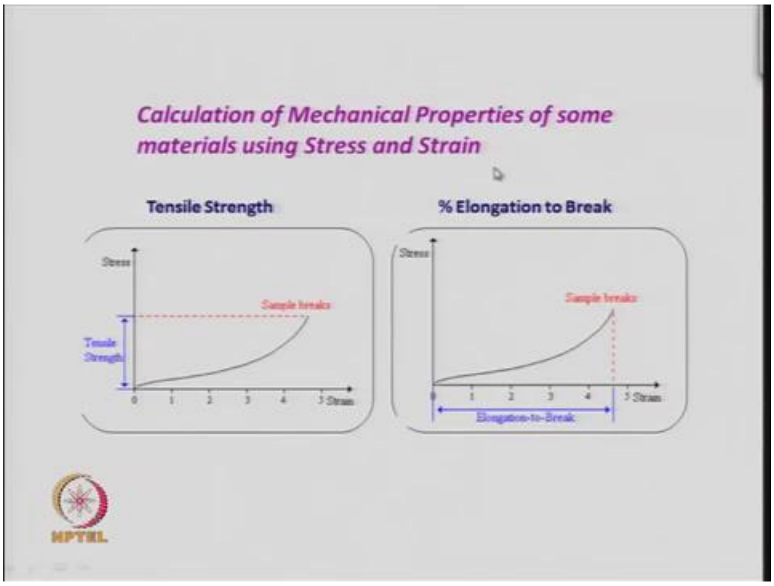
(Refer Slide Time: 09:34)



Now, what when we say about hardness, so mechanical properties many times refers to hardness or strength, what you mean by hardness, it is the resistance to plastic deformation, that means how much strain it can take before it become non-linear, so that is called the hard material. That means, it will remain, it shows resistance to plastic deformation, so this can be measured, the hardness can be measured by the depth or size of indentation.

That means, if you make a indent that is you strike the material with some force with a needle or with a particular shaped object, then work to how much depth you can make that indentation tells you about the hardness of the material. So, now a days you can study the using what is called nano indentation techniques or nanomaterials.

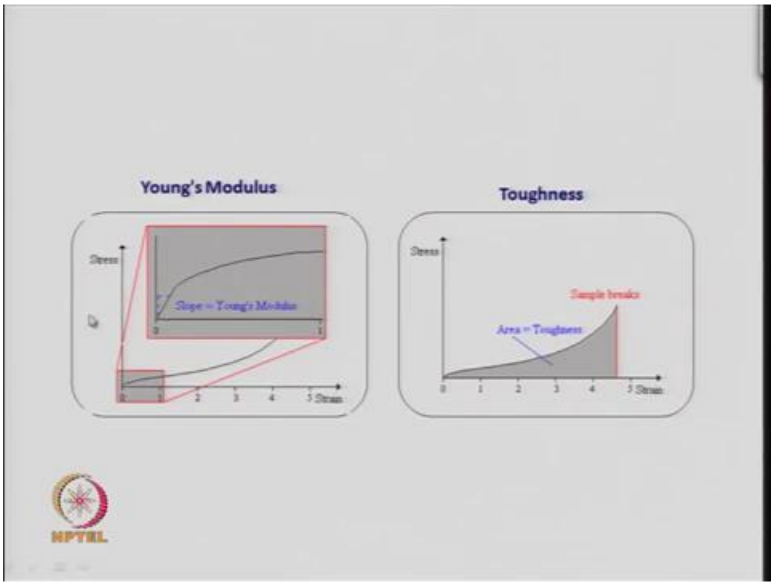
(Refer Slide Time: 10:51)



Now, mechanical properties if you want quantitative, so you measure for example, in a stress strain curve, most of the times we are measuring stress strain curves for materials when we are studying their mechanical properties. So, here you are plotting again stress and you find that the stress varies like this and beyond this there is no plot, because the sample has broken here.

And the maximum value of stress till which the sample exists before it breaks, it is called the tensile strength and the strain. The maximum strain that it can achieve before it breaks is the elongation, which a material can undergo before breaking and that is call elongation to break, how much elongation the material can undergo before it breaks.

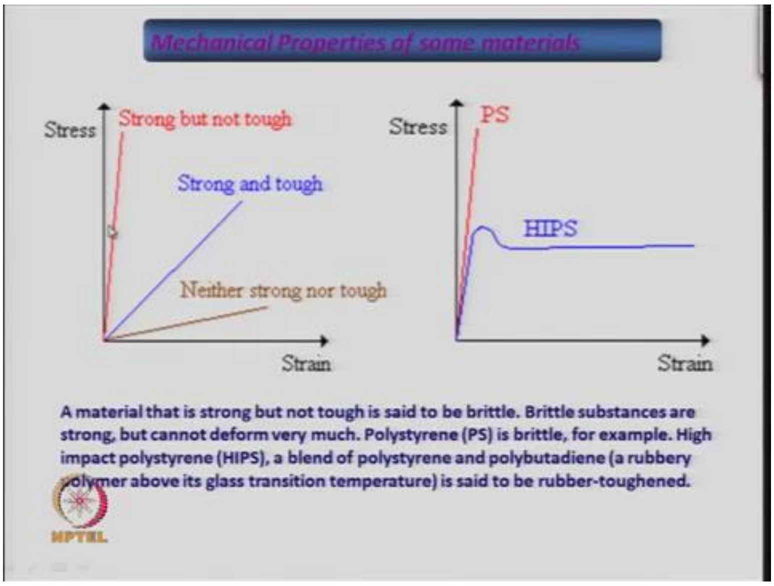
(Refer Slide Time: 11:54)



The young's modulus can be obtained from this slope of the linear part, so if your plot is, if you will zoom in this region the lot of nonlinearity here, if you zoom in here and make it large. Then for a small region you see that the plot is nearly like a straight line, it is linear, and from the slop of this linear part of this plot between stress and strain, you get from the slope the young's modulus.

And from the area under the curve, so your curve was here if you take this plot and draw a line to the x axis, then the entire area this is the same plot which is shown here. So, what you have done in this case is to draw a perpendicular to the x axis from the point where the sample breaks, and you calculate the total area under this curve and that gives the toughness. So, the young's modulus is given from the slope of the linear part or the elastic part of the stress strain curve, whereas the area under the curve gives you the toughness of the material.

