**Production Technology: Theory and Practice**

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**Lecture - 01**
**Engineering Materials and their Properties-1**

Hello and welcome to the discussion series on the production technology theory and practice. My name is Dr. Sounak Kumar Choudhury, I am a professor in the mechanical engineering department of IIT, Kanpur, teaching here for the last 34 years. My specialization is manufacturing science in mechanical engineering. Apart from that I also work on the unconventional machining, NC machines, manufacturing automation and so on. So, in this series of discussions we will have 5 modules apart from the lab.

The first module is the engineering materials and their properties we will discuss, next module will be on machining on the conventional machining. There we will discuss the theoretical background on the machining processes, we will also look into various practical machining aspects. We will see how some of the very simple simulations and mathematical models are built up. We will see the thermal aspect of machining, stress strain, how the chips are removed, what is the tool, how the tool wears out and so on.

So, there are different aspects, many things that are known to you, but we will discuss the reasoning. Mostly why things happen that way, for example why the chip is hot and so on. The third module will be unconventional machining processes. There we will discuss those unconventional processes or non-traditional processes, as they are also known, electrochemical machining, abrasive jet machining, electro discharge machining, plasma arc, electron beam machining and so on.

We will discuss how these processes work and what is the principle of material removal in each of these processes. What is the kind of energy each of the processes used and why they are called as unconventional machining or non-traditional machining, what is their use, where it is used and so on. Third module that we will discuss will be numerically controlled machines.

There we will discuss what is the difference between the conventional machines, turning lathes, milling, drilling machine and numerically controlled or computer numerically controlled machines. Then the next module we will discuss about the metrology. We will show you different kinds of tools, different kinds of methods that are used for measuring. You know that the metrology is the science of measurement. So, how these measurements take place without which our production is incomplete.

Because we have to know whether we are making the right thing. So, the measurement is a very important phenomenon and we will discuss that in details. Our sixth module will be the lab module. In the lab module we will mostly discuss the conventional machining section along with the fitting and drilling; some portion of the metrology - how these measurement tools look like and how they are used.

And the second part will be the NC and CNC machines - numerically controlled and the computer numerically controlled machines. There most of the attention will be on the principle of working and how the part programming can be made. In theory section also when we will discuss the NC and CNC machines, we will discuss these aspects. In more details, we will show you in the lab that how these things can actually be done in practice or actually done in practice.

So, these are the 5 modules plus the lab as the sixth module, we will discuss throughout the discussion sessions of this course, which we have called as the production technology - theory and practice. So, the first module is the engineering materials and their properties as you can see in this slide here. Materials, overall, can be sub categorized into the metals and non-metals.

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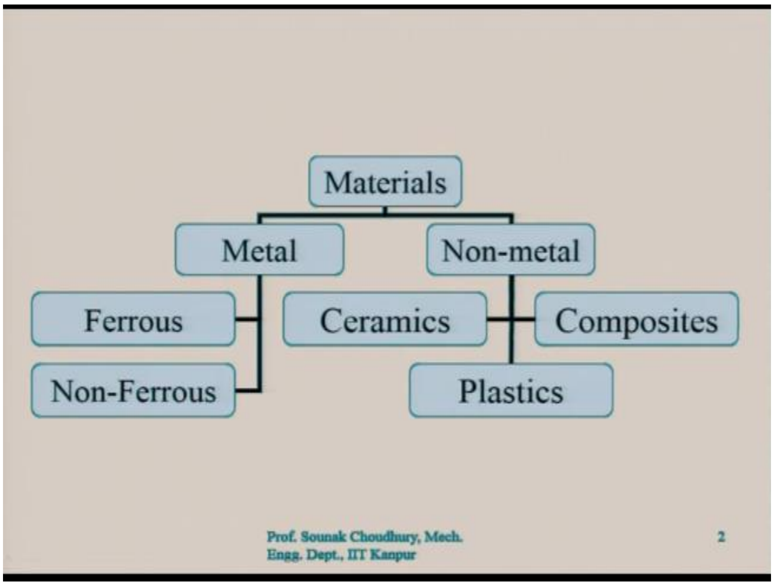


In metal we also have the ferrous metals, mostly based on the ferrous, that is, the basis is the ferrous and there are materials where there is no ferrous. Those are called the non-ferrous materials. Also, there are non-metals and, in the non-metals, we categorize ceramics, composites, plastics - they are non-metal materials. And both metals and non-metals are extensively used in the engineering practice. You understand that the ferrous and non-ferrous metals are everywhere for making blanks, tools and many more.

In the non-metal, ceramics for example, is widely used for metal cutting, for making tools or getting the coating on the tools. Composites are the materials which are light but very hard materials. They are used very extensively these days because they are also lighter than the metals. Then of course the plastics and you see all around us the plastics are there and plastics are also used as the engineering material in engineering practice.

Because the plastics are also very light and plastics have reasonably good properties which are different than the metal which may not be as good as some of the engineering materials. These days there are newer and newer plastic materials which are being invented and some of them are even substituting the metallic parts because they are light, because they can be used in the automobiles, they can be used in the aircrafts for example.

You can see that these days there are gears made of the plastics. Their life may not be as high as the metallic gears but nevertheless they are used because they can be made easily also because there machinability is better than the metal and so on. Those things we will discuss.

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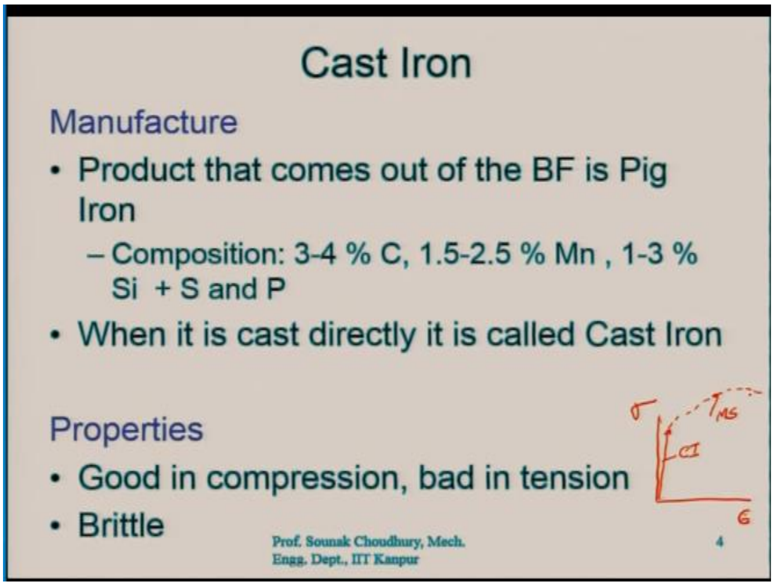


Now, let us discuss the ferrous metals first. Under the ferrous metal the most popular is the **cast iron**, and the cast iron is the product which comes out of the blast furnace that is the pig iron initially. The composition of the pig iron is about 3 to 4% of carbon, 1.5 to 2.5% of manganese, 1 to 3% of silicon and sulphur and phosphorus additionally. So, this is the product which comes out of the blast furnace which is known as the pig iron.

When the pig iron is cast directly, that is known as the cast iron. So, the composition wise it is the same, that is, percentage of carbon will be more than 2% as you understand that because less than 2% will be the steel which we will discuss later. Now the properties of the cast irons are that they are good in compression, but bad in tension; that they are very brittle. As you remember, in the stress strain curve for the cast iron along this Y axis is the stress and this X axis represents the strain.

