Advanced Materials and Processes
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Lecture – 08
Bulk Metallic Glass, Glassy and Amorphous Materials (Contd.)

Welcome to NPTEL, myself Dr. Jayanta Das from Department of Metallurgical and Materials Engineering IIT Kharagpur. And I will be teaching you Advanced Materials and Processes.

In the subject we had already discussed 1 week and couple of more classes, during that time we tried to understand classification of different materials or advanced materials. At the same time we just started our discussion on amorphous solid or glassy materials among all these glassy materials we will be mostly focusing on metallic alloys.

So, there we try to understand what is the meaning of a glass transition? And what are those solids? However, any of the properties in any metallic or polymer or ceramic system depends also on the structure, because structure and properties are very much well linked. And therefore, today we will start our discussion some of the aspect of structure of the solids. Here we are talking about structure means, the atomic scale structure means; how the atoms are organized?

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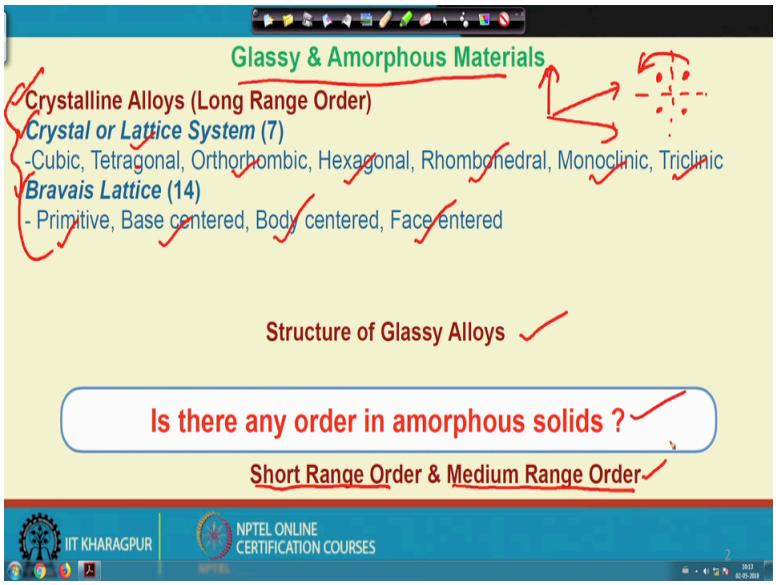

Now, before going to glassy materials or amorphous materials, during our undergraduate studies we already know a little bit about the crystalline solids or let us say in case of more metallurgical sense crystalline alloys, where bonding is metallic. There, we mostly see that any of the crystal structure has some translational symmetry or if we go into x y or z direction. Means any of this direction, then we find periodicity as well as if we rotate a structure ok. Let us say there are 4 atoms we can think about and we can think about such axis and if we can rotate it then you will also get a rotational symmetry.

So, both these symmetry are very much important to understand the structure of the solids. In case of a long range order or long range periodicity, it is already well established that the crystal or lattice systems. So, crystal systems means 7 crystal systems and these are cubic a cubic system means, if we take 6 square and put them together to make a solid, we call it as a cube or hexahedron because there are 6 faces.

Now if we take a cube and stretch it in one direction or other direction then we can also generate other solids. Like tetragonal system or let us say the orthorhombic crystal ok. And similarly we know about the hexagonal structure, rhombohedral structure, and monoclinic structure or triclinic structures.

So, these are the basic crystal system that has been understood by us during undergraduate studies. However, among these structures also we may find some other kind of orders and in total there are 14 Bravais Lattice. The 14 bravais lattice here the primitive one primitive means the same cubic tetragonal orthorhombic hexagonal or rhombohedral or maybe we can simply take 1 atom and put it on 1 of the base of these crystal ok.

So, we call them as base centered base centered structures or also we can take 1 atom and put it in the body of this crystal. So, we call it as body centered structure, body centered tetragonal ok. Like that or maybe we can also put it in the face centered like copper or nickel we take in a cubic system, we call it as face centered cubic and so on.