(Refer Slide Time: 13:21)



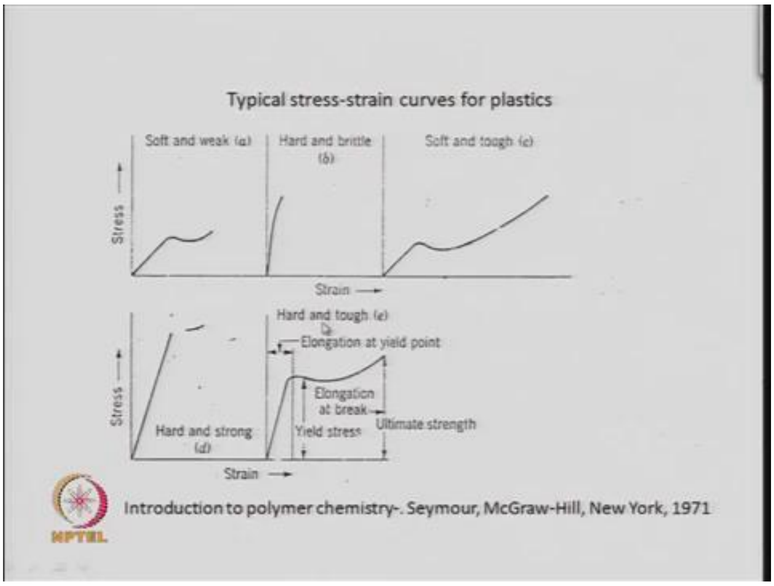
Now, if you see different material, so suppose this is material a, this is a material b, this is a material c, now the differences is for example, in this case it is very sharp the slop, so for very high stress the stream is very small. So, it elongates to a very small extends even though you have given a large stress and that means, it is strong, but it is not very tough.

Now, if the stress is high and the strain is also high that means, you have a plot which is more or less having a slope of 1, then it is strong as well as tough. And if the plot is like this, where you are very close to the strain access, you give a lot of strain you achieve a lot of strain with very small amount of stress, so it is neither strong nor tough. So, these are three examples of how you can discuss a material based on the stress strain curve.

All the three materials are elastic, because they have a linear plot between stress and strain, but the slopes are different and the slopes indicate, whether it is strong or tough or not tough, etcetera. Now, if a material is not tough, then it is called to be brittle that means, that will break very easily and brittle substances are strong, but cannot deform, so it can be strong, but not tough means it is brittle.

So, typically a brittle material will have a plot like this which is strong, but not tough and for example, polystyrene is brittle, whereas high impact polystyrene, which is call HIPS is a blend of polystyrene and polybutadiene, there are two polymers, it is a blend of two polymers and that is called that is more tough. So, when you mix, when you take only polystyrene the plot will look like this, so it will be strong, but not tough when you mix polystyrene with a rubbery material, which is called polybutadiene, then the material become strong as well as tough. And in general we say that the material has been rubber toughen, because this gives us polybutadiene, addition of polybutadiene gives us a feeling as if we are adding a rubber to the other material, because it is nature is little like a rubber.

(Refer Slide Time: 16:34)



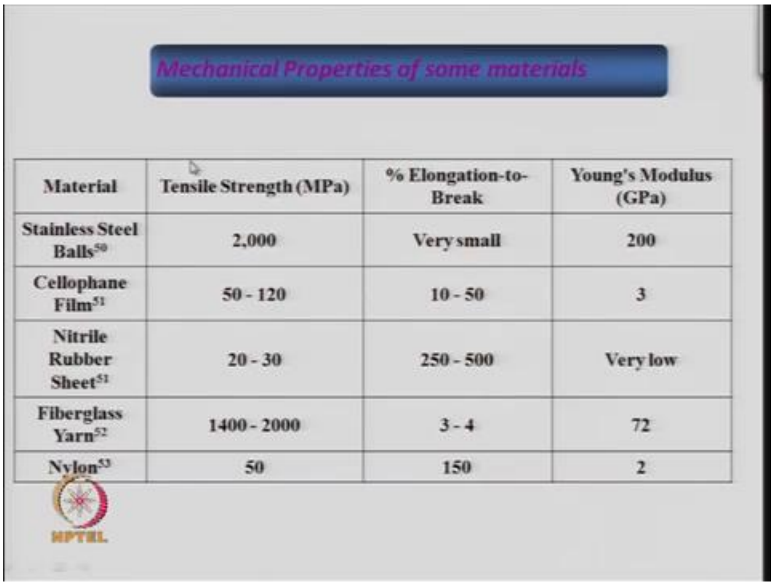
Now, other stress strain curves for plastic, you can see that different type of stress strain curves y axis is in all these cases stress, the x axis in these all cases strain, but you have a different shapes. So, you have a linear region and then there is a non-linear region like this, so this is soft and weak material, because for reasonable stress there is a reasonable strain. In this case it is hard because, for very high stress you have a small strain and so this is a hard and brittle material.

Now, this will be a soft and tough material, because it does not fracture or break until a long elongation are the material can be elongated to a large strain, the strain can be very large before it breaks. Whereas, here the strain is not very large before it breaks, so this is weak material, this is a tough material, because the a strain can take very high values compared to this material.

And this case d is hard as well as strong based on these plots and the quite hard and tough is seen in the plot e, where you have a elastic limit like you have an elastic limit here. And then you have a an elongation that means, without increasing the stress, the material is elongating, so this is elongating till a value, so the maximum elongation or the strain is still this value and then it breaks. So, this value of strain is much larger in e compare to d and so this is hard, because of this it is hard and because of this large strain it is tough.

So, here it is hard because of this slope, but it is not tough, it is strong, because the elongation or the strain value is much smaller in this case compared to this case, here the strain is much larger. So, the material can be extended much larger you can pull the material to a large extend before it breaks, so this is a hard and tough material.

