Fundamentals of Electric Vehicles
Technology and Economics
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Lecture 4
Machine Design-Part 3

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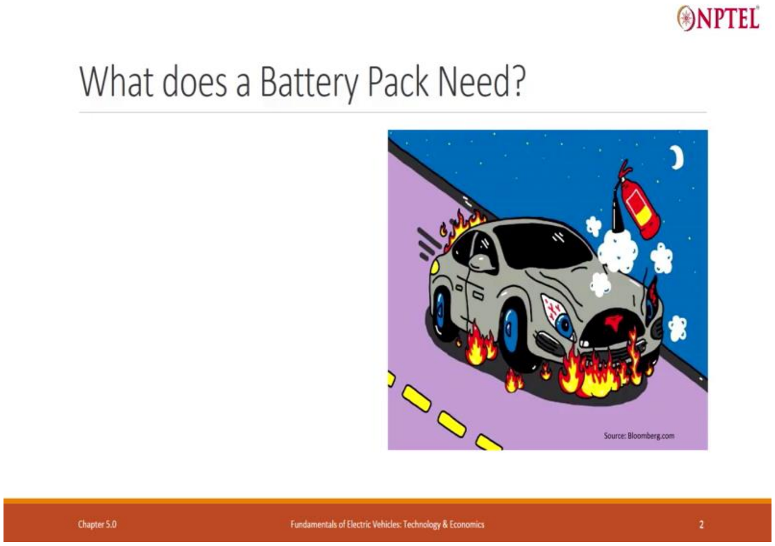

So, what we have done in the last class in fundamentals of battery pack is. What does a battery pack need we have gone to different parameters.

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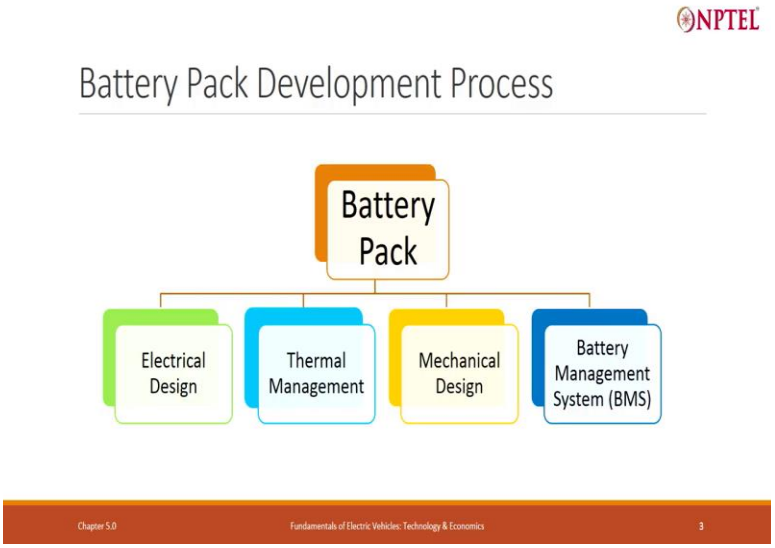

Then we have also talked about battery pack development process. So, we have categorize battery pack into four category electrical design, thermal management, mechanical design and the battery management system. We have talk and sort about all four domain.

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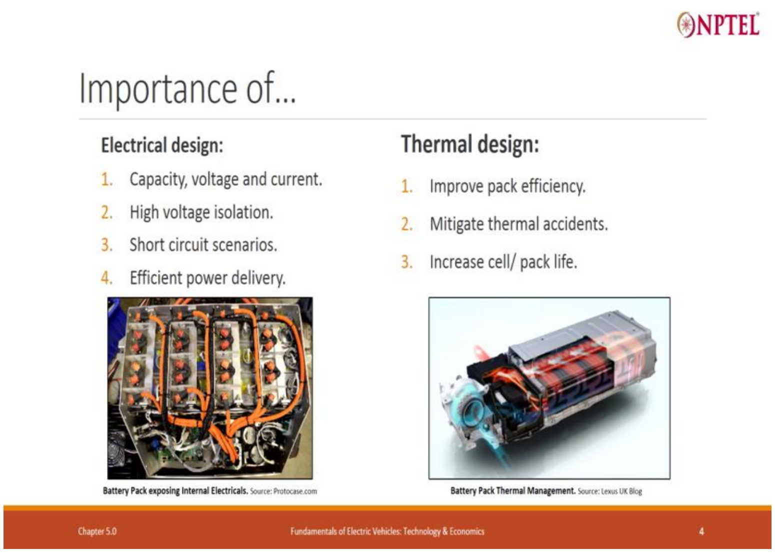

