Building Materials and Construction
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Module - 11
Lecture - 1
Metals: Fundamentals

So far we have looked into the construction materials mainly the ceramic construction materials. For example: there is cement or the products that we produce from cements. So, cement is a ceramic material chemically combined. And we have also looked into brick various kinds of bricks. There are all ceramic materials. Now, in the module 11, we will look into metals. And these are another class of materials, which are most commonly used.

In construction you know you can hardly think of any construction, where metal or alloys. Most commonly rather steel is not used. So, we shall see metals in module 11 and in this first lecture of module 11.

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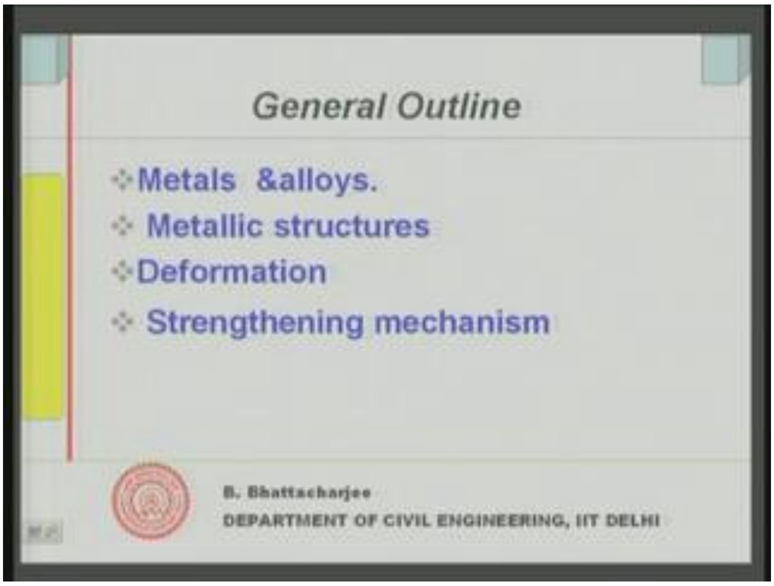

First, we will define metals and alloys. We will try to recall all the basics that we have learnt possibly. In our earlier studies about metals and alloys, then we will look into structures of metals. We shall look into deformation of metals how the micro structure, you know from the concept from the point of view of micro-structure. And then we look into basically, what are the strengthening mechanisms. And discuss about this 1 or 2 of this mechanism today and rest of the rest of them sometime later on right.

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So what is metal? you know in chemistry a metal. It derives its name from the word Metallon is an element that readily loses electrons to form positive ions cations and has a metallic bond between metal atoms. He must be remembering the basic chemistry. Then, there are certain elements which has got electrons in their outer shell; which they can lose readily. So these elements are the ones metals and once they lose their electrons. They become cation and they have.

They form what is known as metallic bond between the metal atoms. We know that metal forms ionic bonds with nonmetals. For example: you know sodium chloride. Now, sodium is a metal forms sodium chloride with the non-metal chloride. It forms ionic bonds. And metal they are described as a lattice of positive ions surrounded by a cloud of delocalized electrons. In case of in chemistry we have learnt. Then there are electrovalent electro you know electrovalent compounds.

There are covalent compounds or electrovalent bonds covalent bond. The 1 of the classes of bond is a metallic bond. And this 1 you have a lattice of positively charged ions surrounded by cloud of delocalized electrons. So, metallic bond is characterized by this. We will look into this little bit more. Now, if you see in the you know periodic table. The metals are 1 of the 3 groups of elements. As distinguished by their ionization and bonding properties along with metalloids and nonmetals metals are metalloids are nothing but semi-metals and nonmetals. So they are the 3 first 3 groups of elements distinguished by their ionization and bonding properties along, with metalloids and nonmetals right.

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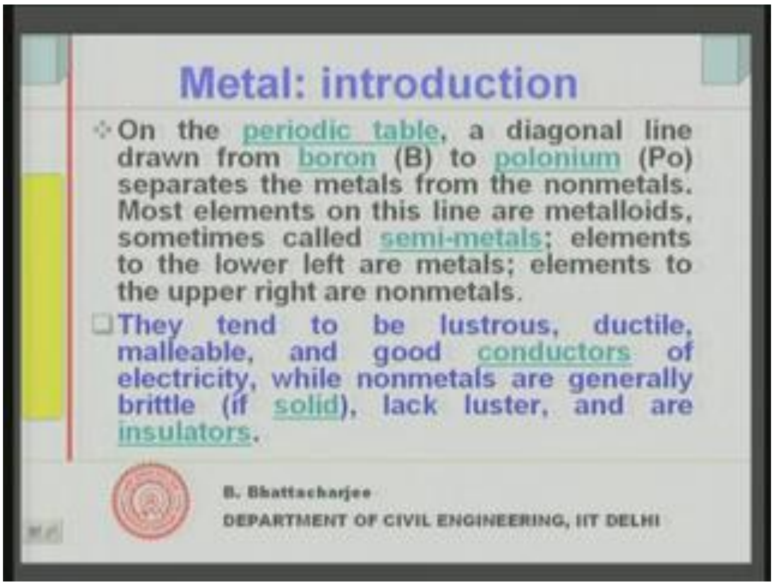

If we look at the periodic table, if you draw a diagonal line between boron and polonium you know if I may say, so somewhere, in the north-west of the periodic table leaving first 2 groups out third 1 will be boron. If you remember, it will be hydrogen helium. And the first group then you will have lithium beryllium; beryllium and then boron. So, from boron to polonium, if you draw a diagonal it separates the metals from nonmetals right; most elements on this line are called metalloids you know they are semi-metals.

Basically elements to the lower left are metals and elements to the upper right are nonmetals that is the lower diagonal right. Or basically m- elements are all metals. And upper diagonal elements are nonmetals. So, that is what we can define what metals are. Now what is important for us are their properties. They tend to be lustrous ductile and malleable. We have some made some discussion about what is ductility. But we will also define them today again if possible then they are malleable.

They are good conductors of electricity also heat while nonmetals are generally brittle, you know they exhibit what is known as sudden failure again; we will discuss this of course we are talking only of nonmetal solid nonmetal. And they are luck luster and are insulators usually they are insulators, for metals and nonmetals. This distinguish distinctions are something like this.