(Refer Slide Time: 19:34)



Material	Tensile Strength (MPa)	% Elongation-to-Break	Young's Modulus (GPa)
Stainless Steel Balls[50]	2,000	Very small	200
Cellophane Film[51]	50 - 120	10 - 50	3
Nitrile Rubber Sheet[51]	20 - 30	250 - 500	Very low
Fiberglass Yarn[52]	1400 - 2000	3 - 4	72
Nylon[53]	50	150	2

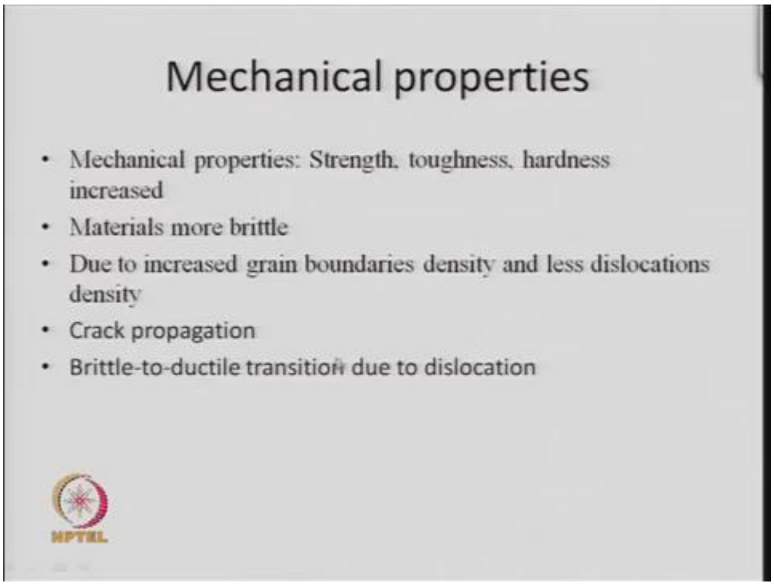
Now, to look at some numbers of the mechanical properties of materials, so if you look at stainless steel balls, they have a tensile strength of around 2000 Mega Pascal's. And their elongation to break that means, how much you can pull them, what is the value of the strain is very small and the young’s modulus is around 200, so these are stainless steel balls. That means, you cannot elongates stainless steel balls very easily, the elongation is very small; all though their strength is very high and their young’s modulus is also quite high.

On the other hand, if you look at a cellophane film, it is strength is very low compare to steel balls, but it is percentage elongation is very high from 10 to 50 and again it is young’s modulus is very low, so it is around 3. The young’s modulus low means ((Refer

Time: 20:42)) this slope will become like this, so the slope being high gives you a very hard character, so here the slope is very high, so young's modulus will be high.

And slope if it is like this, then the young's modulus will be low, so here young's modulus is low and it has more elongation and that is like nitrile rubber and a rubber sheet can be expanded or extended easily and so the elongation to break is much larger. If you take a fiberglass yarn, so like threads made a fiberglass they have a tensile strength, very high tensile strength, but they are brittle they cannot be elongated very much, so they will break if you try to pull them. So, these have very small elongation to break percentage, nylon is reasonable strength around 50, very high elongation to break, but the young's modulus is small.

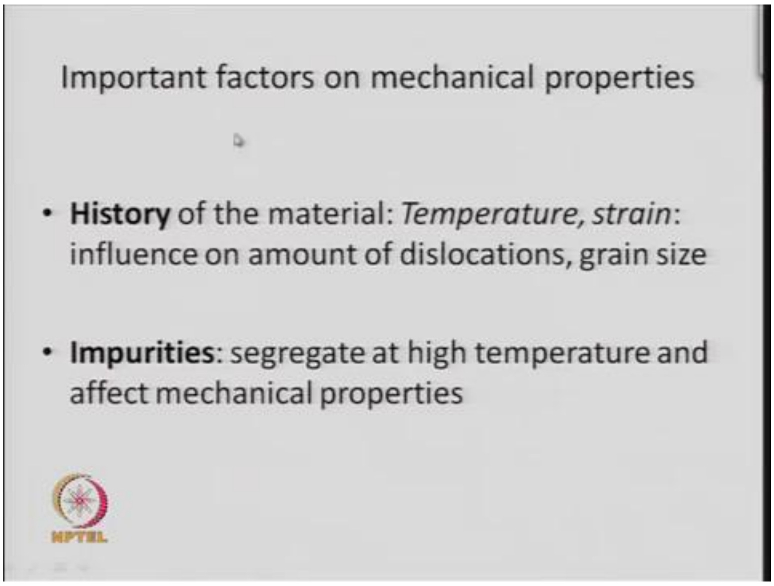
(Refer Slide Time: 21:58)



So, among the mechanical properties that we discussed are strength, toughness, hardness, a more brittle, materials more brittle and this things happen due to increased grain boundaries density and less dislocation density. Then there are other things like crack propagation, how does a crack propagate in a solid in a material and there can be a brittle to ductile transition due to dislocation. So, all these things come under mechanical properties and they change very much as you change the size of the particles.

So, for micron size particles this the heal strength may be something, for the same material with nanosize particles the heal strength may be something else. So, all the properties, all these stress, strain, plots, etcetera will change when you go to from micron size particles to nanosized particles. You will have a change in this stress stain relationships, a change in the slope of a curves, the change in the strain where the fracture will occur will change. So, all these mechanical properties will change as you change the size of the particles, which make that material.

(Refer Slide Time: 23:30)

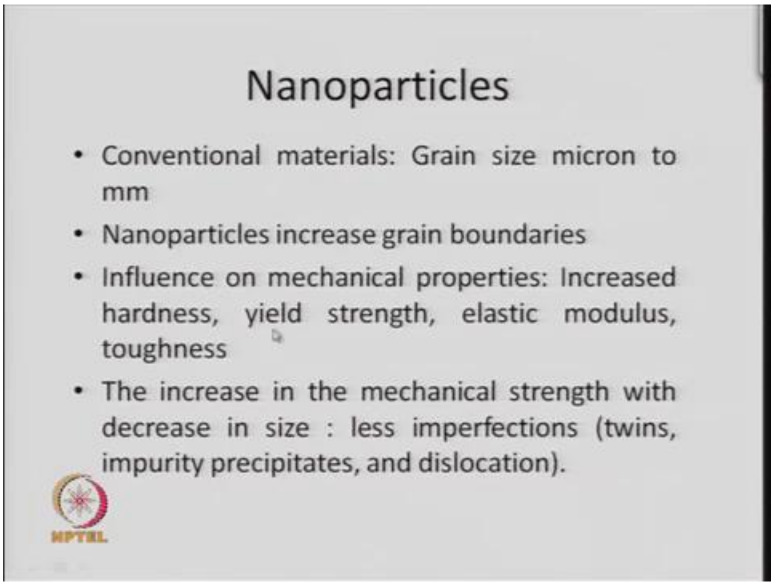


So, other important things which matter a lot when you discuss mechanical properties is the history of the material, how did you made that material at what temperature, did it go recycling, then what is strain was applied and what was it is influence on dislocations and grain size. So, the history of the material is very important, how many times it was heated and cooled and ramped up till what temperature and ramped at what rate, cooled at what rate and then was it kept at some temperature for 10 hours or 24 hours.