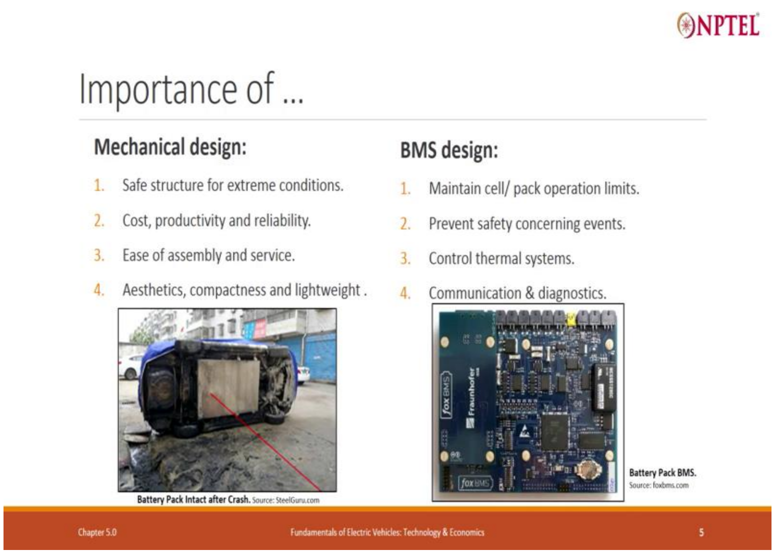

Then we have talked about what are the importance of these four categories electrical, thermal, mechanical and BMS.

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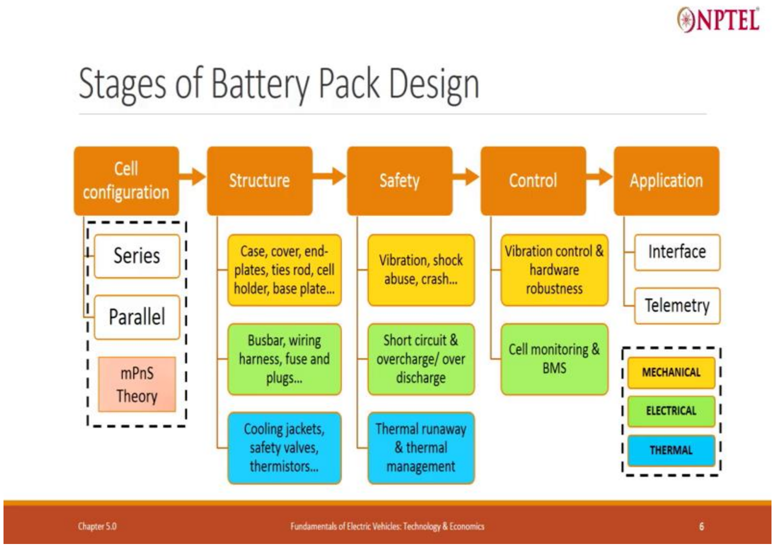

Then we have talked about stages of battery pack design. Where we have talked about how to configure the cells in a battery pack. We have talked in details about mPnS theory m parallel and N series then we have talked about structure, what are things covered in those structures like case, cover, end plates, tie rods by different definition like what would be mechanical, what would be electrical and what would be thermal parts.

Then bus bar, cooling jacket. We again talked about safety where we talked about vibration, short-circuits, thermal runaway and then control of vibration then cell monitoring and BMS and then application in telemetry and interface this what we talked about stages of battery pack design.