Even though all these understanding is well developed. So, far however, questions always come to your mind what do we mean by a structure of a glassy alloys or glassy materials. And so, is there any kind of ordering in a amorphous solid or any glassy structure, that basically a questions that come to our mind. And whether all the different glasses has the same structure, because I told you about a concept that whether a liquid is

a is a frozen and make a amorphous solid. Even though we understood that there is a phase transition, but questions definitely come to our mind, whether the liquid has very similar structure, as a amorphous structure, or it is different.

So, in that aspect people think about that yes there is some sort of short range order or let us say medium range order exist in these glassy alloys. So, what do we mean by short range order. A short range order means, that the length scale means, the ordering or let us say a cluster of the atoms that has a length scale of something like to two nanometer in size or less than 2 nanometer. So, you can easily imagine if the distance of 2 atom is somewhat like 3 angstrom and if it is 20 then there cannot be in 1 direction more than 6 atoms.

So, something like 30 or 50 atoms make a cluster and people are trying to understand the symmetry of those structures of the short range order and people try to think about it. And so, in a medium range order also people think about that that may exist in a glassy structure; and this medium range order means basically somewhat in the range of 2 to 10 nanometer size or 8 nanometer size ok.

So, they are a little bit larger size cluster people think about. So, today we will try to understand a how this structures a link and what are the different solids exist? And how are they are similarities and so on. So, the basic understanding is required to understand this subject.

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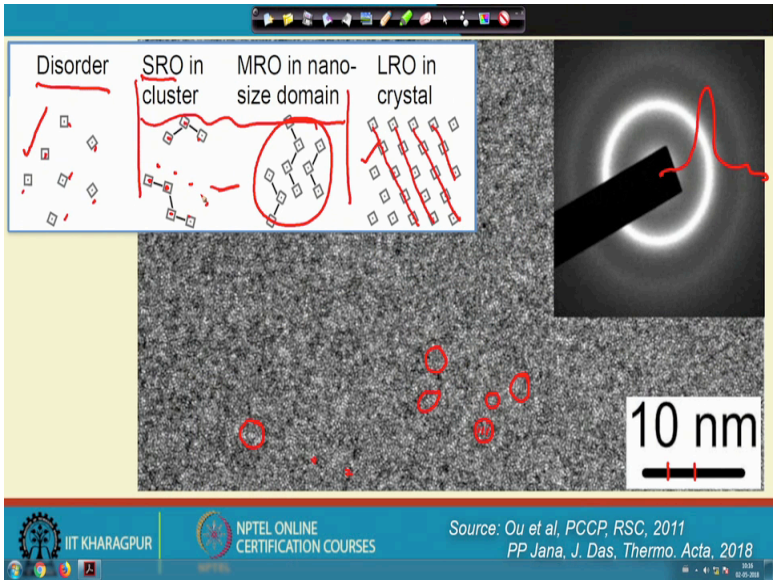

Let us have a look at one of the one of the glassy alloys that has been studied under high resolution transmission electron microscope. So, you can see that here the atoms are not at all periodic, it is very clear you can look at any of the places any of the zone. And you can look at that yes there is almost no symmetry, and that is also understood by the selected area diffraction, if you integrate I already discussed you earlier that it will give you such kind of diffraction pattern ok.

And so, , but still if you closely look at any of these zone, which has a somewhat length scale this is 5 nanometer and this is something like 2 point 2.5 nanometer and so on. Even there you can see that yes it appears that some planes are there and some symmetry probably exist in such a very very small scale.

So, in 5 or some nanometer scale there is some symmetry and so, if we think about and comparing these structures with liquid and so on for liquid is a complete disorder ok. So, atoms are just randomly organized, but in case of a short range order, let us say short range order clusters we may think about such kind of atomic positions or they say nuclear position of the atoms. And we can think about that 3 or 4 atoms or maybe a little bit 4 or 5, 6 atoms has some sort of some sort of regularity, I would never say them as a nanocrystalline structure ok. So, these are not crystalline at all ok.