All this will affect the grain size, the grain boundaries, the dislocation density and hence, it will affect the material characteristics and especially the mechanical properties of the material. So, the history of the material is very important, apart from that impurities in the material are very important, so you may have small amount of impurities in a material.

And in the same material, if you take another sheet the concentration of impurities may be different, then the two materials will show very different properties. Because, these impurities they segregate at high temperature, when your heating and cooling which is you are working on these materials, these materials undergo several of the cycling. Then these impurities, which are present in these materials, they will segregate at high temperature and will affect the mechanical properties when the material is cooled down to room temperature. So, the history of the material and the impurity is present in the material will affect the mechanical properties of the material very seriously.

(Refer Slide Time: 25:29)



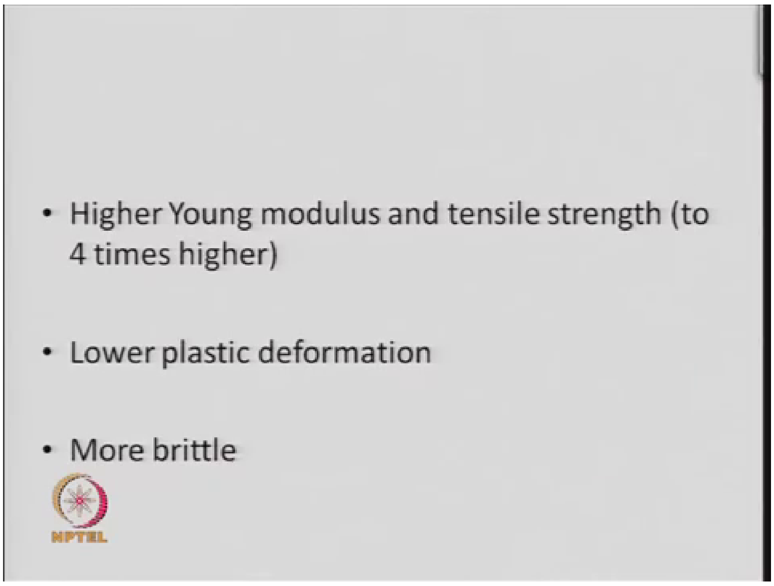
Now, we come to specifically nanoparticles and their mechanical strength, so conventional materials as we have been discussing, so mechanical properties and those mechanical properties depend on their grain size, which are normally in the micron size range. So, in nanoparticles, because the size of the particle is small, hence you will have much more grain boundaries that means, there will be many more interface between small particles, if you have large particles the number of interfaces will be small.

If you have small particles like nanoparticles, it will increase the number of grain boundaries and that will have an influence on the mechanical properties. It will increase the hardness, it will increase the yield strength the elastic modulus and the toughness, all these effects are basically due to the fact that you have increased the grain boundaries, when you have decrease the size of the particles.

Both of them have the same particles, suppose it is iron particles both of them will have a iron particles, but the size of the iron particles in one case may be 5 micron in size, in another case it may be 50 nanometers in size. The two materials will have tremendous difference in mechanical properties, because in one case where number of particles will be much larger, because of the small size that is where you have nanoparticles.

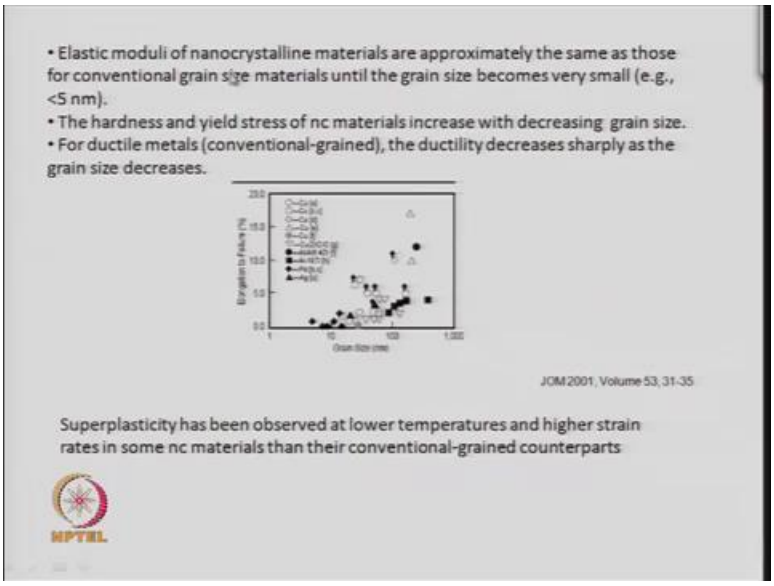
And hence, these small particles will have many, many more interfaces and so the grain boundary density will increase. Now, the increase in the mechanical strength with decrease in size is also due to less imperfections, which are present in the micron size particles, which are due to twins impurity precipitates and dislocation. So, the grain boundary density increases in one factor and the increase in the mechanical strength with size decrease in size is also due to less imperfections in the lattice, that is twins impurity precipitates and dislocation.

(Refer Slide Time: 28:02)



So, when you say a higher stronger mechanical properties, for example you will have much higher young modulus and tensile strength in nanoparticles. Sometimes it may be 4 times higher than the same material, which has got micron sized particles, it will also show lower plastic deformation compare to micron sizes particles and will be more brittle. So, the nanoparticles will be the material made of nanoparticles will be more brittle.

(Refer Slide Time: 28:39)



So, the elastic moduli of nanocrystalline materials are approximately the same as for conventional materials till the grain size becomes very small. So, say you are working with 1 micron or 500 nanometers or 100 nanometers, the change in the mechanical properties are not that significant it is there, but it is not very significant. It becomes very significant when the grain size becomes very small or the particles size becomes very small; example when you go to around size of 5 nanometers are smaller.