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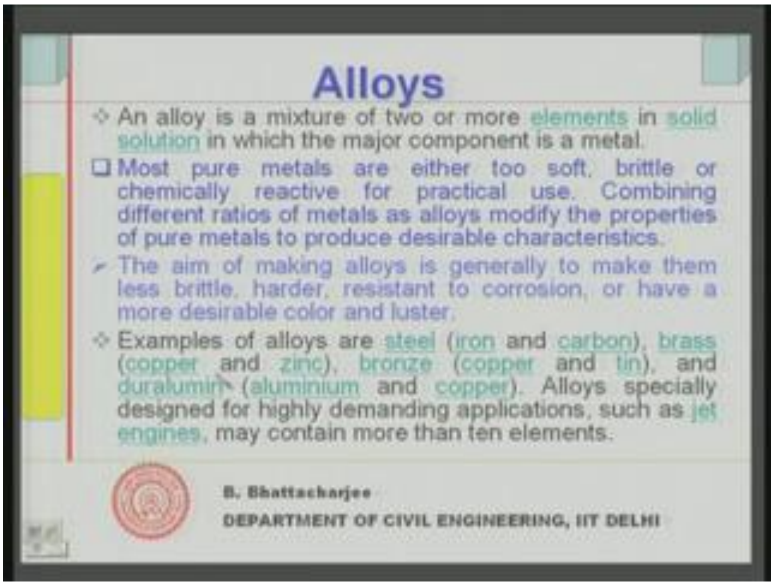

Alloys are mixture of 2 or more elements in solid solution. In which the major component is a metal right. For example we will have some example, I mean you can have metal and nonmetal as well or semi-metal as well. In alloys but one major component must be metals. So, they form solid solutions and those are alloys most pure metals are either too soft brittle. Or chemically reactive for practical use you know this is important most of the metals are brittle soft or most important is chemically reactive for practical use.

So therefore, we combine different ratios of the metals as alloy to modify their properties and to produce desirable characteristics. So that is what we do and that is what mostly we use alloys right; the aim of making alloy is generally to make them less brittle. They will be ductile if we use pure metal rarely, we use pure metal. And most pure metals are not stable themselves most of the metals leaving possibly things like gold or silver.

But, even then gold is usually not used alone; they are used together with something. And of course, you know all other metals, we do not use them pure form very rarely use them pure form. So, by alloying we make them less brittle make them harder resistance to corrosion or have a more desirable color and luster. So, that is the idea that is what we do while examples of alloys are obviously steel, which is an alloy of iron and carbon.

We shall discuss more about this sometime later on brass and copper brass and copper and zinc brass is you know, alloy of copper and zinc bronze is copper and tin. And duralumin used in aircraft is aluminum and copper alloys specially, designed for highly demanding applications such as jet engines may contain more than 10 elements. So, they are specialized alloys in civil engineering course most commonly used is steel. And we have more discussion on steel obviously some uses of brass is also very much there.

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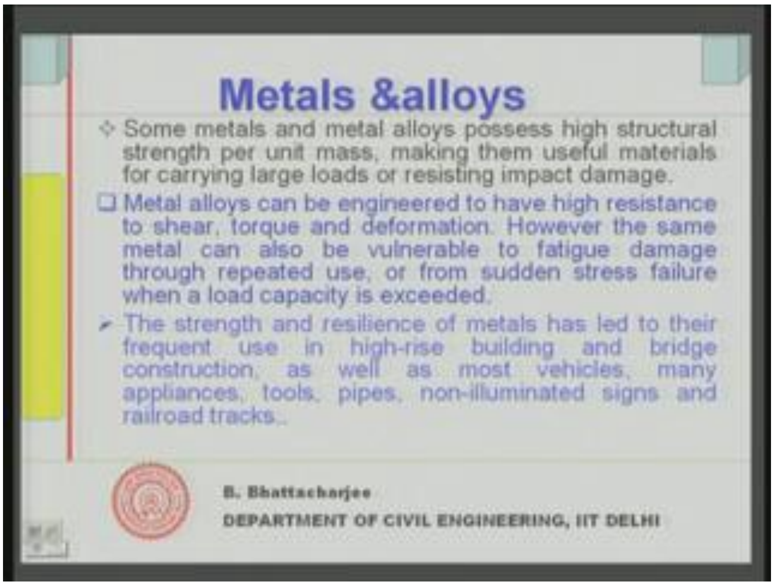

Many metals actually possess very high strength, structural strength you know many metals actually many of them possess high structural strength, for unit mass. This is an important issue strength the weight ratio, strength to mass ratio. And they are useful for carrying large loads and resisting impact damage etcetera. So, since you know they have high strength. So, they can resist take very high load. And they can resist impact damage metal alloys can be engineered to have high resistance to shear torque and deformation.

However, the same metal can also be vulnerable to fatigue; you know fatigue of course, you have some properties not necessarily all properties, some properties you can have high properties high values shared resistance shared torque and deformation. But, fatigue properties could be low right. And that means; under repeated load which you have mentioned a little bit about concrete. So, under repeated load when they use them; they can fail at much lower load or impact load carrying capacity maybe low depending upon the situation strength and resilience of metal as led to their frequent use in high rise building.

So, that is what is most important you know most important is use of this ones in high rise buildings commonly they have been used in high-rise buildings they have been used in high-rise buildings and most commonly they have been used in high-rise buildings and bridge construction. Now, if let us just give an example: if you see the history of let us say tall buildings. Now, empire state building in USA was built in 99 and 33. And this was built in steel.

So use of metals is much before concrete as actually come use of metal as started in very high-rise building you 1 could not have built many you know many tall buildings in concrete. All long span bridges invariably even today, very long span bridges are steel bridges. The main important here is. This material unlike our concrete or similar ceramic materials brittle ceramic materials they are weak in tension. So, unlike them steel or the metals they are also strong in tension.

So where you have large coming in and corresponding tension strength metal was the only solution even today, it is a most innovative, it is a solution. In, fact concrete you just cannot use alone you always used either with steel enforcement or with through steel once in a while of course, with the plastics, but by and large it is the metal again. So therefore, bridges civil engineering cannot be think of 1 cannot think of civil engineering construction without metals namely: mainly of course, the steel right. So therefore, they find their use everywhere you can see also in rails and vehicles etcetera, pipes and so on.

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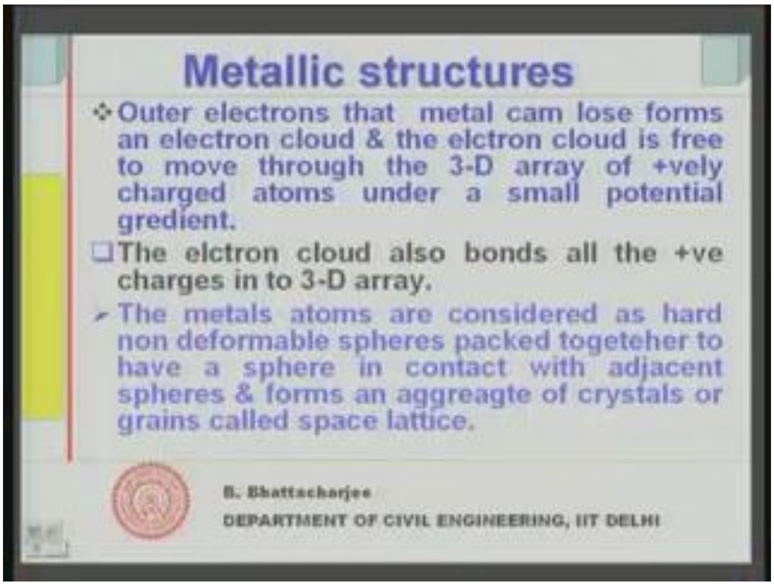

So let us see, what are the structures how does the structure of the metal look micro-structure of the metal we are talking of micro and the micro-structure of the metal how does it looks. And we have -talked about metallic bond, because we said the metal. They form metallic bonds. Now, what is it basically you see they have their outer electrons they can lose very easily right. And this outer electron can form electron they can form electron cloud, they can form electron cloud. And this electron cloud is free to move through a 3 dimensional array of positively charged atoms under a small potential gradient and that is why they are good conductor of electricity.

