Design Practice

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Lecture - 28 and 29
Material selection in Engineering Design

Hello, welcome to the course Design Practice. in lecture Module 26 and 27, You have already learned about what are the properties involved in a selection of a material. Now, in the module 28 and 29, you will learn what are the steps involved in a selection of a material. I will continue to discuss about material selection in engineering design, ok. For selection of any material, it has any material has a lot of attributes; that attribute you can say that density, strength, cost, resistance to bear, resistance to corrosion so on and so forth.

So, for a design demand a certain profile of this things. For example, a lower density material, that material should be a lower density and higher strength and cost should be modest, at modest price.

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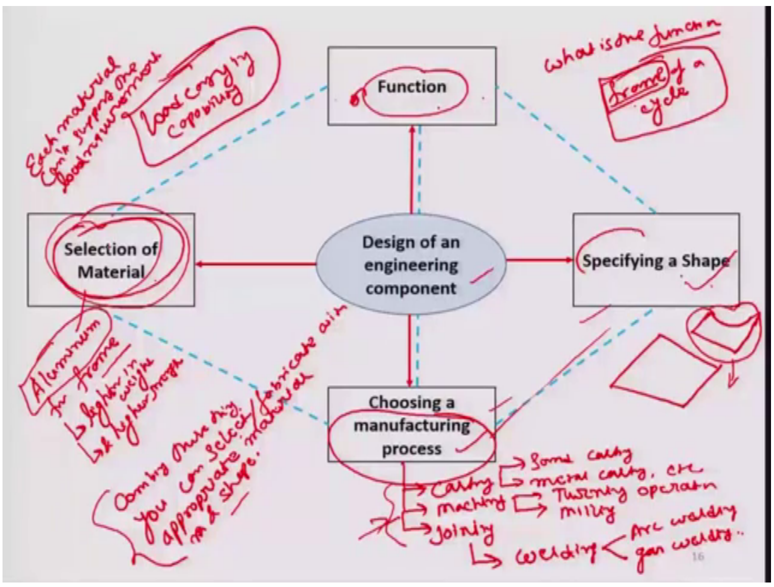

So, here for a designing of any engineering component, it depends on various components, sub components that is called function, selection of materials, etc.

Choosing of manufacturing process specifying a shape and these all attributes are cross linked, inter linked to each other, ok. So, for selection of any material, it starts with a function. What is the function? What is the function? It means suppose that if you want to make a frame of a cycle, so what will be the function of that frame, accordingly. So, this function of that frame will influence the selection of material, and after that suppose that you we you know that frame of any cycle, it carries load of a person or anything, ok. So, that for we have to keep in mind load carrying capability. So, that is the main function of your object. So, we you will have to choose accordingly material of because each material cannot support the load requirement that way we can say that function influence the selection of material again.

Now, after selection of material what happens it influences the manufacturing process, suppose that you select selected an aluminum for frame it poses lighter in weight and higher strength. So, for fabrication of frame which is to be made of aluminum what will the appropriate manufacturing process and process are, lot of process are there manufacturing process are there suppose that casting and it is a sub classification of casting is sand casting metal casting etcetera of again another process is machining is done by turning operation another operation you can say milling, joining for example, welding and welding as a several types suppose that arc welding, gas welding etcetera.

So, to fabricate an aluminum frame of for a cycle you will have to choose appropriate manufacturing process again this process influences the shape means suppose that shape of a frame can be of various type this type or you can say this type. So, now this particular shape may be may not be possible to fabricate in by each process ok. So, you will have to select appropriate everything. So, again this completes the all four components function of your component selection of material and manufacturing process and shape these combining these things, you can select appropriate or you can say you can select or fabricate with appropriate material and shape. So, in this course I will focus only on the selection of material although, the other parameters are also necessary for a design of an engineering component, but I will focus only on selection of material.

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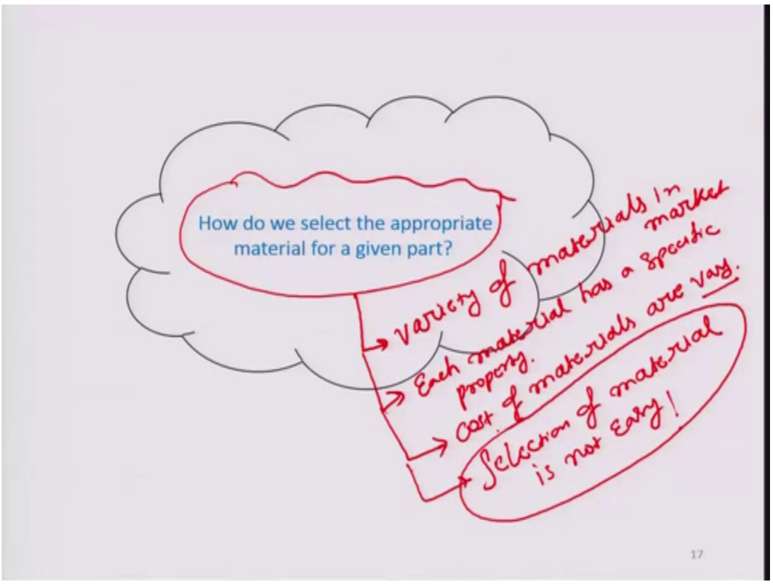

So, question is that how do we select the appropriate material for a given part and this is very important question because we have a variety of materials in market.

Each material has a specific property and cost of materials are vary. So, keeping these points, the selection of material is not easy. Material selection is a step in the process of designing any physical object, ok.