For the cast iron, it goes just up to this and here it breaks at this point. It breaks because it is brittle, it does not have this function like the mild steel. This curve is for the ductile material and this is for the cast iron. Now for the brittle materials, since they break here, they cannot withstand yielding. So, beyond yielding it does not exist. Therefore, here up to this it is the stress strain curve, for which the slope can be found out.

For the mild steel, which is the ductile material, here the curve can go further like this and there are different kinds of mild steel. So, depending on that the curve can be different but they are good in compression. And for that reason, the cast iron is widely used. You know that the cast iron is used in the building material. To make it stronger, the cast iron rods are inserted in the concrete slabs and so on. They are brittle.

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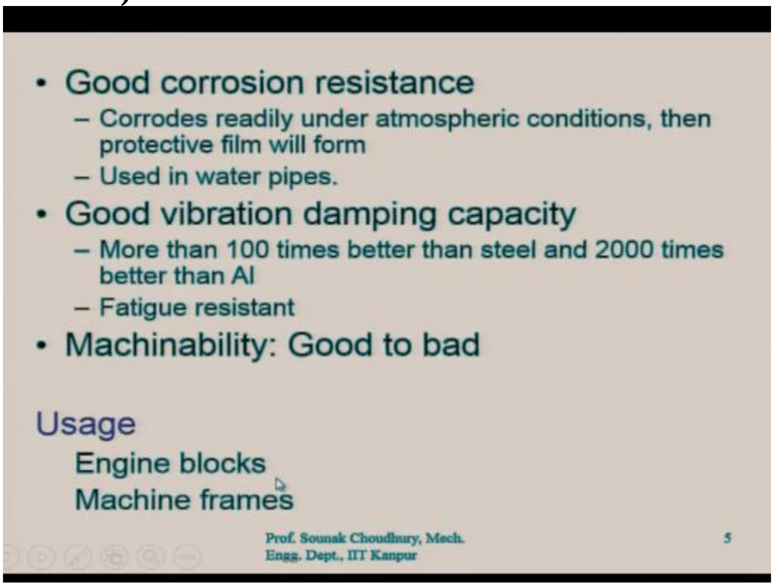


The cast iron has good corrosion resistance. What happens is it corrodes readily under the atmospheric conditions and then that is used as a protective film, a protective layer. So, further the material underneath will not be corroded.The corrosion happens at the top and after that it does not allow the corrosion to go in. Therefore, it is used in the water pipes which are made, as you know,  in huge quantities.

Therefore, the requirements on cast iron is too high . Good vibration damping capacity because as we said they are good in compression, this is more than 100 times better than steel, this is the vibration damping capacity and 2000 times better than aluminium for example, if you compare cast iron with the steel or the aluminium, you can see that this is 100 times better in terms of the vibration damping. So, it has very good vibration damping capacity. It has high fatigue resistance, fatigue is the repetitive load.

So, it can withstand the repetitive load for a longer time than the other materials. Machinability is good to bad in the sense that you know it is a brittle material, it is a hard material and ,during machining it will have discontinuous chips and therefore, we say that machinability is not very good, but also not so bad. Now its usage in engine blocks - cast iron is used widely in making the engine blocks or machine frames.

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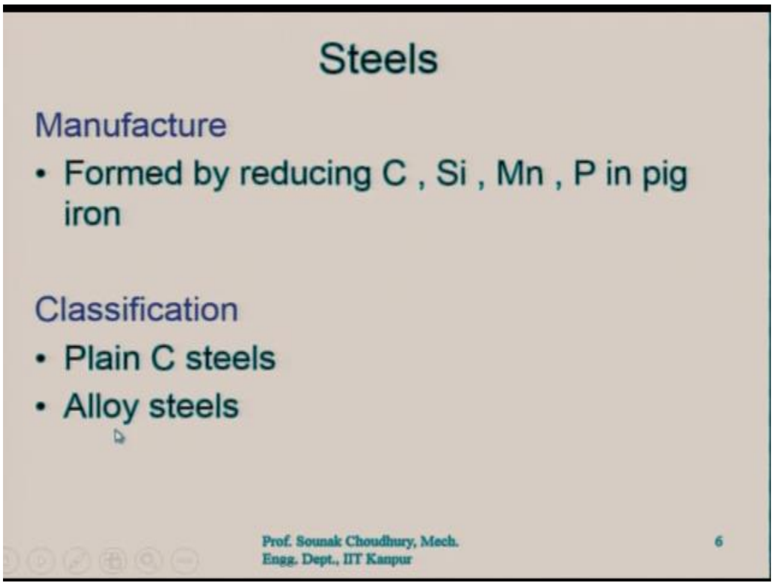


Next is the **steel**, where as I said that percentage of carbon if in case of cast iron, it is 3 to 4% in case of steel it is less than 2%. So, steels are produced by reducing the percentage of carbon, silicon, manganese, phosphorus in the pig iron. So, pig iron is from the blast furnace, there we have certain composition of the carbon, silicon, manganese; reducing those compositions and we are getting the steel. Now, the classification of the steel - there are plain carbon steels and alloy steels.

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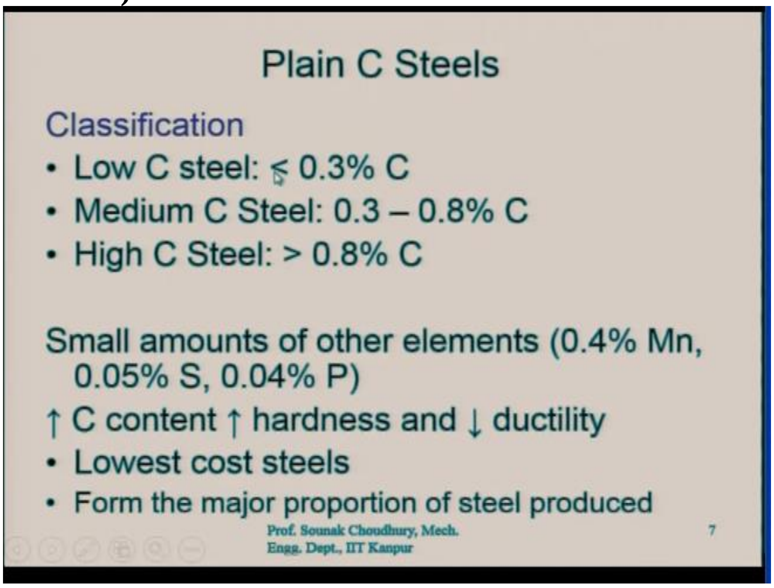


**Plain carbon steels**: under the plain carbon steel we have the low carbon steel where we have the percentage of carbon less than 0.3%. Then we have the medium carbon steel. Medium carbon steel is a little more than the low carbon steel in terms of carbon content and it is between 0.3 and 0.8%. So, you understand that the medium carbon steels have different grades depending on the percentage of carbon. In some grades it may be 0.3 and 0.4, 0.5 and so on but not more than 0.8% of the carbon.

**High carbon steel**: there the percentage of carbon is more than 0.8%, along with the small amounts of other elements apart from the carbon like 0. 4% of manganese, 0.05 % of sulphur, and 0.04% phosphorus. These are the materials which are added along with the carbon in these percentages, which are very small percentages in comparison to what we have seen in case of the cast iron.

Now, more the carbon content, more will be the hardness like in case of cast iron, but less will be the ductility. This is the contradiction between the carbon content, ductility, hardness and so on. Plain carbon steels amongst all other steels have the lowest cost. They form the major proportion of the steel produced because this is cheaper and it is easier to manufacture. So, the plain carbon steels form the major proportion of the steel that are produced in the metallurgy industry.

