Manufacturing of Composites
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Lecture - 06
Selection of Materials

Let us move to lecture 6 which we are going to talk about Selection of Materials. Till now what we have understood is we have understood about matrix fiber, forms of fiber, then we went into little bit of calculations in a tensile load in a transverse, load along the longitudinal direction, along the transverse direction, what happens to the load which it takes and what is the critical volume fraction we need for making a composite and what is the minimum we need.

So, there is a small difference we did calculations and last class we saw. And we also introduced 2 things one is called as weight fraction and volume fraction. Volume fraction is used for theoretical work and weight fraction is always used for manufacturing. And then what is their relationship, how do we derive from weight fraction volume fraction and volume fraction to weight fraction. So, then we saw different types of testing of materials; that means, to say composite is fabricated, what are the different kinds of testing we do so that, we can try to a choose the best out of it.

Now, understanding the testing let us move to the next stage which is called as selection of materials. Selection of materials is a very important topic because here we are trying to cover what is the influence of each mechanical property with respect to performance and with respect to cost.

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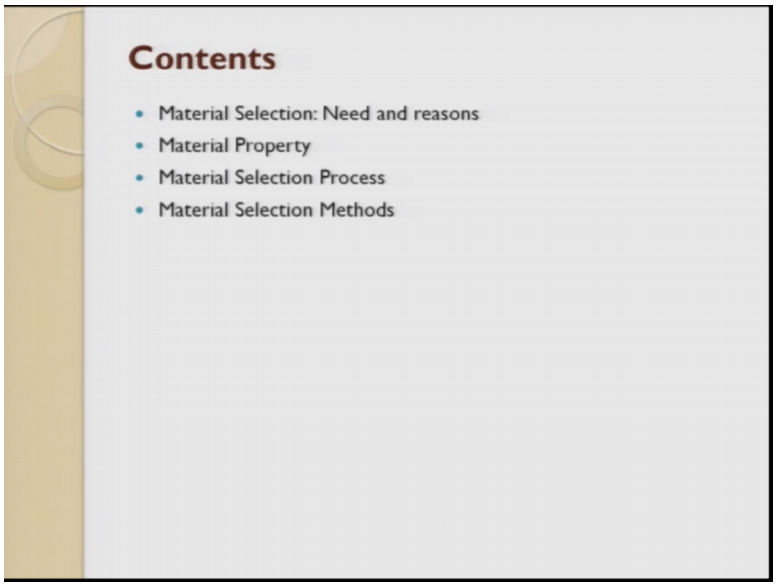

In this lecture we are trying to have content as materials selection, what is the need and reasons, next what are all the material properties, the material selection process and the material selection methods what we follow here.

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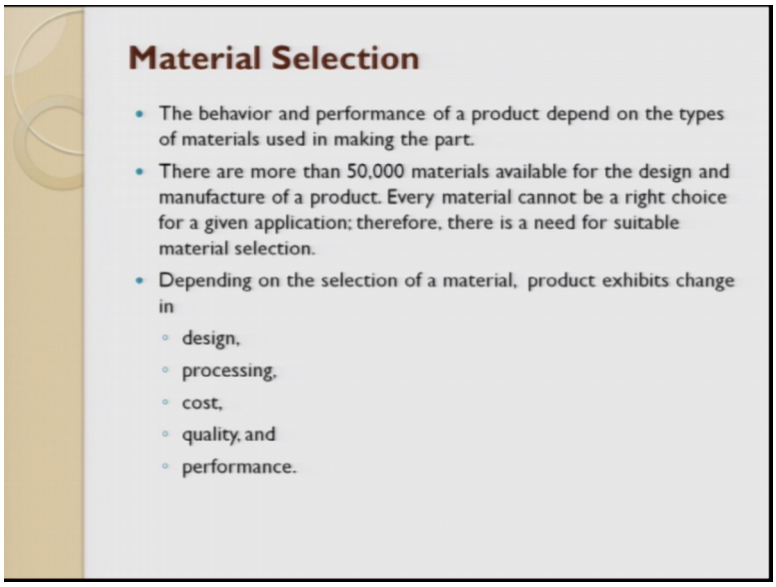

Material selection is very important, also here what we do is, we try to take the behavior and the performance of the product both depending upon the type of material which is used for making a part. For example, a chair can be made out of steel, a chair can be made out of wood, a chair can be made out of polymer material. So, what does a

customer want a customer as far as customer is concerned he is more comfortable he looks for a comfort to sit in a chair, second thing after the event is over the supplier or the even a customer would like to have a stalking sequences that he can store after the event is over in a very short place.