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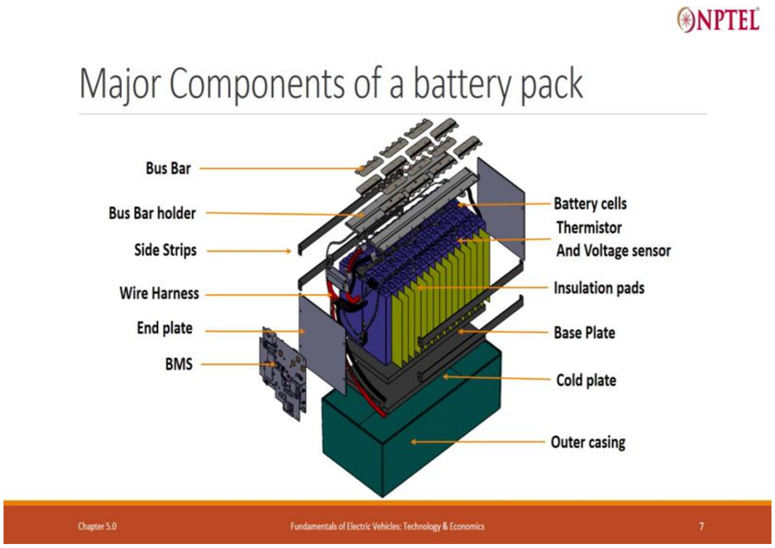

Then we have also seen what are the major components of a battery pack. We have seen what are the major components of a battery pack and then we talked about all the components of a battery pack like battery cells, insulation pads, base plate, side strips, end plates, cold plates, bus bar holder, bus bar, thermistor and voltage sensors, wiring harness, BMS, outer casing and all together.

And this does not change if you make a bigger pack the number of components of each would increase. However, overall it is a same for smaller pack or bigger packs a slide addition depending upon the customer requirement like do we need a vibration control signals in that case, we can provide some accelerometer inside the battery pack that is beyond a particular level of vibration, it will cut off the battery pack like in the case of (())(03:03).

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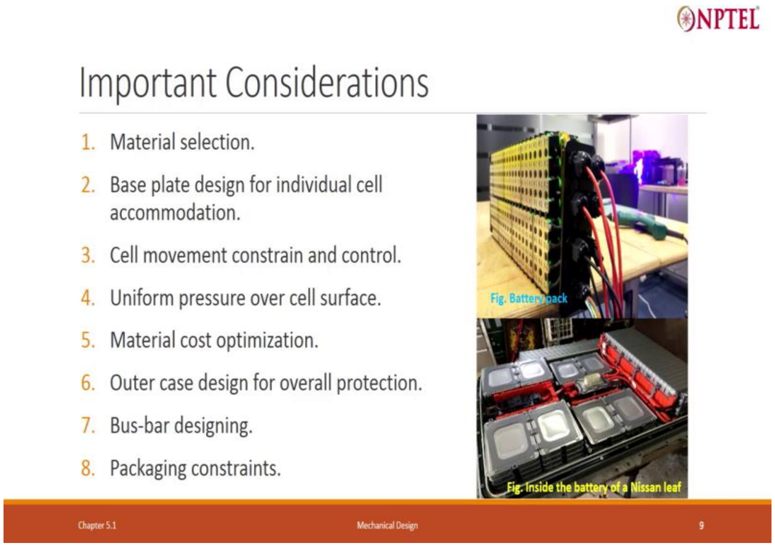

Then we have a started mechanical design and then we have seen important consideration like material selection then what would be the base plate design how to constrain the cell movements uniform pressure overall all cell surface to improve the lifecycle of the battery pack, material cost optimization, outer case design for overall protection and then bus bar designing and at the end we have also talked about why packaging constraint becomes important so that may lead to irregular shape of the battery pack. It may not be a regular shape like a rectangular box or a cylindrical shape, it could be something depends upon the space available in the vehicle.