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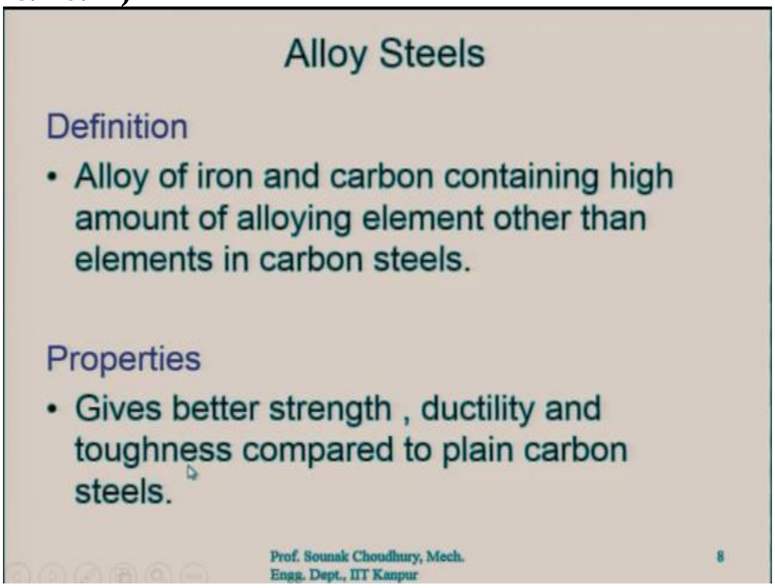


Now, **alloy steels** by definition, are alloys of iron and the carbon containing a high amount of alloying element other than elements in the carbon steel. In carbon steel we have seen that there are alloying elements like manganese, sulphur, phosphorus. In case of the alloy steels, there are high amount of alloying elements other than elements in the carbon steel.

First of all, those elements, such as manganese, sulphur, phosphorus will also be there. Their percentage can be more and there are many other elements which will be used as an as a alloying material and alloying element. Now, the properties of the alloy steels are that they have better strength, ductility and toughness compared to plain carbon steel. This is a major contribution of the alloy steels and the demand in the engineering fields is that the strength has to be more along with the ductility.

Because that will help in the machining - in forming the material. So, those are the demands from the engineering and therefore, the alloy steels came into market since the plain carbon steel and any carbon steels - medium carbon steel or high carbon steel, they were not satisfying these demands of strength, ductility and toughness. So, the alloy steels have started being used in the engineering practice very widely. However, as you understand that the alloy steels will be costlier than the carbon steels for obvious reasons.

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Effect of alloying elements: if you consider manganese for example, manganese improves strength and hardness of the material. Chromium improves corrosion resistance, strength, wear resistance and the hot hardness. You understand what is corrosion resistance, strength, and wear resistance. Hot hardness is something which is different from the hardness in the sense that it is at high temperature, elevated temperature when the hardness is not lost - material is keeping the hardness at elevated temperature that is the hot hardness.

We say that that material has more hot hardness when it can maintain its hardness at elevated temperature that is called the hot hardness property. Next is the nickel. It improves strength, toughness that is to withstand the vibration or shocking shock loads . Molybdenum increases tensile and creep strength at high temperature. Now these effects are given qualitatively but you have to understand that manganese improves strength and hardness within certain level.

So, research was conducted in the alloying material and it is still continuing in the alloying material field. By changing the composition, by changing the percentage of these alloying materials and the combination of the alloying materials different properties can be obtained. So, although it is given just qualitatively, but we have to find out how much exactly certain property is improved and by what extent, that is important.

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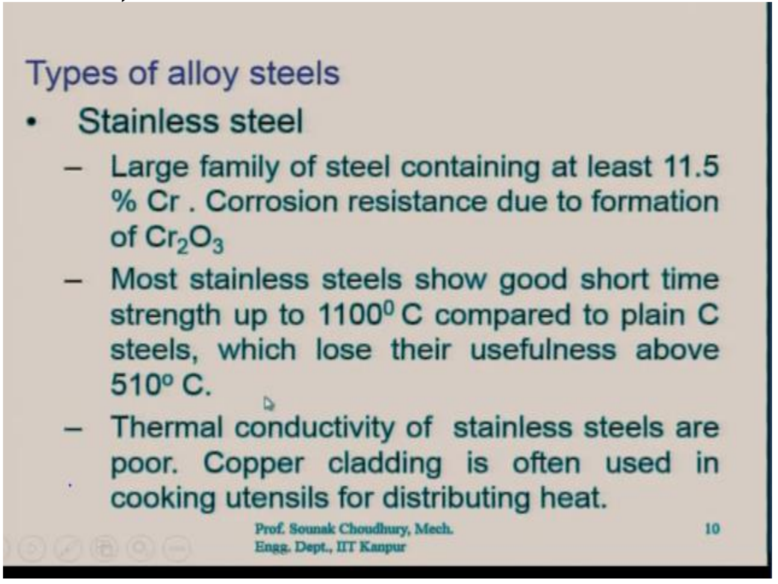


Now, the types of alloy steels. There is stainless steel; stainless steel as you everybody know that nowadays it is very useful and very widely used. Large family of steel containing at least 11.5% of chromium, this is one of the  alloying materials in the stainless steel. Corrosion resistance is due to the formation of chromium oxide since there is chromium. Therefore, it does not allow the corrosion since the chromium oxide is fromed.

Most stainless steels show good short time strength up to $1100^0$C. It is a very high temperature and even at that high temperature it will retain its strength for a short time and after this with the increase in temperature the strength will be less compared to plain carbon steel which lose their usefulness above $510^0$C. So, you can see the effect of the alloying materials.

What we are doing is that in case of plain carbon steel, they cannot withstand more than $510^0$C because they lose their strength and in this case of stainless steel, it can withstand even $1100^0$C. So, more than twice of that. Now, the next property is that the thermal conductivity of stainless steel is poor, copper cladding therefore, is often used in cooking utensils for distributing the heat.

You must have seen the utensils, stainless steel utensils with a copper coating below at the bottom. That is for equal or homogeneous distribution of the heat because the stainless steel is not a good conductor of heat, i.e. thermal conductivity is not very good.

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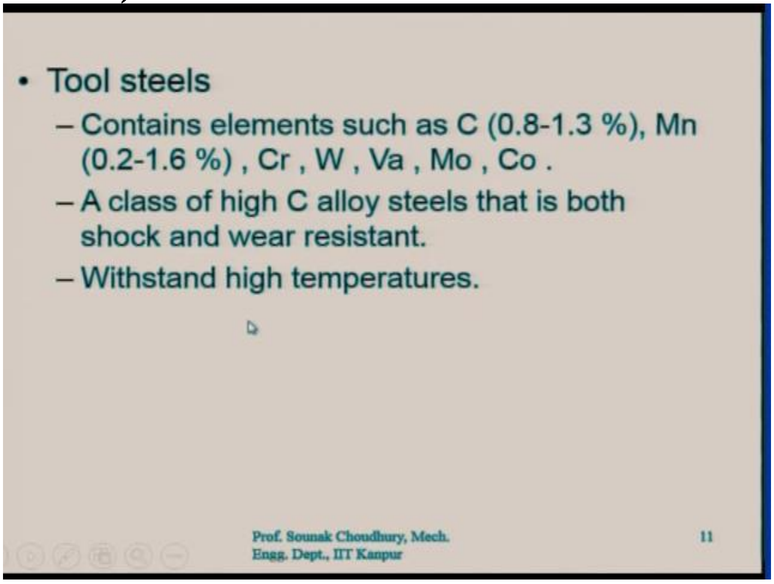


**Tool steels**: by name itself it means that the steels are used to make different kinds of tools for the conventional cutting process - single point cutting, tool milling cutter, drills and also for the metal forming operations dies, punches and so on. Now, tool steels contain elements such as carbon up to 1.3%, it is 0.8 to 1.3%, manganese, up to 1.6% starting from 0.2%. So, it is 0.2 to 1.6% of manganese, chromium then the wolfram that is the tungsten.

