Advanced Ceramics for Strategic Applications
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Lecture - 1
Introduction

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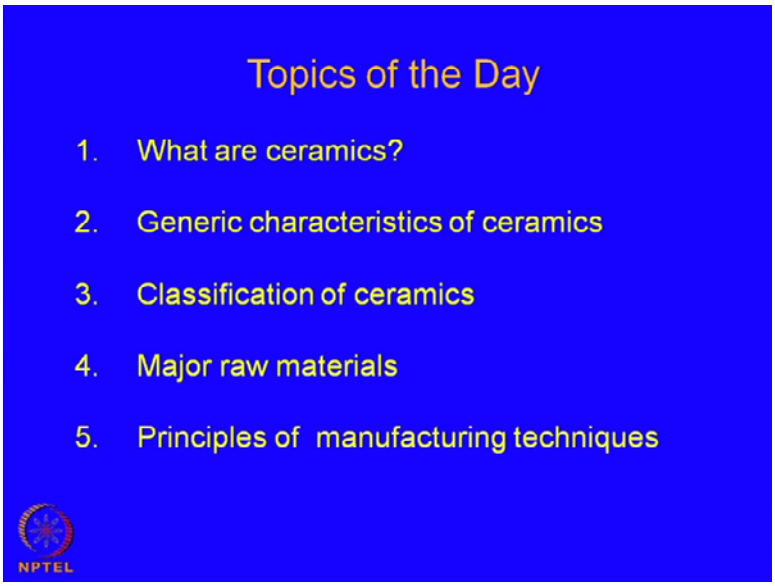

Welcome to the NPL course on Advanced Ceramics for Strategic Applications. This is H.S.Maiti welcoming you to this particular course. To start with, we will discuss some introductory concepts about ceramics, their properties, their characteristics. Then we will come to different classes of ceramics, different materials available to us and also the major raw materials from which these materials are prepared. Finally, we will discuss some of the basic principles of manufacturing techniques of the ceramics.

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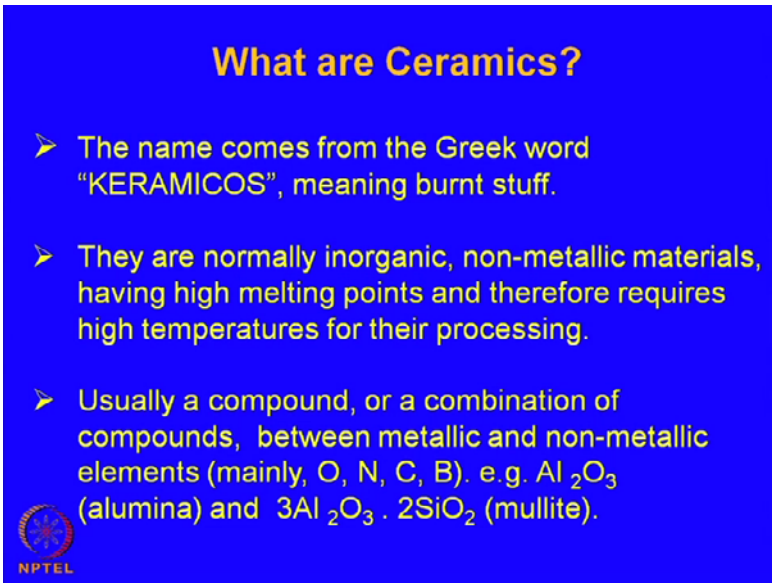

What are ceramics? Well, how do you define ceramics? May be, it is known to many people that this particular name Ceramics came from a Greek word keramicos, which basically means burnt material or burnt stuff. As it is known, the ceramics are known to mankind for thousands of centuries and they are basically prepared from naturally occurring raw materials. They are normally inorganic and non-metallic materials having relatively high melting points, and therefore require high temperature for their processing and application. So, that is how normally we define ceramics.

They are usually compounds, not the elements. But, compounds of different elements or combination of compounds, between metallic as well as non-metallic elements. What are the elements present in different kind of ceramics?

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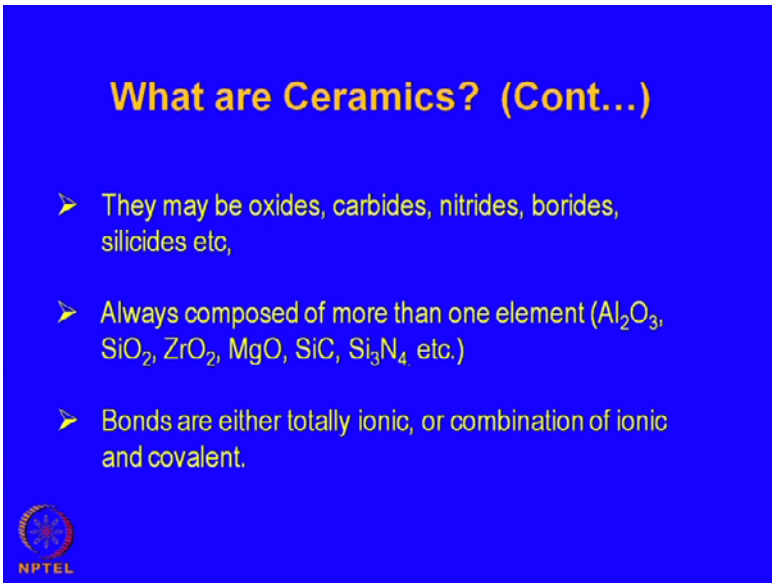

Of course, there are metals, in addition to oxygen, nitrogen, carbon and boron or may be some others. The example may be a simple example or very common example is aluminum oxide. It is a mixture or it is a compound of aluminum and oxygen. Another example of ceramics is a combination of two oxides or compounds of two different oxides like aluminum oxide and silicon or silicon dioxide in a particular ratio, 3 is to 2 and that particular compound is called mullite.

Well, to continue what are ceramics, we also have in addition to oxides, we have carbides, nitrides, borides and silicides. That means, a combination of metal with carbon, a combination of metal with nitrogen, a combination of some metal with boron and also silicon. So, these are more different or uncommon type of compounds, which are available under the category of ceramics. They are always composed of more than one element as it is already been seen and two another examples are silicon dioxide, zirconium dioxide, magnesium oxides, and silicon carbide. That is one kind of carbide, a combination of silicon and carbon. Then you have silicon nitride, a combination of silicon and nitrogen.