However, maybe some sort of a medium range order domain also people may find as we also find in case of a high resolution transmission electron microscope, but in case of a crystal we can definitely find a very very regular periodicity of the atoms or interplanar spacing and the distances are very much well defined.

So, here this is if it is a very very well defined system and in 1 hand I have a liquid structure, then somewhat this glassy alloy structure fall in between these between 2. So, from a complete disorder to a complete long range order there is some symmetry may exist. And so, we will continue this with further discussion and that will be very much interesting to us.

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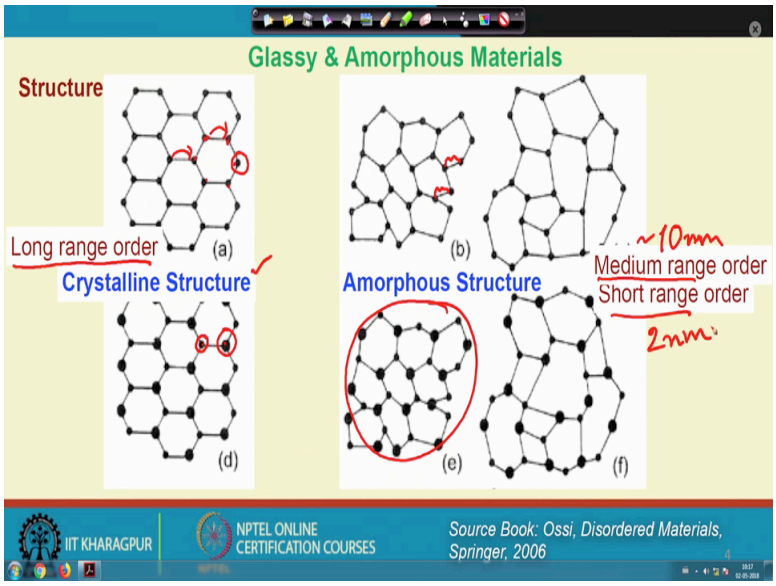

Let us try to see what I was talking about, that if I take a very very schematic of the structure of a crystalline solid. Then here you can see this is a hexagonal arrangement or let us say hexagon and you can definitely find the periodicity of the atoms and so on. And, we can also think about let us say similar atoms or maybe we can have a dissimilar type of atoms, where this is small and this is a larger one. So, this is somewhat like a more ordered structure or order periodicity of the smaller atoms inside a hexagonal structure.

So, so, we can think about this is a long range order here, but if we takes very similar structure and then make these distances very different. And so, we can create a somewhat like a disorder or amorphous solid. There may be some cluster we may find some symmetry, but it is not at all a complete disorder ok. So, this is such kind of cluster we are talking about in case of amorphous material.

So, this is like a medium range order which is in the order of somewhat like 10 nanometer or let us say a short range order we are talking about something like in the range of a 2 nanometer. So, therefore, we need a very basic understanding of the structure of the solids which are well defined by a several mathematicians.

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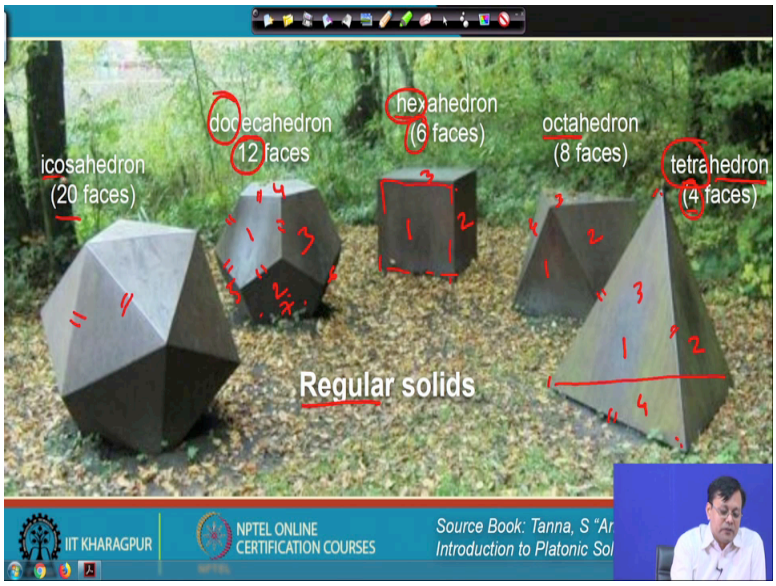