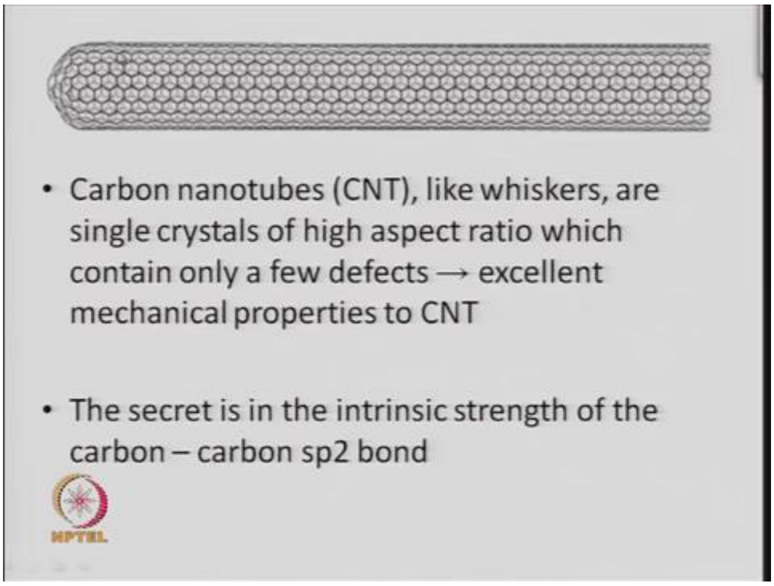
Then there is a the drastic change in the yield strength and other mechanical properties, for example here you can see the elongation to failure, you can see that for grain size here you are around 7 or 8 nanometers and here you are around say 200 nanometers. So, from around 7 nanometers to 200 nanometers, you have this percentage failure and that is much less when you have small particles.

So, for ductile materials the ductility decreases sharply as the grain size decreases, so this is for ductile materials and it has the ductility is very small and it decreases sharply as the size falls below say 20 nanometers, so this value of this elongation failure is very small. So, there is very less failure compared to when you have particles of 200 nanometers and above this a sharp jump and this superplasticity has been observed at lower temperatures, and higher strain rates in some nanocrystalline materials than their conventional grained counterparts. So, at a much lower temperature you can see superplasticity, so basically a when you are going from the elastic region to the plastic region, where the linearity of the stress strain plot changes to a non-linear behavior. That range, the elastic deformation range can be changed with the size of the nanoparticles and superplasticity has been observed at lower temperatures and higher strain rates in nanocrystalline materials.

(Refer Slide Time: 31:32)

So, as the grain size decreases to nanometers, the frequency of dislocation decreases, while grain boundary sliding increases. So, these are two different activities in materials very well known in materials, you have what is called grain boundary sliding and you also have what is call dislocation movement or dislocation activity. And if you are decreasing the grain size, so on the right side you are decreasing grain size and you see that the dislocation activity is decreasing. While the grain boundary sliding is increasing and these things the grain boundary sliding and dislocation movement affects the mechanical properties of these nanocrystalline materials.

(Refer Slide Time: 32:24)



Now, these nanocrystalline materials like carbon nanotubes have been discussed in the literature to large extent, lot of studies have been done on the mechanical properties of carbon nanotubes. Carbon nanotubes are nothing but if you takes single sheets of graphite, so one sheet of graphite is made up of hexagons of carbon and if you roll them, then you can get this a nanotubes.

Of course, some of the hexagons have to become pentagons, where it is closing at the end, so if you have nanotube, to close the end of the nanotube you must have pentagons as well as hexagons. So, basically from a graphite sheets, you can think of getting carbon nanotubes made up of carbon atoms and predominantly a hexagonally arranged carbon atoms.

Now, these carbon nanotubes can be many kinds can be multi walled, they can single walled, they can be double walled, they can have different diameters. And if you can grow them in large quantities like whiskers, then they can and if you can make them with few defects, then they have very good mechanical properties. So, carbon nanotubes of high aspect ratio, that means very long carbon nanotubes with the small diameter, so the aspect ratio is the ratio bit of length of the tube divided by the diameter.

And if you have a higher aspect ratio, then those type of nanotubes are excellent for mechanical properties, they are very good mechanical properties. And carbon nanotubes are among the most well known nanomaterials, which are being use for mechanical a strength additives many many different materials. And this key thing the secret is the carbon-carbon bond, the carbon-carbon bond between carbons, all of them are carbon atoms and each carbon is bounded to other carbon using what is called a sp 2 bond. A sp 2 hybridize bond that means, 1 s orbital and 2 p orbitals hybridize to form sp 2 linkage and these are strong bonds coal and bonds, and that gives you the strength of this material.

(Refer Slide Time: 35:09)

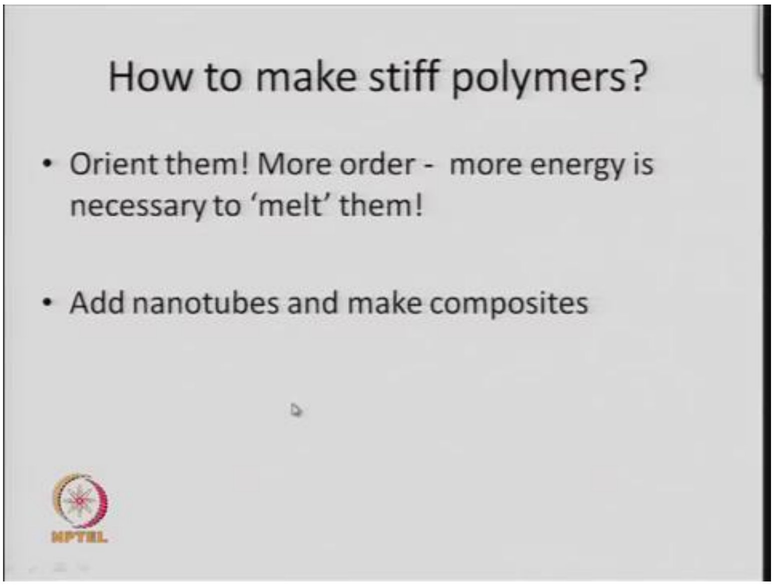
Comparison of Young modulus

Material	Young modulus (GPa)
Rubber	0.1
Al	70
Fe	200
SiC	440
Fe nanoparticles (100 nm)	800
C nanotubes	1000
Diamond	1200

Now, if you compare the young’s modulus, you can tell something about the strength of the materials, so if you see rubber it has a young’s modulus of 0.1 Giga Pascal's. Whereas, if you take aluminum metal and look at it is young’s modulus it is around 70 Giga Pascal's takes something like carbon nanotubes that is 1000 Giga Pascal's. So, it is very strong carbon nanotubes compare to even iron, so all of you know people works with iron, you have iron graders and iron bars etcetera, you can see carbon nanotubes are much stronger than even iron.

