Manufacturing Guidelines for Product Design

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Lecture-09
Selections of Materials-II

Namaskar friends, welcome to session 9 of our course on manufacturing guidelines for product design. We are currently in the 2nd week of our discussion and our target in week 2 are the engineering materials. We want to have a basic idea or a broad picture of the various types of engineering materials that can be used for making different types of products. We have already seen the categorization or the classification of the engineering materials.

We have seen that there can be broadly metals and alloys, polymers, ceramics, composites as well as certain advanced materials such as nanomaterials or shape memory alloys, so the classification is well known to all of you by now, we are now trying to understand that because of the wide variety of engineering materials with having different characteristic features in terms of their physical properties, chemical properties, manufacturing properties.

Depending upon these properties we have to select the best material. So we have a problem of plenty at hand, there are so many materials having so diverse properties, how to select that which one material or which one of them is going to suit or is going to help us achieve our intended function for our product or is going to help us to satisfy the needs and requirements for which the product is being developed.

We have taken very big examples like metallic bristles for brushing of tooth for brushing of teeth, so we cannot use metallic bristles for brushing of our teeth, because the bristles have to be light on our gums, otherwise the gums will start to bleed. So therefore the selection of a engineering material for a specific application depends upon the service or the need and requirements that the product is going to fulfil for the customer.

And for that the engineering materials play a very important role, many time we have to see there are material available, there are fabrics available which have very long life, but we cannot select that fabric for making of the socks, because we must replace our socks every 6 months or everything 3 months because they sometimes get warn out, sometime they start smelling bad.

So depending upon the intended function we have to select the engineering material, of suppose somebody develops a material for the bristle of the toothbrush that once as a child you buy a toothbrush and then you need not replace that throughout your life will that be advisable depending upon the hygiene and the other conditions we have to see that what are the materials properties that we are required to satisfy the intended function.

So there are number of other parameters that govern selection of the engineering materials and today we are trying to further see that sometimes using concepts of mathematics we can try to come up with solution or try to solve the problem of material selection. So the manufacturing guidelines for product design we are going to see in today's session with emphasis on selection of materials that is the second part.

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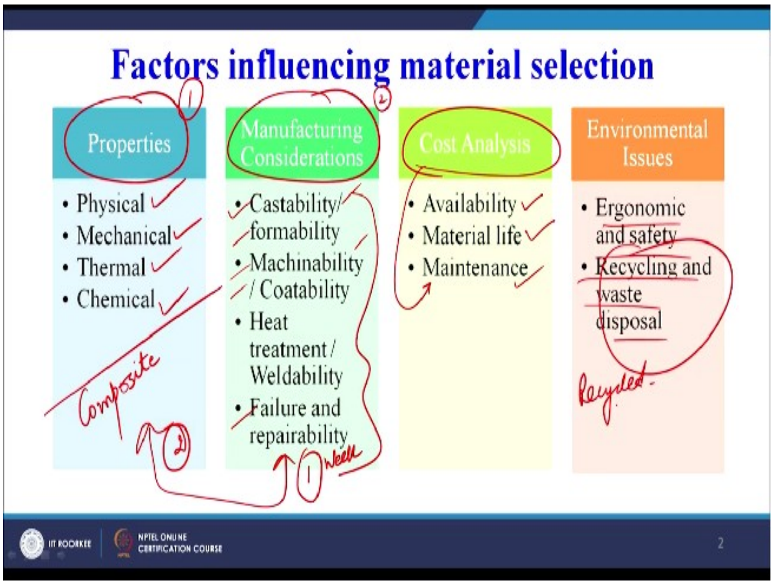

In first part we have seen the basic aspects, today we are going to see the applied aspect. Now let us see that what are the various factors that influence the material selection. In our previous session we have already seen that what are the various physical properties, we have already seen for the different types of materials mechanical properties, thermal properties, chemical properties.

So the properties of the engineering materials is the most important criteria which has to be taken into account. Then the manufacturing considerations are also very very important, we may definitely be able to find the material here and suppose we find that the composite material is satisfying our requirement, all the requirements that are there in the product design. But maybe then we are not able to find any manufacturing process which can make the composite as per the required product design.

Therefore alongside the properties of the engineering materials we must also considered the manufacturing consideration, we must understand the castability, formability, machinability, coatability, then failure and repair also sometimes play a very important role. For example we have designed a product, we have installed the product or engineering structure and it has got damaged because of certain unwanted circumstances or uncertain unwanted events or certain accidental events.

If we do not have a repair strategy in place definitely the product will not be the product will not be able to provide the intended function for which it has been designed or installed. So therefore the repair maintenance also has to be identified in the very beginning only and then for repair and maintenance we have to select our engineering materials in such a way that the repair and maintenance is easier.

So first thing are the properties, second is the whether we will be able to manufacture the product with the selected material economically, whether it is visible can we get that shape, can we get that size. So that can we get that complexity that is there in the product design using any one of the standard manufacturing processes or we need to modify our manufacturing processes to suit the needs and requirements of the product design.

All those things have to be considered during our process of selection. Then the other parts the allied parts are also equally important,these 2 things we are focusing currently the manufacturing consideration in the 1st week we have focused and we have tried to see the process capabilities, engineering materials we are focusing in week 2 and further all these processes whatever is written casting, machining, sometimes injection moulding, compression molding specially for plastic parts.