Well, any compound has certain category or certain classes of atomic bondings because you are dealing with two different elements and is known from the chemistry knowledge; some of these compounds are ionic in character. Bond is ionic in character and some others are covalent and so on. When you talk about ceramic materials in general, we

have a variety of bonds. Some of them, particularly the oxides are totally ionic in character, whereas, if you talk about carbides, nitrides, borides and silicides, they are partially ionic conductivity, sorry, ionic bonding. Whereas, mostly they are covalent bonds or covalence is the character of these bonds.

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What are the different general characteristics of ceramics materials? You have seen there are oxides, carbides, nitrides, silicides. Can they have some common features? The most important characteristics of any ceramic material, it is brittle. It does not have the necessary plasticity like metals or other plastic materials. So, it cannot be extended or it cannot be deformed. The deformation is very little, before it breaks. So, that is the characteristics of brittles and all ceramics materials have this particular property.

Then, you have another very important property. In general, most of the ceramics chemically inert. They do not react with other chemical or environment and therefore, they are quite stable. Chemically very stable materials mostly. They have long life. They are durable for a long time. So, that is another good advantage as far as the ceramics material is concerned. In addition, they have very high strength. Of course, when we talk about strength, we have to define what kind of strength it is. Ceramics are very strong when a compressive load is applied. However, if you apply a bending load or tension load, they are quite weak. So, unlike metals or even polymers, ceramics have this kind of weakness. Although, they are very strong under compressive load, but they cannot be

bend. Then the brittleness comes in. In addition, they are hard and therefore, wear resistant or abraded resistance; they can be abraded. If they cannot be abraded, they can abrade other materials. Normally, they are electrically as well as thermally insulating. That means, the electrical conductivity is very poor as also the thermal conductivity.

Refractory nature means, is basically high temperature resistance. As per the definition, ceramics are high melting materials and require high temperature for their processing. Therefore, refractory is the most common candidate material to be used as a refractory material for lining of furnaces particularly, where very high temperature has to be withstood. Chemically stable, as it is already mentioned. That is why durable also and so as far as the magnetic properties are concerned, most ceramic materials are non-magnetic. But, there are exceptions. These properties are however not common to all ceramics, in fact.

Ceramics as a group has the widest variety of different physical and chemical properties. We will discuss them, what are the different extreme properties. Sometimes, ceramics are insulating as just mentioned, but not necessarily all the time. They are groups of ceramics, which are semiconducting. Others are conducting almost like metals and then few decades back, two or three decades back, we have also got a completely new range of ceramics, which are super conducting. So, ceramics as a group has the widest spectrum of different physical and chemical properties and that will be discussed in the next classes.

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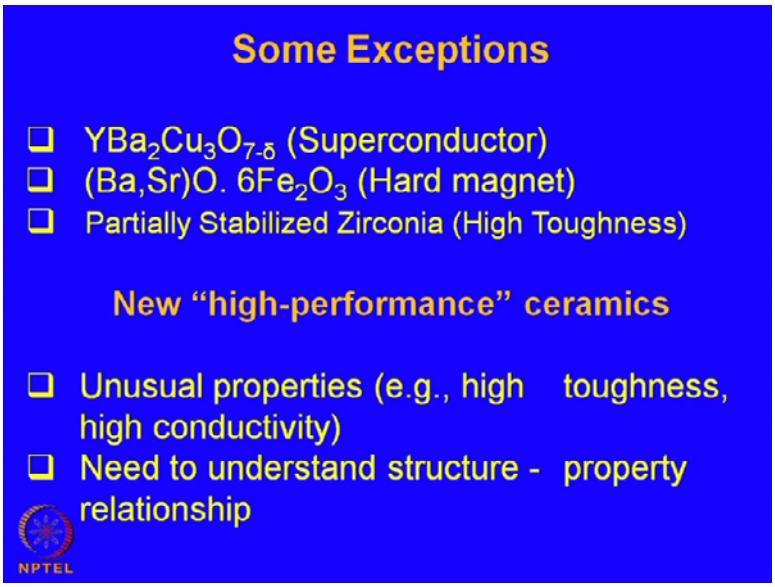

Some exceptions we have just discussed that what are the common features or common characteristics of the ceramics as a group. But, there are many many exceptions as I just mentioned also, super conductor. There is a compound, an oxide of iterium, barium and copper, which shows super conductivity and this is a very recent discovery. Although we have said, most of the ceramics are non-magnetic but there are magnetic ceramics as well and this is one such example. It is an oxide or barium or (( )) along with iron oxide, which is called barium ferrite or barium hexaferrite and that is hard magnate.

Once you magnetize them, it forms a permanent magnate. In terms of mechanical properties, although most of the ceramics are brittle, but there are tough ceramics also. One of the examples; there are many tough ceramics have been discovered in recent times. One of the examples is what we call partially stabilize zirconia, zirconium oxide or zirconium dioxide to which some amount of iterium oxide or calcium oxide is added. It is basically a solid solution. It is called partially stabilized, because it has a combination of monoclinic or tetragonal and cubic phase. Therefore, it is not fully stabilized. In the fully stabilized condition, it is completely cubic phase or cubic structure. Whereas, when it is partially cubic and partially tetragonal or mono clinic, then it is called partially stabilized zirconia. So, that is one of the tough materials. Of course, compared to steel, it is much less tough. But, compared to many other ceramics, it is much tougher. We will discuss them later on.

Then, you have few high performance ceramics, which demonstrates unusual properties. For example, high toughness, high conductivity, which I mentioned few minutes back. So, you will have a range of oxides or ceramics, which are tougher in mechanical property terms and the electrical properties, are also very different from other ceramics. So, we need to understand and there is a need, how this property really gets developed. What is (( )) and therefore, we need to understand the structure property relationships. In material science, the basic subject of material science, in which ceramics is one of the components, if you want to understand the properties, whether it is mechanical properties, electrical properties, magnetic properties, the dielectric properties, all these things originates from its structural characteristics; atomistic structural character or crystal structure characteristics. Both, crystal structure and micro structure, everything is important to understand, if you want to explain some of the properties, which will explode in practical science.