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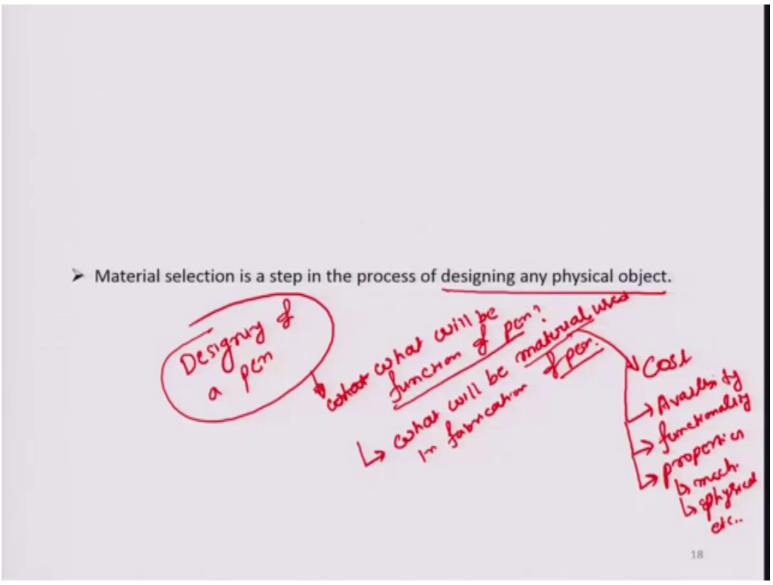

Suppose that you are designing of a pen. So, first step will be how, first function what will be function of pen? First question, then after designing the function of pen what will be material used in fabrication of pen, and we will have to keep in mind cost availability functionality and properties like mechanical physical etcetera. So, metal selection is a very crucial step in a process of designing of any physical object.

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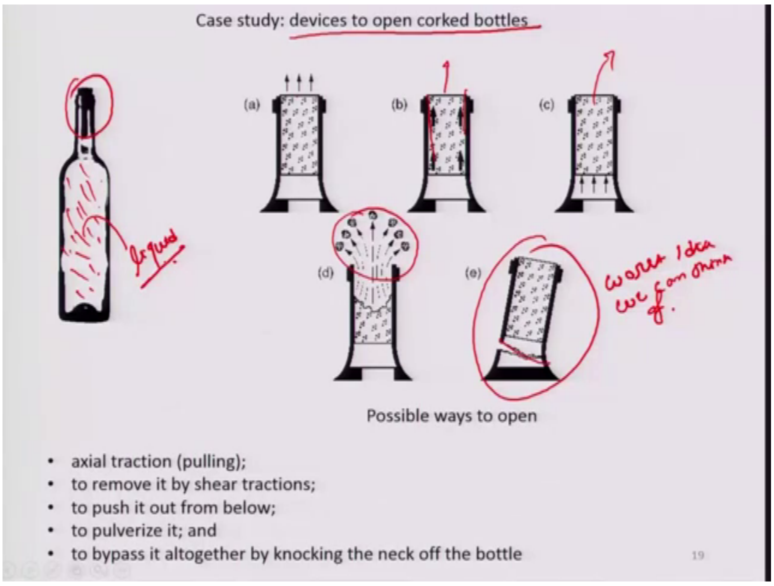

I am going to explain metal selection while choosing, using a one case study.

Suppose that we are, we want to make a device to open a corked bottle. This is the wine bottle and cork is placed on the top. So, these are the various possible ways to open the cork. First what are the process axial traction you are going to pull the cork, top open the bottle. Second, this is to remove it by shear traction. Suppose that you are applying something here one force, so that it will get and if you will pull here. So, your cork will bottle will get open. Third one is push out from below if you are applying a one force from bottom side, then also it may take out from the bottle. Third one is pulverizing it. So, it is very time consuming and not a good idea and to bypass it all together by knocking the neck of the bottle is this is the worst idea we can think of because the things inside the bottle may be very costly or a precious thing for a moment. So, you cannot break the bottle from the neck and to get that liquid.

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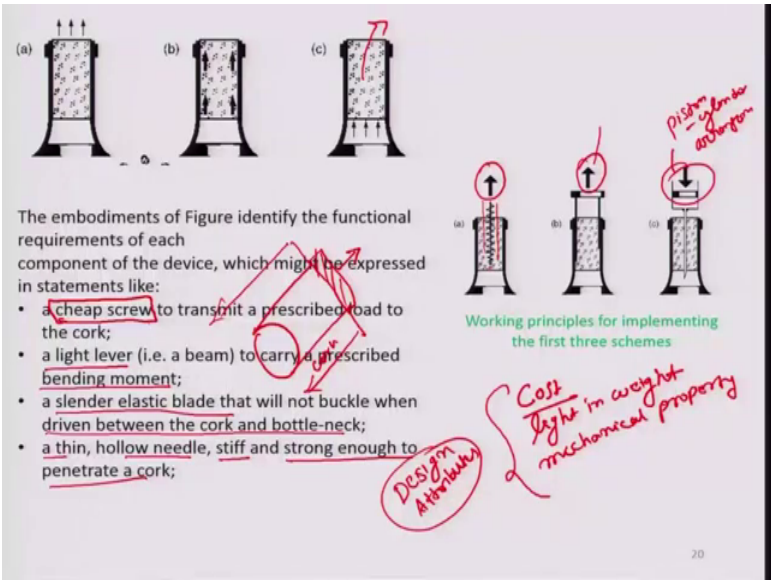

So, I am taking only three ways to open the bottle. These are the and possible way to open that bottle working principal suppose that if you want to open from by pulling the cork. So, what you can do is, you just you will put a screw here, and it will up to the corks bottom portion and then, you will pull it. So, then cork will get removed. Second one you will make an arrangement, so that it will like just like here hollow thin tube at this portion, we will get inserted into cork and then after you will pull it.

So, that cork will get removed from the bottle and third portion is that you will make a hydraulic pressure kind of piston cylinder arrangement that is called alignment to apply a force from the bottom side, so that cork will come out from the bottle ok, but the embodiment of the figure identifies the functional requirement of each component of the device which might be expressed in statements like a cheap screw to transmit a prescribed load to the cork, ok. It means your attributes for the designing of openers what is the cheap screw, it means cost. Second one is a light lever to carry a prescribed bending moment means light in weight a slender elastic blade that will not buckle when driven between the cork and bottle neck.

It means that is the mechanical property and a thin hollow needle stiff and strong enough to penetrate a cork. Again it is a mechanical property. So, this your design attributes to make a cork opener.

