Advanced Materials and Processes
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Lecture – 03
Introduction (Contd.)

Hello, welcome to NPTEL, I am Jayanta Das from department of metallurgical and materials engineering, IIT Kharagpur, I will be teaching Advanced Materials and Process. Today we will try to learn the different classifications of advanced materials, which means structural or functional.

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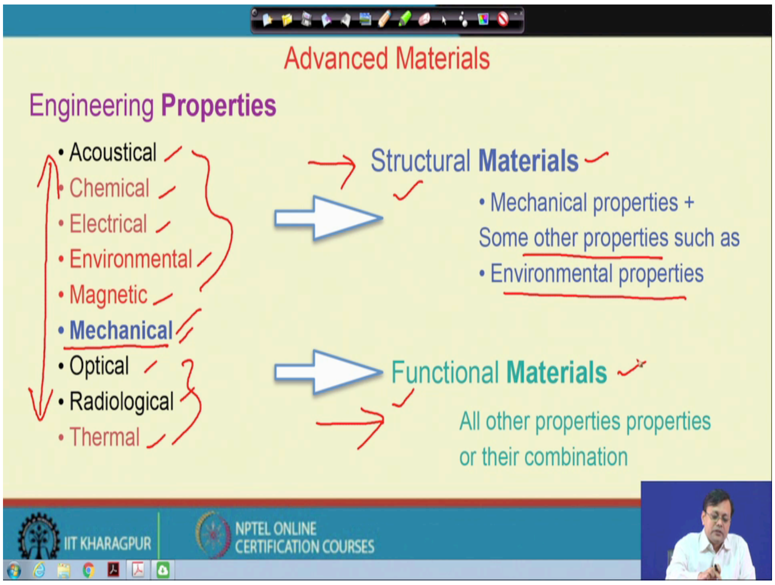

As I discussed earlier that 9 engineering properties are very much important for any applications. So, in the left hand side you can see these are the properties, materials has been selected based on all this properties like, acoustical, chemical, electrical, environmental, magnetic, mechanical, optical, radiological, thermal. Usually among all these 9 properties, these mechanical properties are very much important for any structural application.

So, the structural application is somewhat important; however, mechanical properties mean the strength, toughness, fatigue, fracture along with, ductility, malleability. All these properties fall under the category of mechanical properties. However, when a structural material is selected not only these properties are verified, or characterized whether they really show the desired properties or not; however, some other properties are also scientist usually look at. Like environmental properties. If we like to make an offshore structure, then material not only should show a good strength and mechanical properties,

However they should show also good properties to combat any kind of corrosion, whether it could be aqueous corrosion, or it could be some other kind of high temperature corrosion, like if we have to design a turbine, then both mechanical properties as well as high temperature properties are important. Whereas, usually all these other properties are considered as a functional properties of materials. So, we usually see these two different categories, where structural properties and functional properties and, the materials use for them are called as the structural materials, or functional materials.

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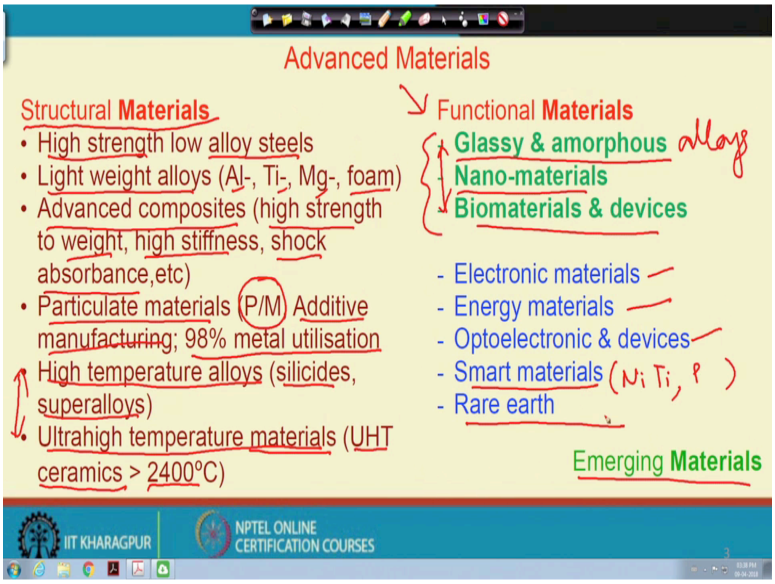