We are going to cover in our subsequent session, so our primary focus is on these 2 aspects that manufacturing aspects as well as the material aspect. Then finally we also have to consider the cost, you was ultimately we have to make a product in the most economical manner. In cost analysis we have to see the availability of the materials, we have to see the life of the material, just now I have given an example.

That if just now I have told you that if the material life is too long and we are using it for making a shirt I may not like to wear the same shirt throughout my life, I may like to change the shirt every year or maybe 1 and half year or 2 years, 2 and half years. So the material life is also very very important. Then the maintenance of the material that we have already seem that the maintenance must be easy.

So the cost analysis point of view is important because the maintenance will also if we require frequent maintenance, for example we have a again I am taking an example of underwater application. So we have underwater application, some materials we have selected for that structure, suppose every 6 months we have to do the paintings, so the maintenance becomes a costly affair.

Whereas if we select a material or engineering material which requires no maintenance however it must be costly in the beginning, but over the life cycle the cost becomes less because after every 6 months we need not stop the operations and do the painting of the structure. So why not to select that material which requires no maintenance. But initially may be it may be slightly costly.

So that kind of trade off has to be done when we are selecting engineering materials for a particular product and that will help the company to save lot of money, then finally we come to the environmental issues. So we have to see the ergonomic and the safety aspects, recycling and waste disposal very very important as we record these session may be in the 2nd week or 3rd week of June lot of emphasis is there on minimising the plastic waste.

Different organisations with different rules are being passed every day in the newspaper we see that the use of plastic has been banned or use of plastic carry bags has been banned, therefore there is a need to select the material for our product which can be recycled which can be easily disposed into the environment without causing any harmful impact on the environment.

So the selection of engineering material for a particular product design will basically depend on these 4 important parameters that is the properties of the engineering material, the manufacturability of a engineering materials, the cost of the engineering materials as well as the end of life of the engineering material or end of life issues of the engineering material that whether it can be recycled or not.

Whether it can be easily disposed of into the environment without causing any harm to the environment. So these 4 factors are the broad factors that have to be taken into account. I think I have explained in detail, now quickly we will see each one of them, so factors influencing the material selection, so from properties we have not touch down the dimensional tolerance.

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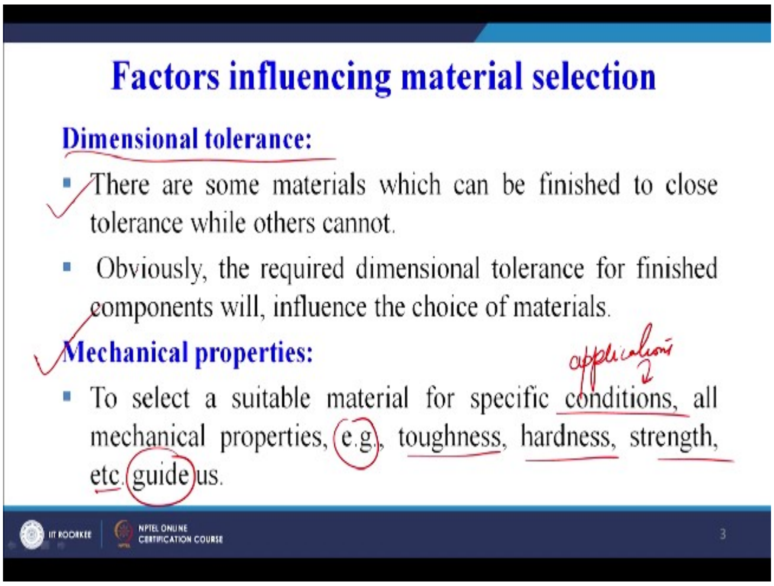

So there are some materials which can be finish to close tolerance while others cannot. So we have to select a material depending upon the dimensional tolerance requirement in our product design we have to select a material which can provide us that kind of dimensional tolerances. If we are not able to get the dimensional tolerance the quality of our product will suffer. So therefore we have to select a material as per the dimensional tolerance achievable with that material.

For example if we talk of metal and a polymer so with both we can achieve a certain degree of dimensional tolerances. So we depending upon the application we will see that here better dimensional tolerances required. So let us select x material and we can discard or screen out the y material, obviously the required dimensional tolerance are finished components will influence the choice of materials.

So then the mechanical properties to select a suitable material for specific conditions, in place of conditions we can write specific applications also which is subjected to different types of conditions. All mechanical properties these are just the examples given like toughness, hardness, strength etc. They will guide us they will act as a guiding factor. So whenever we select a engineering material.

For example we have to design a new design for a tie rod, or if any engineering component, we will see the material property table and then see what is the tensile strength of this materials, what is the compressive strength of this material, what is shear strength, what is the impact strength, what is the modulus, we will try to see all the properties and finally if the property satisfy our requirement then only they will select that engineering material or we will out of a library of engineering material.

We will select the material which is satisfying all the requirements that are that have to be satisfied for selecting a particular materials. So we for example we design a particular product, we as per the in-service requirements we list down that the tensile strength for this material must be more than this, compressive strength of this material must be more than this, so when we look at the data table or in the handbook of material we will see which material is satisfying this requirements.