So their structure is basically they have the positively charged cations and electron clouds, which are actually free to move. In this in the 3 dimensional array of this positively charged atoms or cations and that is what is the basic metal structure. This electron cloud also ensures the bond between these positive charges in the 3D array. So, bond between this 3D array is also ensured by this electron cloud, because they are positively charged. And this negatively charged cloud to the bonds just positively charged cations and. So let us see what are the structure how does the structure of the metal look micro-structure of the metal, we are talking of micro and the micro-structure of the metal.

The metal atoms are considered as hard non deformable spheres packed together to have a sphere in each sphere is in contact with another sphere. So, sphere in contact with adjacent spheres and forms an aggregate; aggregate of crystals or grains called space lattice. So, metals basically you know they are considered as hard non deformable spheres. These cations are hard non deformable spheres and they are packed together. This 1 sphere is touching with the other 1. And you know each sphere is in touch, in contact with the adjacent spheres. And forms an aggregate or crystals or we call them grains.

So, this spheres put together the forms a crystal or a grain and this grain we call as space lattice. So, in a space lattice they form, you will have you know several I mean; this spheres which are basically nothing but cations which are closely packed. And they are touching with each other and this 1's forms an aggregate of crystals a set of crystals or grains and both things we will call as space lattice right. So, that is what is a metallic structures?

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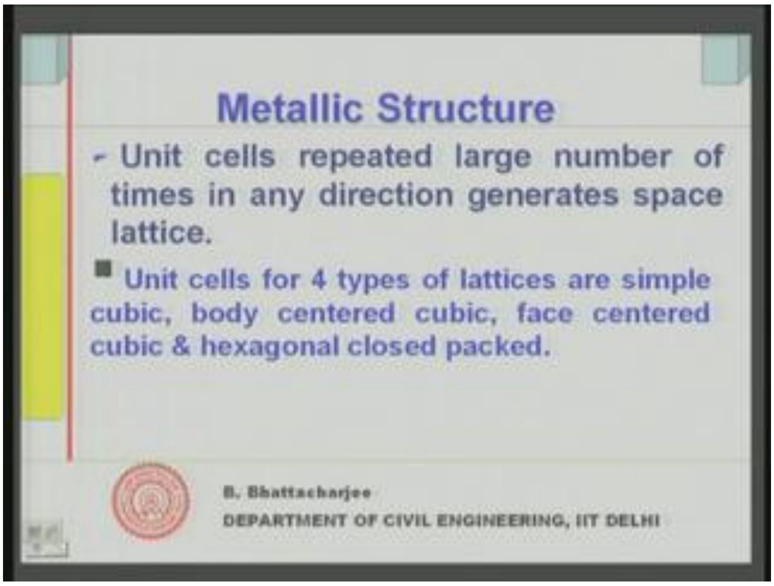

We take unit cells, which are repeated large number of times unit cells are nothing but the arrangement of those right. And these are repeated large number of times, in any direction to generate the space lattice. So, the space lattice actually as number of unit cells and each unit cell have got atoms spherical, you know adjacent to each other touching each other right.

There are 4 types of lattice that has been identified of course; the first 1 is not much is not impractical metal it is never practically, not seen not much. This 4 types are simple cubic, body centered cubic, face centered cubic, hexagonal closed packed right. So, this is BCC, FCC and HCP. These are the 3 main types of structures, which we will see them a little bit more in details, in the next 1.

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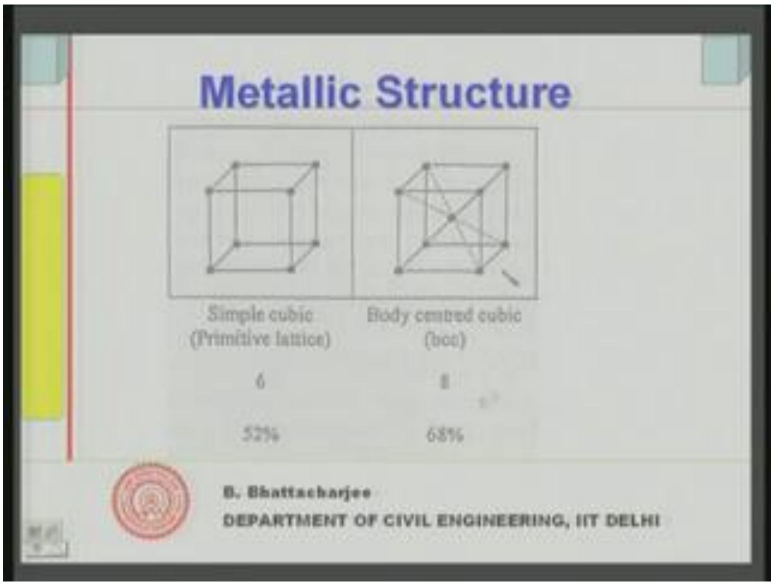

So, if you follow this metallic structure a simple cubic primitive lattice would look like this. In this 1 you have center of the spheres located, you know this is the unit cell; which will be repeated several times to form the space lattice. As we have said earlier. And simple cubic type of simple cubic type of unit cell will have 8 atoms, at 8 corners. They will have 8 atoms at 8 corners right. And 1 can very easily see, you know this is a center of those centers of those atoms. And because each atom is touching with each other and this is the length of the cube.

Now, since there are 8 atoms you know this one-eighth of each of the atom will be there in unit cell. So, one-eighth of 8 such cell that means; you will have within the cell you will have, total volume of a single atom and this cube is of course size would be equals to you can find out its size. And the size would be equals to you know one can find out what is the volume of this unit cube correspondingly. And this length will be equals to the diameter or 2R or if you calculate out the space or packing density. It would turn out be 52 percent, It is basically quite lot of, in the system.

So, in this 1 there are 1 this is body centered cubic you have 1 center of one of the atom is here. And there are 8 more atoms and if you similarly, calculate out there packing density will be 68 percent is the atom and 32 percent is a space in this. So, this is what is this is what is simple cubic and body centered cubic.