Now, let us see the wide variety of advanced materials, which is what are keep on going developed day by day and, what are those materials and if you can simplify all these different materials. So, in the left hand side you see, I have listed the structural materials, like advance low alloy steels, or high strength steels light, weight alloys we know the density of aluminum, titanium, magnesium those are very very less, below 6, also we can make very light weight structures by some foams, or metal foam, where a metal a network structures is there, which is in combination with some air bubbles those are called as foam.

Also, the advance composites, these composites are being developed in consideration with high strength to weight ratio, also very high stiffness, like if one has to design a aero plane wing. So, the stiffness should be very high. Otherwise the wing will be bended and therefore, composites or some light weight alloys, with some composite microstructure, lamellar structure all these things are considered. At the same time, these composites are also prepared for good shock absorbance properties etc.

Now, the fourth class of materials are particulate material, particulate materials means metal with particle shape, those particle size could be different from micrometer to nanometer, in different length scale. And those are usually processed by powder metallurgy technique, and, we take the advantage of additive manufacturing technique, where we start from the powder particles and use some energy source whether it could be laser and, then integrate or make bonding between those particle in order to make a bigger object, or desired object, or pre-designed object using some software.

So, the laser beam runs across a pre designed shape and, that is called additive manufacturing. There is definitely a large benefit of these additive manufacturing over conventional casting process. Because, we know the pre desired shape, we do not need any risering, or like in case of casting almost 40 percent metals become useless, because of cutting down of the risers and different gating system and so on. Therefore, these additive manufacturing become very popular these days, where 98 percent metal could be utilized.

Now, the other category of materials usually for higher temperature here, high temperature alloys like silicides based composites, or superalloys which are used at higher temperature, here higher temperature means we are talking about above 300 °C and so on, up to let us say something like 1000 °C to 1200°C and, people are keep on developing these alloys. On the other hand, there is also another category of materials those are called as ultrahigh temperature materials.

Here materials we intentionally used because those are mostly ceramic, because the melting temperature of ceramics are very very high, mostly above 2400 °C. And those ceramics can sustain very high temperature and can retain the strength and therefore, the large effort is being made these days to develop these ultrahigh temperature ceramic.

Whereas, the second category of these advance materials are the functional materials. The emerging or very recent development of these materials has occurred like glassy and amorphous alloys ok, alloys, nanomaterial, biomaterials and devices, in all these three cases definitely we need some mechanical strength; otherwise we cannot use this material. At the same time there is also need some other properties which are functional properties

Now, lot of other materials also have emerged these days as a functional materials, like electronic materials, like energy materials means energy storage, As well as energy harvesting either from sunlight, or may be some other sources, there are several optoelectronic materials and devices, smart metals or materials like nickel titanium ok.

Where material remember it is shape that is called as smart material, or may be piezoelectric material and all these materials falls under smart materials. At the same time there are large effort also getting involve to develop rare earth base functional materials, in several magnetic materials sensors and so on. There are so, many application of rare earth element and so on, which are very much important.

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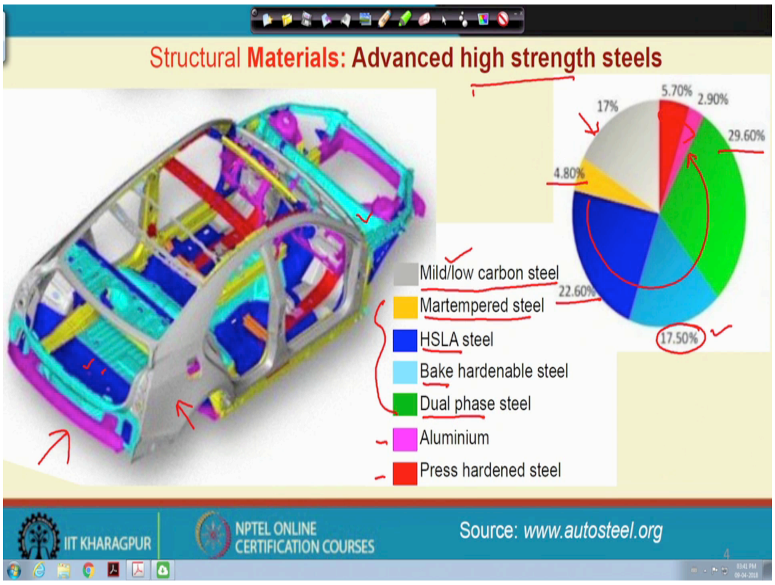