So, so, far the understanding is like that, that the whole universe is made out of these 5 regular solids. And I show you, here, the 3 dimensional structure of those regular solids, because solids are in 3 dimensional right.

And also this regular has a particular meaning; a regular means that the sides are equal in length. How it is? So, here I saw you a solid which is made out of a triangle side ok. And triangle, it is equilateral triangle, because this is a regular triangle and we have 4 faces 1 2 opposite side there is a 3 and the base that is the 4. So, that is why this 4 basically came here that the 4 faces.

And this idea of this 5 solids has developed very very long time ago, we will come in a minute, but this 4 faces here in a Greek terminology is called as tetra and this hedron means basically sit I mean sitting ok.

So, people think about or always they thought about this, that these are the regular solid the whole universe is made of. And we can take again such a triangle and put 1 2 3 4 and also other side 4 and we can make 8 faces of a solid. And this is called as a since it is 8 it is called as a octahedron. Now let us take an another face, that is cube which is represented here by square and if we take 6 of such square, because 1 2 3 and opposite side is also another 3 because there is a base. So, this 6 is the hexa and we call it as hexahedron ok.

And, very similar way we take here a regular pentagon; a regular pentagon means that all these sides are equal in length. And we take 12 of such pentagon 1 2 3 4 5 here 6 bottom 7 and the other side. So, all together there are total 12 faces, we call it as dodecahedron. And, we can again take a regular triangle and we can take 12 of such regular triangle in order to make an icosahedron.

So, the idea here that as per mathematicians concept, that these are the 5 regular solid which make any of the structures of this universe ok. And, whether these ideas are today's concept or very ancient we will look it in a minute however this regular solids are also often called as platonic solid.

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So, in the ancient time almost the idea evolved in the year of 700 to 400 BC in several places of this world like in Greece ok. In India, in Japan, in China, in several mythological concepts they used to express that 5 basic elements or classical elements that constitute this universe ok.

So, a tetrahedron is represented with the fire or fire is a tetrahedron is a symbol of fire and this one is for air, a cube or a hexahedron to represent the earth and the icosahedron to represent the water and the ether or the world or universe actually is represented by dodecahedron.

And so, the mathematician try to understand yes definitely the idea has evolved very very long time ago and we are continuing those concept, and there must be some link with taking these regular solid and to make some sort of a plane out of it or to create a plane in 2 D and tried to look at their symmetry of the structure. And so, these are very very interesting subject. And let us try to understand that in a minute.

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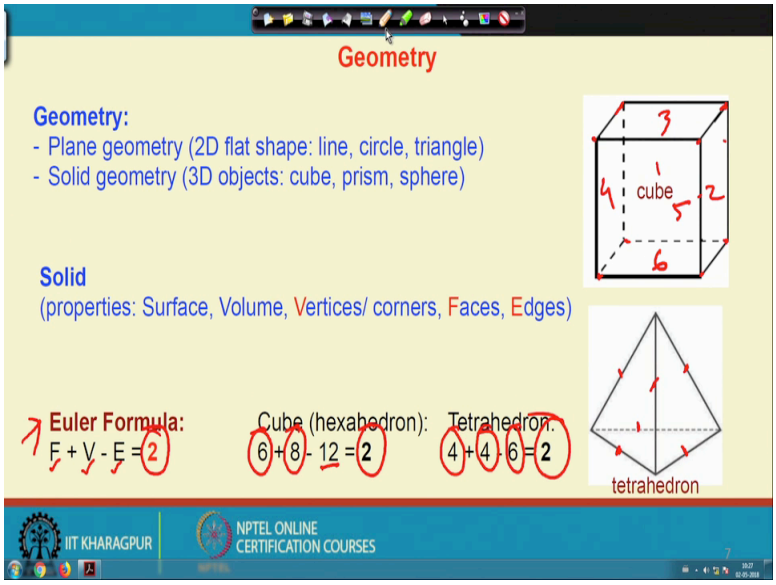