So, these are the 2 requirements. Generally we have a customer for doing this you can choose wood as a starting material, steel as a starting material and plastic as a starting material polymer does not corrode in due course of time. So, polymer has a longevity in work. The wood based and a steel based they always have a environmental influence on the product and over a period of time they both get deteriorated very fast. So, both the steel chair, as well as the wood chair has can be folded. You can think of a folding process and then stalking it together, but the only thing is when you work with steel or when you work with wood the number of parts which are involved for assembling and making a chair is very high. So, the assembly process is very high the maintenance cost is also very high. Now keeping all these ideas we are supposed to choose a particular material.

When we choose a particular material keeping all these things as prerequisite then what we do is, we choose a material, then corresponding to that material we choose a process. In fact, there is one more important aspect in all these choice making is the cost, what is the cost I give for that product. Keeping all these things; cost, mechanical properties and other endurance properties into consideration, we have to choose a material, so that we make the customer happy. Here the first, the behavior and the performance; performance is how good the product performs or how happy is the customer. Performance of a product depends on the type of the material used in the product. There are more than 50,000 materials available for design and manufacturing of a product today.

The spectrum is very large. Gone those days, you have only 3 parts 4 parts or 4 different materials we choose that and start making it. People thought this part which is of structural component, this has to be made out of steel, is now replaced by polymer matrix composite. The weight has gone down, the performance has enhanced and as far as polymer we have already known that depending upon your requirements you keep adding ingredients to meet out your properties. So, there are more than 50,000 materials available for design and manufacturing of a product. Every material cannot be a right choice for a given application. Therefore, a suitable selection has to be done or an

optimum selection has to be done for choosing a material. Depending on the selection of a material the product exhibit changes in design, processing, cost, quality and performance. Interestingly, the shape of the product can be changed to meet out the requirements.

For example: if you think of having a square shaft, it can be merged circular, keeping manufacturing as a important, giving more weight ages to the process we can always make it cylindrical. Earlier square sections or rectangle sections, box sections were thought to be very difficult in manufacturing. Today there are lot of new process and the process ease has happened. So, we can design any component that we can manufacture the same.

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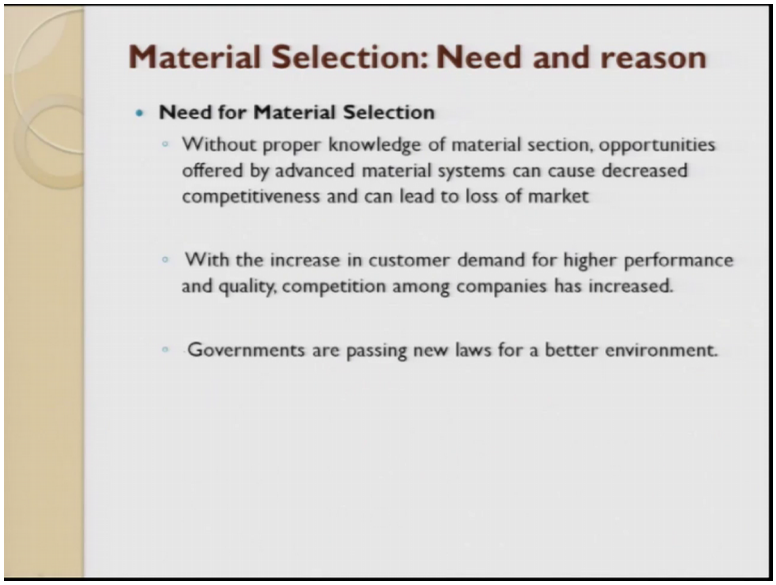

What is the need and reason? The need for material selection, without a proper knowledge of material selection, opportunities offered by advanced material systems can cause decreased competitiveness and can lead to loss of market. If you make a wrong choice of material, for example, sensors where initially thought of to be made by glass, then they moved to silicon and today they are made out of polymer. Polymer is lightweight; roll to roll manufacturing can be done very easily.

If you do not have the proper awareness, knowledge, about the material selection then you will not be able to push your product or your product will not be much successful in the market. With the increasing of customer demands, today, customer is becoming more

and more demanding. What he wants is, he wants a very lightweight part, which can do multiple operations or processes and which is having very low maintenance, with low costing. So, you see all these demands which customer puts in front of manufacturing is all contradicting to each other. But still he says I will give you this much price, so that means to say, he wanted to buy the product in a very economical manner.