Now let us start with the structural materials and, how we are going to apply and develop the steels from very old concept, on today if we look at the structural component of a high end car, which are shown in the left hand side here, you see different colors are given in order to show different grade of steel. Where a conventional grade of steel are well known, which are also used for any kind of house hold structure making like mild steel, or low carbon steel.

But there are large number of steels are also used for constructing the cars. These are the portions which are made out of low carbon or mild steel, but here we use high strength low alloy steels, here we use bake harden steel. This is a very special grade of steel where carbon atoms are purposely sit down near the dislocation core and, it increases the strength almost 3 to 4 times. If a mild steel has a strength of 200 MPa the bake hardenable steel goes up to 700 MPa. On the other hand, they have a very good quality of malleability.

Now, dual phase steel are also often used, for constructing. Also little part of aluminium or press hardened steel, in the right side you see the total percentage of the steel used for any car, where dual phase steel cover around 30 percent, where more than 20 percent of the steels are used as a high strength low alloy steel and, bake harden steel is almost like 17.5 percent, only 17 percent of the steels, which are used for constructing a car as a mild steel.

So, one can see that how large amount of advanced structural steels are used these days even for making a car and, the demand is also high to develop these high strength steel. There are many mechanism, there are many assumptions, or simplifications microstructural basis and so on for development. And there are definitely a certain amount of tempered martempered means of martensitic tempered steel are also used around 5 percent whereas, 5 percent are used as a aluminium and press hardened steel in this strange. So, one can see that even these days, for constructing a car all these advance steels are used.

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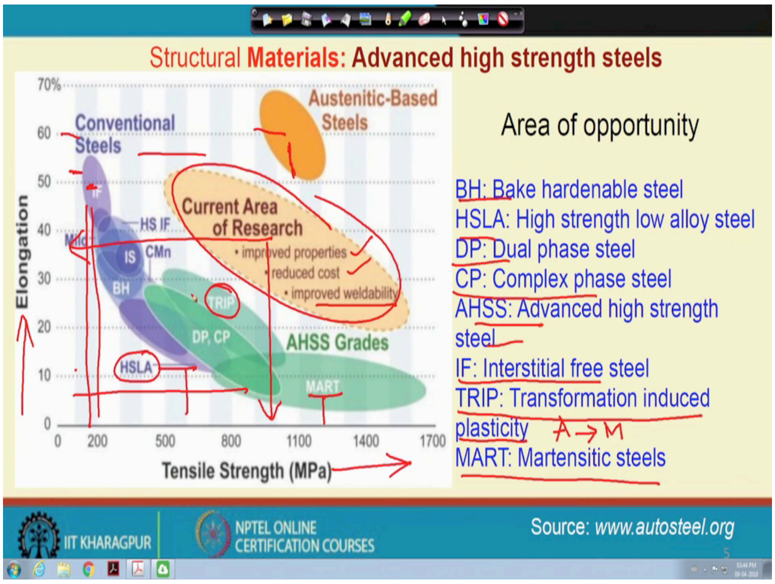

Now, let us have a look at the area of the opportunity, like the bake hardened steels as we said, HSLA dual phase steel and complex phase steels, advanced high strength steels. You can see here, this is the plot of elongation versus the tensile strength. One can see, the conventional steel have a strength level of 200, where one can get something like 50 percent, where interstitial free steel gives you very high ductility and very poor strength. Whereas, a HSLA steels are lying here, which has something like 10 percent and 500 mega Pascal strength, the MART stands for the martensitic steels, which has very high strength whereas, very poor ductility means the formability is very poor.