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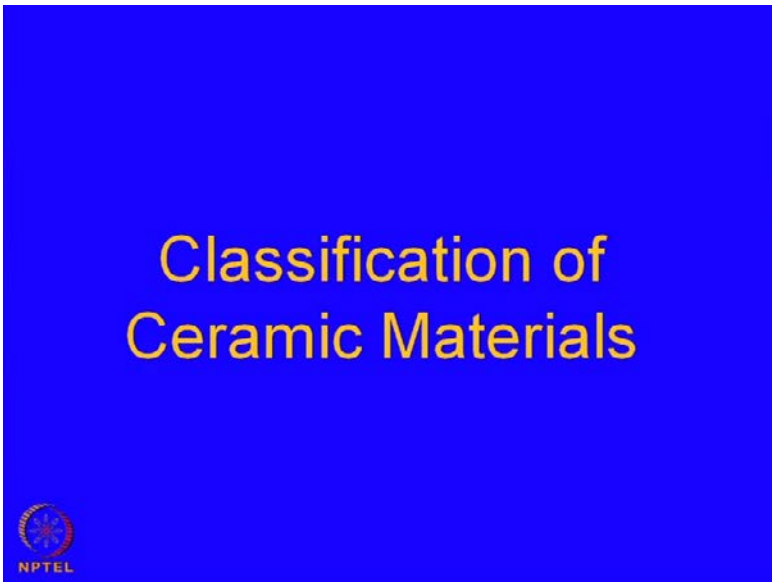

So, having known that there are variety of properties, variety of materials from the chemical or the bonding point of view, we must now how to classify them.

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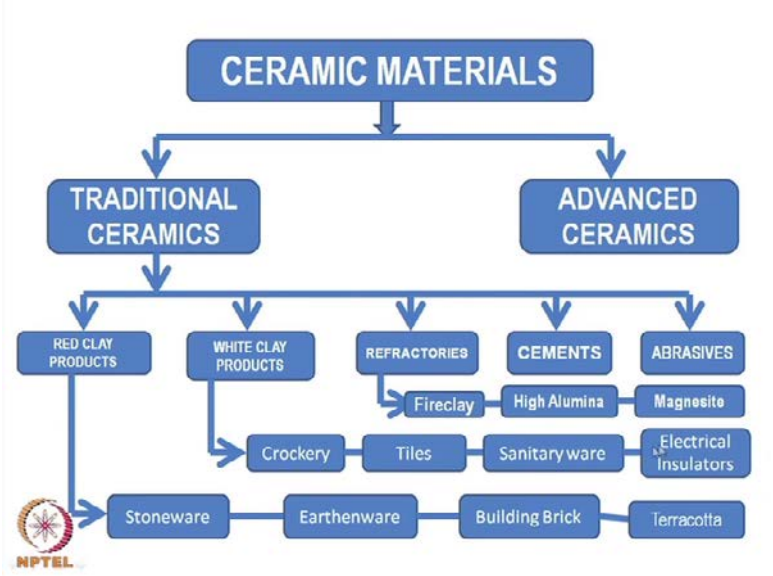

Can we categorize them under different groups? Yes, you can certainly categorize them under different groups. So, ceramic material as a whole, can be grouped under two important sub groups, what is called, one group is called traditional ceramics and the other is called advanced ceramics.

This course is particularly on advanced ceramics. So, most of the time we will spend on advanced ceramics. However, we must differentiate. You must be able to differentiate. What is it? How it is advanced. Advanced relative to what? It is advanced related to traditional ceramics. So, you must know what is traditional ceramics and also how to differentiate the advanced ceramics from the traditional ceramics. So, let us look at it.

We classified traditional ceramics again under different heads like red clay products, white clay products; refractories and then we have cements and also have abrasives. These kinds of applications had been known for a long time, particularly red clay products. Because, many of them, the red clay as well as white clay, they use the most crude form of raw materials, which are available in nature. For example, red clay products. They are basically ordinary clay available in nature at different parts of this earth crust or earth surface. We will discuss in a few minutes how exactly the ceramics are prepared. Ceramics are basically starting materials or powders and they get consolidated and then one of the major steps of brining in strength to the ceramic material is what we call firing or heating to high temperature. So, this red clay the

common clay, when we heat to high temperature, may be about 800 to 1000 degrees centigrade, they convert to a strong body having a red color and this red color basically comes from iron oxide. So, the clay, which is normally available, contains lot of iron oxide and when it is fired, it produces what we call the brick red color. So, all the products prepared from normal clay or common clay is known as the red clay products, because of the red color. They are the most crude way of ceramics. Although they are known for a long time, but they are the crude way of ceramics and they have many different forms.

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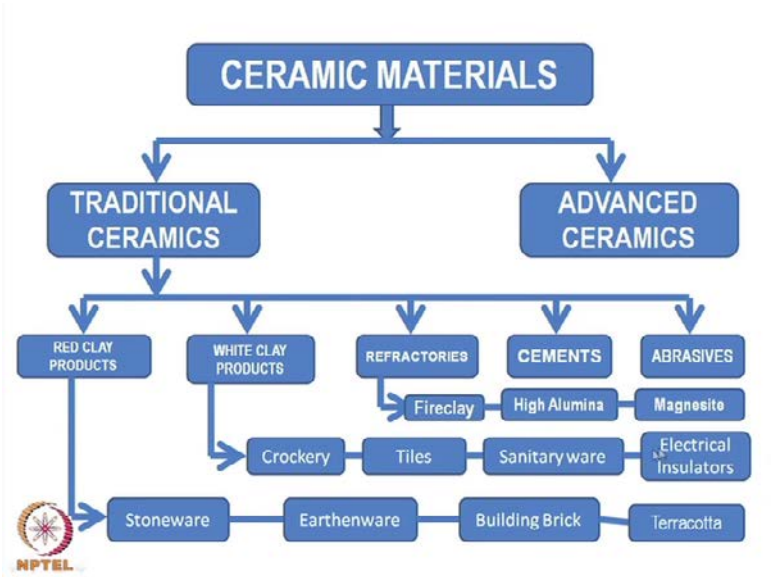

One we call stoneware. Then we call earthenware. Building bricks, normal building bricks, from which the color gives the brick red color and then terracotta. The figurine, the different art work, all these things can be made from the common clay. So, they are grouped under red clay products.

However, there is a another variety of clay, which are relatively pure form of clay, which does not contain that much of iron oxide and their particular mineral, the Kaolin or Kaolinite is the major component of white clay. Again, available in nature as a raw material, as a mineral and that can be directly taken from the mines and process it a little bit and then give it a shape and fire it once again about slightly 1000 degrees centigrade, so that, you get a range of different products, which are known to the mankind for a long long time and they are all called white clay products, because the color is white. They of

course can be colored by addition of controlled amount of coloring elements, but in general, they are white in color and therefore, sometimes the whiteness itself is an attractive feature of these products. For example, in crockery or in tiles, sanitary wares, electrical insulators. Of course, the electrical insulators are not white in color as all of us know. Electrical insulators are brown in color and they have been intentionally colored by addition of certain oxides again. So, these materials, the basic raw material or white clay products or in other words, sometimes we call them porcelain products. We will find what are the different components of this white clay products or porcelain products or sometimes called white wares. Sometimes, they also called triaxial porcelain because they require three different ingredients. We will discuss that later. So, it addition to red clay products, we have white clay products.