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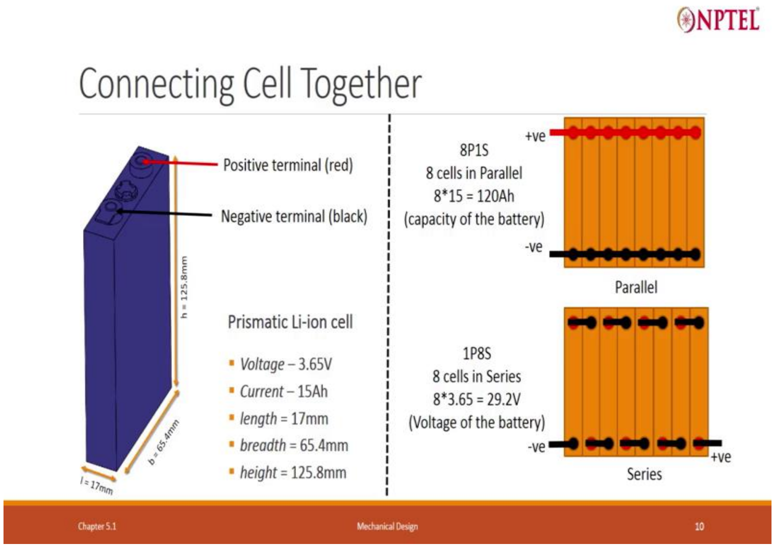

Then we have started the mechanical design and then the first things in a battery packs come how to connect the cells together and there we have talked about parallel and series configuration a parallel configuration adds up the ampere hour current its add up the current. However, series combination adds us add up the voltage and in a pack you may need to go on both parallel as well series. So, generally we go parallel first and then series second, this is what we have discussed in earlier chapter in chapter 4.

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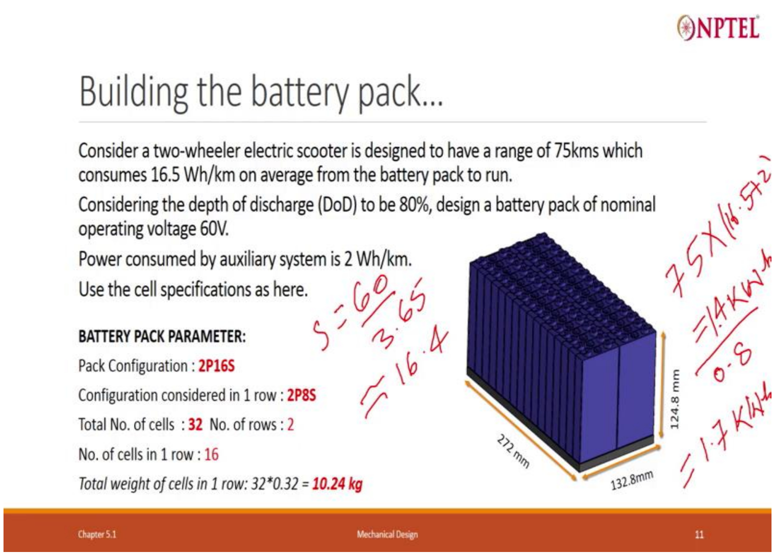

Now, in building battery pack we have also talked about how to build a battery pack. So, we have assembled the cells a particular configuration a particular voltage and the particular Ah based upon the energy requirement of the vehicle and we found out the pack weight is coming around 10.24 kg.

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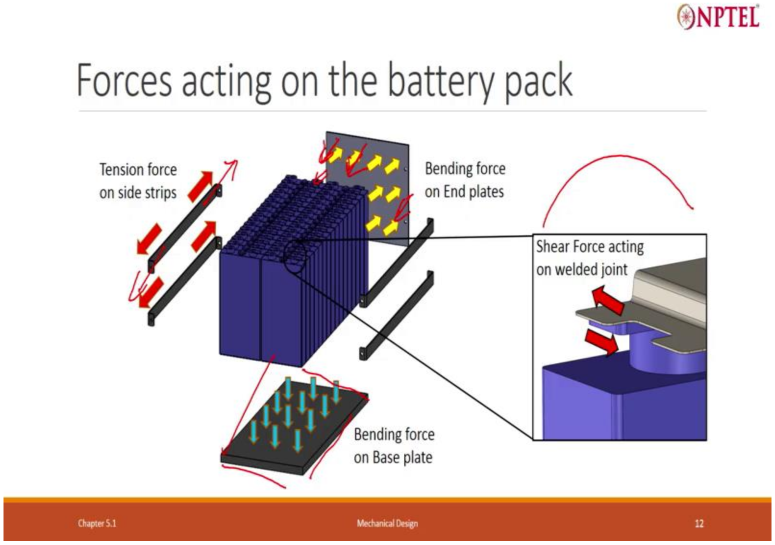