So, the current area of research of development of steel is lying here, where we need improve mechanical properties, in terms of elongation means malleability, or plasticity, or shaping as well as we need a higher tensile strength. And this is the demand on today. Definitely reduction of the cost and joining of the steels in terms of weldability is also important. Whereas one can look at the austenitic base steels are very highly alloyed steel, they have relatively higher ductility, or elongation as well as a relatively higher strength than the conventional steels.

Also that is another category of steels, which is also at front stage that is called transformation induced plasticity here, during deformation an austenite phase transform into maternsite ok. And also there could be some twinning induced plasticity and, this

TRIP get steels are also very well known for very high toughness because, they absorb very high energy before failure.

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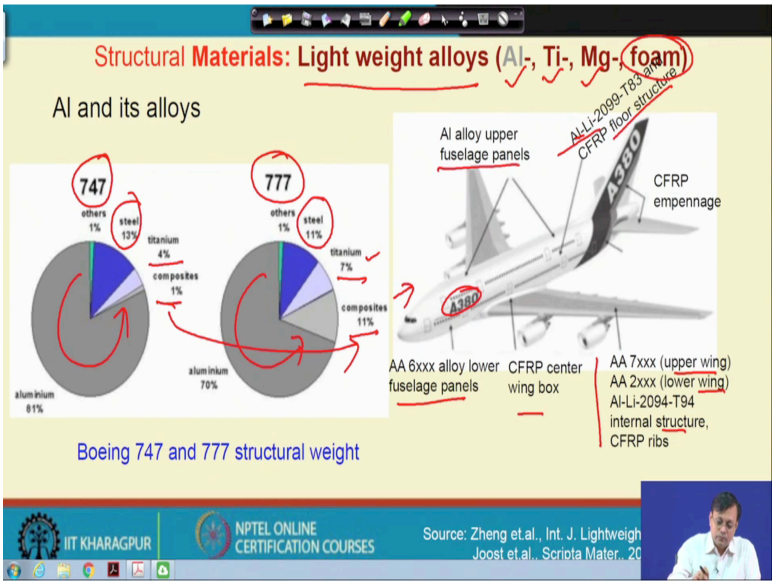

Now, let us look at for the structural materials the lightweight alloys, in case of lightweight alloys mostly aluminium based alloys titanium alloys, magnesium alloys and their foam are quite relevant. In case of making an aeroplane as an example a 380 can see that, how much is the usage of different aluminium base alloys and, you can see all over. So, the fuselage panel ok, the floor structures ok, and then the upper wing, lower wing, internal structures, the wing box, fuselage panel all of them are made out of aluminium alloys, or aluminium lithium alloys.

There are different grades of aluminium alloys, on the other hand one can look at a very old model of 747 Boeing and these days 777 Boeing, here also the application of aluminium alloys are very high, almost 80 percent and also let us say something like 70 percent, definitely one can look at the use of titanium has increased a little bit, which is also a lightweight alloys and much higher strength, than the aluminium and let say the usage of steels are also get lowered with the expense of composites and let us say titanium. So, from the earlier work and earlier ideas of using composite has changed and, from 1 to 11 percent almost 10 percent has increase these days.