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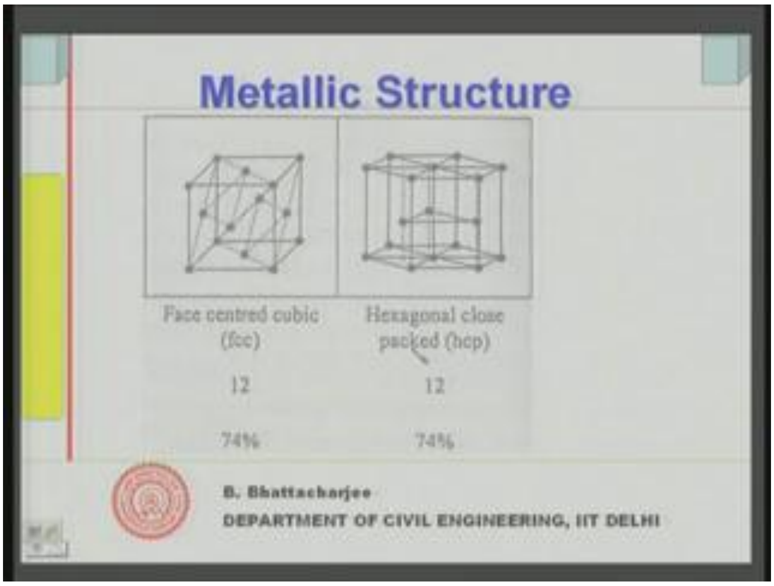

Now, the other 1's are face centered cubic and hexagonal closed packed. Now, in face centered cubic you have again 8 on the 8 corner and on each center of you know on each face. They are 6 surfaces and on the center each surface center of 1 of the atoms lie. So, 1 2 3 4 5 and 6;, so center of the 6 atom or spheres lie on to the surfaces 6 surfaces. And in corners lies another 8 surfaces. And if you calculate out, which you shall do Just try to find out. If you calculate out its packing density will turn out to be 74 percent.

Similarly, hexagonal closed packed system something like this it as got, as you can see you have got in hexagon at the base you have got 4 plus 3 7 center of 7 atoms lies here, 3 lies there. And again seven lies up anyone can calculate out, what will be the packing density of any 1 of the system.

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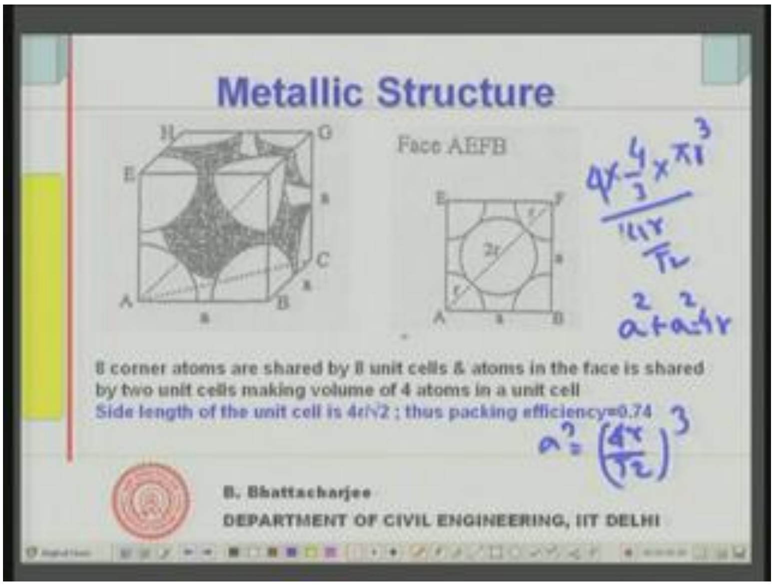

We just try to calculate for 1 of them for example if you calculate out for. If we calculate out for the face centered cube you can see that there are 8 corner atoms. And shared by 8 units. For example, this corner atom it will be shared in 8 such units, because these are the replicates you know there is 8 such units. So, one-eighth is in this cube and in 8 such units. We will have one-eighth of each of them. So, one-eighth of this 1, so there are 8 such units and it is shared each of this atom is shared in atom is shared in 8 unit cells. So, one-eighth volume is here and you have got at the faces 6 faces. There are 6 such 6 faces center of 6 atoms like. So, therefore, half of the volume of you knows 6 atoms.

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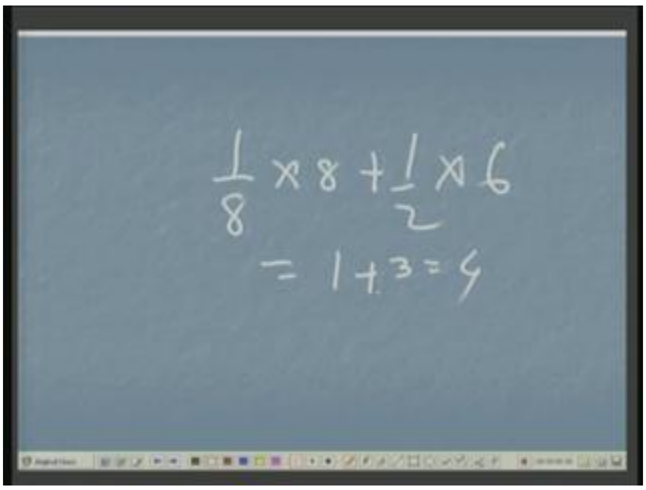

So, total number of atoms would be one-eighth into 8 plus half into 6 and that would make it 1 plus 3 equals to 4. So the volume occupied volume of the atoms in 1 unit cell will be equals to 4 atoms. And what is the side length of the unit cell this we can find out. Because, if I take any one of this face. Let us say this ABEF, face if I take. This is the face which has got a you know is a sphere which has got a center on to the face itself. So, it will be something like this and. This one-eighth out of which 4 this 1's, this 1 they would like this.

So, therefore, this diagonal 2R and if the diagonal is equals to 2R, then I can find out A square plus A square will be equals to 2R square. It will be equals to 2R plus you know 4R. So, it will be equals to 4R. So, from this you can find out A will be given as 4R divided by root 2. And then since you know A volume is nothing but A cube. So, A cube is equals 4R by root 2 whole thing cube. That is the volume and there are 4 atoms which each atom actually will be 4 by 3 into phi, you know or phi R cube into 4.

So, this divided by 4R root 2 cube, this equals to 0.74, you know this equals to 0.74 as we are finding here. So, therefore, 1 can find out 1 can find out the packing density of such a system. And for all other systems 1 can find out. So, we are not really interested in details of this packing density. But, just as an example it was thought that we will give you this idea. So, this seems to be out of the 4 types simple cubic seems to be having maximum. The least voids are with this and HCP least are the most closely packed systems are these 2 ok. So, metals are packed in this manner right.