The customer demands for high performance and quality and competitiveness among company, has increased, so a proper choice of materials is very important. And today, the government norms have also become very stringent; they are now talking about a green earth. So, where in which the material which is been chosen for making a product, what the government norms are pushing very hard is, it should have minimum carbon footprint, it should be biodegradable or it should be recyclable. So, these things put a huge demand on the designer to make a proper choice or to make a material selection proper to achieve the product.

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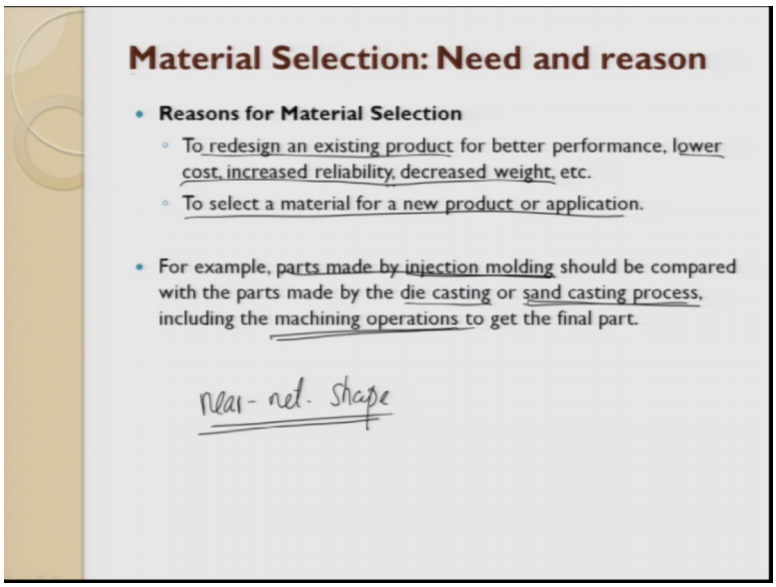

So, the other 2 points which are very important is to redesign an existing product. Whenever a product is made, if the product is made out of a material which is the ultimate which cannot be recycled which cannot be reworked then there is a huge problem in those materials. Today, what is happening, the designer is told that please give a small window such that we can try to redesign or re define the product, such that, it can meet a customers or it can be made to meet to a set of customers. To re design an

existing product for better performance, lower cost, increased reliability and decreased weight, etcetera are some of the reasons which push for material selection. To select a material for a new product, we always have to do a material selection.

Let us take an example; a part can be made by injection molding should be made; so let us take a simple example of wheel rim which is used. Earlier days, these wheel rims were made by casting. The same wheel rims today are been made by pressure die casting and these wheels today they are been added more reinforcement using carbon fibers and other things and they are thinking of making these wheels by injection molding process. So, basically it was initially cast iron, from there they went into aluminum, lightweight, high strength and mass production was batch production was done and from there they are now trying to move to injection molding process, keeping polymer, they are reinforcing with carbon fiber, making it light and making it high performance, such that, they can be doing a better performance to the customers.

So, for example, if you have a wheel rim to be made this can be made out of the 3 choices. One is casting process, it can be made by die casting process or it can be made today they are looking at injection molding process. Injection molding process, polymer is used and the carbon fibers, I said the carbon fibers can exist in several forms. They try to make a 3 dimensional reinforcement and inject polymer into it and where in which, there also thinking of placing a location for inserts. So, this is what it is.

So, when casting process was thought of there was a lot of machining operations which was included, we were not able to make near net shape process, near net shaping, which is the big advantage of polymer matrix composite. So, this was not been achieved by sand casting processes. When it came to die casting, yes, we were able to make and when it goes to injection molding we go very close to the final product itself. So, for doing this you should have a proper knowledge about the material selection for the product.