So, in the concept of geometry of solid the geometry could be think about in terms of a 2 D or let us say 3 D. In case of 2 D we call it as a plane. So, a plane basically means that it is a flat surface. A flat surface how we can make some different objects there like a line if I draw a line, I can put this line on this flat surface. I can simply take a circle and I can put it on a plane we can make a triangle and we can put it on a plane. So, this is a 2 dimensional.

However, the solids which I have shown you let us say like a hexahedron or cube or maybe we have seen sphere which looks like a football or let us say a soccer ball. So, so these are the usual solid geometry. Now, in case of this solid geometry these are the 3 D object. However, we can take those flat shape and join together to make a 3 D solid; like here I have taken a flat square and I have if I take 6 of those squares then I can make a cube.

Now, the solids are have some definite properties what are those property I said just a minute ago, that you can take flat surfaces to join and to make a solid. So, here definitely

the solid has surface, solid has a definite volume because we can put some water into it and this may be like a container I can accumulate some water into it right. And so, therefore, all these solid should have some vertices. So, the vertices means are the corner or vertex this is the plural form of the vertex.

So, now the there should be some faces. So, these are the faces or let us say the surfaces or there are some definite edges. So, these are the edges. So, in case of regular solid the edges are equal in length. Now along this direction along these direction, Euler has provided us a very very helpful formula that if you add faces plus the vertices minus the edges it will be always equals to 2 and how it become? Let us take a cube ok.

So, I said cube has 1 and 2 3 4 5 and 6, 6 faces right. So, 6 faces and what else I have? I have vertices means corner. So, 1 2 3 4 5 6 7 and 8. So, this is the 8. And now if I simply subtract the 12 edges you can see here. So, it is become basically 2 very similar way like a tetrahedron. I have total 4 faces, I have total 4 vertices and I have total 6 sides, because 1 2 3 4 5 and 6 sides. So, these are the edges ok.

So, it will also become is equal to the 2. So, this a formula is very much useful to understand the properties of the solid.

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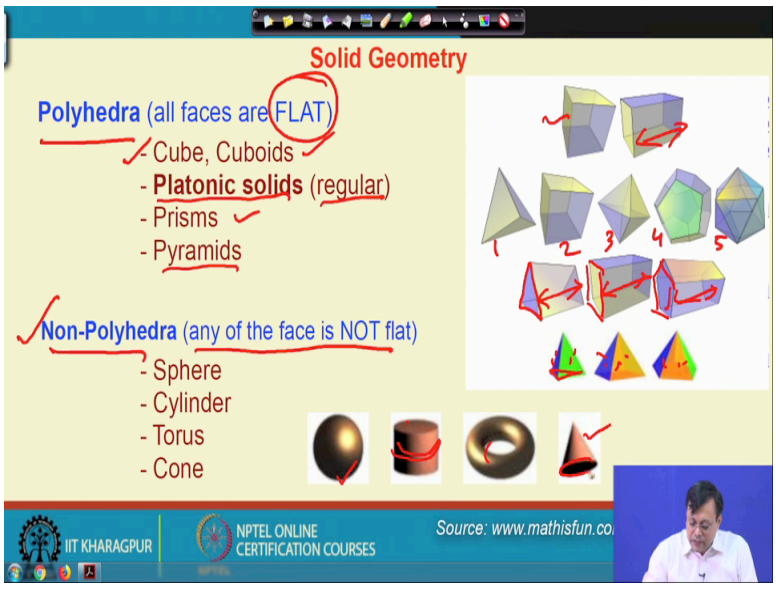