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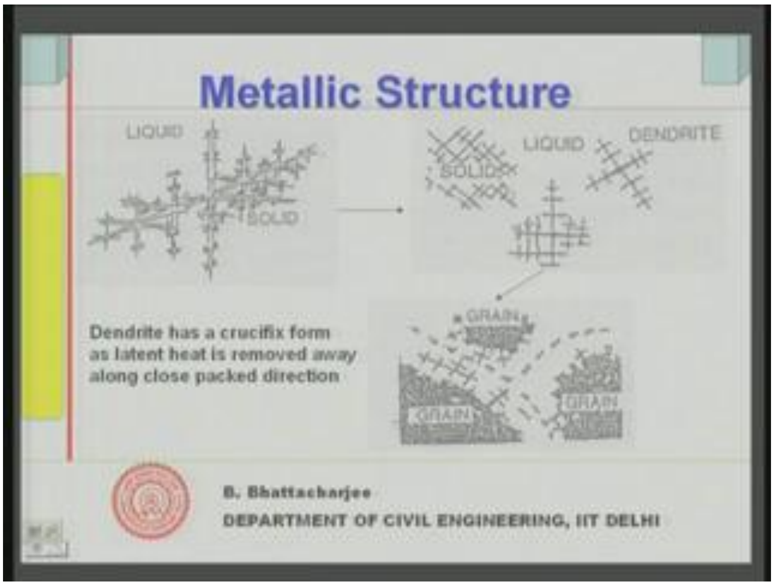

Now, how does this structure forms, we can see this. So, there are packed in this manner in their solid structure. Now, initially metals are always formed from the liquid structure. Initially they will have you know there will be molten state when we are forming them and when they form actually they form into this kind of a structure from liquid to solid formation at certain locations. This side of style type of structures will be formed. This structures, we call as dendrites structures from liquid to solid formation when it takes place.

Thus structure dendrites structure formation takes place and this dendrites have crucifix form crucifix like form. This is because; latent heat is removed away along the closed packs direction because of the closed. Closely packed direction along the closed packed direction latent heat is removed. They tend to form this form of a crucifix structure right. Followed from this 1 such dendrites are formed. This dendrites will be formed at several places you know, so you will have several centers at which will take place. And you will have dendrites here dendrites there and dendrites there.

So, when in molten state, because most metals will be formed from a molten state to a you knows solid form. So, in this first step what happens in the liquid as we cool it down the dendrite formation will take place. And this takes place in several places. And followed from that is a followed from that is grains formation, because when this dendrites are formed. And more dendrites are formed, because solidification takes place solid form, because I said there is 1 solidification takes place.

First it takes, in the shape of this dendrites and as further and further more of them is formed. They actually form into solid grains and there will be dendrites and solid grains and many places right. So, that is would be the next third stage and then as cooling takes place, it results in crystalline solid phase comprising of close packed grains differing in orientation with discontinuity between, adjacent grains at boundary.

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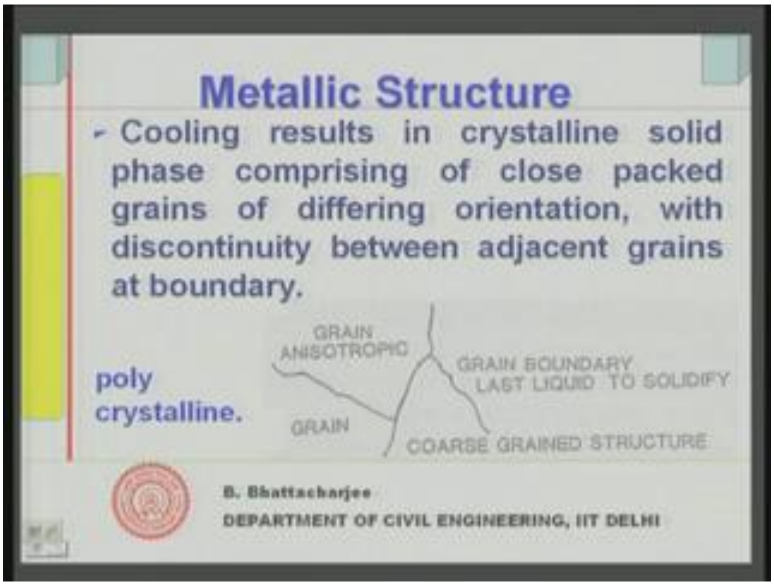

Let us see the figure this will give us idea. So, when such grains are forming solid grains would form. And several such grains would form and this results in crystalline phase, which will have closed packed grains formation. But, this grains formation since, it as started at different places and forming in different way. There can be different differing orientation and different, you know different orientation and different crystalline orientation is possible. And then there would be when they join of fully.

There will be discontinuity between these adjacent grains at the boundary. So, at the boundary there could be discontinuity, because from somewhere this, you know dendrites would have formed. And, then the solid grain formation started. It continues to grow and it will have a given crystal orientation some other places, you will have different crystal orientation and this forms. So there will be some kind of grain boundary right within a grain boundary I have 1 type of crystalline structure.

In another kind of grain boundary, I will have another kind of crystalline structure. And all this makes it a poly-crystalline structure. So, all this makes a poly-crystalline structure. So, metal as actually crystalline structure, which are formed because of the closely space, I mean closely packed cations, which are in contact with each other they form, you know form the space lattice after that you know rather unit cells.

This unit cell repeated from the space lattice or grain or crystalline structures. And this crystal structures they can be different in the metal and it is therefore, poly-crystalline. So, metal is therefore, poly-crystalline right.

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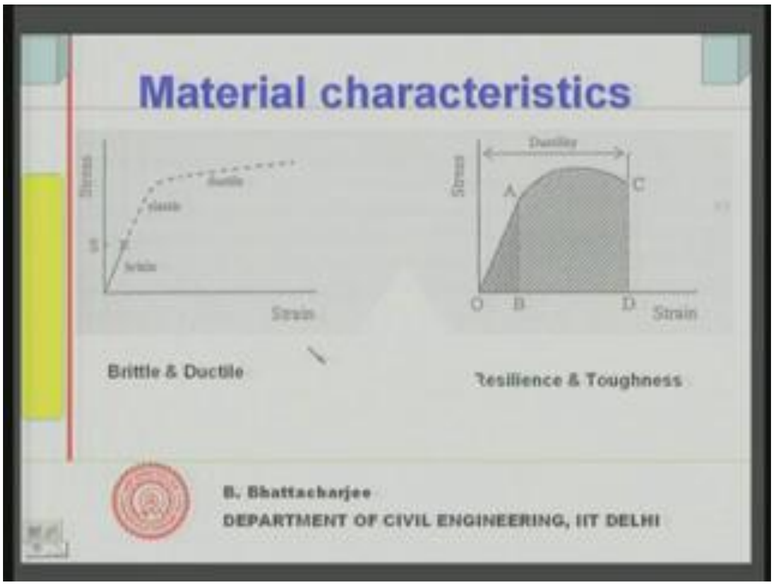

Now, we talked of properties of the metal. So, just let us define or recall we might have mentioned these properties, but let us recall again. The most important of course, the mechanical properties we are looking at and some of those mechanical properties.

Let us define we might have already stated sometime, in connection with the concrete and let us relocate some of them. So, usually if you remember now, we said that nonmetals are usually brittle. If you recall the curve of concrete or you know this is a small portion. But, mostly brittle metal pure brittle metal will do, will have a stress and curve like this right. Then but this is elastic. If you recall we discussed about this sometime, but a ductile material will have lot of deformation lot of deformation beyond this.