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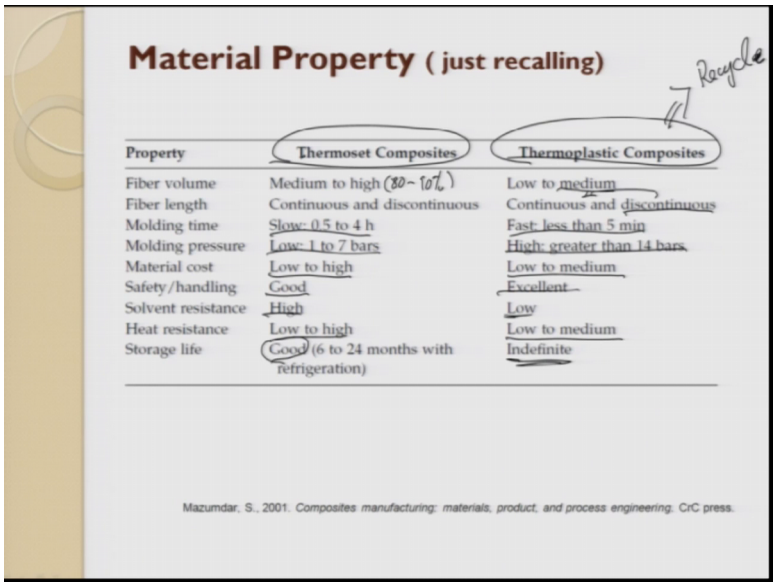

So, this is just a recap, you can see that we saw about thermosets, thermoplastic composites, thermoplastic, the major thing is recyclable, but here it is non recycle. The fiber volume fraction it can go from medium to high, it can go from low to medium, why because, when you keep a pre-form and the matrix if it is in a liquid state, it can easily flow and try to take a shape. But whereas in thermo plastic you always apply a pressure, where in which you keep a pre-form of reinforcement and you apply pressure and then push it inside, you cannot go more than medium. Here you can go to as high as 80 to 90 percentages. So, here the fiber length can be continuous, it can be discontinuous; predominantly here it is discontinuous, today, it is getting moved to continuous. The mold time in thermoset is somewhere close to 4 hours, but here you see it is less than 5 minutes. If you are looking for mass production then thermoplastic composites are very good.

The pressures which are involved is 1 to 7 bar. We will see where is this pressure used in thermoset, when you talk about manufacturing of composites, here the pressures are very high. So, when the pressure is very high, what happens, it is a viscous fluid flowing and then you have a pre-form already laid there. When you inject it at a higher pressure, since it is a viscous fluid, the pre-form can move, so, it is very difficult for you to hold the pre-form and then inject it. If at all, you put a spacer, that spacer becomes an integral part of the composite, spacer or a holding device. Material cost is low to high; it is low to medium. Safety handling is good; it is excellent, because predominantly, thermoplastic

polymers are solid.

They are available in pallet form; they are also liquid form. The solvent resistant is very high; the solvent resistance is low. Because, the material can be etched if you use for acid applications, but, where as if you choose a proper thermoset, it is very high. Heat resistance it is almost the same, because it is a polymer material. The storage life is very good and it is indefinite, so that means to say, it can be there for any time. So, this is a recap which we already saw. These are some of the properties you should know before making a choice for making or a fabricating a composite.

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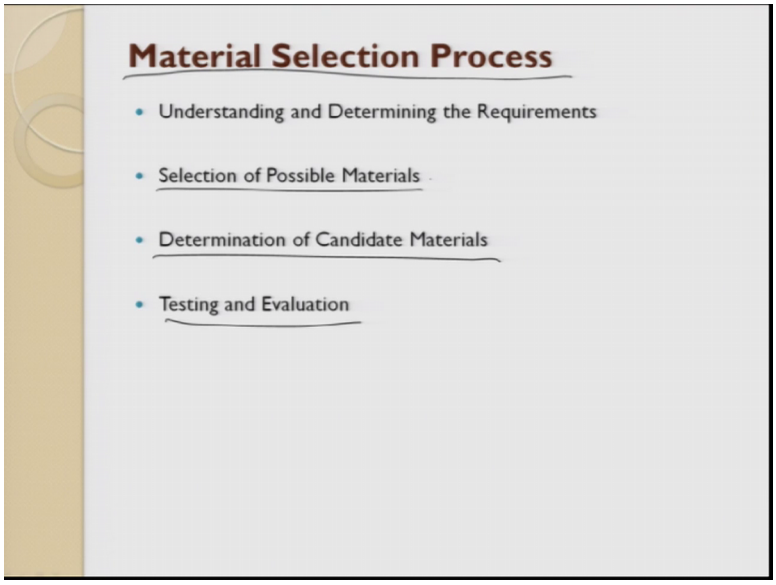

The material and selection process can be now divided into 4 things; one is understanding and determining the requirements see that is the biggest problem. As a manufacturing engineer, we, many a times do not understand the customer's choice or the customer's requirements. So, that is what, in design process they say, please do an empathy study. Empathy study means you become a customer for that product and you list out, what do you expect from the product. The material selection process first starts from, what does a customer wants, understanding and requiring the requirements.