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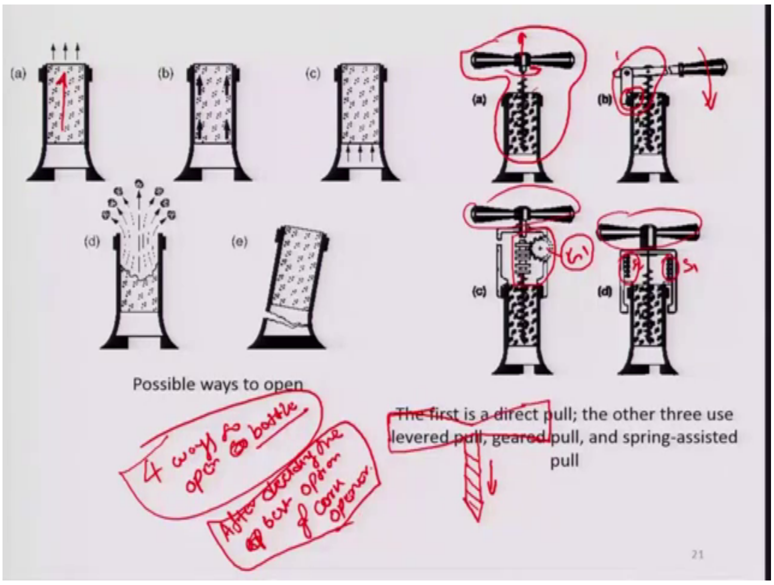

So, here what we can do that for previous one to make axial pull, this may be a possible way to open the cork. So, here what how it is made one dumbbell shape handle and at centre there is a screw and it will go through the cork. First there will be a you can handle, you can apply compressive low force on screw handle. So, the screw will get inserted into the cork, then you just it will rotate and make a pull, so that it will get open. Second thing, the other three is that is the levered pull that is the gear lever pull either you can apply a make a lever arrangement. So, that will give that portion will get fixed at top portion, top bottom, top corner portion of the cork and then, you will apply a force.

So, due to the torsion, it will get removed. Third one is the geared pull. Here there is a gear arrangement, so that when you will rotate handle, due to this arrangement what will happen this gear one will rotate and it will transmit power to that gear and it will help you to get removed that cork from the bottle and for first portion spring assisted pull, a spring assisted pull is meaning your applying a force. So, due to the spring force, these are the two springs s 1 and s 2. What will happen there will be compressive load will apply and after rotating that handle, so that it will get opened. So, you can see that they have four possible ways to make a cork opener, either you can use a direct pool or either you use geared pool or use spring or a geared pull spring assisted pool, so direct pool. So, these are the four way to open bottle.

Now, after deciding the best option of cork opener, what you will think now material what be the material of each component. So, again then metal selection comes into the picture.

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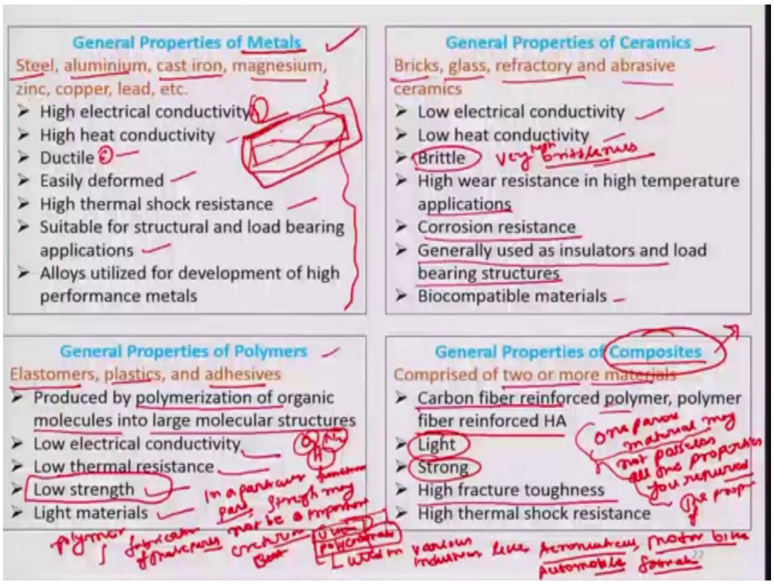

So, here are some properties of the materials. So, first general properties of metal. I will talk about metal. So, common metals are steel, aluminum, cast iron, magnesium, zinc, copper, lead etcetera. These things, these metals can be used to make your cork opener, and these properties, these metals have a specific several property high electrical conductivity, high heat conductivity ductile easily deformed, high thermal shock resistance suitable for structural and load bearing application alloy utilized for development of high performance metal. So, there are variety of properties for these kind of metals, but to select a particular material, what you will have to look into these things.

Suppose that you are making a handle, cork handle. So, there will be you will use your and to make it rotate clock wise either or anti-clock wise, this property is what required. These are the non irrelevant property ok, but ductile. So, this is also not required, ok. So, appropriate accordingly you are though according to your functionality, you can select your material. Second property of ceramics, these are the common ceramics available. We have bricks glass refectory and abrasive ceramics and these materials have several properties, low electrical conductivity, low heat conductivity, brittle in nature. Ceramics are very brittle, very high brittleness, you can say, high wear resistance in high temperature, application corrosion resistance generally used as insulator and load bearing structure and biocompatible materials and properties of polymers, common properties are elastomers.

We have discussed in earlier modules plastic adhesive. Plastic and these are produced by polymerization of organic molecules into large molecular structure and it contains oxygen, nitrogen, hydrogen. These elements are present in polymers, ok. Low electrical conductivity, low thermal resistance, low strength lighter material, but strength of polymers is lower compared to metal or ceramics, but in a particular part, strength may not be important criteria. So, strength may not be important criteria. So, that at places, those we can choose polymer for fabrication of those parts, but we have a variety of polymers which now we have varieties like Ultem, polycarbonate. These are the very higher strength. These are very high strength material and it is used in various industries such like aeronautical, again in a motor bike fabrication, auto mobile etcetera.

Other materials are composites. Composites are made of two or more materials, ok. From past several decades, the significant in research has been made in area of composites because by if you are supposing that one parent material may not possess all the properties you required. So, if you will mix another material with this first material, so that is the composite. You will make a composite, so that your goal will get achieved because after making composite, the property of hybrid material will be higher than your parent material, ok.

These materials are carbon. For example, carbon, fiber and post polymer fiber reinforced and these poly composites are lighter in weight and very strong, high fracture toughness, high thermal, soft resistance and so on. So, you can see that from this slide there are a metal ceramic polymer composites and each material have variety of proper properties. So, you have to you will get confused when you will be going to select your material basis on only properties of the material, ok. So, you will have to think beyond of this.