So, W came from the Latin word wolfram which is the actual meaning of tungsten. In English it is tungsten. So, it is W but otherwise you can see that chromium is like Cr also Cr, vanadium Va, molybdenum is Mo and then cobalt is Co but this is the wolfram so, this is the tungsten. Now, as you again understand I will just repeat once more that this is a range. So, depending on the exact carbon content and depending on the exact manganese percentage you can have different properties in the tool steels.

So, tool steels grades can be different depending on the percentage of carbon within point 0.8 and 1.3%. The percentage of manganese within 0.2 to 1.6% and so on. Now, these percentages of chromium, tungsten, vanadium, molybdenum and cobalt, these percentages are very small. So, they are not mentioned. In some of them it is 1%, for others it is about 1.6% and so on.

Let us see the other properties of the class of high carbon alloy steels that is both shock and the wear resistant. Tool steel is a modification that is another class of these high carbon alloy steel. It has both shock and the wear resistance properties, it can withstand shock. Now, where we need that shock resistant in the tool still? Consider having a turning tool, the single point cutting tool, which is fabricated out of the tool steel.

So, in case of inhomogeneous hardness in the workpiece which may happen because of the inclusion of hard particles inside the workpiece. Whenever the tool is going through the material and because of the inhomogeneous hardness, the forces will fluctuate. Because of that fluctuation, there will be some shock imparted to the tool.

So, that has to be withstood and this kind of tool steels which is another class of the high carbon alloy steel as I told you, it has this property as well as it can resist wear to a large extent. Withstand high temperatures particularly that it retains it hardness at an elevated temperature.

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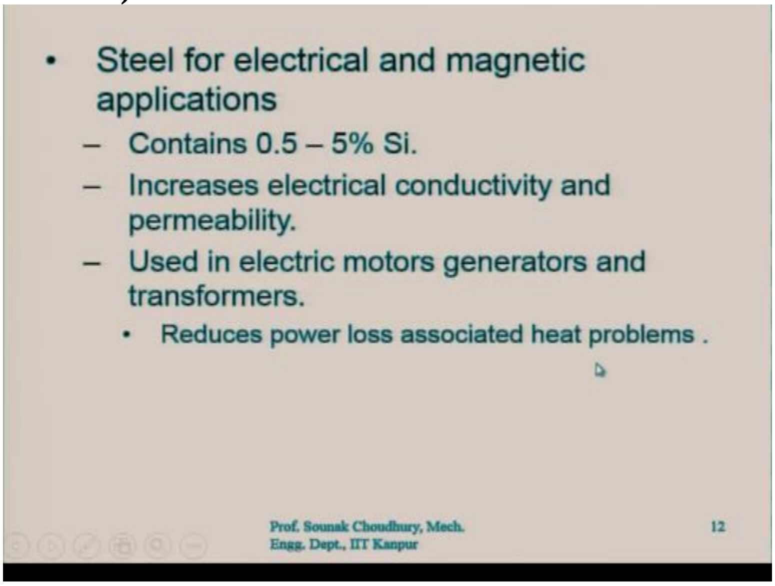


Steel for electrical and magnetic applications: those compositions will be different because the demands from those deals in the area of electrical and the magnetic applications will be different. Those kinds of steels may have 0.5 to 5% of silicon that increases the electrical conductivity because we need it for electrical application and permeability. So, because of that these two properties such as conductivity and permeability are given by the silicon.

Percentage can be varied from 0.5 to 5%. Depending on exact percentage of silicon we will have different grades and levels of the permeability or the electrical conductivity. Such kind of steels are used in electrical motor generators while winding the wire for transformers and motors apart from the structure.

Reduces power loss associated with the heat problems - meaning that these steels are specially made so that at high current and at high voltage due to heat produced there, the power loss should not be there which in case of transmission is very important and so that the output could be according to the input that is given in the generators or the motors and transformer. Let us discuss some of the non-ferrous metals and let us see how they differ from the ferrous metals in terms of properties, in terms of usage and so on.

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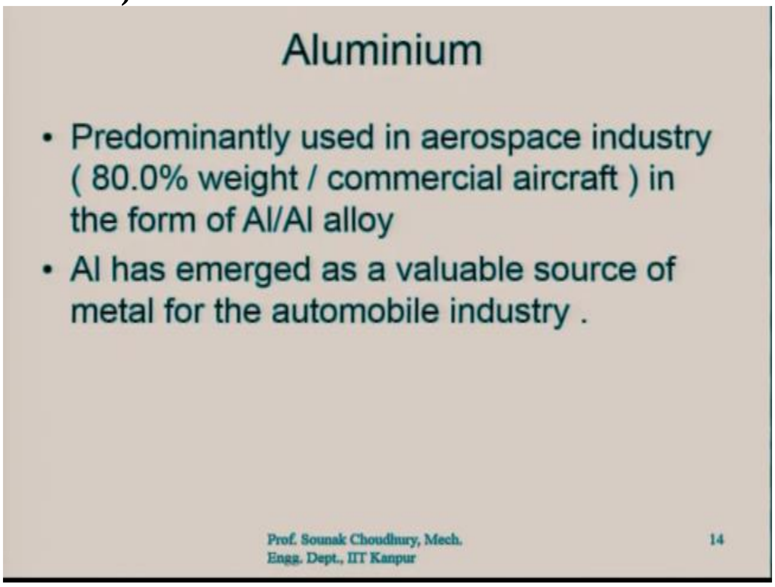


First representative of the nonferrous material is aluminium which is very widely used. As you understand, this is a light material, this is a relatively cheaper material.

Nevertheless, aluminium is predominantly used in the aerospace industry because it is light and 80% weight by commercial aircraft is born by the aluminium parts.

These parts are made of aluminium and aluminium alloys. This is in the form of aluminium or aluminium alloy. I am coming to that aluminium alloy which will give you different properties of the aluminium. Aluminium has emerged as a valuable source of metal for the automobile industry again because of the lightweight, because of the sufficient strength. Of course, it is again the aluminium alloy mostly not the pure aluminium.

And because of these properties in the automobile industry, it is very popular ,and , when the automobile is becoming lighter, it will actually consume less power. Therefore, it will consume less fuel and that is very important and if we are gaining in the weight of the automobile, a drastic reduction in the power and drastic reduction in the fuel consumption can be achieved. Such automobiles are being designed these days, which you can see on the roads.