So, of course, the toughest or the hardest is diamond which has a young’s modulus of 1200 Giga Pascal's. So, carbon nanotubes come out to be very strong materials, these nano structured materials made up of carbon-carbon bonds, which are s p 2 hybridize give this high strength character of the nanotubes.

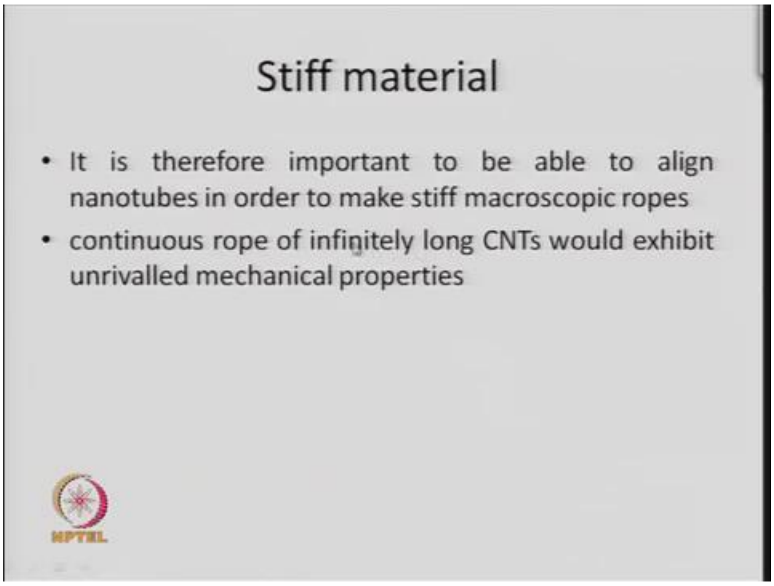
(Refer Slide Time: 36:24)



Now, if you want to make polymers, which are hard or stiff, then you have to orient them that means, arrange the polymers in an array, a parallel to each other, so more order then you need more energy to melt them. So, they that means, you are increasing their hardness, so if you want to make stiff polymers, you orient the polymer fibers and in addition you can add nanotubes like carbon nanotubes and make composites of them.

This way you can make very stiff or hard polymers from soft polymers, so if you have a polymers which are a bundle of fibers, which are pointing in all kinds of different directions; if you take them and try to arrange them by doing something such that, all the fibers lie along one line. So, then it will become ordered and if you want to disorder or break them more energy will be required and so an array of ordered fibers is much stronger than same quantity of disordered fibers. And you can further make them stiffer by adding nanotubes to make nanocomposites.

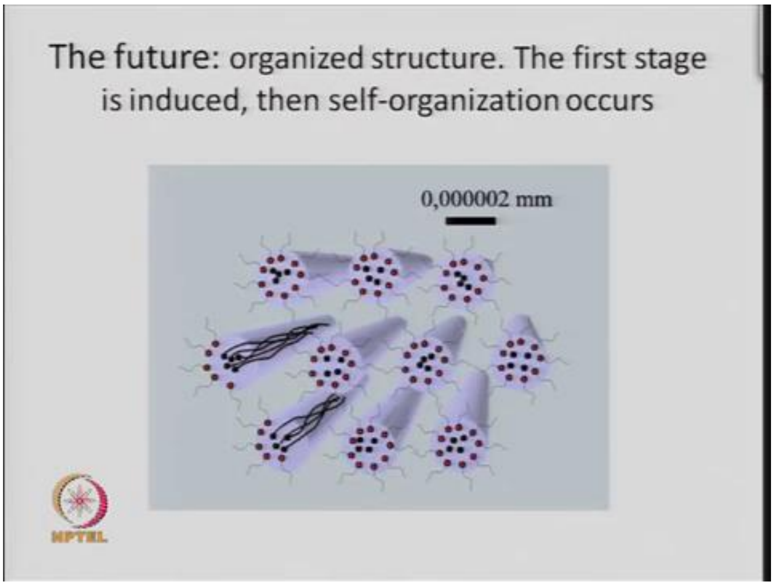
(Refer Slide Time: 37:54)



Now, this we already discussed that how to make a stiff polymer is to orient them to aligned them to make stiff macroscopic ropes, because if you have many fibers sand you aligned them, it will appear like a rope with many threads. And if you can make a continuous rope of infinitely long carbon nanotubes that would have very, very high or very strong mechanical properties, it is even calculated that you can lift people in the space by using elevators, which will be a hell together by carbon nanotubes.

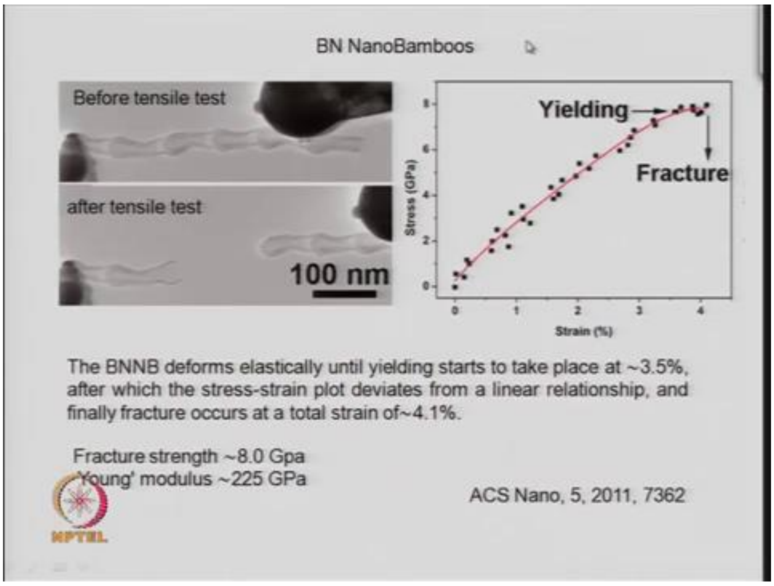
So, if you can make ropes of carbon nanotube, you can make what is called space elevators, which can act like a elevators which can lift you from the earth to somewhere in space. Of course, this is prediction and based on the mechanical properties that you can get for identical diameter of steel wires, if you compare them with carbon nanotubes, which are aligned, then carbon nanotubes ropes will be much stronger than steel ropes or iron ropes.

(Refer Slide Time: 39:19)



So, this is the future is to organized the structure, so you have to make a rope with all these fibrous things organized like this and that will give you the strength of this bundle. So, each of this nano fiber should be aligned in a particular direction such that, it appears like this bundle and then many of this bundles together will give you the real strength or power for the rope to carry very, very heavy loads.