Then there are others, which are used for high temperature applications called refractories and once again, they will have several sub groups depending on at what temperature they can be used, what is their melting point or softening points. Fireclay is another kind of clay. Once again available in nature or in the form of a mineral and that mineral can be directly fired to high temperature and form a shape. So, it has some amount of aluminum oxide and some amount of silicon dioxide. That forms fireclay. In fact, ceramics have been classified in terms of their alumina content; alumina or aluminum oxide. Aluminum oxide, the content of aluminum oxide actually determines the temperature up to which it can be used. Higher is the aluminum oxide content, higher is the temperature it can resist. Therefore, the temperature or in refractive terminology, it is called refractoriness, the refractoriness of high alumina. Refractory is more than that of the fireclay refractory.

In addition, another oxide, again which is available in nature, magnesium oxide. In fact, magnesium oxide is not as such is available. It is magnesium carbonate, which can be calcite or heated to high temperature to form magnesium oxide and that magnesium oxide is also a very good refractory material, extensively used for steel making. So, these are different variety of refractory, which are known to mankind for quite some time. Then we have an another group of studies in ceramics, which are known once again to the human beings for a long long time and as you know, cements is one of the most important building materials used today on all kind of structural applications, whether it is building, bridge, or roads.

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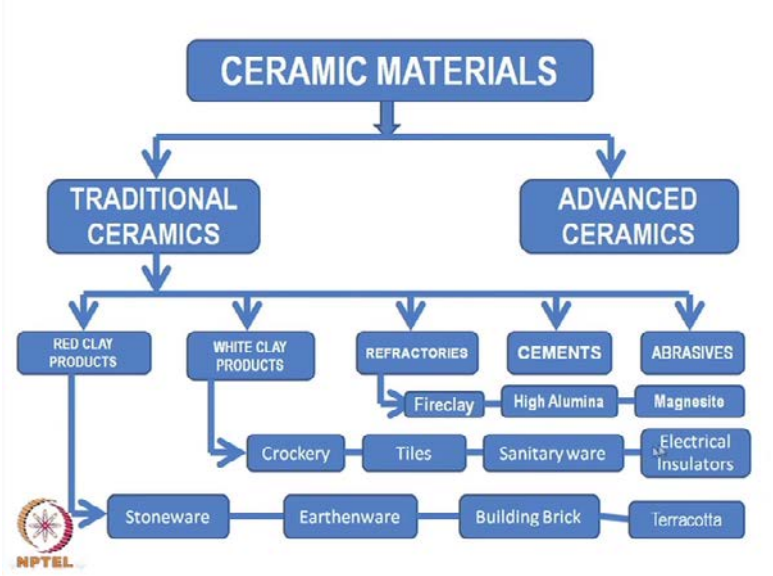

Cement is another very important group of ceramics, which is used and one of the highest tonnage materials produced across the world. It is basically a combination of calcium oxide, silica and aluminum oxide. It forms what they call a pozzolanic compound or pozzolanic property. It develops a pozzolanic property, so that, when it acts with water, it forms harmers. So, it a cementitious property develops just by adding water to it. Of course, it needs high temperature for its preparation. Just by mixing aluminum oxide with silica or silicon dioxide and calcium oxide will not found cement. It has to be fired. It has to be heated to a very high temperature of let say 1500 1600 degrees centigrade.

So, that is another variety of traditional ceramics, which is has been known for quite some time. Others, the last one in this group is abrasives. Primarily because ceramics in general are hard, so it can scratch any other surface, particularly the metal surface. Any metal surfaces can be scratched by ceramics. Of course, there are different varieties of ceramics. Some of them are little softer than the others. So, in case of ceramics or the abrasives, we use the harder variety of ceramics. So, these are the groups of traditional ceramics and the different kind of raw materials or the compounds we use.

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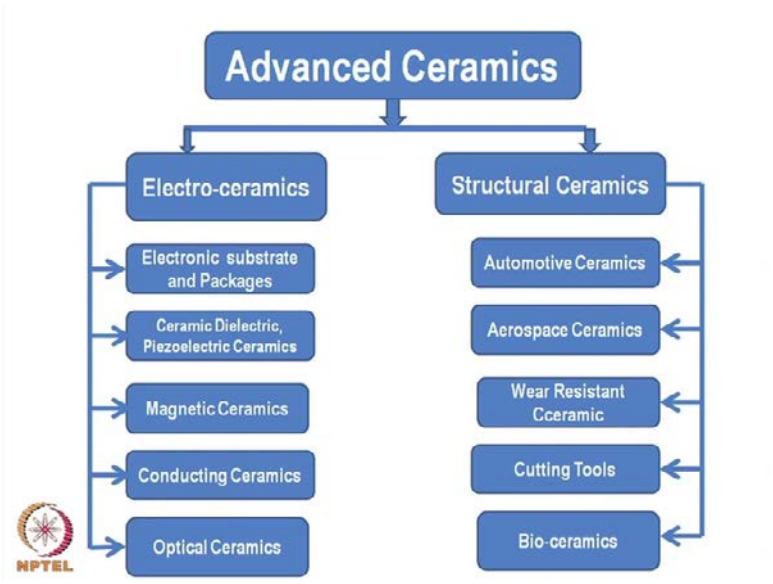

The next group which is basically the topic of this particular course is advanced ceramics. What are these advanced ceramics and why there called advanced ceramics. There are two sub classes of advanced ceramics. One is called electro-ceramics and the other is structural ceramics. As the name suggests, electro-ceramics actually deals with the electrical properties. There are varieties of electrical properties, as I mentioned few minutes back. So, we need or there are large variety of properties, which can be exploited for industrial purposes or application point of view and those things were electrical properties is the primary properties, which is exploited. They are called electro-ceramics.

Under that group, you have various applications, various properties as well as their application areas. For example, we have electronic substrate and packages. These are basically insulating materials, pure oxides and they can be formed in thin sheets form or different other application techniques can be used to form different shapes. We will discuss them at a later stage. So, but basically, in the electronics industry, you need many insulating oxides, particularly aluminum oxide is one of them. Then there was nitrides also, which can be used. But, they exploit and or in those applications, we really exploit their insulating properties.