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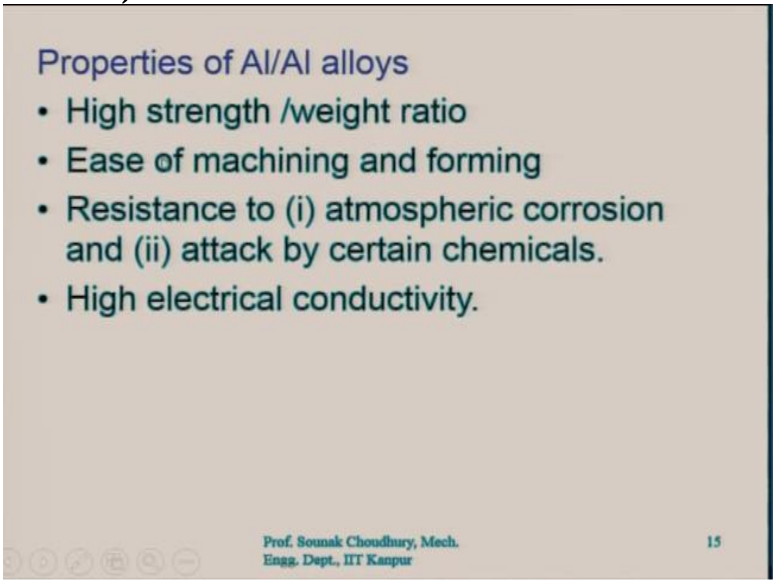


Properties of aluminium and aluminium alloys: First of all, high strength to weight ratio. The ratio of the strength to weight is very high. So, we understand that for less weight very high strength can be achieved. Next is the ease of machining and forming because it is relatively softer material. Therefore, the machinability is good and the formability is better.

In metal forming you can have different kind of material, different kind of parts using the casting as you understand of the aluminium you can have different kinds of parts. So, after casting it can be actually machined easily if it is required. Similarly, after forming it can be given a finish shapeif it is required. In that case machinability of the aluminium will be better and it is a very desired property because in many cases after the casting, after the metal forming out of aluminium material, we need to have the final shape by machining.

Next property is the resistance to atmospheric corrosion and attack by certain chemicals. Aluminium always will have a very quick formation of the aluminium oxide layer and that aluminium oxide layer like in the case of cast iron, that we have discussed earlier, will serve as a protecting layer on the top of the workpiece. Therefore, we are saying that the resistance to atmospheric corrosion is high for the aluminium alloys.

Pure aluminium will have a quick formation of the aluminium oxide on top of it which is hard and attacked by certain chemicals. Aluminium and aluminium alloys have the high electrical conductivity and due to that in the electrical wires also you can find that a large amount of aluminium and aluminium alloys are used.

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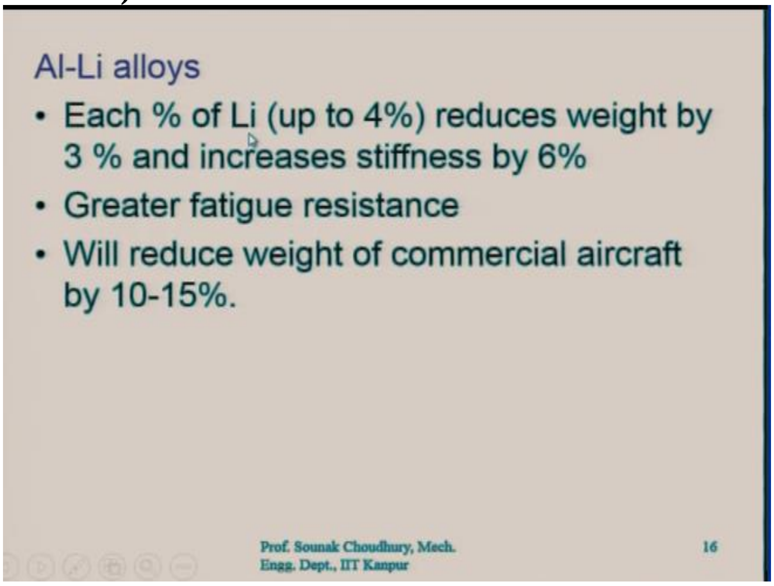


In aluminium lithium alloys, each percentage of lithium up to 4% reduces weight by 3% and increases stiffness by 6%. This is the experimental results and you can see the effect of each percent up to 4% reduces weight by 3% this is a drastic reduction in the weight and increases the stiffness by 6%. So, both these characteristics like the weight and increased stiffness are desirable in the engineering materials and in the engineering parts.

So, the role of lithium is great in case of the aluminium alloy that has been found out by research, particularly the greater fatigue resistance. So, the repetitive loads can be withstood by such aluminium lithium alloys and it will reduce weight of commercial aircraft by 10 to 15%. 10 to 15% reduction in the commercial aircraft means a huge reduction not only in weight, but subsequently in power consumption.

Power consumption means the fuel consumption, less fuel will be consumed and you understand that in the aircraft the fuel is very expensive, because very high quality fuel is used and if the weight is reduced, power is reduced and the fuel consumption is reduced, it is a great achievement for the aircraft industries.

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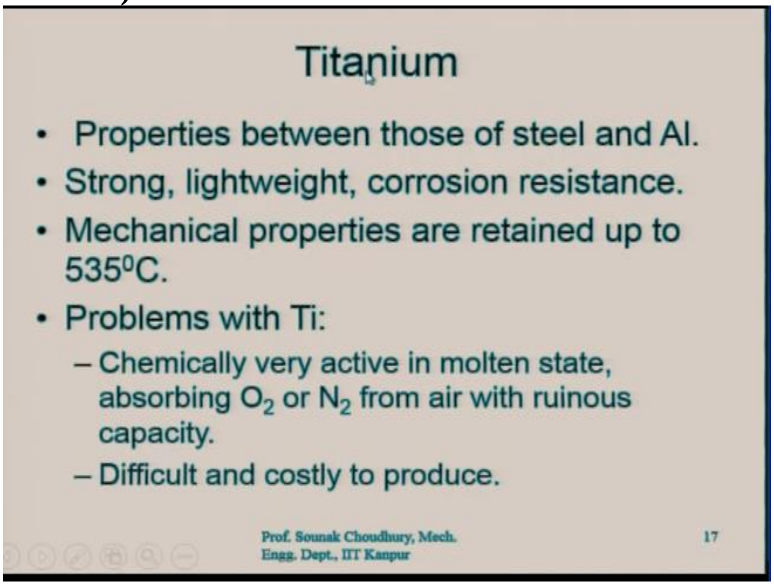


Titanium properties are between those of steel and aluminium. So, you understand that all the properties that the steel and the aluminium have, the properties of the titanium will be in between. We will discuss in details what are those strong, lightweight, corrosion resistance. These are the three properties which are also very important for the field of engineering materials because materials have to be stronger and the weight has to be lighter.

It also cannot have the corrosion otherwise in the long run the part will be destroyed. The corrosion goes into the material and it destroys the part by reducing its strength and finally, it can actually break. Mechanical properties retain up to $535^0$C particularly the hardness. So, the hot hardness is reasonably high.

At this temperature the properties, including the hardness, are retained for the titanium parts for which the titanium material is widely used in engineering. Problems with titanium are that they are chemically very active particularly in the molten state, when it is being produced, when it is being melted for example for casting.

Since titanium is chemically very active, it can react chemically with the atmosphere or with other gases, absorbing oxygen particularly nitrogen from air with ruinous capacity. So, in the molten state particularly it can absorb oxygen and nitrogen from the air to such extent that it can actually ruin itself. The properties of the titanium can be ruined because of this absorbed oxygen and nitrogen; difficult and costly to produce. So, the titanium material is very rare and it is very expensive.