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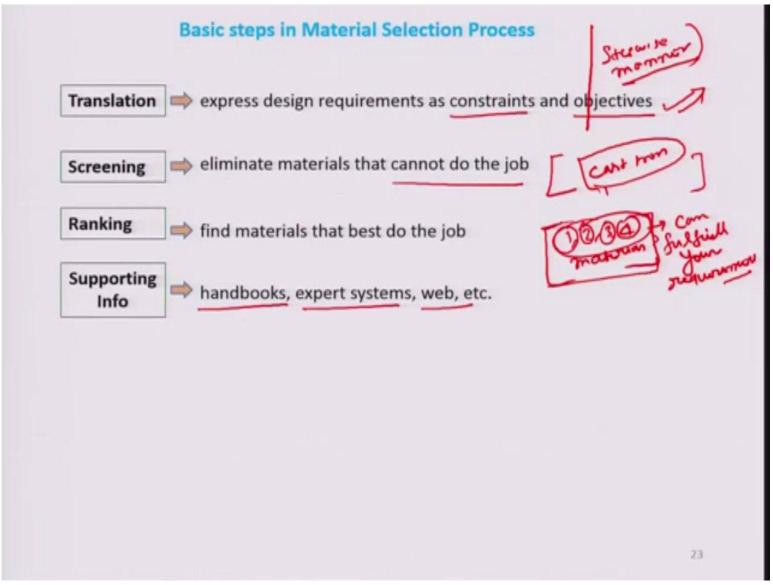

So, basic steps in metal selection process, now we will discuss how will select material and in a stepwise manner, ok. First step is translation. Translation it express design requirements as constraint and objective means first you will have to define function and objective of your design that is the translation. Second step is screening; so screening because you have a variety of materials in your stock. So, the eliminate materials that cannot do the job, suppose that if you are making an electrical electric insulator product.

So, you cannot use metal, you cannot use cast iron. So, this material you can easily you can eliminate. These kinds of things, material you can easily eliminate on basis of your requirement. Then, ranking, after elimination of some material, there will be also still there will be few materials. Now, we have to rank them, find material that best do the job suppose that and you after screening you have one, two, three, four materials and these all materials can fulfill your requirement. Then, it is very confused situation which material I am going to select, ok.

So, there is a way to how can select best out of four materials. So, that is the ranking and fourth step is supporting info, ok. After selection of your material, you just compare these material properties and with respect to your requirement in handbooks expert systems, web page journals etcetera, so that to confirm whether you have selected right material or not, ok. First in steps in material selection process, first I will discuss translation process.

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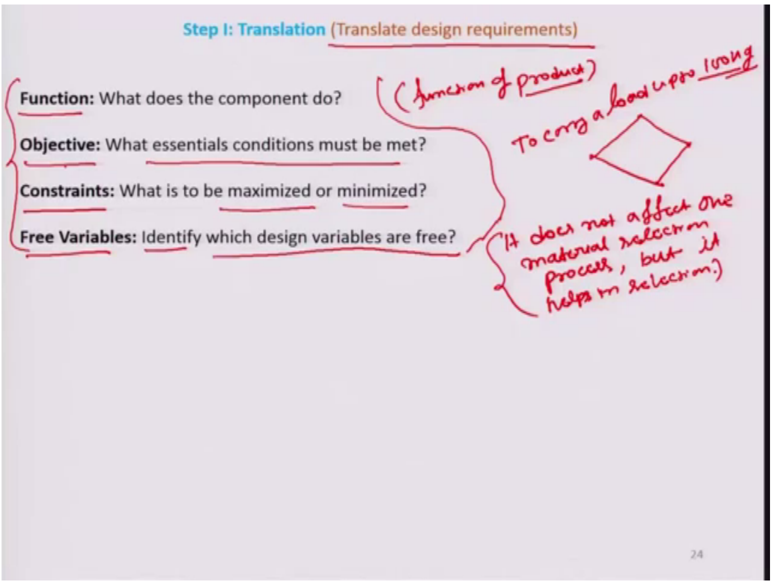

In a translation translate design requirements, first you define what has the, what are your requirements to design anything, ok? First you will have to decide your requirements and function of that product which is which you are going to design, ok. So, in for translating the design requirements, there are four parameters that is the function, objective, constraint and free variable function. It means what does the component do to define the function of product again objective what essential condition must be met, for example, if you are making a cycle frame.

So, the main function of these frame is to carrying a load. So, you will have to essential, so what will be the essential condition to carry a load up to. Suppose that 100 kg. Now, what is to be maximized or minimized constraint? What is the constraint you have because in a real value program, always there will be constraint with your objective. So, we within you in a constraint environment, you will have to optimize your optimum function and fourth one is free variable. This is to identify which design variable are free. Free variable means these are very independent variables and it you can, it does not affect your selection process. So, suppose that if you it does not affect the material selection process, but it helps in selection ok. So, we have four parameters function objective constraint and free variable to translate design requirements, ok.

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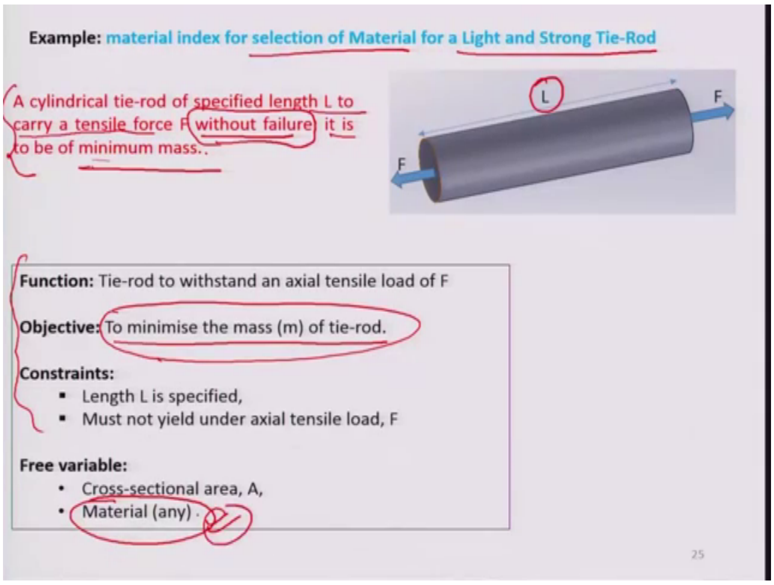

So, I am going to explain translation using one example, ok. We are going to select a material for a light and strong tie road. There is a road of length L and there are cylindrical road of specified length L to carry a tensile force F without failure, ok. This is the and it is to be a minimum mass, ok. These are the requirements of your problem, function. What is the function of this rod? Tie rod to withstand an axial tensile load of F here, load on statement you can see that a specified length L to carry a force F objective to minimize the mass of the tie rod because it is to be of minimum mass. So, we will have to minimize the mass of the tie rod. That is the objective we will have to keep in mind. Fourth one is constraint. Constraint L is specified means the length of tie rod is fixed. You cannot change the length of your tie rod.