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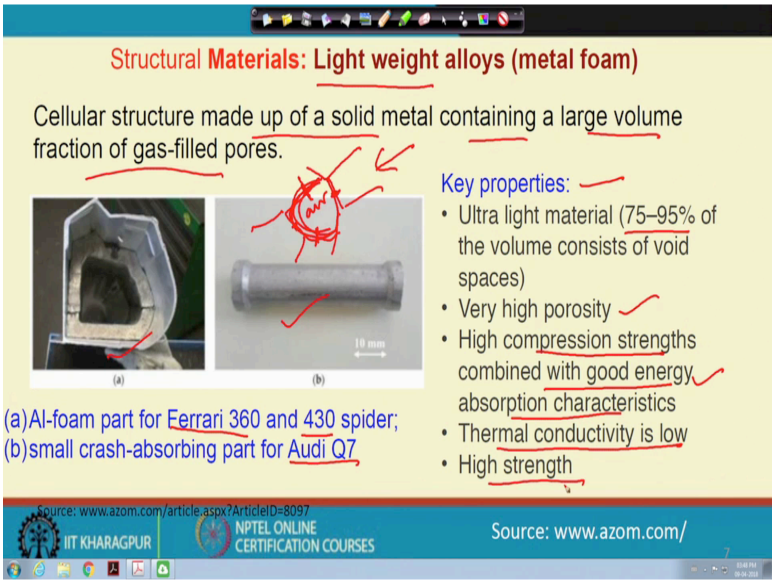

Also as I said that the metal foams are very much important, to produce light weight materials, which is basically a composite like microstructure with air bubble in a in a metallic component. So, I show you two of the example, from the Ferrari 360 and 430 here is one component that is a aluminum foam, also the Audi 1 component, these are all foam structures. Mostly it looks like a cellular structures. So, cellular structures means these are the metal part, and, inside there is air bubble ok. And it is made of a solid metal containing large volume fraction of gas filled pores, and, this could be open pore or maybe the close pores.

However the key properties of such metallic foam is ultra light weight because, 75 to 90 percent of the volume consists of only void or spaces, due to very high porosity and, very high compression strength combined with good energy absorption, because whenever we put some thrust, then these foam structures basically here breaks and, it absorbs lot of energy.

Because once it breaks then the crack tip get blunted , there is air inside and it has to find out a neighboring places where, the new crack has to be open. And therefore, it can absorb a very high amount of energy, thermal conductivity is also low yes, because of the discontinuity also, their relative strength to weight ratio is also high.

So, that is why we choose these lightweight alloys for structural purpose, I will also use metallic foam for any kind of energy absorption purpose, or also for construction.

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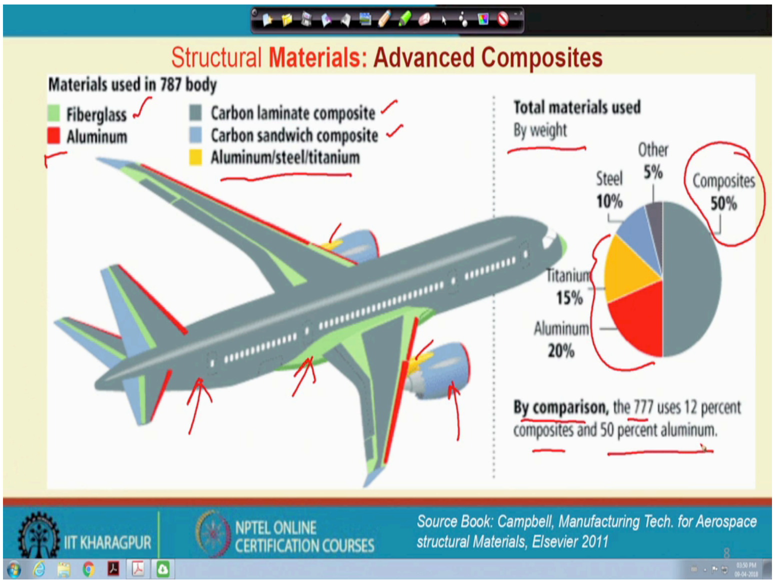

Now, let us a talk about the composite. And what is the idea of composite these days because even for making flight, so much composites are in used. So, here I show the conventional aluminium alloys, or steel, or titanium which are are shown here with yellow colour. And the pure aluminium is also or used. So, this is the area where these alloys are used. Whereas, the rest of the structures are used with carbon sandwich composite, or carbon laminate composite and also with some fiber glasses.

So, here these are the component where, fiber glasses is often used and, here some sandwich composites are used and these are the laminated composite, even though the outer case is made out of aluminium alloys. So, the total material that is used for making such flight, by weight one can look at, where the composite structures inside by in terms of weight is almost reaches up to 50%. So, by comparison, the 777 uses 12 percent of the composite and 50% of the aluminium

So, here you see that there is lot of development is going on, even though the idea was to use lightweight alloys, but these days the lightweight alloys, advanced alloys are also replaced by advanced composites.