Then you make a selection of a possible material, then what do you do is then you make a determination of the candidates material, then you do what testing and evaluation, before the product goes into the market. So, here first you understand the customer, then you try to select all possible, that means to say, you choose only polymer is good. Now,

in polymer you have a 3 classification thermoset, thermoplastic, elastomer. So now, you decide, No, I will use only thermoset. In thermoset, you have polyester, you have epoxy, you have vinyl ester. You have so many things available, in this which one do you choose, and again after choosing it, what should be the reinforcement. So those are possible things.

Then what do you do, you determine the candidate material. You cannot go by just by qualitative parameters; you have to convert the qualitative into quantitative values. When you convert into quantitative values, you have each material will have some rank or weight age or whatever it is, we will determine that, then what we did is we identify a candidate, then we do testing and evaluation.

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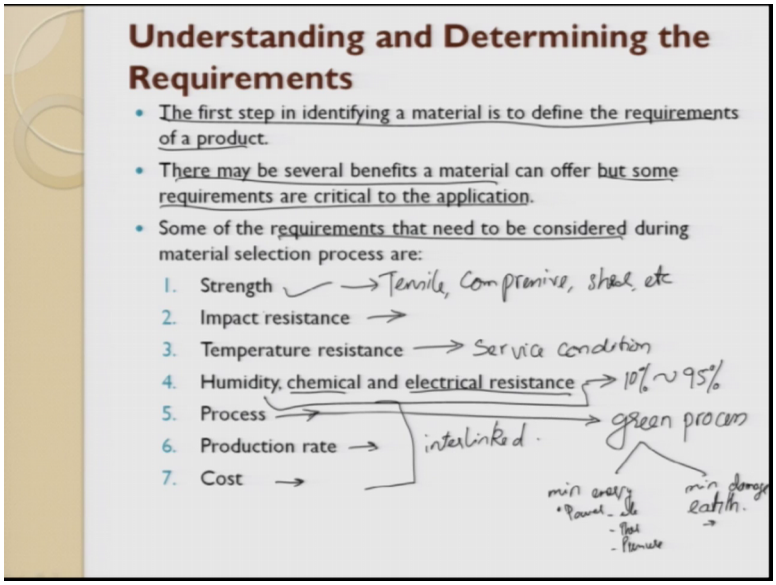

So, the first step is in identifying the material, is to define the requirements of a product. When you look at a product, generally a product does not undergo only one property or the product never demands only one property. There are many properties, for example, let us take a chair; in a chair, we always think that there is compressive load alone, but there is compressive load, on top of it you sit down and slide and move up and down, when you do it your hip goes sliding, the bottom bench where you sit, there you have some sliding load coming up and the place where you rest your back there also you slide, is a second point. The third thing is roughness, it has to be as a smooth as possible. Fourth thing is when you sit on a chair we sit as an impact load. When you sit as an

impact load, the chair has to take impact load also, so that the toughness should be high. Now you see, we thought initially it is compressive, but, you see lists of properties are required. Mechanical properties are required from a product and then on top of it, the other things are the color and the texture all these things play an important role.

The first step in identifying a material is to determine the requirement of the product. Once that is done then the next step becomes very easy. There may be a several benefits a material can offer, but some requirements are critical to the application. So, out of this so many things, whatever I said for a chair, by in large, a chair has to take a compressive load, it has to distribute the loads between the 4 legs and it has to have impact load. This is very important.

So, first what did you do, you listed down all the properties what you want from a product, then you picked up the most critical ones and then you tried to solve the most critical ones. They are called as primary requirements and there are something called as secondary requirements. Secondary requirements, we will try to accommodate, but we will not give the more weight age. Suppose you do not do this analysis, in industrial in term they do something called as ABC analysis. If you do not do this ABC analysis, we will try to take a property which is very trivial or a secondary property and start giving more weight age for them, but ultimately the customer will not be happy.

There may be several benefits a material can offer, but only critical applications you should look and choose a material. Some of their requirements that need to be considered, I am listing now, majority is mechanical, then it is environmental, one is strength. What are the strength; it can be tensile, it can be compressive, it can be shear right and it can be shear etcetera. Impact resistance, as I said, it is very important. Then it is thermal resistance, this is what I was telling in the last class about service condition, what is the ambiance it is present, in which ambiance it is present, so that, it is expected to perform.