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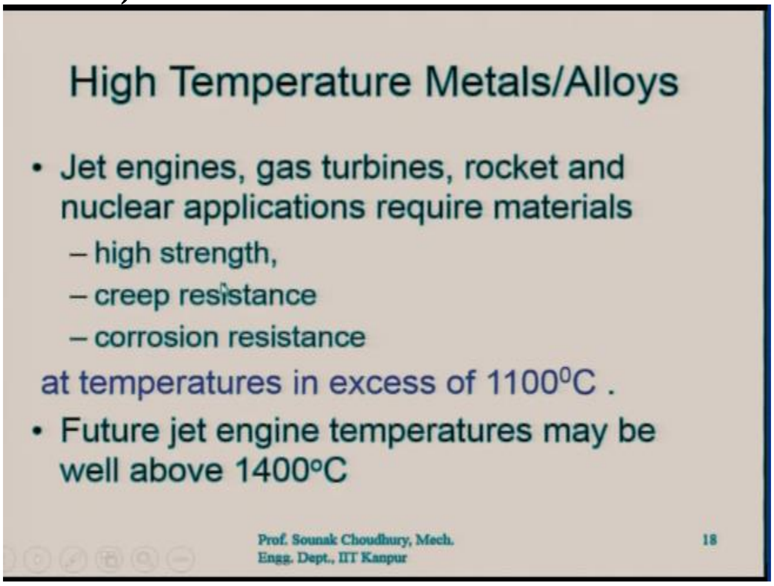


High temperature metals and alloys, jet engines, gas turbines, rocket and nuclear applications, require the materials with high strength, creep resistance, corrosion resistance since they are working at a very high temperature. So, the forces exerted will also be higher, and the temperature rise will be higher.

So, for all this it needs the corrosion resistance, creep resistance and the high strength of the material at temperatures in excess of $1100^0$C. At this temperature all these properties should be retained, that is, high strength, grip resistance and corrosion resistance.

But we always ask that these properties should be retained at higher temperature because mostly in the jet engines, gas turbines, rockets, nuclear applications the temperature goes beyond $1100^0$C. So, at that high temperature when these properties are retained that is valued and that is desired. Future jet engine temperatures may well be above $1400^0$C, because the speed is increased and therefore, the temperature is increased and the forces exerted on them are also increasing.

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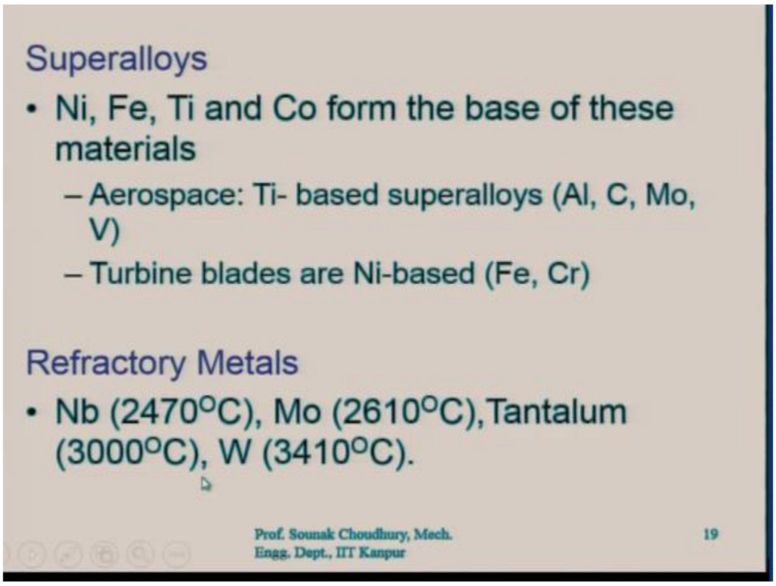


Therefore, materials like super alloys are invented. Nickel, ferrous, titanium and cobalt form the base of these materials. These are the super alloys formed by nickel, ferrous, titanium and cobalt. In aerospace particularly the titanium based super alloys, for example aluminium made of aluminium carbon, molybdenum, vanadium along with the titanium. Titanium will be the base which is very widely used in the aerospace particularly because they are very light.

Strength wise also these parts are used in the aerospace industry. Turbine blades are mostly nickel based along with the ferrous and the chromium. So, these are the super alloys which will have superior properties that are required and used in the aerospace industries particularly because turbines mostly are used in the aircrafts for making the blades, housing and so on.

**Refractory metals**: niobium I suppose, can withstand $2470^0$C, molybdenum can withstand $2610^0$C. Tantalum can withstand even more up to $3000^0$C or tungsten can withstand $3410^0$C. So, these refractory metals are used for making the layers in the furnace where the metal is melted.

So, there the temperature becomes very high and we cannot have any loss in the temperature. Therefore, inside those furnaces, there is a layer which is made of the refractory metals that should withstand very high temperatures which is beyond the melting temperature of many metals.

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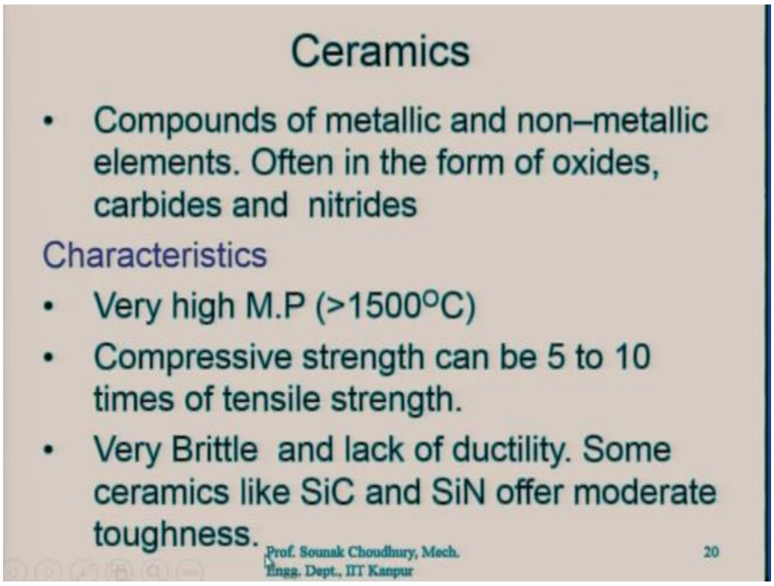


**Ceramics compounds of metallic and non-metallic elements**: these are the ceramics often in the form of oxides, carbides and nitrates. There are different kinds of oxides and different kinds of carbides that we will discuss and the nitrates which are the ceramics. Now, the characteristics of the ceramic are that they have very high melting point, melting point is more than $1500^0$C. So, at very high temperature it cannot melt.

Compressive strength can be 5 to 10 times of the tensile strength. Ceramics are the brittle materials. So, their tensile strength is not high, but the compressive strength is very high, up to 10 times more than the tensile strength. Because of that property of high compressive strength the ceramics are very widely used.

Very brittle and lack of ductility; some ceramics like silicon carbide, silicon nitride offer moderate toughness. They can reasonably well withstand the shocks. Now, ceramics are overall not very good shock absorbers, in case of tools in machining, the tools are made of ceramics, but those tools cannot withstand the vibration in the machine tool. If the tool vibrates, then the ceramic tools can break. So, in case of turning tools, the ceramic tools are made fatter, so that they can withstand high fluctuation of force.