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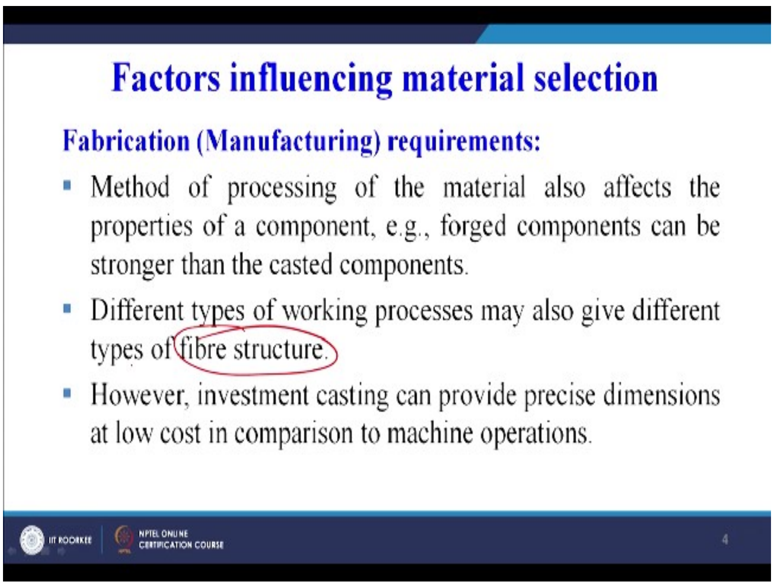

So accordingly we will select the engineering materials, so the mechanical properties play a very important role in the selection of material, then the fabrication of the manufacturing, the second column that we have seen in the diagram today, method of processing of the material also affects the properties of a component. For example forged components can be stronger than the casted components.

And therefore the manufacturing process will also play a very important role in the choice of materials. Now we want higher strength for our engineering components and we are going to use forging process to get that higher strength. Then the material also has to be selected in such a way that it can be forged properly, it must not happen that we have selected a material which is not we can say friendly to the forging process.

So that is the selection of the process will also have a influence on the selection of the material and vice versa also selection of a material will also have a influence on the selection of the manufacturing process. So different types of working processes may also give different types of fibres structures or the microstructure. Fibre structure is specifically if you talk about the composite materials more specific about the polymer matrix composites materials.

But if you talk about the metals when we process then using different types of processes their microstructure also gets affected. So if the microstructure gets affected the properties will also get affected and these properties will definitely influence their performance during the in-service or in-service performance of the components will be affected by the manufacturing process.

So we need to understand that we have selected material x, we are processing it with process y, so material x processed by process y, how it is going to influence the microstructure of the material, and how that microstructure is going to affect the performance of the material when it is going to be exposed to the service requirements. So one example is taken here investment casting can provide precise dimensions at low cost in comparison to the machining operations.

So one very good example is taken here, that if we have to make a very intricate metallic part we must go for investment casting because machining of those intricate features will definitely add a lot of cost of processing into the product. So investment costing is better when very very intricate details are required in our product. So the product can be a jewellery item we see that the jewellery items are very very intricate detail.

So if we start machining those intricate detail, it will be a very very expensive proposition, so it is always better to use investment casting for intricate metallic part. This is one example related to how manufacturing processes can also influence the selection of the engineering material. Now the cost of processing also is very very important.

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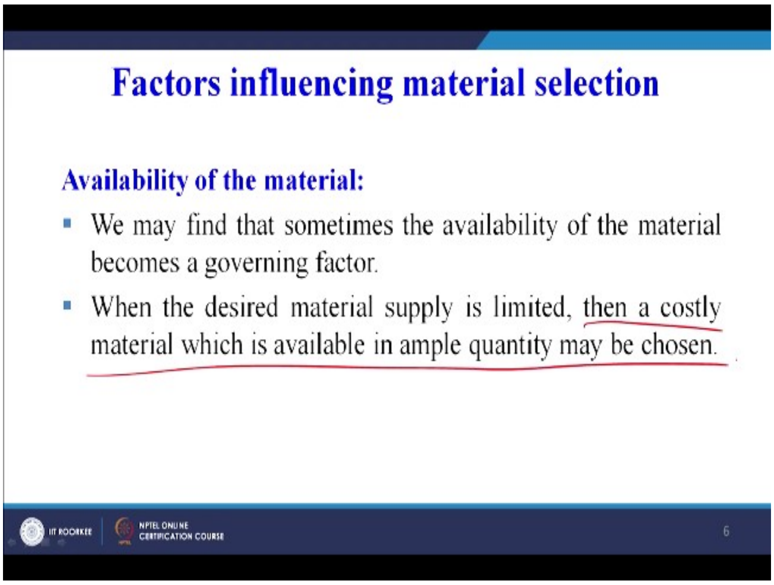

In most of the industries the processing cost and other cost such as overhead cost account for 50% of the production cost, so once we select the process and the materials we must keep in mind this 50% commitment for the production or for the cost of production, overhead cost is automatic, in automatic industries much more than the a other cost.so if one can somehow reduce all such cost the total production cost will automatically reduce.

So this is not particularly relevant with the selection of engineering materials, but is definitely relevant from the selection of a manufacturing process point of view and indirectly is going to affect the selection of materials also because some materials can be processed with automatic machines and therefore the overhead cost will be influence. Some materials may not may be propose themselves as a good candidates for automation.

So accordingly we will see that we have to select a material which will influence the overall production cost of product, availability of the material is very very challenging task, we may find that sometimes are availability of material becomes a governing factor, now material is not available, what to do in those cases when the desired material supply is limited than a costly material which is available in ample quantity may be chosen.

So we have to see the availability, sometimes the material that which is not available so we have to go for a material which is easily available maybe we may have to pay certain additional money or premium to get that material.