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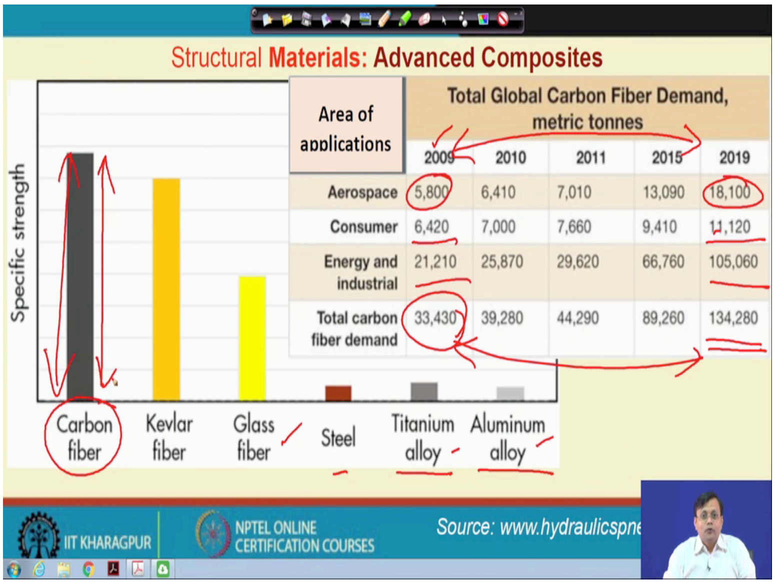

Along this direction, one can look at that why this composite structures are often preferred, compared to conventional aluminum alloys, or titanium alloys, or steel because the carbon fiber has almost a large specific strength, means strength with weight ratio, then these titanium or steel or any glass fiber.

So, glass fiber used as a reinforcement, with some other magnesium, or aluminium matrix that can also be used. The total global carbon fiber demand, in terms of metric tons in 2009, which almost become three times in 2019 as expected, in aerospace sector, in consumer sector it will be almost like doubled, in energy sector it will be also 5 time. And therefore, the total carbon fiber demand is going to increase and one can see, the total multiplication factor by these 10 years from 2009 to 2019.

So, there is definitely a large demand for making composite using some carbon fiber and, also carbon has a very great advantage because, carbon has the highest melting temperature among all the different element in the periodic table.

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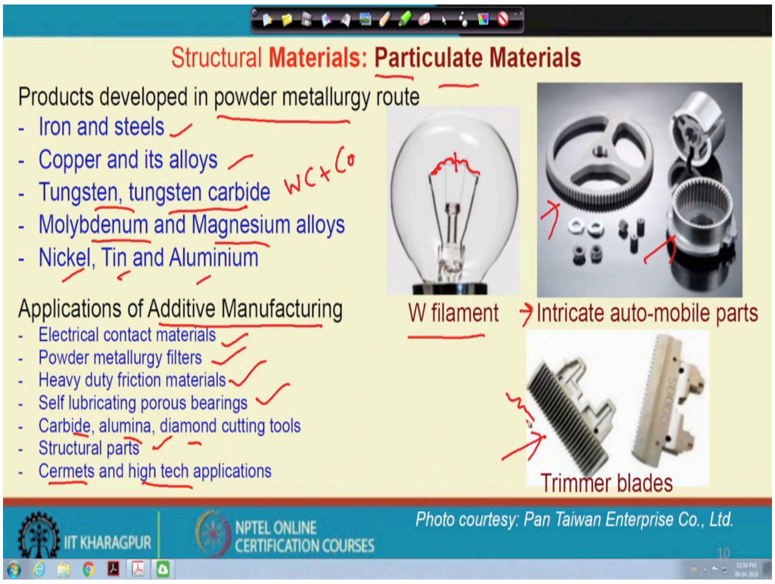

Now, let us discuss about the particulate material, which are used for structural purpose. We know about all these tungsten filaments, which are used in our home. So, these are very small spring and made out of tungsten, there often sagging occurs due to long usage and, the filament goes, breaks actually; however, they are produced by this powder metallurgy technique.