Then, you have dielectric properties, ceramics dielectrics. The insulating materials also have a good capacity or dielectric constant and therefore, some of these oxides can be

used as miniature capacities. Particularly used in electronics industry. Many of these dielectrics, once again have a very special property called piezoelectric property. Piezoelectric property is a property in which we can develop certain voltage by applying a mechanical stress. So, if you stress them, apply some mechanical stress, it generates some voltage. There are many oxides or mixed oxides, which develop this properties and they are extensively used in the electronics industry for many different purposes. We will discuss them at a later stage, but there is another very important group under ceramics, where piezoelectric and dielectric properties will be exploited it to develop different devices are functional materials.

Then, you have another group called magnetic ceramics. Although, most of the ceramics are non magnetic, but there is a special group of ceramics, which actually have a very interesting magnetic property and they are comparable with the normal metallic magnates by like iron, cobal and nickel. They can be used both has a temporary magnate or electro magnate and also as a permanent magnate. One example, I have shown you, little bit, few minutes back is barium ferrite or strontium ferrite, which actually has a permanent magnate property. So, there is a group of magnetic oxides also present are available to us. We have then another conducting ceramics. These are, we have discussed insulating ceramics here and then we have magnetic ceramics and then conducting ceramics. They can be semiconductors; they can be conductors or even super conductors. So, there are very, very, basic sciences that we have understood, how as physics we have understood, why these ceramics or these compounds behave in this manner. So, there is gamut of many different compounds, which have this conducting property. So, they can be classified or the group can be classified as conducting ceramics.

The last one in this series is optical ceramics. Although ceramics in general are opaque, that is, light cannot pass through it. However, under special circumstances, if you can fabricate or process them in a special way, then ceramics can also be transparent, almost like glass. These are, optical ceramics is not glass. Glass is a different class. We have not discussing here. But, some of these oxides, can also be transformed into a transparent material by heating at high temperature. Under special conditions, one can make absolute transparent ceramics like glass. But, there are crystalline materials and they have many different or special property, which we can exploit for different device making.

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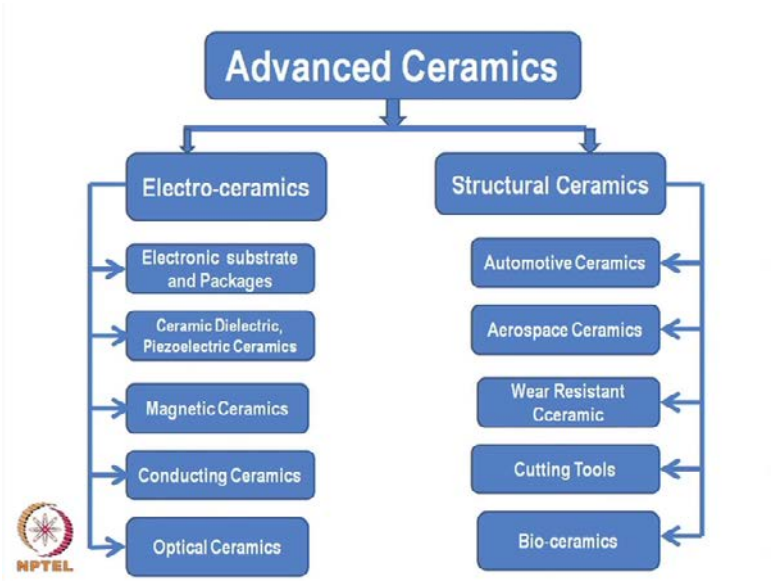

For example, electro optic material or optic electro material can be developed and there are many different things. So, we will discuss these things under the advanced ceramics group of materials. Besides electro-ceramics, you have another very important group, where we actually use the mechanical property or mechanical behavior of this ceramics and that is why they are called structural ceramics. So, it is a mechanical property which becomes important here. They also can be classified under different groups like automotive ceramics. Well, automotive engine is primarily, as we know of, primarily made of metallic materials; different kind of alloys because it has to withstand very high pressure as well as very high temperature, because of the combustion of the fuel. But, ceramics can replace some of the metallic components in this case.

One of the advantage of ceramics is it can high temperature and therefore, better than metallic materials and therefore, it has an advantage. It has an edge over metallic materials. In addition, under compressive load, they can also withstand very high pressure or very high stress, mechanical stress. So, some of the components of the automotive sector can be replaced or has been replaced by ceramics. Particularly, by some of the top ceramics and the advantage is, you can operate the auto engine at a relatively high temperature.

It is also known from thermo dynamics that if you operate it cannot engine at a high temperature, its efficiency goes up. So, that is the driving force. That is the attractive

feature of ceramics by using some auto components, particularly the engine block. You can raise the temperature of operation of an automatic engine and thereby have or get a much higher efficiency. So, actually it helps in two ways. It consumes less fuel and less pollution. So, ceramics has a great advantage, if you can use that under high temperature conditions or high pressure conditions.

The other group, next group is the aerospace is almost extension of the automotive sector. You can have turbine blades in the aerospace or aero engines. The turbine blades are normally made of very high quality metallic alloys, but it has its own limitation, as far as the temperature of operation is concerned. If you can coat them with a ceramics, which can resist much higher temperature, you can operate a gas turbine at a much high temperature and therefore, get high efficiency and less fuel consumption. So, this is once again another attractive feature of ceramics, where you can use them under very stringent conditions, high pressure conditions as well as high gas velocity conditions, as well as high temperature conditions.

So, these are where it is the, these are the areas where you actually exploit the high temperature and high strength conditions or thermo mechanical properties of ceramics to generate a better and more efficient engines. Because of the hardness, we knew about abrasion resistance, but then it has been extensively used these days for many wear resistant ceramics, may be different kind of ceramic coatings. When you talk about abrasive on the traditional ceramics side, it is actually normally the grains, grains of ceramics. But here, the wear resistance ceramics is actually either a lining on a metal surface or a coating on metal surface, a thin coating on the metal surface. So, these are being used more extensively in high application areas as wear resistance coating or sometimes as tiles.

Then, we have cutting tools. Once again, the high temperature and high strength property, the thermo mechanical property of ceramic compounds or ceramic materials are exploited in making high performance cutting tools, high speed cutting tools, because it generates, at the cutting tip, it generates very high temperatures, when you are trying to cut metals or turn metals with some cutting tools, ceramics is a much better option than the normal tools, tiles. So, it needs high temperature and high hardness at high temperature, high hardness and that can only the provided by ceramics materials.