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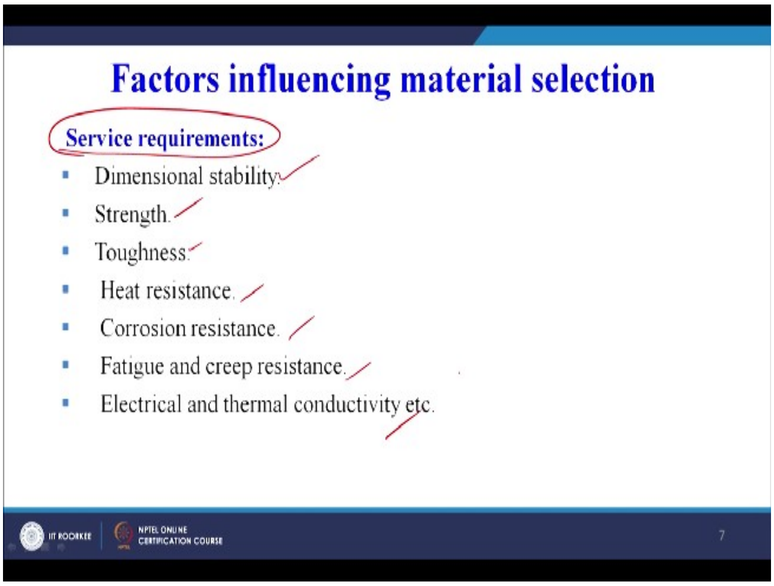

So the factors influencing material selection service requirements the kind of conditions the product is going to be exposed to is definitely going to influence the material selection and therefore the dimensional stability maybe the dimensional stability on exposure to heating condition. So if you remember we have already seen that polymers are not that good under hot temperature or at high temperature.

So in those cases the dimensional stability that may become a issue. So similarly the strength must not get affected by the environment. For example the component or the part has to be used in the freezing conditions or a metallic part exposed to the freezing conditions over a long period of time. So freezing condition may affect the strength of the material. So therefore the in-service conditions also play a very important role while deciding that which material must be chosen.

So the material must not be susceptible to environmental conditions of service requirement, many times the wear and tear maybe a important design criteria. So we have to select a material which are the hard surface, so that the wear and tear does not take place. So the toughness, heat resistance, corrosion resistance, fatigue and creep resistance, electrical and thermal conductivity. So depending upon the situation in which the product is going to be used it is also going to affect the choice of material with which we are going to make that product.

So example already I have taken that if the material is not that resistant to heat we must select a material which is better heat resistant. For example the ceramic material so where the temperatures are going to be too high we must avoid the use of polymers there, we must propose the use of ceramics in those circumstances. So depending upon the kind of conditions we must select our engineering materials as well as the in-service requirements material of the product will definitely dictate the choice of the material for a specific application.

Now the selection of materials let us try to take an example that how we will go about selecting a particular material or what is the procedure that we must follow. So in particular the selection of a specific engineering material for a part or component is guided by the function.

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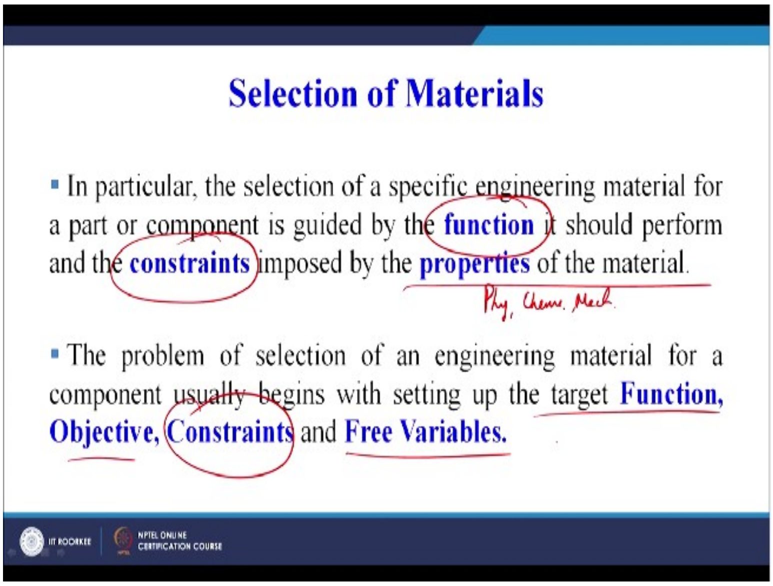

Already in the previous slide this discussion has come into picture, the function is very very important, it should perform and the constraints imposed by the properties of the material. Now properties of the material already we have seen properties can be the physical properties, then there can be chemical properties, then there can be mechanical properties. So the properties of the material will definitely pours certain constraints.

And we have to see that what is the intended function of the product which is being design. The problem of selection of an engineering material for a component usually begins with setting up the target function, so first we need to see what is going to be the function and regarding the function and the functional analysis we have taken already recorded a curse on product design and development in which we had discussion on value engineering which is an important technique that we use for functional analysis of the product.

So we try to understand the function of a product, for example if we say the spectacles that we use, so what is the function of spectacles, the function is improve vision, if we use newspapers the function of newspaper is provide information, if we talk about watch or a wall clock we will say display time, so 2 word functional definition for each product we can take. So for any product that we are designing we must first list down what is the function which is the product is going to be designed for or what is the intended function of the product being design.