Then, second must not yield under axial tensile load F. It means you will have to design tie rod, such that it can carry a load and sustain it. It is shape and size, so that failure will not occur. That is the constraint. Now, free variable is the cross sectional area. Cross sectional area is not mentioned. It means you can choose any dimension of cross sectional of your tie rod material, you can choose any material, ok. Now, that is the material any, but using within this environment objective of minimizing the mass of the tie rod and these constraints which material will be good that is we will have to decide.

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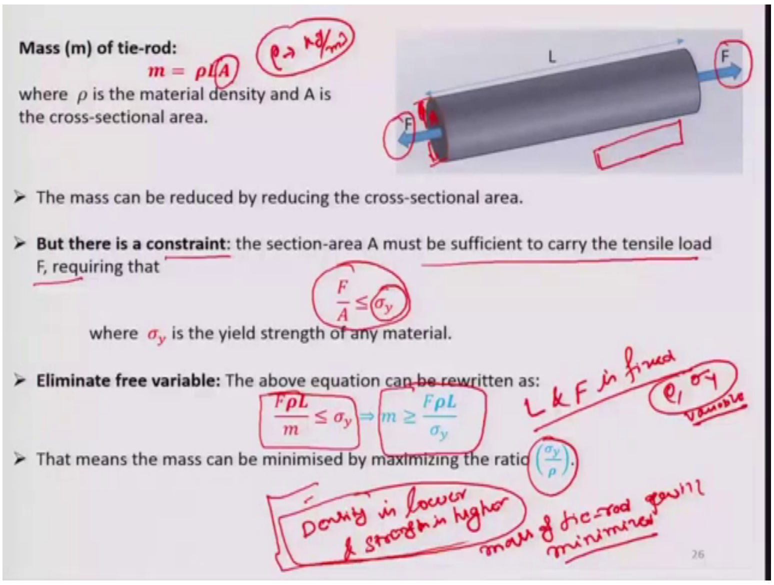

So, mass of the tie rod, what will be the mass of the tie rod mass is a density into length into cross sectional area density. Its unit is kilogram per meter cube. It is a material property, ok. L is a length of your tie rod and A is the cross sectional area of your tie rod. So, from this equation you can see that rod and L pho is material property and material is supposed that for particular material, it is constant and L is also fixed, so that only variable is A. So, m to minimizing the mass can be reduced by reducing the cross sectional area because m is directly proportional to area.

So, if you will reduce the cross sectional area, then mass of the tie rod will get reduced, but there is a constraint. The section area must be sufficient to carry the tensile load F because you are not going to only design the tie rod because here one constraint is that you are applying a load also axial load f. So, suppose that if you will reduce the cross section of your tie rod, what will happen? It will get thinner and the load carrying capability capacity will get reduced. So, what is the constraint? The section area must be sufficient to carry the tensile load f. That is the requiring that F by A is lesser than or equal to sigma y. Sigma y is yield strength of any material. We discussed earlier module what the yield strength is. So, if you reduce now eliminate free variable.

$$\frac{F}{A} \leq \sigma_y$$

So, what we are doing, we are substituting the value of cross sectional area from here. What will be a is equal to m by rho L.

$$\frac{F\rho L}{m} \leq \sigma_y$$

So, by after putting this we are getting this 1f rho L by m is equal to sigma y and finally this one. So, here you can see that in this expression rho is a material property, L is fixed, F is fixed here, L and F are fixed. So, only variable is that rho and sigma y variable. Now, our free variables are, what is our free variable? It is any material and any material. So, now that means, mass can be minimized by maximizing the ratio sigma y by rho, it means if we select a material such that their density is lower and strength is higher, then what will happen the mass of will minimized.

See here what we did we just formulate our requirement and we converted into what will be the we just reduced our domain to selection of a, for selection of material. So, what is the domain? Our domain now density the material which has a lower density and higher strength, then if you will use that those materials, then our mass of tie rod will get reduced.

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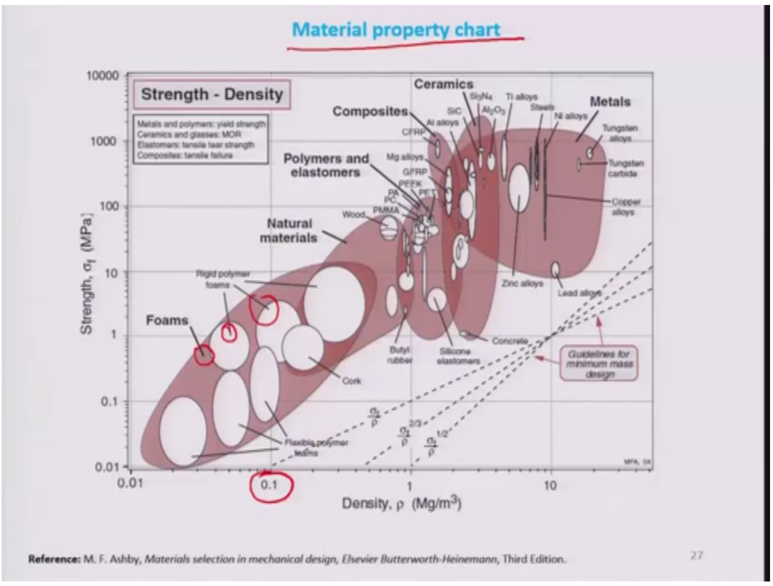

Now, this is the material property chart. So, here our goal is to maximizing the ratio sigma y by sigma. This material chart is proposed by Michal Ashby and in this chart, we can see that their variety of materials and it is plotted against strength verses density on log plot and here you can see that for suppose that if you want to select material for lower density that is suppose we are that I am going select for 0.1 and higher strength, then what material will be good for us rigid polymer, this one foam here variety of foams are different types of foams are available.