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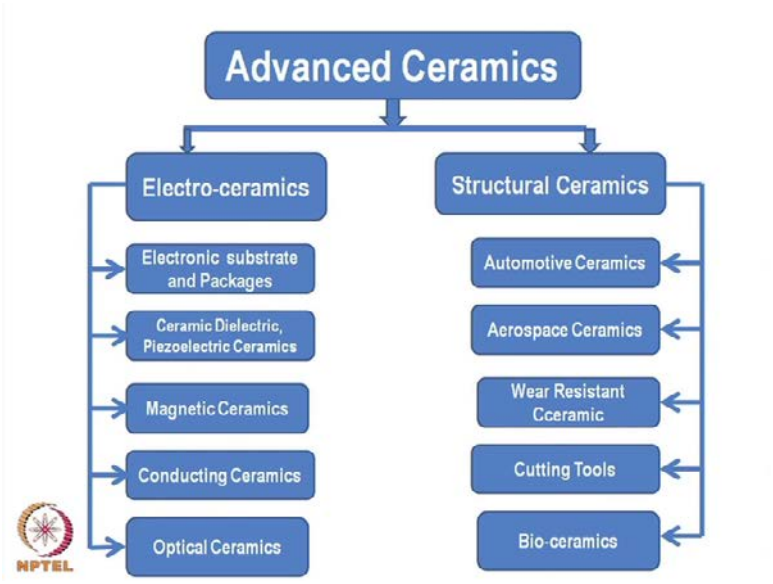

Cutting tool applications has become again a very, very important application structural ceramics. Finally, a completely new area of ceramics has come up once again in the last couple of decades, two or three decades and this is called bio ceramics, biomedical implants. In our body, we have bones and those bones are basically, one of the components of the ceramic materials, hydrated calcium phosphate or sometimes it is called hydroxyapatite. So, bones contain lot of ceramic materials or compounds and that can be artificially made outside the given body and can be replaced. If there is a fracture in some of the bones, in some of the joints, in particular either knee joint or hip joint, so they are actually the load carrying points of the joints of the human body and you can replace them with ceramics, the fabricated ceramic shapes. Therefore, there is huge potential of ceramics being used as biomedical implants and it is really been used these days.

In addition, there are many other ceramics, which can also be used for bio medical purposes and therefore, that group of ceramics, of course, not only uses the mechanical property, high strength of the materials or high hardness of the material or abrasive property of the material but also it needs different kind of chemical, inertness, as well as some times reactivity with the body fluid. So, ceramics is inert as far as the body fluid is concerned and therefore, ceramics, a group of ceramics has come up in very recent years is bio ceramics. So, there are whole lot of ceramics materials available to us, whose properties were not known earlier, may be 50 years back, we are not knowing many of

this properties of these oxides, some carbides or nitrides, but now, we have understood many different properties and naturally more and more applications areas are coming up. So, that actually comes from the so called advanced ceramics, which is quite different from the traditional ceramics, which we have discussed few minutes back.

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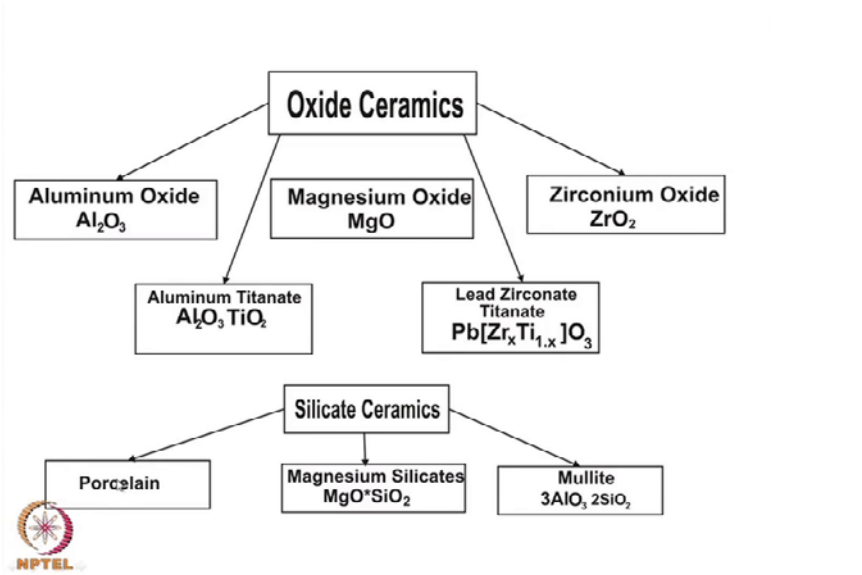

Well, we start with the different classifications. As I mentioned earlier, there are oxides, there are carbides, there are nitrites and all of them are grouped together under ceramics. So, among the oxide ceramics, we have earlier mentioned, once again I am reemphasizing that there are aluminum oxides, there magnesium oxides, and there are zirconium oxides. These are simple oxides, where only one particular metal is involved along with oxygen. Whereas, there are complex or mixed oxides, sometimes they are also referred to as mixed oxides like aluminum and titanium, that forms aluminum titanate.

Then, there is mixed oxides for its solid solutions of lead oxides, zirconium dioxides and titanium dioxides, which are called lead zirconate titanate. Sometimes, in brief, it is called pb z t. Here, silicate ceramics; silicates are basically used in traditional ceramics. Most of the silicates, if there naturally occurring; some of these silicates are naturally occurring and porcelain is one of the areas where silicates are very much extensively used. But, in addition, we have more purer variety of oxides like magnesium silicate or 3

ALO 2 2 SIO 2, it is a mixed oxide or aluminum oxide or silicon dioxide or a particular compound or particular mineral is called mullite. These have different properties.

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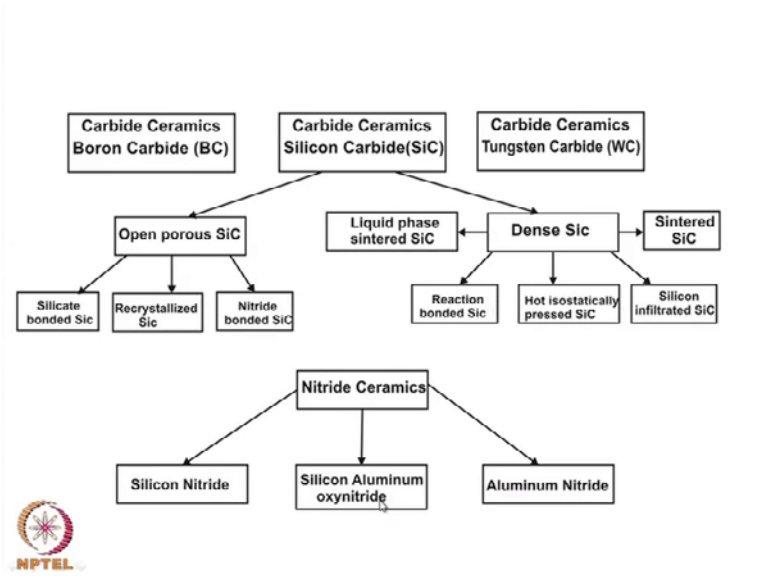

Once again, they can be used as a refractory material, high strength or high performance refractory or these are possible, it can be used in some of the insulating components. Well, besides oxides, you have carbides and nitrites and there are many different carbides and some of them have been already discussed. So, here is boron carbide. One of the hardest material next to diamond. The boron carbide is one of the hardest material next diamond and it is an industrial product. Silicon carbides is extensively used as structural material and structural ceramics and then you have tungsten carbide, which has been known for quite some time, but it also can be grouped under ceramics, because it is a basically a carbide. These carbides are tungsten carbide, has been use in cutting tools for a long time.