You know, it will show a lot of deformation beyond this point, what you can call point or something beyond this you will have lot of ductility. So, brittle elastic and ductile materials that we have understood, but I think we talked about elastic material which is you know if you release this stress. It will come back to its original shape brittle materials will simple fail somewhere here. So usually, the nonmetallic materials are of this kind but metallic material many of them could show this sort of properties.

So you have a stress curve of course, some portion will have elastic beyond that you have you have a portion where. The ultimate strength is somewhere here, but it reaches finally it fails at large strain. So this defines the ductility this line defines the ductility that is the deformation capacity. This area under this curve up to this AOB we define it as resilience is the energy it can absorb till elastic limit.

This is an important property particularly important for similar places where, it would absorb a lot of energy. And then when you release the stress, it can it can come back to its original condition without any kind of permanent deformation. So, that is resilience property and toughness is defined total area under this curve toughness is defined as area under this curve stressing curve is the energy that it can actually withstand before failure total energy it can absorb strain energy it can absorb before failure.

So what you have seen ductility of course, many metals are elastic up to certain limit. And then of course, it is ductile and then it as got high toughness and some amount of resistance you know resilience also is there. So, these are the properties are important and we will look into this.

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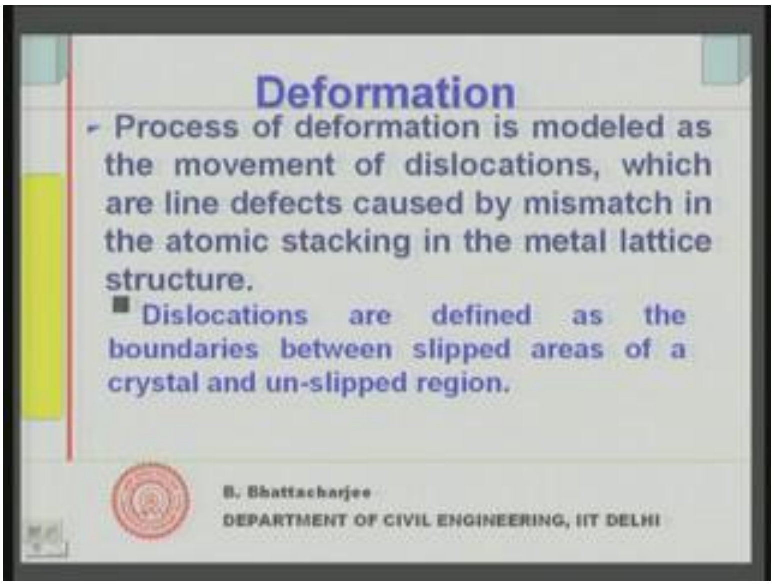

Now all this property, when you are looking at characteristics it to deformation. And we have seen deformations of nonmetallic materials deformation of nonmetallic materials. Now let us, see deformation what is the micro-structure how was the micro-structure related to the deformation of metallic materials.

Process of deformation is modeled as a movement of dislocations is modeled as the movement of dislocations, which are actually line defects caused by mismatch in the atomic stacking. In the metal lattice structure, this is basically line defects and caused by mismatch in the atomic stacking, in the metal lattice structure some examples. We will try to see dislocations are basically deformation is nothing but movements of dislocations.

And these are some sort of line defects and these are caused by mismatch of the atomic stacking, in the metal lattice structure. So dislocations are defined as the boundaries between slipped areas of a crystal and un-slipped region. We will have some diagram to explain this better. So, process of deformation is modeled as movement of dislocations.

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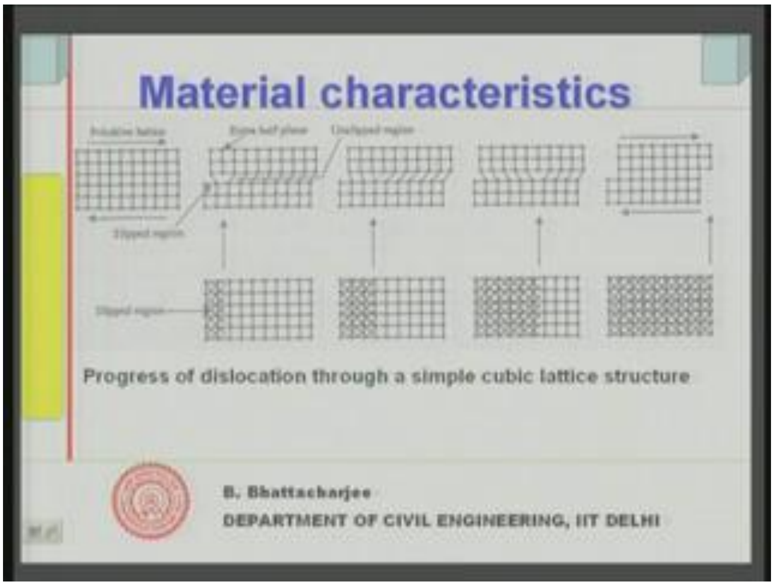

Let us see this diagram this will make it clear-progress of dislocation through a simple cubic lattice structure. Now is it this is we have taken a primitive lattice that is just simple cubic although as we said that rarely this is not a common structure that is seen in metals. But, for a stimulation purpose this is pretty easy to explain. So, you have region here, you know this is a stress around a region. And you have slipped region here and this portion if you see it is un-slipped. So, these are your these are your attempts these are your attempts.

So this 1 instead of like this being like this it has become something like this and this is what is a slipped region, the stresses around a slipped region and the slipped region then further moved slipped region then further moved. These are un-slipped region and as you can see the slipped region as increased un-slipped region is here and this slipped region as it further increase. Finally it gives raise to the deformation, so that is what it is the progress of dislocation through a cubic lattice is shown.

This is the stress corresponding to this. Now, this is the stress region since the slipped have moved there this is the stress region. Now, the whole thing is something like this, so this shows the movement of dislocation.

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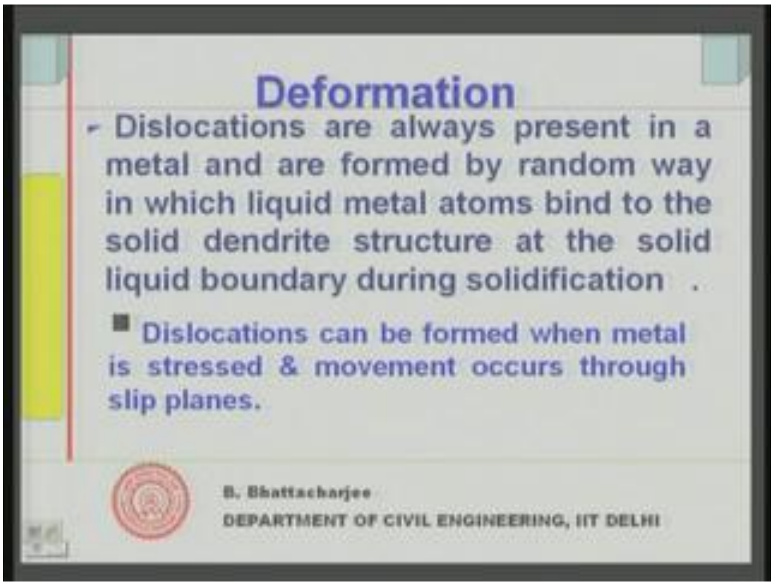

So, dislocation takes place you know dislocation takes place along what is known as planes. So, are the present they are always present in a metal. And they are formed by random way, in which liquid metal atoms binds to the solid dendrite structure, at the solid liquid boundary during solid during solidification.