So, here variety of this is the material property chart from this chart, we can easily select we groups of material that can be used for fabrication of your product.

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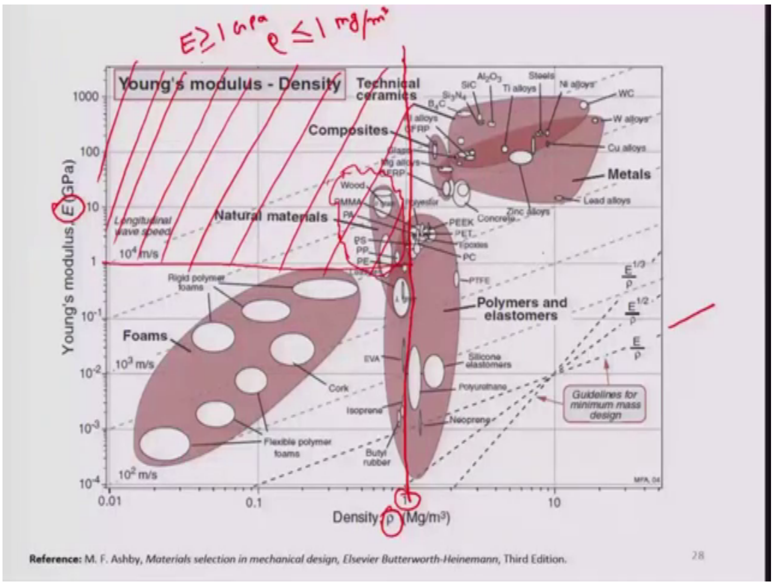

Another that is the strength verses density. Another plot is Young's modulus verses density, ok. Here you can also, you can formulate your problem in function of Young's Modulus and density, so that you can select appropriate material. Using this plot here you can see for a particular suppose that density is one, you are taking one milligram per meter cube and for that vertical line, and if you are going to select higher material which has Young's modulus of one Giga Pascal ok, then your domain will be suppose that E should be equal to one Giga Pascal requirement is such like such kind of things and density should be lower or equal to one milligram per mega gram per meter cube.

Then, what will be your search region? This will be your search region. So, you can see that you just omitted lot of materials from this chart and only now we have only group of few materials, ok. Now after that you can again you can select most appropriate material in next steps.

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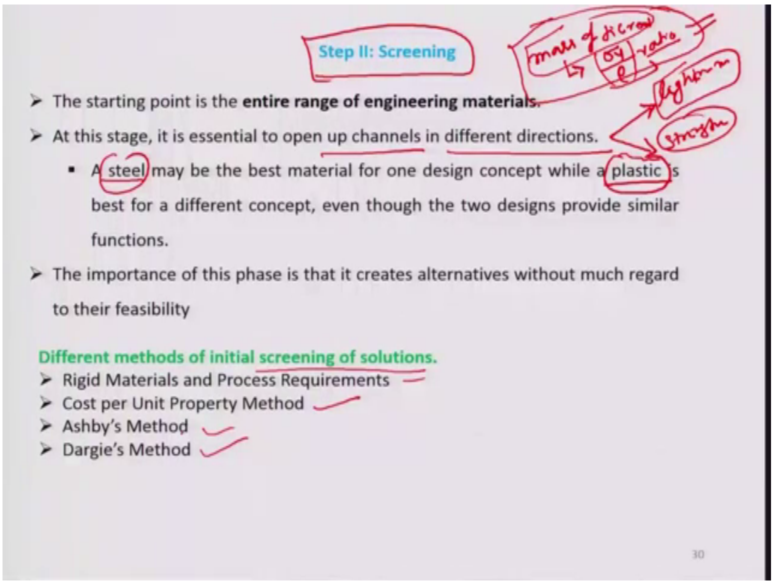

After deciding your requirement and defining everything objective function and your constraint and then, after second step comes out that is the screening, screening of material. In earlier program problem our goal was to how we will reduce the mass of tie rod and we concluded that it can be minimized by maximizing the yield strength by density ratio, ok. Now, after getting these things, we will have to screen the material which can group of material which can satisfy this requirement, ok.

Now, screening the starting point is the entire range of engineering materials or is that we I showed you in very first slide in lecture module 26, there are variety of materials are there to fabrication process, in a fabrication process. So, we cannot look every material for our fabrication of our product, ok. Now, at this stage what we will have to do first we will have to open up channels in different direction, ok. It means if suppose that if you are going in only one direction suppose that for lighter, you need lighter material.

So, if you will select only keep in mind only this thing material which is very light in weight, so that I can make our product with those materials. So, that was not a good idea. We will have to consider another such that there is strength. Strength should be higher this strength property, so that you will have to open your channels in different multiple direction, so that you can get your appropriate material for fabrication. For example, a steel may be the best material for one design concept while a plastic is best for a different concept even though the two designs provide similar function. It means steel and plastic. The part made with either a steel or plastic have a same functionality, but different properties, ok. So, you will have you will have to choose either plastic or a steel on basis of your requirement, ok.

Now, the importance of this phase is that it creates alternatives without much regard to their feasibility, ok. Here you have selected only into 2-3 material. A steel plastic this kind of things, but still you have not achieved your goal because these are different, this phase is different, ok. So, still they have a no feasible analysis has been done. Now till now, first. So, there are various methods of initial screening of solution. First rigid material and process requirements cost per unit property method, Ashby method, Dargies method and there are variety of more methods are available for initial screening of your material selection.