Now, let us say there are some other terminology we must learn that these are the polyhedra. In case of polyhedra what is interesting a polyhedra meams basically we are

talking about the solid, that all the faces are the flat. However, in case of non polyhedral any of the face is not flat, let us have a example what are those polyhydra we want to mean? Like a cube, like a cube or cuboids how they are?

So, this is a cube, if I stretch it in one direction it will be cuboids or let us say the regular solids, which I told you. Here, I termed here like a platonic solid because these are well known as platonic solid. So, these are the 5 different platonic solid I just explain you in a minutes ago.

And let us say I can also take any of these regular triangle and then stretch it in one direction then I will get some prisms or maybe I can simply take a square and stretch it in one direction. So, this will be also a prism or maybe I can take simply a pentagon and then stretch it then I will also create a prism. Whereas, there are some faces and we put let us say some triangle 2 or 3 or 4, 5 and so on. So, we can create some pyramids. So, these are all the solids the unique thing that the surfaces are flat ok.

So, these are called as polyhedra. Now, if we think about a sphere definitely there is no flat surface and we call it as a non polyhedra this is a sphere or maybe a cylinder where one of the surface ok. Here this is not at all flat. So, this is also a polyheda maybe we can simply think about a torus, which is also a non polyhedra or maybe we can simply think about a cone where even though there is a flat surface here, but this surface is not flat. So, these are the non polyhedra. So, we are mostly interested about this platonic solid and regular geometry.

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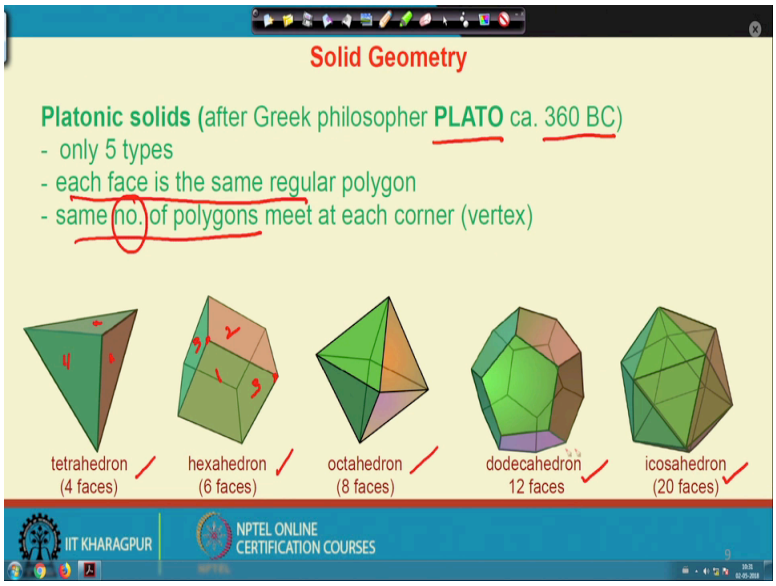

So, in case of this platonic solids, this name actually came the platonic, because of a Greek philosopher around 360 BC a Plato, his name was Plato and he basically explained that there is only 5 type of such solid is possible.

So, there is some uniqueness of the solids that each of the face is the same regular polygon ok. So, the regular polygon means I am talking about if you look at this face this face this face or in the opposite side they are all same ok. And the interesting thing is that the same numbers of such polygon meet at each corner or vertex.

So, if we think about this particular corner then here 1 2 3 and here also you can see the same 1 2 and 3. So, the same number of such polygon basically meets at each and every corner. And therefore, this tetrahedron, hexahedron or cube or octahedron or dodecahedron or let us say icosahedron they are basically made of.