So, there are always present in a metal and they are formed by random way, in which liquid metal atoms binds to the solid dendrite structure at the solid liquid solid liquid boundary during solidification. So, while solidification this would be present, because the random way in which the liquid when it is solidifying right. The, you know liquid metals are binding liquid metals atoms bind the solid at the boundary that you know boundaries of the dendrite structure.

That gives raise to this sort of dislocation they can also be formed due to stresses. So, they can be formed stresses and movements usually occur through what is known as slip planes. So, movements occur through slip planes therefore, what we have understood deformation in metals is basically nothing but movement of the dislocations. And dislocation do exist in the structure always, because of the formation process of the formation itself. And they can be also formed by stress; they can result in dislocation.

So when these are present in your loading there can be movement of this dislocation further you know causing deformations ok. So, this is what is basic mechanism of deformation in metal structures the details of this of course, we are not going to look into, but just in sort of introduction although we have taken the simple cubic lattice for example, but can occurs in any other kind of lattice. But, this is only for the purpose of explanation that the simple case was taken right. But, the details are not really of much of a interest much of our interest at the moment.

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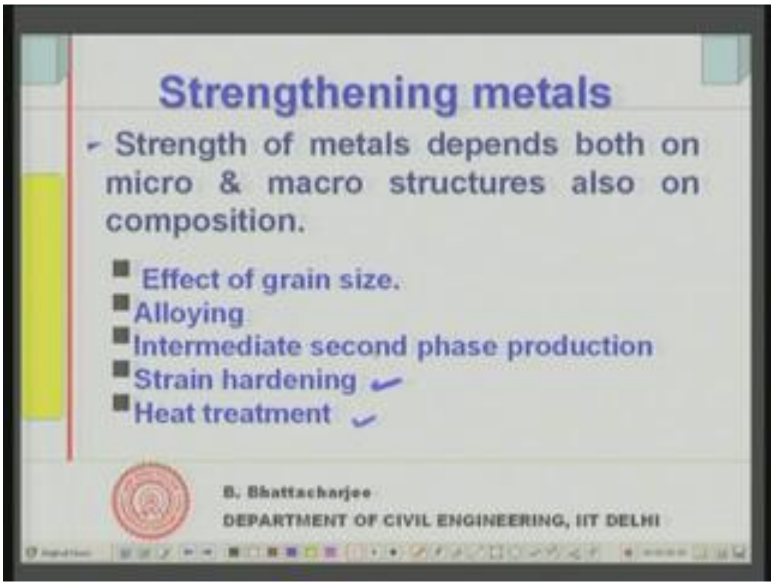

Now, how do we strengthen the metal strengthen metal depend upon, its micro structure macro structure also on composition you know how a strength of metal would depend on its micro structure, macro structure and also on composition. Now, what is micro structure lattice structure of the lattice itself, rather simple cubic or phase centered cubic etcetera.

Micro structure is the poly-crystalline structure which is their overall poly-crystalline structure single crystal structure is the micro structure and they will be, in micro structure it will look at some position in single crystalline structure some other case. We will see some other crystalline structure, but you look overall to the structure then it is poly-crystalline. So, both this would actually go under properties of the metal and also it depends upon the composition also it depends upon the composition.

Now, how we can actually strengthen first thing we will see that effect of grain size. The grain sizes can grain sizes you know strength by grain size. It is governed also by alloying we will see them and intermediate second phase production. These are the ways which you can then strain hardening and then heat treatment. Now, we will look into the effect of grain size today. We are quite familiar with this just as an example.

We will discuss this of course; sometime later in detail this is quite familiar to us. And this is also quite familiar to us strain hardening is quite often used in reinforcement bars in deformed bars. And we will discuss this course in details quite often used, and so is heat treatment when in thermo-mechanical it treated reinforcement bars. So, we shall see this to effect sometime later on. But today of course, we will see the effect of grain size.

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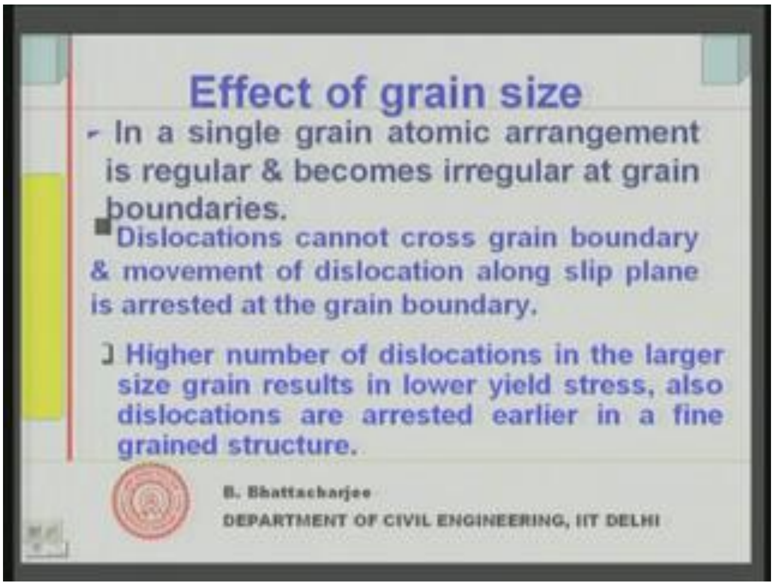

In a single grain we have seen that: atomic arrangement is regular and becomes irregular at the grain boundaries, because we have seen that in you know the within a grain boundary. It is the same crystal structure that would be formed and since there are different locations at which they started or dendrite formation started you have cry different crystal orientation at different places. So, when overall solid formation takes place when overall solid formation takes place and they come and then they join each other.

So at the boundary you have change of the crystal structure. So, within a grain boundary you will have same type of crystal structure, you will have same type of crystal structure and also we have seen that dislocations actually, takes place within the same type of crystal. So, as the crystal progresses as the dislocation progresses. It will get struck in the boundary, because you know it will get struck at the boundary, because then you will have a different grain structure.

So, dislocation cannot progress beyond a boundary and of course, a linear effect is not a plainer effect, it is a linear effect in 1 dimensional effect and along the slip planes. It is just arrested at the grain boundary. Now, higher number of dislocations 1 can find in larger size of grains you know similar to what we said earlier also defects are present in the. If you remember when we talked about concrete or cement, we said the defects are present right, in the beginning. Even before you applied any load and here also we know dislocations are available right, in the beginning itself, because of the formation process itself.