Then comes humidity; the relative humidity in certain parts of the country, you can see, it varies from 10 percent it goes up to 95 percent, you see so much of water in the atmosphere, your work piece, your product should not absorb. Then on top of it, chemical and then electrical. Chemical is corrosive environment, electrical, sometimes we use it for insulation properties also. Then process; this process is directly, process,

production rate and cost, these 3 are interlinked. And we are always looking today for green process. What do you mean by green process; 2 things: one is minimum energy and minimum damage to earth. So, this energy can be in terms electrical power, it can be thermal power, it can be pressure, whatever it is. Here minimum damage is after the ingredients of the process should not, you should know to dispose it in a fashion such that it does not damage mother earth.

So, we are always looking for, these are some of the selection processes. These are some of the requirements in the selection process to decide a material, selection of a possible material as I told you wood example, polymer example, a steel example for a chair, we will keep that example and walk through the slide.

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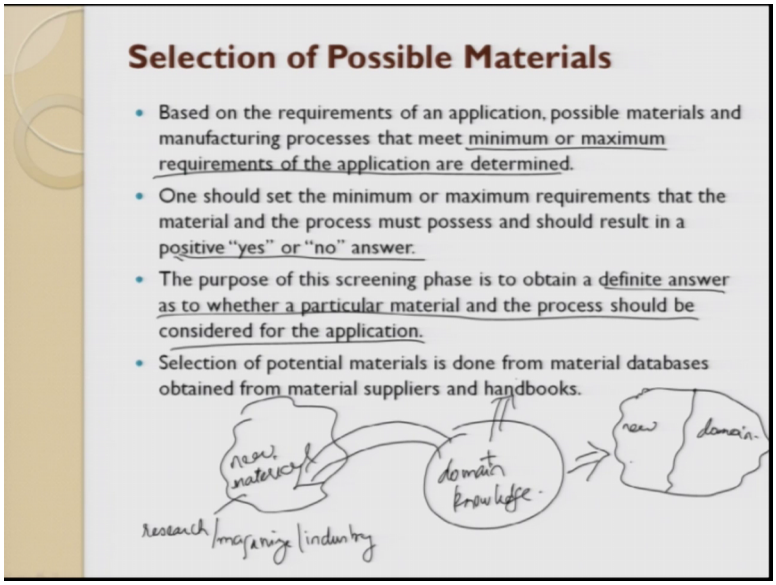

Based on the requirements of the application possible materials and manufacturing process that need minimum or maximum requirements for the application are determined, so that means to say, you have to list down all the processes and then all the properties and then you start picking them, you should have a big matrix in front of you. Then one should set the minimum or the maximum requirements that the material and the process must possess and should result in a positive yes or no answer. Now, we are getting into the grading of it. The purpose of screening phase is to obtain definite answers or to whether a particular material and a process should be considered for this application.

Many a times what I means this is the domain knowledge we have, these are the new materials which come into the market. We have a domain knowledge we have to go here and pick that knowledge and once you start picking this, now, what you have is your domain knowledge is increased. So, new and domain it gets expanded now, this entire zone is now the amount of exposure you have, so that, you choose a proper thing.

Generally, the new material comes out of research slash magazine slash industry introduces it. And the domain knowledge predominantly can be handbook which is static one, which gets revised once in 10 years or something. You have a knowledge plus you go for hand books, material supplier and then try to get. So, all these things are used for choosing, for selection of a possible material, for making a product. Why am I spending more time, because many a times, we understand sitting in a room we think that is this is what is the customer's choice and we start doing it. But really, if you go down to the customers, get his details, list it down, analyze primary and secondary then only you will be able to make a proper choice.

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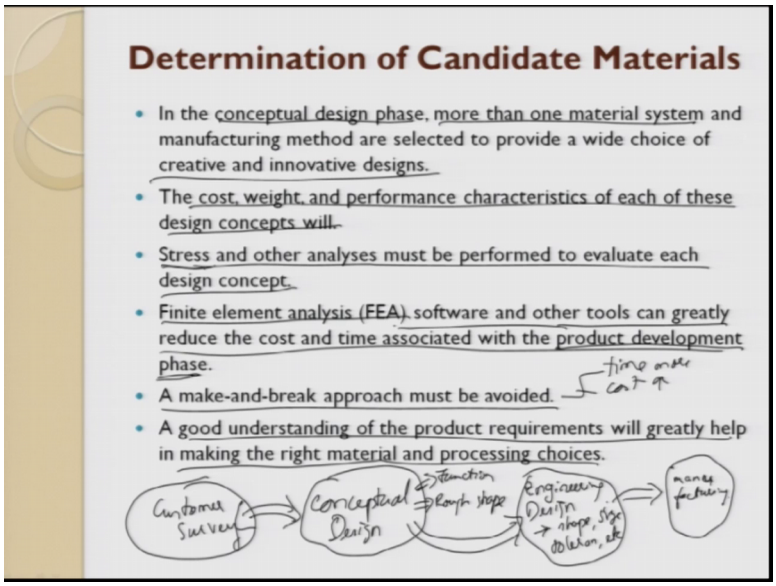