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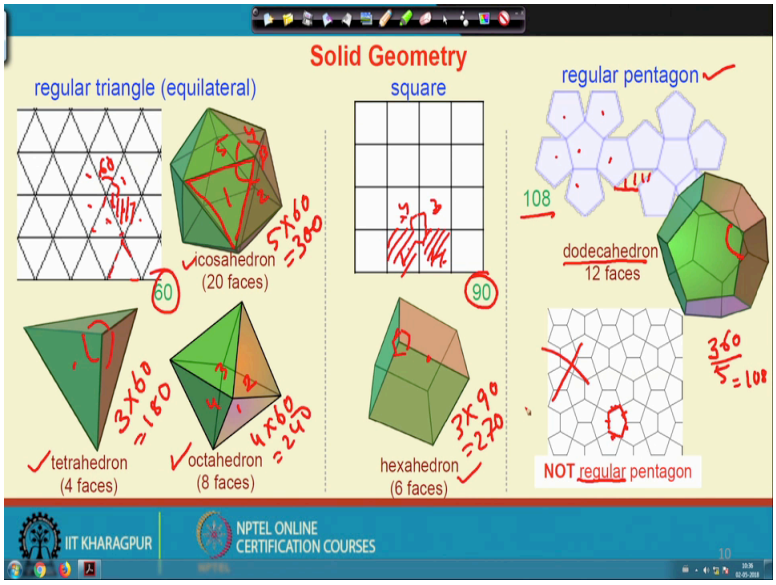

However, however if I think about making this solid geometry and take any of those flat surfaces to and put them in a 2 dimensional way, then how they basically looks like? Let us have look I take a triangle, because here the tetrahedron octahedron or icosahedron they all have a regular triangle a regular triangle means I am talking about equilateral triangle.

So, here you see this is also equilateral triangle everywhere there is a equilateral triangle, and if I join these all these equilateral triangle then I can fill up a 2 dimensional 2 dimensional area ok.

And here these are the angle that is 60 degree right. So, this is a 60 degree angle. So, here 6 such triangle meets together and if I remove any of these triangle from there I can create a solid and if I join together let us say I remove any of this. So, then I have 1, 2, 3, 4, and 5 and here if you have look 1, 2, 3, 4 and 5 ok. So, the angle here this angle addition of these angles are 5 into 60, which basically means 300 right. So, here very similar way if I make the addition of these angles, then here there are 3 faces multiplied by 60. So, it is 180 degree.

In case this case, there are 4 so, 4 into 60 so, 240 like that. Now if I move on to a next geometry that is the hexahedron here the uniqueness is there that all are all the faces are the squares. So, if I take the squares and join such 4 squares 1, 2, 3, 4 squares then I can make a plane ok. I can take out simply one of those square and join together and then I will definitely get a cube.

However, it is not possible if I take this square to join this 2 1 and I cannot get a solid out of it that is the problem. So, here the angle is 90 degree. And definitely this corner has 3 into 90, which basically means 270 degree. Now, the interesting thing is about a dodecahedron why, because this is a pentagon and this angle if I measure then it is 108 why, because 180-360/5 is equal to 108° ok. And now I take these pentagons and put them together and try to fill a 2 dimensional plane.

You will see that there is always some empty space remain and it is not possible to to cover that space or maybe I can take, let us say some more, but it will never end up to cover, there is always some empty space there. I am talking about a regular pentagon. So, this means there is some lack of symmetry in this structure.

However, I can take pentagon, which are not regular, in that case I can definitely fill a 2 dimensional flat surface, and you can see here I have shown you some non-regular pentagon, which basically means that the sides are different ok. And so, we can create the space, but this is not our interest because we are thinking about the periodicity of the structure and we need to consider only the regular structures.

So, today we tried to understand the different aspects of those solid geometry and different platonic solids, which are very important to understand the glassy or amorphous alloys, we will continue the discussion in the next class.

Thank you.