But, today some of the tungsten carbide has been used by or replaced by other more advanced ceramics like silicon aluminum oxynitride or even silicon nitrite and so on. Well, ceramics in general are porous because the basic raw material from which most ceramics are prepared are powders. So, powders get consolidated and then are given a shape, a geometric shape and then you actually hire them or same them at a high temperature and while the mechanical strength increases, but all the pores, the inter particle porosity or openness need not get completely sealed. So, you do not get

completely dense ceramics all the time. It is, you need special attention to make completely dense material. But, in general, you start with porous material. So, ceramics are in general porous. We will see at a later stage, how this porosity can also be utilized for many different industrial applications, but generally porous or the general tendency is to reduce the porosity. Sorry, so you have open pores in silicon carbides. We can have open pores and these pores, sometimes has to be sealed or you have to make a dense material and for that, there are different techniques like, we add some additional material, so we have silicate bonded silicon carbide, recrystallize silicon carbide and nitrite bonded silicon carbide.

In most of the ceramics, many times we use some bonding material because bonding is always difficult in ceramics because particles or fine powders are bonded together, so that, you get a strong material. So, there are different kinds of bonding mechanisms or bonding philosophy, so which one can make a dense material. These are silicon bonded silicon carbides, silicate bonded and then we have recrystallized. That means, you heat it to very high temperature, so that you do not need any other bonding, but they themselves bond together. That is what you call recrystallized silicon carbides. Sometimes nitrides, silicon nitrites is added as a bonding material. So, these are variety of different products one can make from the basic materials of silicon carbides.

On the other hand, we have dense silicon carbides, where a liquid phase has been added. Some open have been used. Different oxides have been used. They form a liquid phase at very high temperature and then fill up the pores and that is why we get a dense material. Sintered silicon carbides is, once again at a very high temperature, just like we crystallized silicon carbide, this also a high temperature sintered silicon carbides. Silicon infiltrated silicon carbide, that means, at high temperature silicon melts and then fill up the pores in between the inter particle space. Inter particle spaces can be filled up at silicon metal and that is silicon infiltrated silicon carbide. Hot pressed or hot isostatically pressed.

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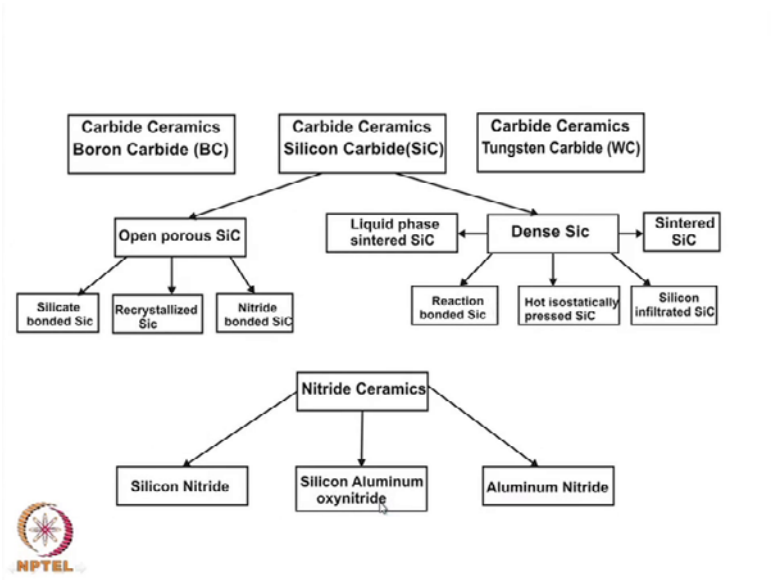

Well, normally ceramics and initially pressed or given a shape or consolidated at a room temperature and then heated. But, in this particular case, this is a variety of material or a particular type of material, in which material is pressed or consolidated and heated simultaneously. Therefore, you can get a much finer grain material and this material has much better mechanical property than the normally porous materials. So, there are different techniques of making the same material in different microstructures or different state of consolidations and accordingly, develop different mechanical properties. So, micro structure is a very important aspect of preparing or developing structural ceramics. We will discuss them again in greater details at a later stage.

Nitride ceramics, we have discussed oxides; we have discussed carbides, then these are the few examples of nitride ceramics. Simple one is a silicon nitride and then you have oxynitrides. So, it is a combination of silicon, aluminum and oxygen or you can have aluminum nitride. So, these are all different covalently bonded materials and having a very high strength as well as high temperature property. So, there are nitrides of different types. We will take examples of that at a later stage.

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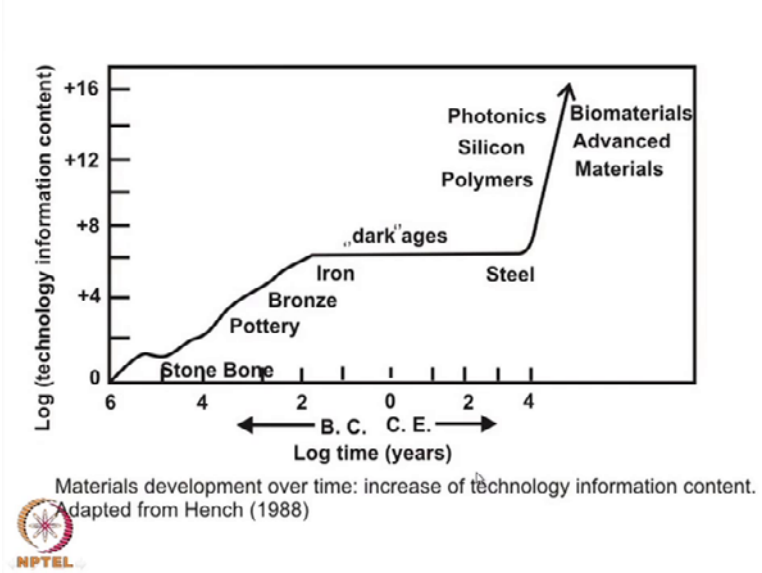