And then we have started what are the force acting on a battery pack. So, it has a base plate, it has a end plates, it has side strip, it may have other component also, but right now we focused on this three and then there is a bus bar which is connected with the cell which is connecting all the cell's together. So, what we have talked about the major force, what is the dominant force. So, what we talked about that on side strips, it is generally tensile force which is dominant on the end plate it is basically bending force which is dominant. On base plate it is a bending force which is dominant and the connection between cell and bus bar it is a shear force which is dominant.

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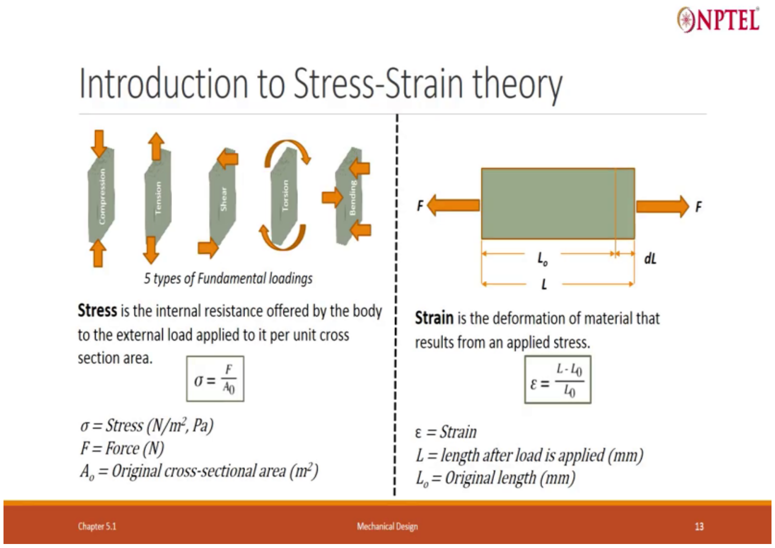

And then we have started stress strain theory where we have talked five different types of fundamental loading then stress and then strain.

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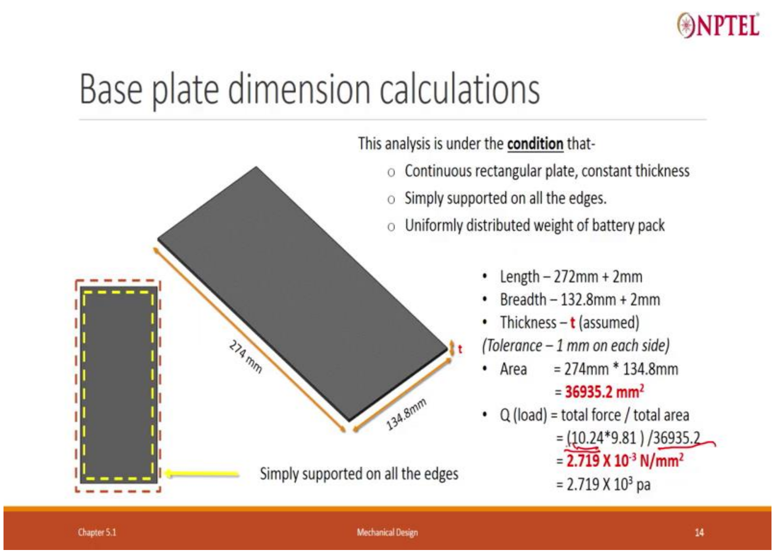

Then we have started calculating the base plate dimension calculation. So, we know the length and the width of the base plate. However, what was not known was the thickness. So, based upon that with giving some extra tolerance of 1 mm in base plate. So, we found that the length of base plate is 274 mm, the breadth or width of the base plate is approximately 135 mm but thickness is not known so thickness is depending upon the engineering calculations like, there are some criteria is like we need to have a minimum deflection. It should be able to take the weight of the cells as well as other component what we have done right now is so is the weight of cell. Then something like what we need is to minimize the cost of material, not only the cost of material we also want to minimize the weight.