So right in the beginning you have dislocations present, in the structure of the metal itself and you know larger the size of the grain. This would actually will have more number of possibly more number of dislocations probability of finding more number of dislocations, in a larger size grain is much more than finding in a smaller size grain. So, in a smaller size grain you will have, you know assuming that. similar type of process of production of this.

Grain is you know, similar type of production after all they are pulling and in the same process basically dislocations are formed. So, if you have a larger grain we would like you to find more number of grains there more number of dislocations there whereas, in a smaller grain less number of dislocations. And then again the other effect is that as the grain as this you knows; as the grain I mean within the grain boundary itself, dislocation cannot progress.

So, when you have smaller number of grain or smaller size of grain smaller size of grains number 1, we would like you to find out less number of dislocations within it. And this dislocation cannot progress you know the critical stress. It can only progress beyond a critical stress level and not beyond a high stress level beyond before that it cannot progress. So, when you have smaller number of you know the fine grain size result in lower yield stress and the dislocations are arrested earlier in a fine grained structure.

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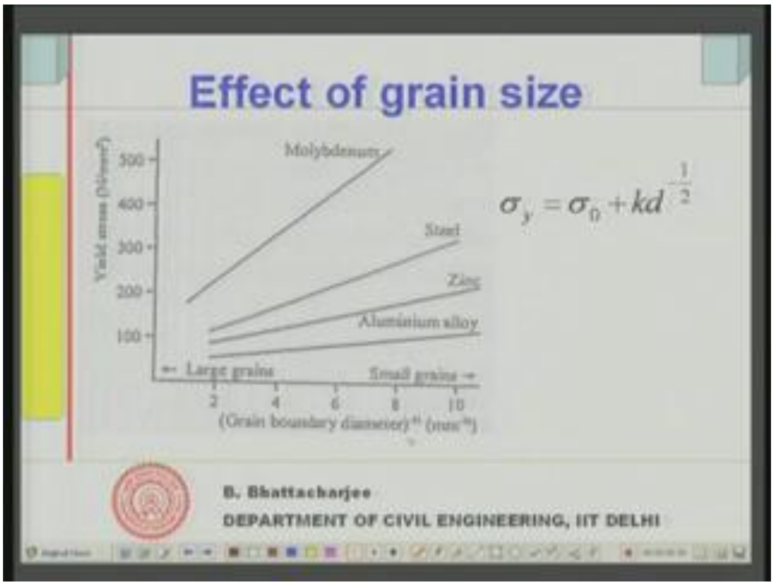

So, this is ensures that if you have finer grain size, you will have more. If you have a finer grain size, you will have more strength. So, this is be actually absorbed when yield stresses are compared with the grain boundary diameter grain boundary diameter you know. If you consider equivalent diameter grain boundary area and consider the equivalent diameter. This exercise it is this exercise actually root over under 1 by grain boundary diameter as been plotted, grain boundary diameter is plotted in millimeters and as this larger grains.

Because, this is 1 over diameter to the power half is plotted and on this side is the stress. So, with this side as I go have smaller grains this side I have larger grains and you can see the stress for different metals. For example: this steel it is here and zinc it is here aluminum alloy. So, when you have got smaller the grain size become smaller the stress increases, with finer grain size the stress increases. And this is when equated to a formula.

The stress is a function of k d to the power minus half k d to the power minus half; you know this is a linear graph as you can see. So, some sigma 0 plus k and this is a constant sigma 0 is of course, a constant again the intercept possibly on to the line and d to the power half. So, therefore, it shows that when I have a finer grain boundary, when I have a finer grain structure. The stress is likely to be higher and in a grain structure. So strength of the metal will be higher when I have a finer grain boundary structures. So, that is what the effect of grain boundary right is.

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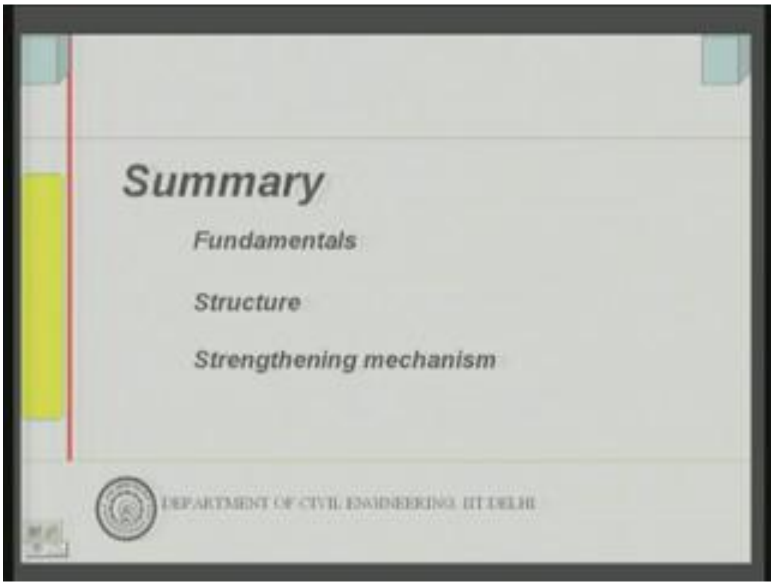

So, that is that is you know the effect of other effect like effect, the effect of intermediate phase alloy effect of heat treatment and next class. Now some of this of course, we are familiar, we are quite familiar because strain hardening and heat treatment. These are 2 familiar phenomena we have seen and quite often we have used in the reinforcement of the complete structure. So, anyway this is what we look, into the next class. And, then we will look into the carbon system their applications to civil engineering structures right.

So, what we have discussed today, we have defined what are metals, discussed something about the fundamentals of metals. Then, we have tried to discuss; discussed about the structures of the metals and also, but we mean by deformation you know first we looked into the structures of the metal what are the possible structures. As we have seen unlike we have also looked into the micro structure of ceramic materials like cement micro structure and here metallic structures, which as you know we just looked into this. And unlike those 1 where it was basically, the cement material which are pretty weak much weaker and therefore, not very strong material.

The metallic bonds are much stronger. And therefore, you get quite high strength as well; are also much better. That is what, we have looked through the micro structure through, the metallic bond and also the you know like the metal structure. Micro structure of the metal, then we have tried to look into what is deformation? What we you know the deformation, as we understand how it is by the micro structure. And then lastly we have tried to look into, we have named basically, the strengthening mechanism. That is that is effect of grain size on the stress.

That means; if you can improve the grain size you can make it finer grain size instead of a coarse grain size that strength would be improved that is what we have seen. And we have looked into other kind of grain sizes other kind of strengthening you know factors which can strengthen the metal. That is the alloying and then the intermediate phase. And then heat treatments also strain hardening. So, we look into those 4, in the subsequent classes.

Thank you.