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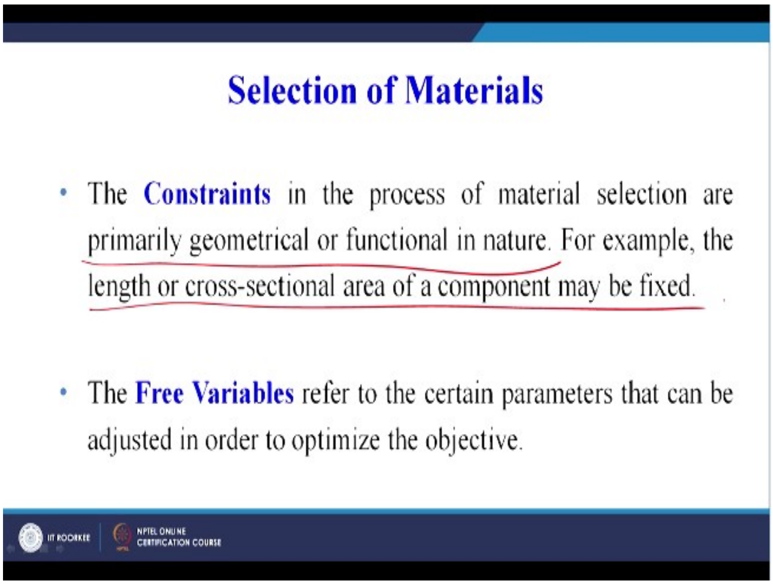

Then we have to look at the objective, what are the constraints, in terms of the material properties and finally the free variables. So let us quickly see this, the constraints in the process of material selection are primarily the geometrical or the functional in nature. For example the length or the cross sectional area of the component maybe fixed. So that is a constraint. For example this dies has to be designed.

So what is fixed there, the height of the dies is already fixed, so that is a constraint, so we need to make it lightweight, sturdy, strong, it must not be having any kind of vibration. So these are some of the important design feature which have to be included in the design of this dias. But one of the thing is the constraints the height we cannot have a dias up to this much height, the speaker is not visible behind the dias.

So that is not may be advisable, that is not going to help with achieve its desired function, a desired function is to provide a platform for a speaker to stand, keep the console and deliver a lecture. So that is what one thing is fixed, that is a height is a constraint in case of design of the dias, the free variable refers to the certain parameter that can be adjusted in order to optimize the objective.

Now there can be certain free variables here which will help us to adjust our objective or which we need to adjust in order to optimise our objective. So the free variables we will take an example in the subsequent slides.

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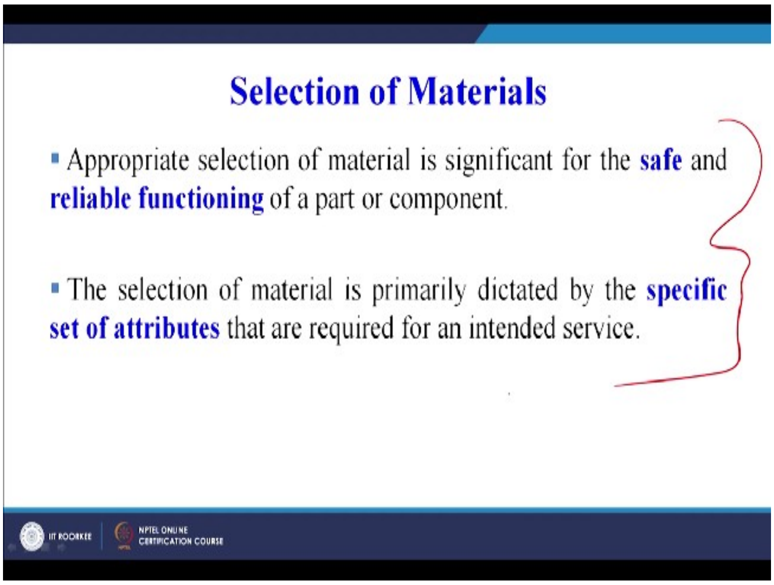

Then appropriate selection of material is significant for the safe and reliable functioning of a part or component. The selection of material is primarily dictated by the specific set of attributes that are required for an intended service. So both these points already I have discussed just now may be 5 minutes back, we when we talked about that we have to focus on the intended function of the product.

And accordingly we have to select our engineering material, so selection of material is primarily dictated by the specific set of attributes. The important point is already highlighted, specific set of attributes that are required for an intended service. So what is required in the product, so that it is able to perform its intended function. So that will define that which material has to be selected for this product based on the constraints and free variables that we have already discussed.

There are certain constraints which have to be taken into account and free variables that we need to adjust in order to satisfy our overall objective. Now we come to a term which we call as a material index.

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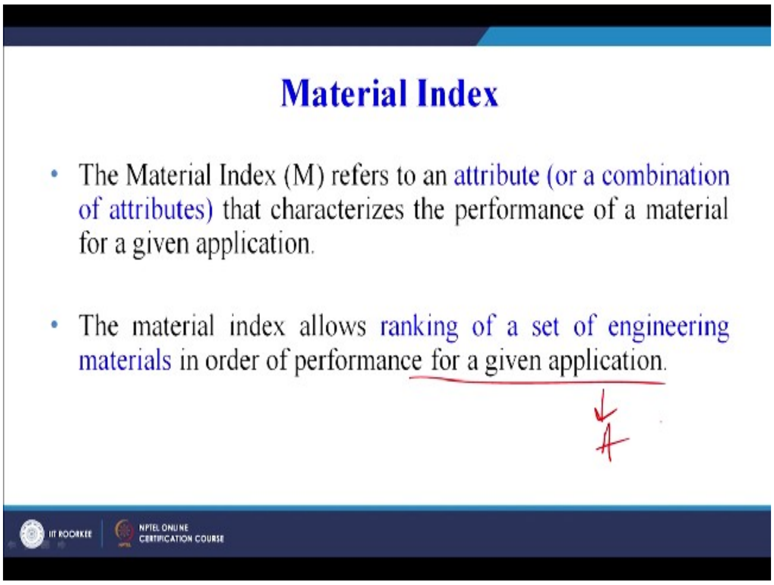

So the material index refers to an attribute or it can be a combination of attributes that characterize the performance of a material for a given application. So material index will guide us in the selection of a particular material or a specific material for a specific application. So the material index allows ranking a set of engineering materials in order of performance for a given application.