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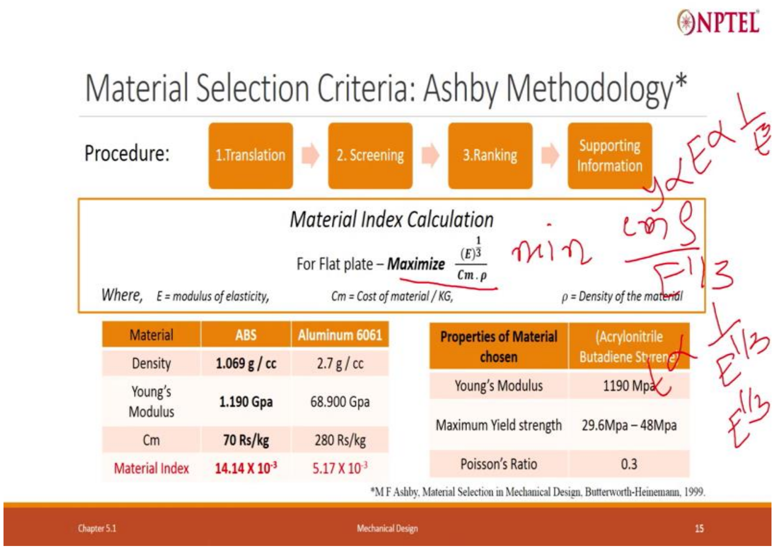

And then we will be starting from today class Ashby method Ashby methodology. So, what is Ashby methodology? It is a process it is a procedure to minimize or maximize the cost in our case or a strength or thickness. So, what are the things comes in that? What is the objective function here? Translation is first to collect all the information together. It has five stages sorry four stages translation, screening, ranking and supporting information. So, translation what we want and how to translate into objective function in mathematical form which we can solve is basically known as translation.

So, what is our basic functions here? Provide the support in base plate if we talked about what is the basic function here provide the support to the weight of cell. What we do not want? We do not want a deflection to go beyond a certain limit that will define what deflection we want 1 mm or 2mm or 5mm or 10mm, then what we are looking for.

The cost to be minimized and also what we are looking for weight to be minimized. Otherwise, we can also say thickness to be minimized by considering that it should be able to support the weight of the cell for now. In future when you are designing a full pack, you may have to worry about other forces also like when there is a vibration.

So, then those terminology based upon the force concept we bring it here. But right now, to make it simple what we are considering the weight of the cells it should support. So, what is our objective basically? This is the translation, these are our wish list which we want it to do. So, what is our objective if I defined properly what it comes minimize the mass and the cost.

If you are minimizing the thickness we are minimizing the mass and at the same time, we are minimizing the cost, why we apply this this methodology. We may have several candidates. We may have a material database. We need to select some material which is of use to us and out of those materials that is known as screening and may have a database of 100 materials or 500 material but then first will it where what we will do after finding the objective function. What we will do we will screen those material like if there is a glass and there is a plastic certainly we would not like to go even for glass even if it is having too much of strength.

So, will exclude those things. Now, if there is a aluminium and there is a plastic so we may like to go with both which gives a better value to our things aluminium or plastic we may like to go if there is a MS mild steel we may like to go. If there is something known as what you say fragile plastic. We may not like to go in that case even though it is strength is very high, but maybe in the shock, if you put a small hammer it may crack, we may not like to go with that.

We may not like to go with the gold we can exclude immediately without even putting the things in the function because it is cost is very high. So, some common sense what we apply to sort least the material we say it is screening. The first we have defined the function objective function and then now we are looking for a material database now what are the materials I can use.

Now, after doing that then I will put every material in this objective function and then we will find out a material index. Now, that is a mathematically solved equation where we are finding the ranking of each of the material which we have screened already. Some screening is nothing but it is a common-sense what material I should use based upon experience or based upon the data available.