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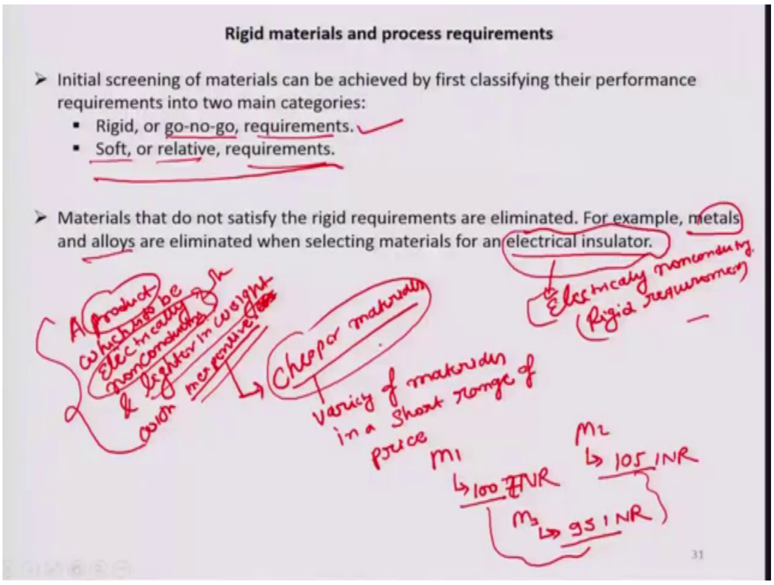

First I will discuss rigid materials and process requirements.

Here initial screening of materials can be achieved by first classifying their performance requirement into team two main category. First is rigid or go-no-go requirement soft or relative requirement, ok. Rigid requirement means suppose that if you going to make a electrical insulator, so that rigid requirement is that electrical insulation, the material that should be electrically insulated, ok. So, you cannot use metal and alloy. So, simply you just eliminate those materials. So, that is the rigid requirements. Your rigid requirement is that electrically non conductivity your rigid requirement. So, you simply just eliminate metals and alloy. So, some significant portion of material list from a material is you just have eliminated using only one rigid requirements, then first second is soft relative requirements, ok. Now, electrical insulator have a variety of material which poses electrical insulation. So, this is the soft requirement. Now, you will have to suppose that a material a product, suppose that you are going to make a product which is to be electrically non conducting and lighter in weight with in expensive, ok. It means you have three requirements. You are going to make a product which is electrically non conducting that is the hard requirement. Second thing lighter in weight and fourth one is inexpensive, ok; so this thing cheaper materials, ok.

So, it may be variety of materials will be there in a short range of price, ok. Suppose that material m1 has a cost 100 rupees and m2 has cost 105 rupees' m3 cost of 95 INR. So, if you are going to make a product which is to be used in highly sophisticated place, then these difference in price is not much important as compared to this one electrically non-conducting, ok. So, here this requirement is soft or relative requirements for this problem statement.

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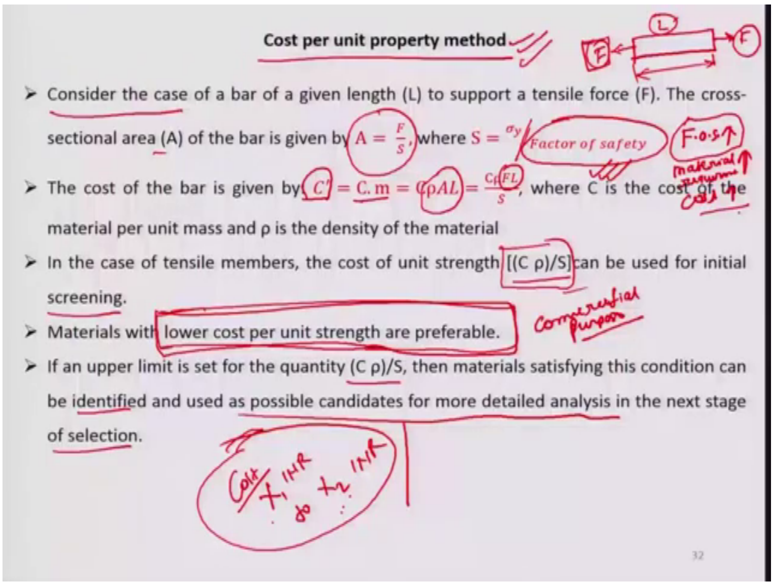

Now, second method is cost per unit property method. So, this method is important where cost of the material plays significant role, ok. Suppose that I will explain this method using one, taking one example.

Consider the case of a bar of a given length L to support a tensile force F. Suppose that there is bar of length L and tensile force on both end is F; the cross sectional area is an of the bar. So, that will be given by a is equal to s by s, where s is equal to sigma y divided by factor of safety. Factor of safety is very important term in designing of mechanical design of material, ok. So, you will have to consider that factor of safety it factors of safety increases, increase in factor of safety will increase material requirement amount of material requirement and cost. So, you will have to select factor of safety very intelligently for your particular product which is to be used in a certain operation, ok.

Now, the cost of the bar that is given by c dash is equal to c into m. M is the mass of that bar or m we already explained in earlier slides. M is equal to rho into a into l and c is the cost of the material per unit mass and rho is the density of the material. By simplifying, on simplifying this, we get C rho F L by S that is the cost of the bar a. In the case of the tensile member, the cost of unit strength C rho by S can be used for initial screening because here F and L both are the fixed condition length of bar or is fixed. That is not going to be changed and F, you are applying a load that is fixed you know the product which is to be used in a particular operation, where that much force will be applied on that product, ok. So, that both parameters are fixed F and A fixed.

$$C^{'} = C * m = C\rho AL = \frac{C\rho FL}{S}$$

So, only this term C rho by S that is going to be the main term for in a cost property in calculation. Now, here material with lower cost per unit strength are preferable because after all you are whatever you are going to make this is for commercial purpose or you are going to make benefit from the commercially benefited from the market, ok. So, this thing is very important. Lower cost is very important parameter in material design selection. If an upper limit is set for quantity C rho by S, then material satisfying this condition can be identified and used as possible candidate for more detailed analysis in the next stage of the selection. So, what you will do first, you will calculate cost of the cost of the cost per unit that material and then, whatever you have think that our cost should be in that range. Suppose that x 1 INR to x 2 INR, then material that should fall between this range, you are only you can select those materials for your fabrication.