Now suppose we have a given application which we can characterise as A and there can be number of materials which can satisfy this application or can be used for this application. So MI or the material index will help us to select a particular material. So it is a kind of ranking 2 or the value which will help us decide that which material satisfies the needs and requirements, the functions of the application A or the product A.

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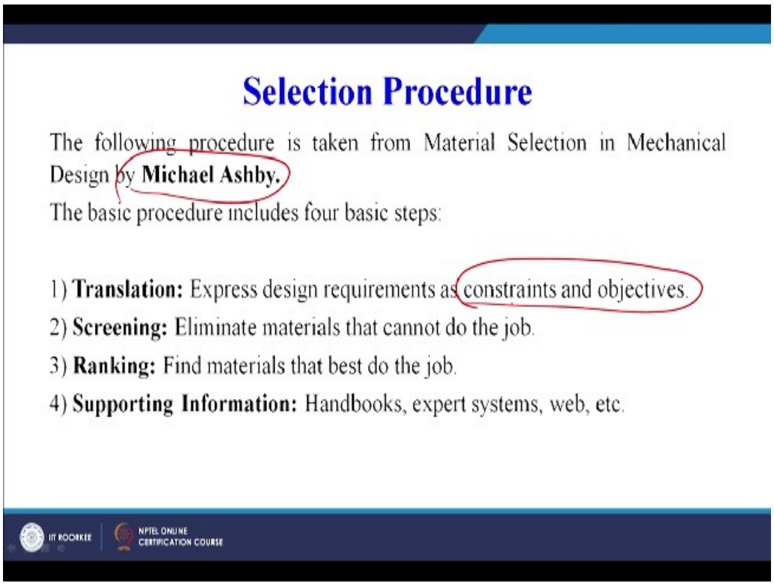

So the material index allows ranking of a set of engineering materials in order of performance for a given application. So we can rank the materials based on the MI value. So the following procedure is taken from material selection in mechanical design this is the source from where Michael Ashby from where this discussion has been taken. The basic procedure includes the 4 basic steps.

First one is translation, express the design requirements as constraints and objectives, we will take an example things will become more clear. So first we have to design requirements we have to write them in terms of constraint. So this is a constraint of that the design. So the one of the constraints can be that the height of this dies is fixed, we cannot change the height of the dies, it is the average height for all the speakers were going to use dias.

So the height becomes a constraint, so this is one design constraint which is already fixed. So express the design requirements has constraints and then we have to list the object is that why this dies has to be designed, what is the objective for the dias. Screening eliminate material that cannot do the job. So then we start screening out the materials. For example we have a constrain that the material that we are going to use or the product that is being design has to sustain a temperature of 2000 degree centigrade.

So this is the design requirement which is the constrain 2000 degree centigrade then we can very easily screen out some materials which cannot sustain such a high temperature 2000 degree centigrade. So some materials already gone, so that is the process of screening. Then ranking suppose now we have left with 4 materials which can sustain the temperature about 2000 degree centigrade.

So then we will drag the materials based on certain other criteria, then we will look for the supporting information from the handbooks or from the experts, there may be certain expert systems or the softwares available which may guide us regarding the materials which are left, some of the materials are already screened out based on the constraints and objectives of the product design.

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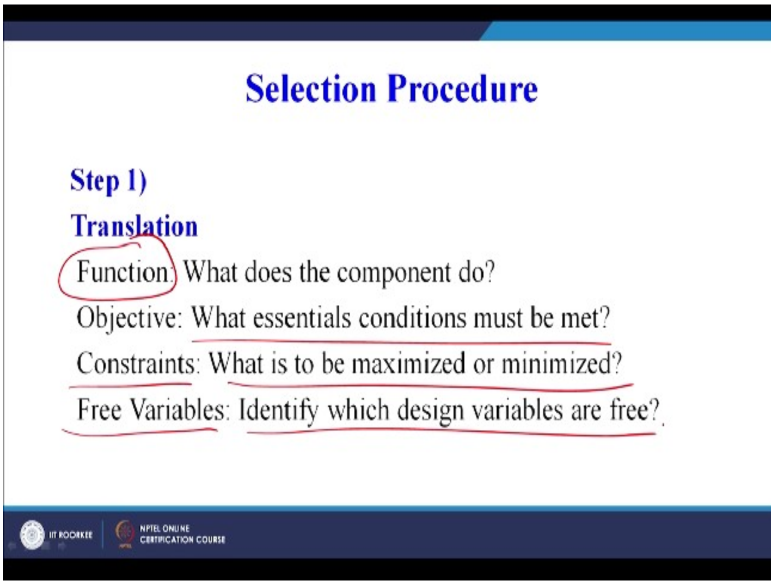

Now the translation let us quickly go through this process, translation first we have to focus on function what does the component do, objective, what essential conditions must be met, constraints, what is to be maximized or minimised as I have already told the maximum temperature may be one of the constraint, free variables, identify which design variables are free. So for this design of this dies the height suppose is fixed.