Determination of a candidate material: in the conceptual design phase, more than one material, if you see that, after you do a customer survey, a designer tries to develop a conceptual sketch, conceptual design. Here, he puts in all the functions, he gives very rough shape, he goes back to the customer and then he asks whether it is fine. Moment conceptual design is analyzed then is cleared or it is accepted, he goes to the engineering

design. Engineering design, what he does is he tries to talk about, he tries to talk about shape, size, tolerance, etc., and then he tries to go for manufacturing. So, this is how it is. Here, the conceptual design phase, more than one material, more than one material system and the manufacturing methods are selected to provide a wide choice of creativity and innovative design.

Suppose, at the conceptual stage itself you freeze, only one particular product, one particular everything you freeze, then what happens is, you will not be able to go back to the customer and say here are multiple choices, you can choose whatever you want, because, the customer will always prefer to have a choice. The customer today, is more intelligent and he never takes it by force, he never picks a product by force. He would always like to have his choice, because, he pays the money for it.

The cost, weight, performance, characteristics of each of the design is done. So, when I say cost, I try to integrate, all the mechanical properties, somehow I try to link it to cost; and weight, because no customer wants to carry a very heavy for let it be a very economical, but if the product is very heavy nobody would like to have. So, cost, weight and performance means in terms of reliability, very low maintenance. For example, a software, you can do multiple tasks, very low maintenance, that is the performance. You buy a mobile phone, you have a several apps loaded on a mobile phone, an operating system several apps, that is performance. Performance, this thing, for each of these design concept.

Then, what he does is, then he tries to take about the stress, this is where an engineer comes. Stress and other analysis must be performed to evaluate the design. Here, I said, in the next process, that is, engineering design has to be done, so, he does it. When I talk about stress, it can be using first principles or it can be using finite element analysis or using some simulation, you try to make and show in a virtual pattern and understand whether everything is fine.

Software and other tools can be used to reduce the cost and the time or the product development phase. So, what happens, there is a terminology called as product life cycle. A product life cycle, nowadays, what is happening is, the product life cycle for a component is reduced from 18 months. Earlier it used to be years, then it has come to months, now it has come down to weeks. So, every new week a customer expects a new

product from a particular company or a more. He just tweaks the existing one and gives a better performing component. The product life cycle time, this is what we are trying to talk about product life development phase, product life cycle time goes down.

Make-and-break approach must be avoided; that means, to say, rather than doing all these involving, understanding the science, what is going behind, we just make individual components and when we do the testing for it and then we say this is good and this is bad. The only thing is, it takes time, it takes cost, but, this is the best method. Time is more, time is more and cost is high, and here, if you want to do some small optimization, between parameters then it is very difficult to do in this make and break approach. So, here, in the earlier one, you have understood the science, you have done the simulation; you have enough of understanding of the material, for its performance.

A good understanding of the product requirement will greatly help in making a right material and a processing choice; this is a very important. So, only after making your right material choice and a proper processing choice, we will be able to deliver the product in a cost effective way.