And the same technique from powder particles, we make a larger shape, iron and steel sector copper and it is alloys, tungsten, tungsten carbide means basically Cermets and so on, where tungsten carbide plus Cobalt metrics are used, molybdenum and magnesium alloys and also nickel tin aluminium, all these products, many products are made from this particulate shape. And here one can look at how intricate the automobile parts can be made out of this like a gear and, lot of component, also for trimmer blade where very intricate structures can be made.

So, the additive manufacturing is a manufacturing technique to start from these particles and to make materials for use for electrical contact materials, powder metallurgy fibers, heavy duty friction materials, self lubricating porous bearings, carbide and alumina diamond cutting tools, structural parts and the cermets of high tech application. So, we have a large use of these powder particles to start with and to make more intricate shape with a very fine and intricate structures.

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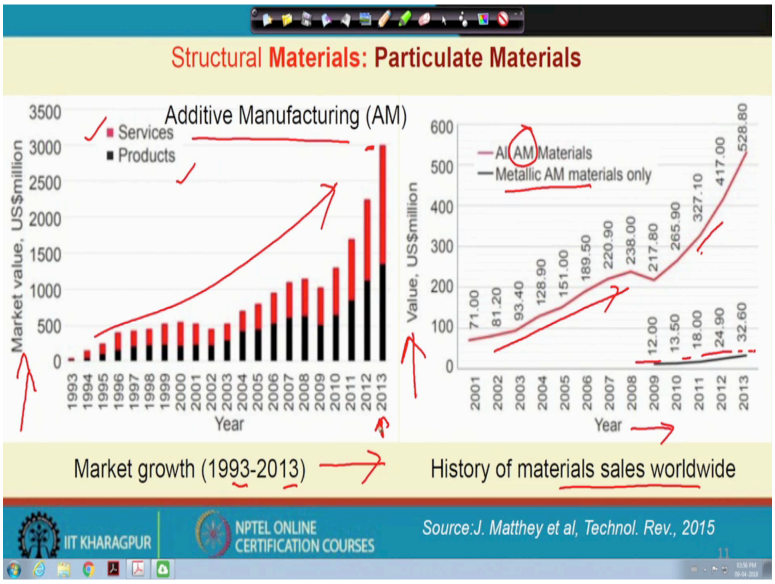

The particulate materials by using the additive manufacturing technique, for making products or services are shown here in terms of the market value and, the market growth from 1993 to 2013, last 20 years. And one can see a exponential growth of the market of this particulate materials for structural purpose, in terms of strength. The very similar kind of scenario, one can look at the value in terms of us million dollars with the year, the history of the material sales as per the world wide, using the additive manufacturing technique. And this is the metallic materials, which are still very less compared to other kind of materials means ceramic, or polymer ok

So, the total market value in terms of us million almost reaches to 3000 million in the year 2013 and, these are the recent data one can have a look at the scenario of current development.

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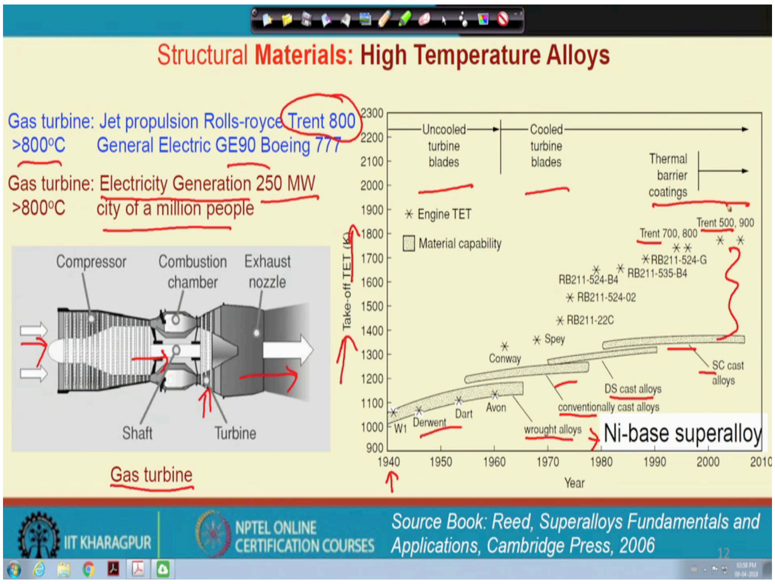