(Refer Slide Time: 39:55)



Now, this has not only been seen in carbon nanotubes, but there are other material for example, boron nitrite, boron nitrite has slight similarities with carbon nanotubes.

Because, boron nitrate also forms hexagonal rings with boron nitrogen alternating in those rings, in carbon based rings which forms graphite, graphene and carbon nanotubes, all the atoms are carbon they form this 6 member rings.

But, in boron nitrite you have similar 6 member rings, but each hexagon has got 3 boron's and 3 nitrogen's alternately placed such that, you get effectively 6 member rings. Now, boron nitrite can also be made into fibers and you can get what people called nano bamboos, so if you have seen a bamboo in a jungle, the bamboo stick looks like this you see it has got a pattern like that, so that is why it is called a nano bamboo .

Because, this diameter is of few nanometers and this length may be 100, 200, 500 nanometers, so this is 100 nanometers, so this may be 500, 600 nanometers. And this diameter may be something like 5 to 10 nanometers; so this is called a nano bamboo and this is boron nitrate based nano bamboo, so together you can call it BNNB. So, BNNB means boron nitrate nano bamboo, it deforms elastically until yields stars to take place at 3.5 percent.

So, if you look at the stress verses strain, so you are increasing the stress, a pressure the force per unit area if you are giving, then you are increasing the strain, so stress by strain till you come to a point you can see here it is no more linear. So, here you start what is called the yield point this is the yield point and then it goes little bit further without any further stress, so without any other further force increase in force there is elongation, so there is strain and that is point is called yield point.

And then after this point it breaks, so it is called fracture point, so the BNNB deforms elastically up till this point it is changing elastically or linearly until at 3.5 percent strain it fractures. So, you can see the final fracture is at 3.5 you have the yield in, the yield point is at 3.5 and the fracture is at 4.1 percent, the fracture strength is 8 G p a. And young’s modulus can be calculated from the slope, stress by strain will give you young’s modulus and the value is 225 Giga Pascal's.

(Refer Slide Time: 43:22)

Now, what are the applications there are many applications, because we are talking about mechanical properties, so mechanical properties wherever you need to give strength, so you can use them either for medical implants or in aerospace or in automobiles all kinds of materials you can apply. So, in medical implants for example, if you need to change a bone, so somebody is bone needs to be replaced, you can use this high strength nano composite materials as bones or implants you can also use these nanocomposites, which are having high strength which are strong and which are long lasting.

That means, they do not get corroded easily by moisture or oxygen, so they can stay in the open environment for a long time rain dust etcetera variation in temperature does not affect them, then those materials are called long lasting materials. And such materials are required for aerospace automotives and electronics depending on the application you have to choose the material. F or example, for biomedical implant you cannot choose any material, the material you put inside the body has to be biocompatible.

So, the material which you are using to make an artificial bone has to be biocompatible it, otherwise the body will reject it. So, the tissue when put a artificial bone at the place where the original bone was the tissues around it will grow, if it does not like this material, then the tissue growth will not take place and the bone will never become part of the body.

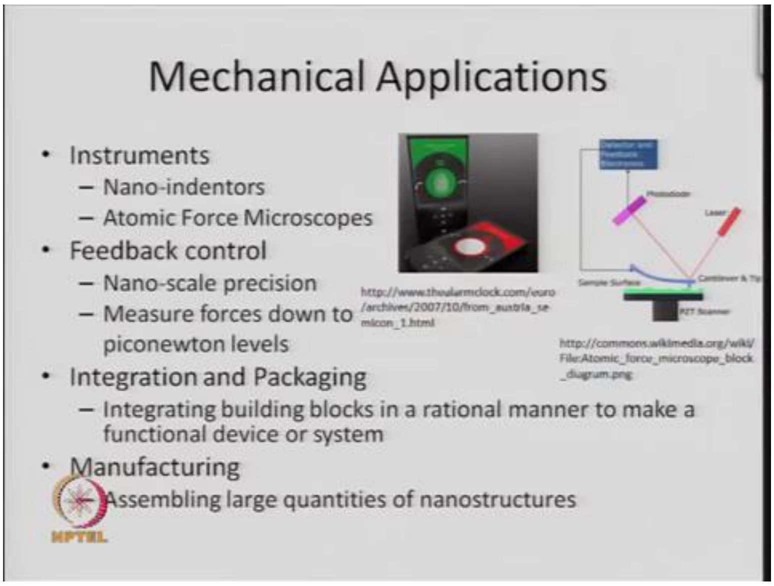
So, depending on the application you have to choose a material, so there are few materials only which are biocompatible and those materials only you can use them in bone implants or as teeth or as plates in the body. But, for automotives and aerospace you have other critical properties, like temperature weather etcetera, which are very important.

So, you can make many nanocomposites based on the applications by taking together both nanocrystalline material and micron sized material. So, many times you marry to properties one coming from the nanocrystalline material, one coming from the bulk material. Bulk material means anything which has got micron sized particles, normal most of the materials have micron sized particles say around a 500 nanometers is 0.5 micron.

So, anything which is 0.5 micron, 1 micron, 2 micron, 5 micron, these are all a bulk materials have this kind of size of particles. And if you want to make a nano composite you make a composite of this bulk material and add some nanoparticles to it, which are the nanoparticles themselves may be the size of the 20 nanometers, preferably below 100 nanometers, they can be anywhere between 5 to 100 nanometers.

And then you mix with the micron size particles to make a cheap and viable alternative, if you use entirely nanomaterial, then the cost will become very high, because to generate or produce nanomaterials for making a thigh bone you need lot of nanomaterial. Instead if you make a composite of having a mixture of nano and micron particles, then you can also gain in strength and you can also lower the cost of production of that bone, because you need less amount of nanomaterials. So, composites that way have that positive point that they are more viable even when you are using nanomaterials, making use of pure nanomaterials becomes a very expensive choice.