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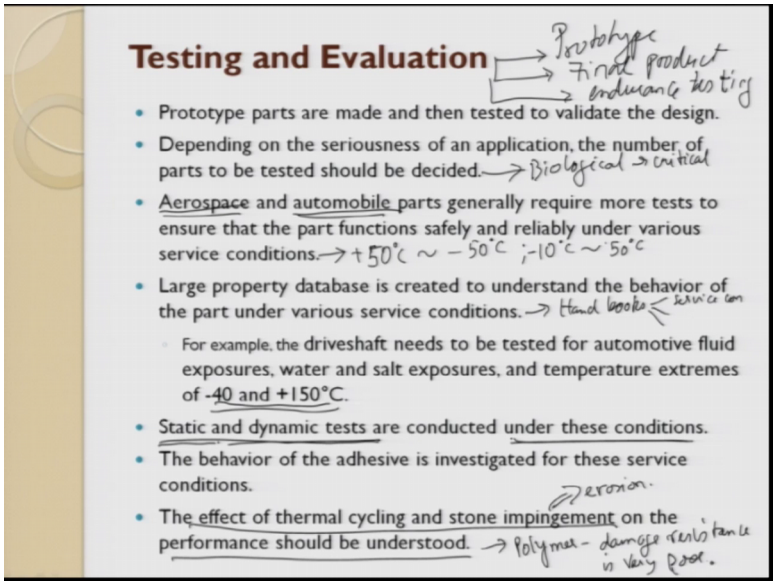

Then testing and evaluation: there are several ways of testing. One is you test the prototype, then you test the final product, then you do endurance testing. These are some of the ones which you endurance testing. So, these are some of the things which generally we do before a product is released into the market. The prototype parts are

made and tested to validate the design, show it to the customers and do some scale down testing of the product and see their performance. Depending upon the seriousness of the application, the numbers of parts to be tested are decided; for example, if it is a biological part, where in biology, these composites are used. For example, now, the differently abled people, there are lot of aides which are being getting developed, so that, to make their life more comfortable. The crutches, the wheelchair, all these things are nowadays developed and composites, so that, it is light in weight.

Here, what they do is, they try to do feel testing and these testing are very critical. It has to undergo an ethics committee test, it has to be tested for a longer period of time and then they are been brought to the application whereas, engineering application supposed to do; there the testing is not considered to be as severe as the biological testing. Depending upon the criticality of the part the number of samples to be tested and tested is also decided.

For aerospace and automobile parts, generally requires more test. Generally in aerospace we require very stringent testing, of course yes, in automobile also, but not as stringent as aerospace, generally requires more test to ensure that the functional part safely and reliably under various service condition work. So, here under service conditions are, for aerospace, it is minus 50 degrees C, to minus 50 degrees C, it has to work; where as in, when you talk about automobile it generally works between you can take it from 0 very rarely it works on minus to up to 50 degree C, maybe this 50 can go up to 50 degree C, yes. Because, that is the atmospheric temperature we have and maybe sometimes it can be tested for even minus 10 degree Celsius, whether the engine components, weather spark plug cranks, all these things can be done. These are the service conditions, and it can be altitude also.

The large property database is created to understand the behavior of the part under various service conditions. So, today what is happening, we have hand books where in which the service conditions are also reported, what happens to the performance at room temperature. We recently worked on a project, where in which we were trying to make cascades; cascades for 2 mating surfaces and we made perfect casting at room temperature, but we did not realize, when it gets for a vacuum testing, these cascades fail miserably. So, room temperature perfectly it works, when it went for vacuum that is a service condition, when it went for vacuum all these cascades fail. Service condition is

very important and today you get hand books which talks about that. Again, when you talk about corrosive environments; corrosive environments like along the beach you are trying to construct or along the beach you are trying to keep a boat. So, what is the corrosive behavior, its impact on temperature? Today, these hand books are coming up and there also research publications coming up and then we do it.

The next important thing is, the evaluation has to be done both in static and dynamic cases. Static cases, we do tensile test, only for one component, but what happens is, as and when, the component is dynamically loaded and unloaded, what is the response, deterioration of this product or this property, this is very important. Today, we have started looking into dynamic testing also; that means, to say, we apply a cycle a fatigue cycle or some cycle, compressive cycle, tensile cycle, compressive loads, tensile loads, compressive tensile loads, so that, we get the output. Static and dynamic tests are conducted and then we try to take the conditions out, so then the adhesion which I have already told.

And the effect of thermal cycle is also talked about, because this stone impingement nothing, but erosion study. For example, we think of a turbine blade, which is used in a aerospace application, a small droplet tries to hit at the surface of the turbine blade, the velocity with which the plane goes each round about 3000 or may be 300, 400 kilometers per hour that is the speed it goes, so, at that speed even a small water droplet becomes a stone impact.

So, we are also trying to look at those things and understand; what is the process. Generally speaking polymer damage resistance is very poor. This is one area, people are trying to add ingredients and make sure that it withstands for a damage resistance. For example; a bird hit or a spanner drop on a wings of a plane, if in polymer, the crack initiation takes a lot of time; moment at crack initiates, then the growth of the crack is very fast.