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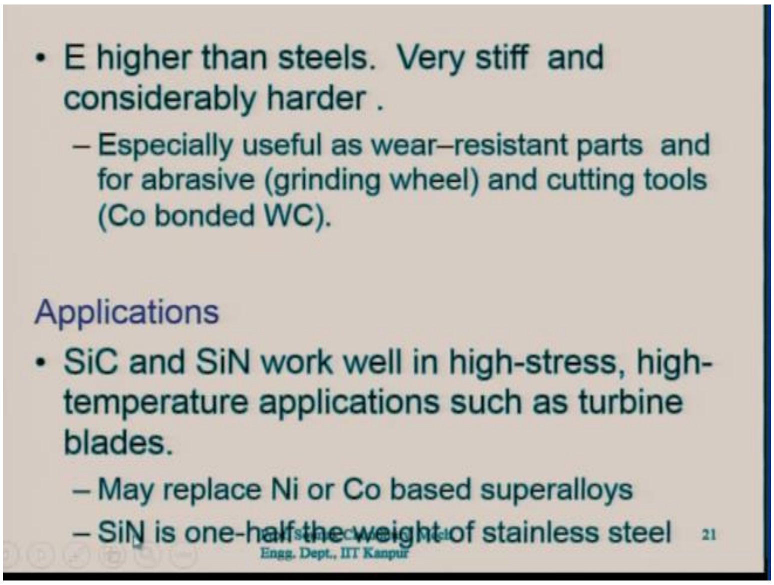


Young's modulus is higher than the steel; Ceramics are very stiff and considerably harder, especially useful as wear resistant parts and for abrasive. Very often ceramic particles are used as abrasive material (silicon carbide for example). Silicon carbide, silicon nitride have the moderate toughness. Those silicon carbide particles are also used as the grinding wheel grits.

These kind of abrasives like ceramics, particularly the silicon carbide, is used in grinding wheels. Cutting tools made of the tungsten carbide are very strong. They are brittle and they cannot withstand shock load, but they can withstand very high temperature and they have quite good wear resistance. These tools do not wear out very easily when they are made of the tungsten carbide.

**Applications:** silicon carbide and silicon nitride work well in high stress, high temperature applications such as turbine blades. So, blades are made of silicon nitride and the silicon carbide as well. May replace nickel or cobalt based superalloys because the properties of these ceramics will be closer to those nickel or cobalt based superalloys. Silicon nitride for example, is one half the weight of the stainless steel. So, these are much lighter materials also.

So, if you are using the stainless steel, the structure will be much heavier than while using silicon nitride. But in case of silicon nitride, it is more expensive than the stainless steel, but where you have the weight as a factor in that case, you cannot compromise with the property and you have to go for the high cost of the silicon nitride.

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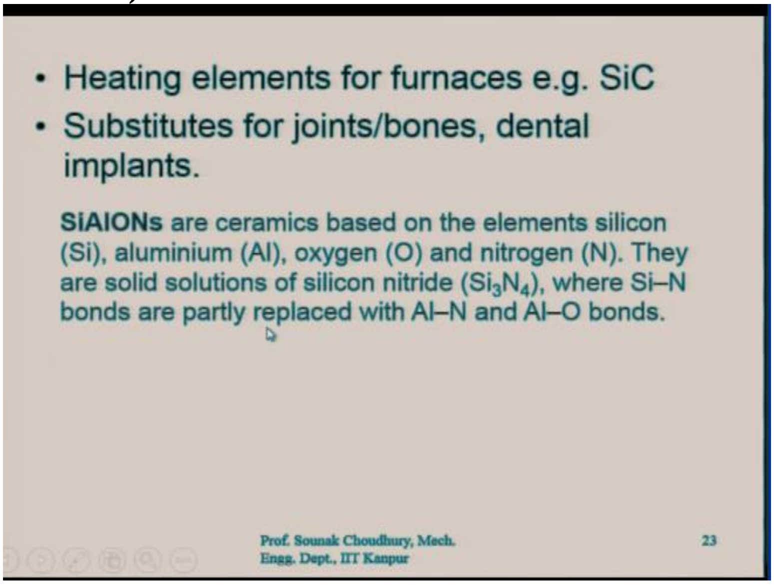


Sialon is a relatively new material. Definition of sialons is that it is ceramics based on the elements silicon, aluminium, oxygen and nitrogen that is why the name evolved as sialon. They are solid solutions of silicon nitride Si 3 and 4 where silicon nitrogen bonds are partly replaced with the aluminium nitrogen and aluminium oxygen bonds. This is how the sialon has been invented that silicon nitride bonds are partly replaced by the aluminium nitrogen and the aluminium oxygen bonds.

They have good resistance to wear and thermal shock. It is stronger than steel, extremely hard and light as aluminium. So, you could see the extremely good properties like stronger than steel, extremely hard, light as aluminium. That means it is using all the good properties of steel and aluminium materials. It has good resistance to wear and thermal shock, but it is electrical bad conductor. So, it can be used as an insulator.

This material retains good tensile and compressive strength particularly up to temperature of $1400^0$C. Ceramics engine blocks are also coming up. so ceramic material is used for making the engine blocks as well. These materials are used as refractory materials in furnaces and high temperature reactors because they can withstand very high temperature, andcan retain good tensile and compressive strength.

So, in the engine blocks and in furnaces these materials are used as refractory materials. It is a layer inside the engine block which is of the sialon material, it is also ceramic material. Heating elements for furnaces, silicon carbide, substitute for joints, bones, dental implants are other examples. This material is now being more and more popularly used in the dental implants and the substitute for the joints.

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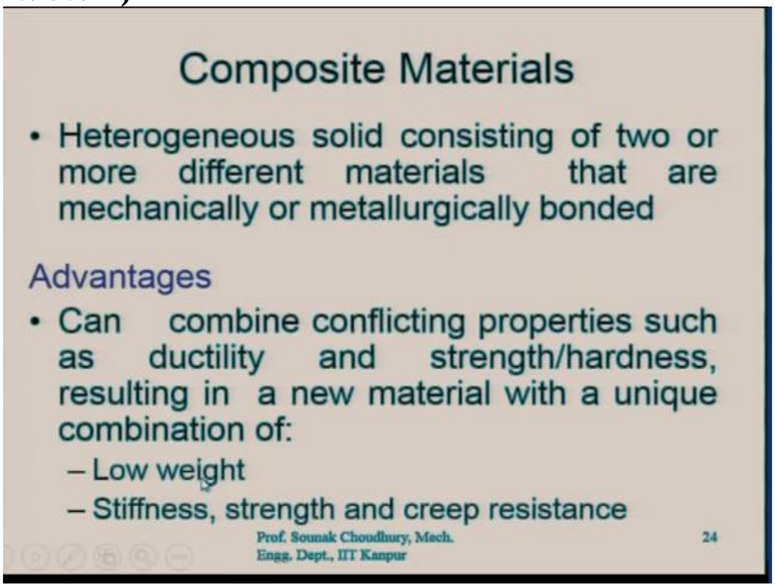


Now composite materials are the materials which have lately started being used very extensively because of their unique properties particularly they are light and strong and they are relatively less expensive, and can be produced relatively easily. Heterogeneous solid consisting of two or more different materials that are mechanically or metallurgically bonded are the composite materials. Once again, these are the heterogeneous solid.

And they consist of the 2 or more different materials that are mechanically or metallurgically bonded. Advantages of the composite materials are that they can combine conflicting properties such as ductility, strength and hardness resulting in a new material with a unique combination of low weight, stiffness, strength and creep resistance.