But the cross sectional area of this stand may be one of the free variable, I can choose the cross sectional area of stand. So that may be a free variable in the design of this dies. So what is first is the translation of our design into function objectives, constraints, and free variables.

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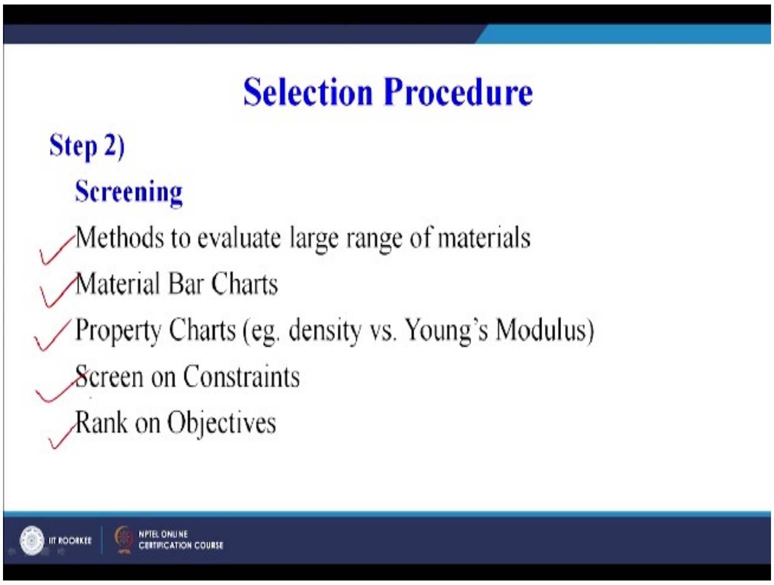

Then we do the screening, we need to develop methods to evaluate large range of materials, we can use the material bar charts and see which are the materials which are satisfying our requirement, property chat as we have seen in one of our previous session towards the end of the lecture I have shown a property chart which was showing that tensile strength, flexible strength, compressive strength, modulus, certain physical properties in terms of melting point etc.

So those type of charts are available we can refer to those charts and screen out some of the materials which are not satisfying our constraints are not satisfying our objectives. Then screen on the constraints and then rank on the objective. So based on the objectives we can rank the materials into the first rank, second rank, third rank. Then the ranking so if what is multiple materials remain after screening very very important.

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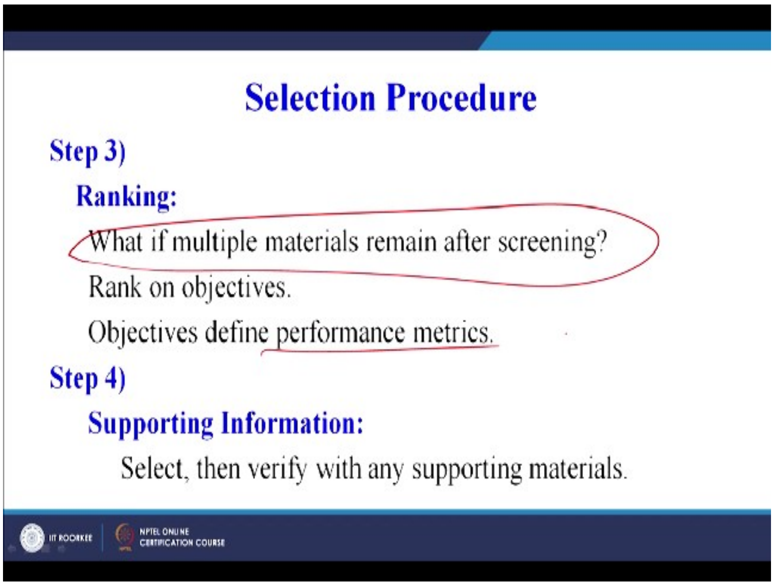

Now 3 materials are there which are left after screening, then we can rank on the objective that depending upon the objectives of the product we can rank this material or this is the material which is satisfying the objectives more closely as compare to the other materials. So objectives will define the performance matrix. So there will be certain performance metrics for the product which can be in terms of for example we are designing a new engine.

So that the efficiency of the engine can be one of the performance metrics and depending upon the 3 materials that are left after the screaming of the other material we will rank them that which material is going to affect the performance metrix in more positive manner, then supporting information we will try to derive from the experts, from the books, from the handbooks, from discussion with the experts or the knowledgeable people in that specific engineering domain.