(Refer Slide Time: 47:58)

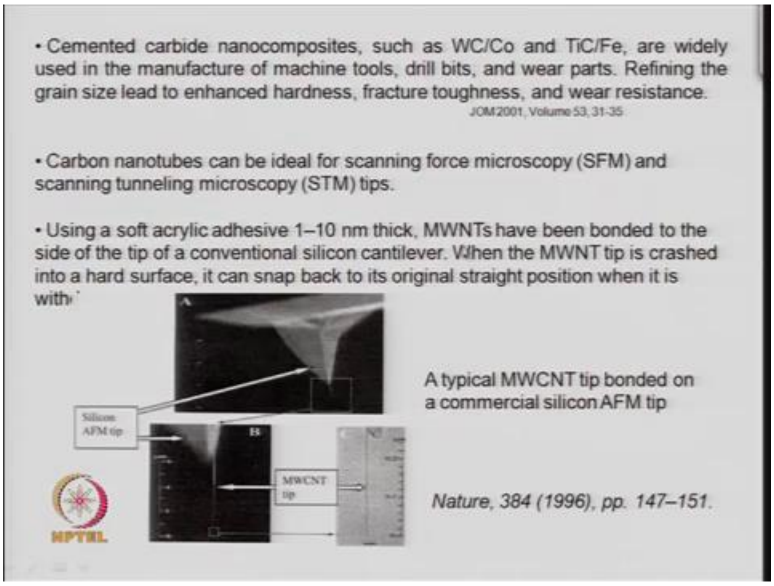


So, typical mechanical applications, here what we look that applications in biomedical a like bones implants or like in automobile industry, electronics, aerospace etcetera. And also for mechanical applications where you need a hard material for example, as nano-indenters, so nano-indenters are used in atomic force microscope as the tip. So, if you have a AFM tip, so this is a cantilever and in the atomic force microscope you have a cantilever, which has a tip.

And this material which forms the tip has to be very hard, because it strikes the surface which you are trying to study, so when it strikes if this cantilever tip is not hard, then it will break. So, you need very tough cantilever tips to act as nano-indenters and to be used in atomic force microscope. Of course, you have other things you using atomic force microscopy with these nanosized indenters, which are very hard and with the proper feedback control, you can major all these forces on the surface of this material using this cantilever tips.

So, this is used at two major forces down to piconewton levels, so very small force being generated on top of the surface can be measured using these atomic force microscopes, which use cantilever tips, which are hard materials; and can measure the forces on top of the surface. Then nanomaterials can be also use for integration and packaging, you can make the building blocks and integrate them to form a functional device or system. Of course, to manufacture or assemble large quantities of nanostructures is a challenge and it has to be done in a very, very competitive environment, there is lot of research is how to assemble large quantities of nanostructures.

(Refer Slide Time: 50:33)



So, these some examples of these cantilever tips, so I showed this is a cantilever, ((Refer Time: 50:43)) this is the surface, and this is the cantilever tip. Typically in a AFM the laser light is guided on the back side of the cantilever, which is deflected on to a photo diode and any change in the position of the cantilever tip, can be determined by the deviation of the reflected beam of the laser.

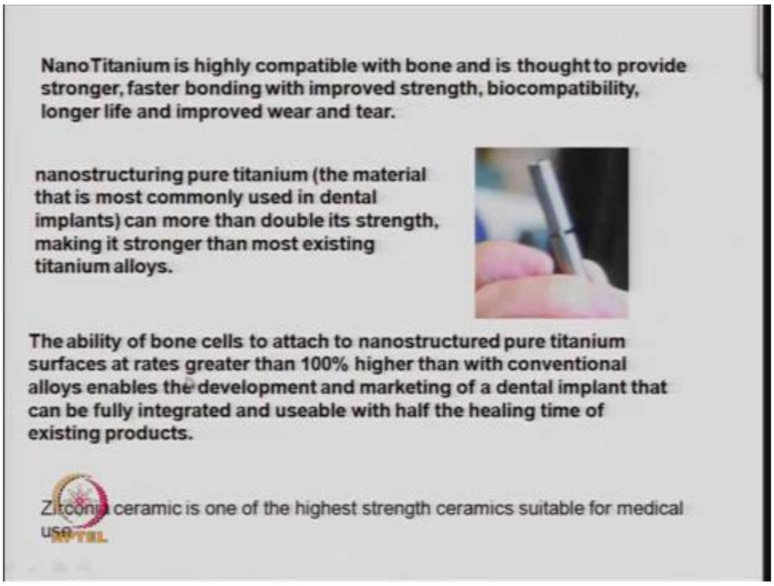
So, the photo diode majors the deflection in the reflected beam coming from the laser and from that it can calculate accurately, the force between the cantilever tip and the surface and that is in piconewtons. And so this is a SEM picture of a cantilever tip, this is at the bottom of the tip, if you can see there is one thing, wire kind of thing and that is one multi walled carbon nanotube, which is bounded to the AFM tip, this AFM tip is the cantilever and this AFM tip is made of silicon.

And at the bottom of the silicon you have one carbon nanotube and with that carbon nanotube, which you have attached using a soft acrylic adhesive, you can then scan the surface using the cantilever. So, when the multi wall nanotube tip is heating the hard surface, it can snap back to it is original straight position when it is pulled back. So, the multi walled carbon nanotube gives it is the flexibility to touch even a hard surface, because a bounce is back from that hard surface.

So, many such nanocomposites have made for example, tungsten carbide nano composite with cobalt titanium carbide with the iron are widely used in the manufacture of machine tools drill bits. And wear parts, so these kind of combinations of very hard materials and nanomaterials are widely being used for forming tool bits and drill bits etcetera. In the manufacturing industry which leads to enhanced hardness, controlling the grain size of one of the components of this nano composite, you can enhance the hardness the fracture toughness and wear resistance.

And carbon nanotubes as we discussed are ideal case for being used as flexible tips on top of a standard silicon tip, it can be joined using an adhesive. And since it will be flexible, it can snap back to it is original form after heating the hard surface. So, these are some of the things that one can do with carbon nanotubes and with nanocomposites.

(Refer Slide Time: 54:05)



Another thing is nanotitanium, nanotitanium is very important in the medical industry, because titanium is biocompatible and so nanotitanium, nanocrystalline titanium is being used in many dental implants etcetera. It is highly compatible with bone and is thought to provide stronger, faster bonding with improved strength biocompatibility longer life and wear and tear. So, it is double the strength, if you take nanostructure titanium it is double the strength compare to normal titanium alloys used in dental implants. And the bone cells attach to the pure titanium surfaces at rates greater than 100 percent, so nano titanium or zirconia base ceramic, there are many such nanocrystalline ceramics which are of use in the medical industry. So, with that we come to an end to this lecture on mechanical properties and we have the last lecture in which we will do the conclusions of this course.

Thank you very much.