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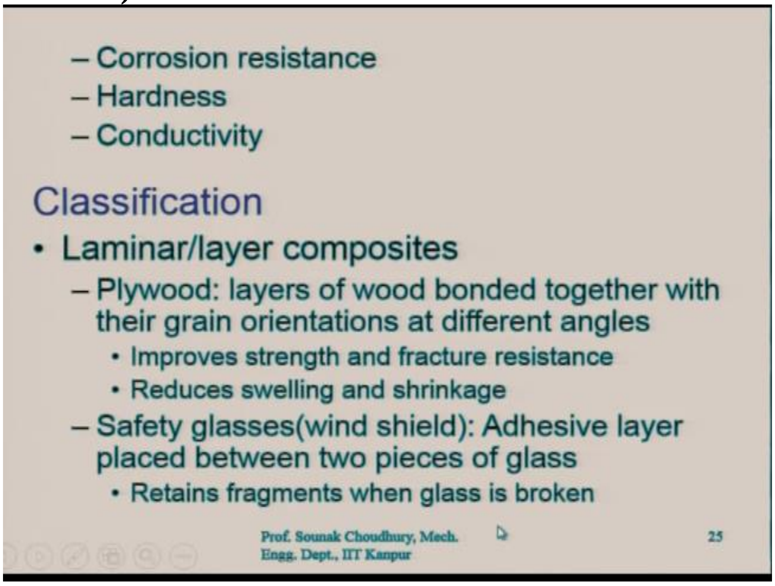


Good corrosion resistance, high hardness and good conductivity are some of the properties of composite materials. You must have observed that if you have a hard material normally they are brittle. So, if a material has high strength, though it may not have the ductility, material with high hardness  will not have the ductility and so on. So, in case of composite material, this is the advantage that it can combine these conflicting properties, it can have the ductility as well as the hardness, these are the unique properties which are desired in the engineering materials.

Many of the engineering parts require very high hardness and they should be also ductile to a certain extent. I will give you examples in the course of our discussion that we need to have the parts, and the tools which will have the hardness as well as ductility. Now, as I said these composite materials are of low weight stiffness strength and creep resistance, high corrosion resistance, of high hardness and high conductivity.

Now, the classification of the composite materials. It may be laminar or layer composites, plywood have the layers of wood bonded together with their grain orientations at different angles. So, this is called the plywood, this is also kind of a composite material. Improves strength that way because it has the grain orientation at different angles .

Reduces swelling and shrinkage. This is very important particularly for the household doors and windows as you understand that under the rain, they should not swell or they should not shrink at the higher temperature or when the humidity is less for example.

In the dry condition they should not shrink. So, the plywood is also a kind of composite material. Further classification is safety glasses, wind shields, adhesive layer placed between two pieces of glass. This is how the safety glasses and the wind shields are made because they have the adhesive layer, so they cannot actually break/shatter in pieces but they retain the fragments when the glass is broken.

This is important. You might have observed that the wind shield of an automobile does not shatter if it is broken. It does not break into pieces it but breaks and stay there, the pieces can stay there. This is done by the adhesive layer placed between the 2 pieces of glass. This is how the safety glasses are made. So, this is also kind of a composite material as per the definition.

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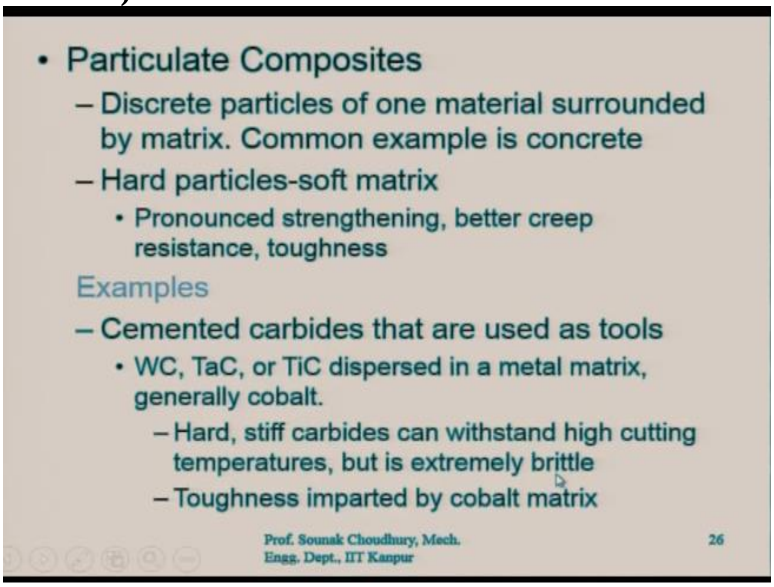


Particulate composites are there, particulate composites are the discrete particles of one material surrounded by a matrix. Common example is a concrete it is a discrete particle of one material like cement, surrounded by matrix. So, this can be the cement and the granules and then the sand. That will be the concrete having pronounced strengthening, better creep resistance and toughness.

Examples: they are the cemented carbides that are used as a tool, tungsten carbide, tantalum carbide, titanium carbide, dispersed in metal matrix. So, these are the cemented carbides as you may remember that these are the materials also they are used for making the cutting tools. Generally, that metal matrix used cobalt. So, the cobalt metal matrix and the powders will be tungsten carbide, tantalum carbide and the titanium carbide.

As a result, you will get the unique properties that we have discussed, i.e. high strength material that can withstand shock loads, it can withstand the fatigue and so on. Hard, stiff carbides can withstand a high cutting temperature that is very important, but they are extremely brittle. Toughness impacted by the cobalt matrix. So, cobalt matrix improves that shock absorption property to an extent.

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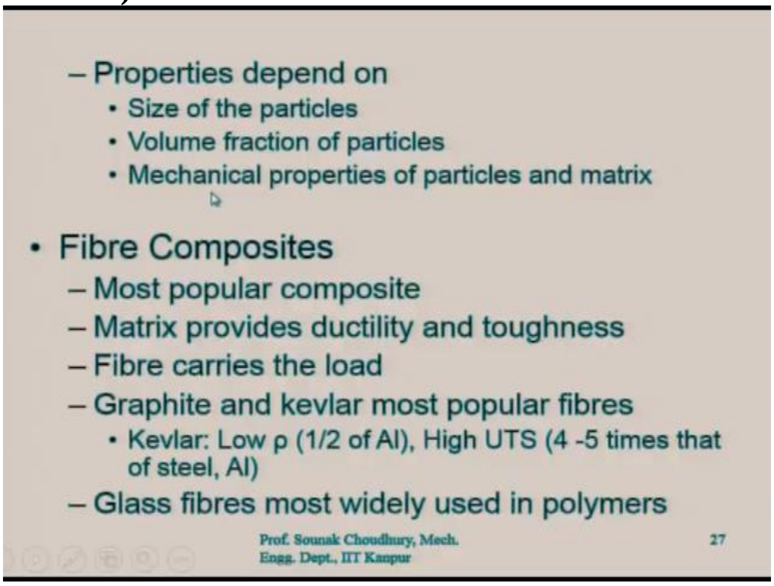


Properties also depend on the size of the particles, volume fraction of particles. That means, how much which particles are in which volume, i.e. what is the fraction of this volume, fraction of those particles in that volume and the mechanical properties of the particles and the matrix both. In the composite material, the properties of these particles or the matrix may not be retained.

The properties normally are better than the properties of the particles and the metrics taken individually. Therefore, in the composite material the properties that you are getting will be unique and this is different, it may be different from those particles and the matrix.

But it will depend on the size of the particles - volume fraction of particles you understand that smaller particles are better than larger particles because the density is more. And therefore, it will be stronger. So, volume fraction of particles has the same kind of an explanation why the properties can be better if the volume fraction of particles is more, but not in all cases - it depends. So, the rest of the material on the composite materials will be discussed in our next discussion session. Thank you for your attention.