Materials development over time: increase of technology information content.
Adapted from Hench (1988)

Well, we have just given you some idea what is the so called traditional ceramics. That means, ceramics materials which are known for a quite long time and then we are beginning to know more different kind of materials, more purer variety of materials, different kind of compounds, which are having different exotic properties. Whether it is a mechanical property or whether it is electrical property or so on. So, you have a group of materials which are being developed or coming up as having many exotic properties. Obviously, these exotic properties can be exploited for our benefit for industry purposes and so on. So, that is a clear distinction between one group of traditional ceramics where the raw materials are primarily clay based products or the naturally occurring raw materials, whereas there is a another group of materials, pure oxides, synthesized compounds like nitrites, and carbides. They are not available in nature as such. So, we have to take purer variety of material and then synthesize under laboratory conditions are in the industrial conditions and develop different properties.

So, we will not be discussing in this course about the traditional materials any more, but we will focus our attention to that exotic materials, specially prepared material, so that, you can develop unknown properties and exploit them for our benefit. So, there is a development, which is taking place over centuries, right and this is the kind of graph one can plot.

We can say, the so called material use is concerned, the whole spectrum of the centuries can be divided in different parts. It started with stone age, then came pottery or white wares and then came metallic materials and we tried and learned how to extract metal from the minerals. One came from the copper age, where the bronze came in and it is an alloy of copper and zinc. Then came the Iron Age, where you understood, mankind came to know how to extract iron, the largest or tonnage wise the largest group of materials produced used for different structural applications. So, this is how it got developed over the centuries. These are all Before Christ, BC. Then there is a null period. Not much of development, two plus as far as new material is concerned.

Then of course, after iron, one could find out the advantages property of steel and then suddenly there is an extensive development or extensive knowledge as far as the new materials are concerned. We could understand the semi conducting property of silicon and then we also came know about polymers, which are a group of materials itself and then photonic materials. Photonic materials are basically like optical fibers, or basically glass fibers. So, glass were known but the basic property or the development of glass fiber, we came to know only about 40 50 years back.

Then, we have advance materials. Some of them, all of them are not ceramics materials. Some of them are composite materials, ceramics metals, metal metal composites and then as I mentioned biomaterials. Biomaterials also include; I gave the example in context of the ceramics, but ceramic materials is not the only material which can be used as biomaterials. Biomaterials can contain metals, polymers, composites and so on and so forth. This steep rise is coming up and it is continuing now with the explosion of knowledge, the explosion of scientific knowledge which we have been generating over the few decades.

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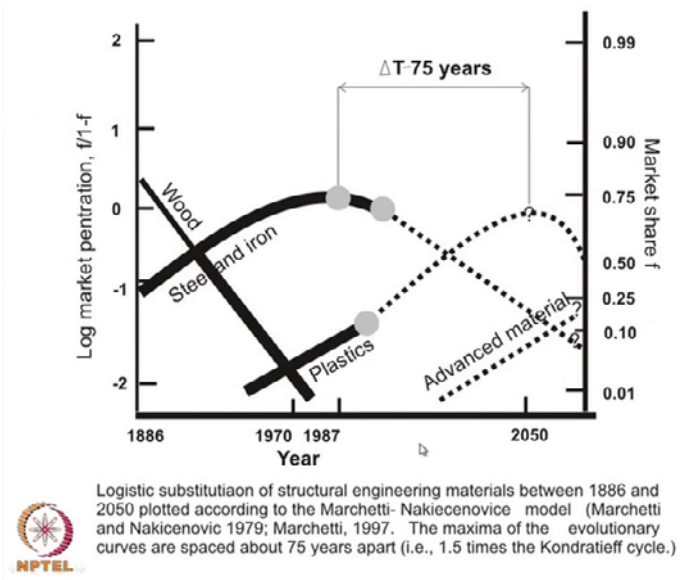

Logistic substitutiaon of structural engineering materials between 1886 and 2050 plotted according to the Marchetti- Nakiecenovice model (Marchetti and Nakicenovic 1979; Marchetti, 1997. The maxima of the evolutionary curves are spaced about 75 years apart (i.e., 1.5 times the Kondratieff cycle.)

So, this is the era where advanced materials have come in and advanced ceramics is one of the components of that. If you take this graph, you will see the natural materials like wood, the use of wood is going down, in fact, to some extent intentionally, because of environmental issues. Steel has been started a couple of centuries back and then we have an increase in their use, but around 1987 80's or 90's it got its peak and currently, it is dropping. So, the use of steel is dropping as far as the structural material is concerned. Some of it is getting replaced by plastics, but many of them are getting replaced by composites and ceramics. So, ceramics has not been specifically mentioned here, but these advanced materials actually constitute a major component is ceramic materials, right. So, you use of advanced ceramics is increasing and it is expected to increase for quite some time now. As you can see this graph, it has been extended beyond 2050.

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Well, now we come to the raw materials, raw materials for the traditional ceramics. Because, we have discussed for traditional ceramics and advanced ceramics and we have tried to differentiate from the property point of you, but there is a strong dependent on the raw materials use for this and there are different components or raw materials, particularly in traditional ceramics. As I mentioned some time back, there are, recall sometime back is triaxial porcelain, because there are three different components of this composition. One is plastic material and there is fluxes. There are different purposes for which there are used and then we have Fillers, which provides the basic mechanical strength to the body, ceramic body. So, these are three components of the white ware body or the traditional ceramics materials. One is the plastic materials and there is fluxes and another is fillers. So the plastic materials is basically clay or talc is another silicate, basically magnesium silicate, hydrogen magnesium silicate and then we have feldspar, and that is again another mineral which is used as a flux, because it melts at a low temperature.

Then, we have some non fluxing materials like quartz. So, these are the three components normally used as a raw material for the traditional ceramics and they are all natural occurring. It needs little bit of mineral they differentiation, and then they can be directly used for the product fabrications, whether it is crockery or whether it is tiles, sanitary wares and so on. So, with this we close this lecture as far as the traditional ceramic is concerned. In the next lecture, we will see what are the different raw materials

used for advance ceramics and then what are the different or the different common ceramics processing techniques, which give rise to the product formations or the product development.

Thank you.