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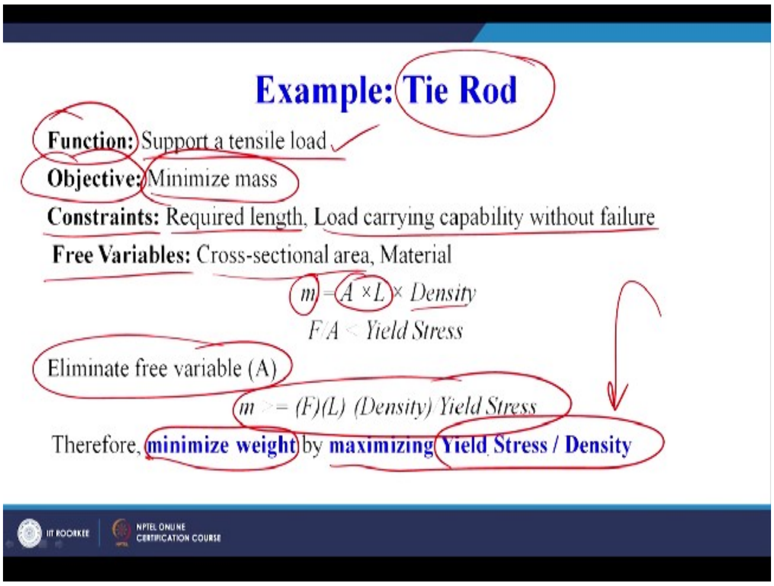

So they will help us to take a decision regarding the choice of the materials. Now let us take an example of a tie rod, we have to design a tie rod, so the function is to support a tensile load, we must know the function, what is the objective of our material selection, we have to minimise the mass, what are the constraints, the constraint is the required length is already fixed.

So l is already fixed, load carrying capability without failure that is also a constraint. O we have to support a tensile load, so it must not fail under that tensile load, that is also the constraint, the length is also a constraint, the objective is to minimise the mass of this tensile sorry mass of this tie rod, so the free variable in this case as I taken the example of this dies design of dies, suppose the height is a constraint here.

The cross sectional area of the stand can be a free variable, so that we can design as per our requirement or to satisfy the object, so the objective in this case will be different wherever in our example that we have taken of tie road the objective is very very very clear that is we have to minimize the mass of this tie rod. So the cross sectional area of the material is given A, so we will see that the mass is given by the volume A*L, A is the cross section area.

L is the length, so volume*density and F/A is the force per unit area that is being given by yield stress. So we have to eliminate this free variable A we have to design or we have to select a material for the cross sectional area, we have to decide the cross sectional area length is fixed, we have to minimise the mass of this tie rod, that is our objective, so we can see that what can be the cross sectional area which minimizes our mass without affecting our load carrying capacity without failure.

So this equation will help us to fix or select our material, so here we see density/yield stress is a parameter which can help to decide a material. So therefore if we have to minimise the weight we can do it by maximizing the ratio of yield stress to density. So we have to focus now on this equation of yield stress not the equation but the ratio the yield stress to density. Now suppose we have 4 different materials available with us.

We will see the yield stress for the material and density of the material and wherever we get this maximum ratio of yield stress to density or for the material for which we get the maximum ratio for yield stress to density that material we will select for our application that is the tie rod in this case. So the 4 things are very important what is the function, what is objective with which we want to select the material.

What are the constraints and what are the free variables that have to be taken into account, once that is ready then simply we can try to fix up the material properties or the material index which will help us to select the or rank the engineering material for that particular application. The material index M1 in this case becomes.

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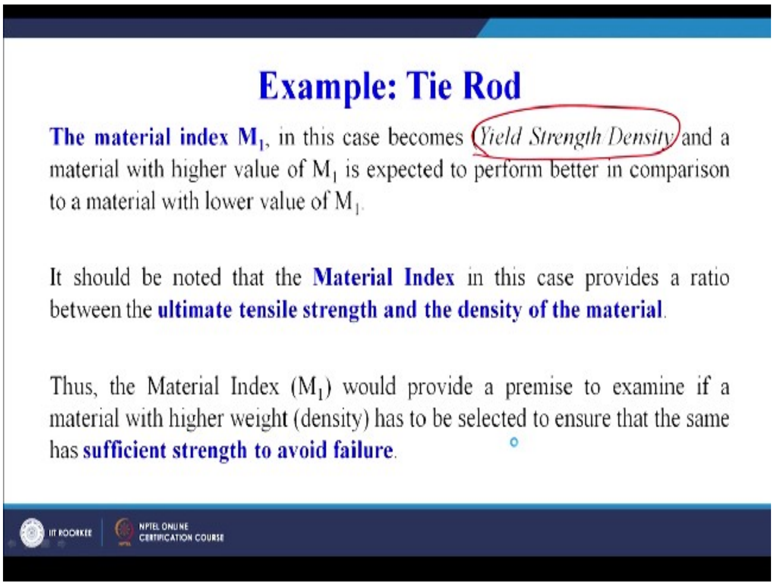

So the material index is yield stress/density and a material with higher value of M1 is expected to perform better in comparison to a material with lower value of M1 that we need to maximize as we have seen in our previous slide also, yield stress/density. So the yield stress/density is an important material index which will help us to rank the various materials which are left after the screening process.

So it should be noted that the material index in this case provides the ratio between the ultimate tensile strength and the density of the material. Thus the material index would provide a premise to examine if a material with higher weight has to be selected to ensure that the same has sufficient strength to avoid failure. So here we will see that if the weight is more whether it has the strength or correlation between the density and the resistance to failure under the tensile load becomes the important parameter or a important guiding parameter for selecting a material.

With an overall objective of minimizing the mass of the tie rod, so with this we come to the end for today's session, in our last session in this particular week that is week number 2 we will focus on the important engineering materials and will try to see that what are the broad applications for these engineering materials, our focus will be on metals and alloys, ceramics, polymers and composite.

So after completing the discussion for week 2 I think all product designers or all learners will have an idea that what are the engineering, different types of engineering materials, what are the special characteristics of the various types of engineering materials, how to select a engineering material for a specific applications and what are the broad application areas of the various families of engineering materials. So with this we conclude the session number 9 of our course on manufacturing guidelines for product design, thank you.