Now, there are also alloys, which are developed for a quite long time from 1919s for used in the gas turbine for the development of space vehicle and also for the aircraft. Here, the nickel based super alloys are quite important, in the left hand side we see a gas turbine engine, where the gases enter through the compressor, which goes through a combustion chamber and, this is the turbine here and goes out of the exhaust nozzle.

So, like as an example, GE or jet propulsion general electric engine, a Trent 800 for GE 90 Boeing 777, those are used for temperature greater than 800 °C, or let us say for electricity generation 250 MW of those kind of gas turbine engine, which can cater service to a city of millions of people. And the production technique has changed time to time from wrought alloys, to conventional alloys, to cast alloys to let us say the single crystal cast alloys. And here this engine, a model Trent from GE. And, one can look at that even though the materials are developed by most sophisticated technique, but there is a large gap between the takeoff temperatures.

So, here turbine entry temperature is a temperature, which is very crucial to get a much better heat extraction from a Carnot cycle. The previously those turbine blades where undercooled, uncooled and here these are the cooled turbine blade and, in the recent days the thermal barrier coatings are often used.

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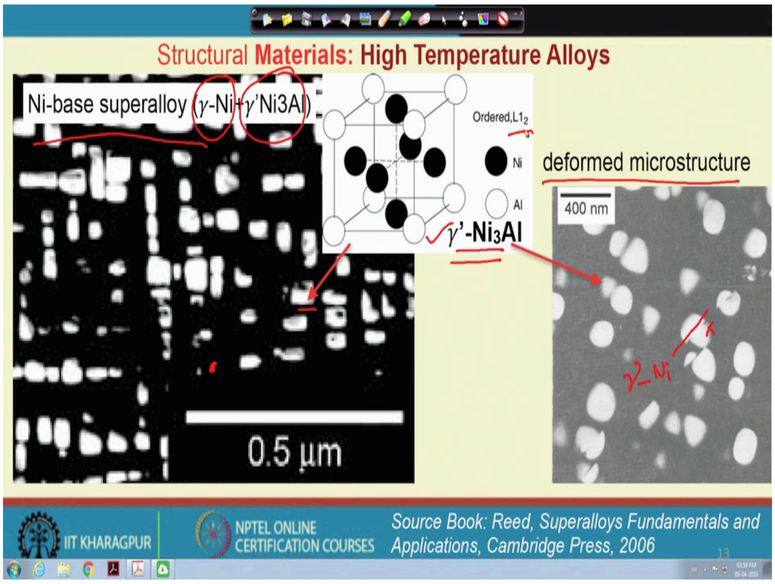

And one can definitely look at the benefit of such, I show you here the microstructure of such a superalloys nickel based superalloys, where the gamma nickel is this phase and the white colored phase are the Ni_3Al precipitate, which is the ordered intermetallic and at very high temperature it assist on dislocation passing, when dislocation going to pass it has to cut through and, this is the deformed microstructure of such a super alloys.

So, we can see we can increase the strength of this gamma nickel matrix by this precipitates, and, this precipitates are ordered structure of L1 two structure of Ni_3Al. And this is the strategy of developing super alloys. So, today we have learnt the different categories of structural materials and, functional materials will be discussed in the next classes.

And we try to understand how these advanced materials are classified and, even today there is a large or demand on developing advance high strength steels. So, one has to look at the light weight alloys, the advance high strength alloys, the foam structures, making some integrate structure from starting from metal powder, where the utilization is very high, yield is very high, it does not go like a casting technology, where metal utilization is less and so on.

Thank you.