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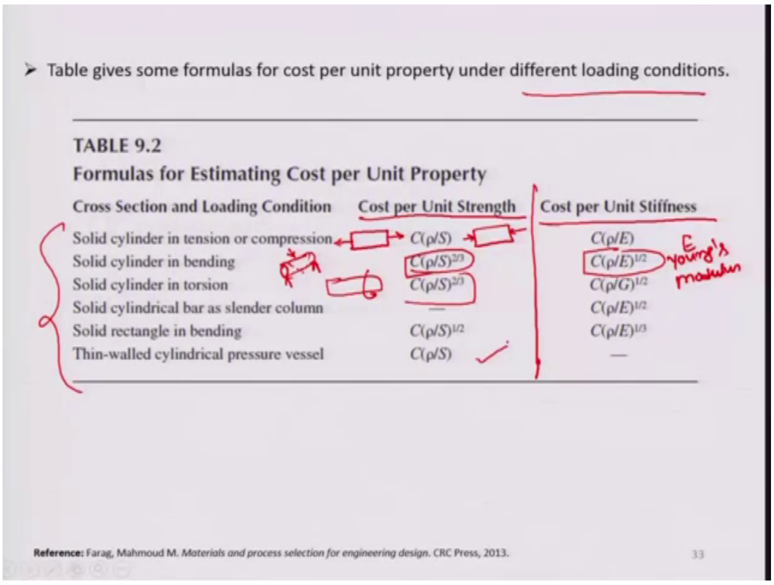

Now, these are the sub standard formulas for cost per unit property calculation using different loading condition. Suppose that there is solid cylinder in tension compression. Solid cylinder in tension compression means this is the cylinder that is the tension and if you are applying a load like this that is the compression solid cylinder in bending, here you are applying a load. So, that it will get bend.

So, cost per unit strength will be this one, if you have density and you know density and yield strength of your material, then you can use this formula. Either you can use this formula if you are using Young's Modulus, you can it means you can design either cost per unit strength or cost per unit stiffness. Both are. E is the Young's Modulus solid cylinder in torsion if you are applying a twisting moment here like this, then what will be cost per unit strength solid cylindrical bar as a slender column solid rectangle in bending thin walled cylindrical pressure vessel. So, these are the different loading condition and cross section. The cost per unit strength as well as cost per unit stiffness changes.

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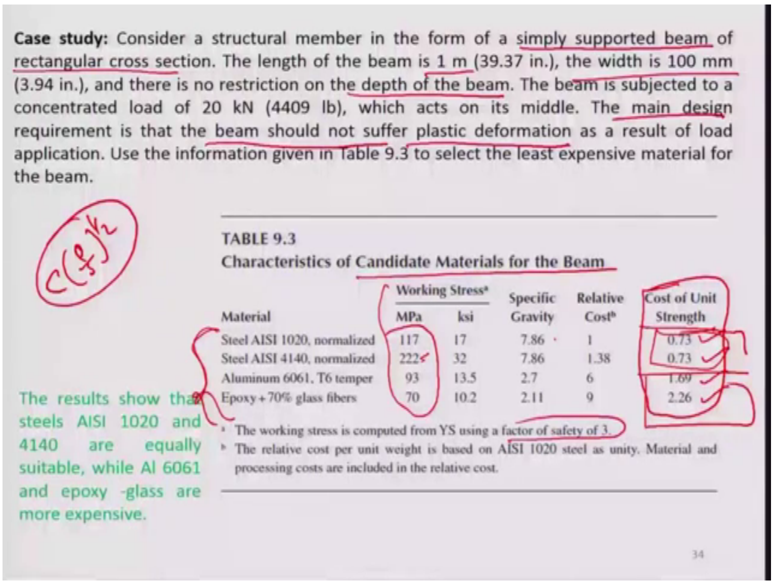

Case study: Consider a structural member in the form of a simply supported beam of rectangular cross section. The length of the beam is 1 m (39.37 in.), the width is 100 mm (3.94 in.), and there is no restriction on the depth of the beam. The beam is subjected to a concentrated load of 20 kN (4409 lb), which acts on its middle. The main design requirement is that the beam should not suffer plastic deformation as a result of load application. Use the information given in Table 9.3 to select the least expensive material for the beam.

$C(\rho/S)^{1/2}$

TABLE 9.3
Characteristics of Candidate Materials for the Beam

Material	Working Stress[a] MPa	Working Stress[a] ksi	Specific Gravity	Relative Cost[b]	Cost of Unit Strength
Steel AISI 1020, normalized	117	17	7.86	1	0.73
Steel AISI 4140, normalized	222	32	7.86	1.38	0.73
Aluminum 6061, T6 temper	93	13.5	2.7	6	1.69
Epoxy + 70% glass fibers	70	10.2	2.11	9	2.26

[a] The working stress is computed from YS using a factor of safety of 3.
[b] The relative cost per unit weight is based on AISI 1020 steel as unity. Material and processing costs are included in the relative cost.

The results show that steels AISI 1020 and 4140 are equally suitable, while Al 6061 and epoxy -glass are more expensive.

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So, I am going to explain using this case study. Here what program is statement is that considered a structural member in the form of a simply supported beam of rectangular cross section. The length of the beam is 1 meter, the width of a 100 mm there is no restriction on the depth of the beam means depth of the beam is the free variable. So, the beam is subjected to a concentrated load of 20 kilo newton which act on its middle. The main design requirement is that the beam should not suffer plastic deformation as a result of load application.

So, these are the requirement. The main design requirement is that what the requirement is beam should not suffer plastic deformation. That is the constraint that is the free variable and other parameters are given, on basis of that they have this table. They have calculated and found that there are four materials which can full fill this criteria and candidate metal for the beam and here for working stress and 117 mega Pascal for AISI 1020 AISI 4140 4222 mega Pascal and these are already considered, they have consider factor of safety of 3, and specific gravity of these materials are 7.86 2.7 2.11, and using this value and earlier formula this one because this solid rectangle bending this formula will be suitable for our this question C rho by S1 by 2 that is the cost per unit for this simply supported beam rectangular cross section.

They have calculated for each material. Cost of rate for each material now we can see that for AISI 1020 is cost per unit 0.73. This is 0.731, 0.69, 2.26, but for four materials can fulfill our criteria. So, what material we will select again? So, the result shows that steel AISI 4140 are equally suitable and while 16061 and epoxy, both are more expensive, ok.

Now, we are again we have omitted the material. So, now we are reduced our material range of group of material in only two. So, we can select either two materials, ok. Till now we have already learned about translation steps and the screening steps in this selection of material, ok.

Now, I am closing this module and in the next module, I will discuss rest of the two steps that is involved in a selection of material.

Thank you.