Now, ranking is whatever material we have screened. Now, we are putting in the objective function and getting a value known as material index objective function is known as material index, right side there is some mathematical term related to what are the things we have discussed cost, thickness, weight, strength all the things together and then we find out the ranking. Now, if I have to be if my function is maximize then we will go for which has the highest ranking if my function is minimize I will go for lowest ranking material.

And then supporting information supporting information is that once we have selected the material can it work something else also, like if I have to select if my if my thermal if I have to worry about that my heat should be transferred quickly. So, I will go for a material which has a higher thermal conductivity I can either insert in that in objective function but in that case objective function become complex.

We do not want to make the objective function too complex. So, that after screening I will see what are the secondary functions I have if I have to release if material index comes ranking comes similar for two materials then out of that two materials or three materials if I have to select one material then I will start looking for the secondary function secondary functions mean in some cases we may require to transfer the heat very quick.

Sometime we may not sometimes we like to retain the heat. So, let us suppose if we have selected two material if two materials has come of the similar ranking. One is let us suppose plastic or ABS which we used generally for making battery packs another one is let us suppose aluminium. If my if heat transfer has to be fast, what material we will select. If the ranking is similar or same. We will select aluminium in that case because aluminium thermal conductivity is very high.

If I do not want to release the heat or I do not want environmental condition to impact my battery pack that means I do not want outside heat to enter inside the battery pack what we will do in that case. We will try to take a material which if they have the similar material in that will try to take a material which has the lowest thermal conductivity.

So, in that case we will try to go for a ABS. So, this supporting information also helps a lot of time to select a particular material. So, next so we are talking about material index calculation. So, what we have discussed that, we want to minimize the deflection and the deflection is proportional to, why is my deflection that would be proportional to Young’s modulus of elasticity and that is proportional to 1 by t cube, t is nothing but my thickness.

So, if I am worrying about t, then it should be if we want to maximize then sorry if you want to maximize t or me, if we want to minimize t what is our aim is to minimize the t. If I take t up, so 1 by E will come to minimize 1 E to the power 1 by 3 will come this will come if I take t here then this will come 1 by E to the power 1 by 3.

That means if I want to minimize t, I have to minimize 1 by E to the power t by 3, E is a constant for a particular material but we are selecting several material so E is different for several material. So, that is why E becomes function all other things length is fixed, width is fixed, again density would change material to material but density terms comes in to mass as well as in deflection.

So, we will select only one density. So, what is the function here what we are using a function is maximized. So, if I have to maximize what I have to do, E to the power will go at the top because if I have to minimize 1 by E to the power 1 by 3 will be there if I have to maximize just it will go in denominator.

Now, it is in so it will go in numerator right now it is denominator minimize. If I have to maximize it will go to the numerator. The similar way the cost, what I want to do with cost? Cost I wanted to minimize. So, if I wanted to minimize then the cost would be directly proportional to the some numbers whatever the cost of that one. But what is my objective function t is maximized so it will go to denominator. So, here if I am maximizing this function if I am maximizing this function, the cost is getting minimized.

Similar way, what is my aim to minimize the weight. However, so if you take some function minimize weight. If I have to maximize then 1 by weight. It will come in denominator. So, that is how this function is here. So, what we have seen thickness weight and the cost and these all the things we are maximizing, objective function we are maximizing.

So, thickness is getting minimize, cost is getting minimize and the mass density related to mass it is also comes into the deflection equation, but we wanted to minimize if I have to put this as a minimum function if I want I wanted to put minimize then this would have come Cm is the cost of material row by E to the power 1 by 3. If anything, we wanted to maximize it is directly proportional and if you reverse inversely proportional if we make it inversely proportional then it becomes minimization function that is what I am trying to do here. Minimize cost, minimize weight, minimize the deflection.

So, now we have got two materials ABS and aluminium. What we require is minimum information right now for selection of the material. What are the minimum information we require is the density, Young's modulus of that particular material and the cost of that material with that we can find out the material index. Now, higher the material since we have put maximize function so higher the material index we will select that material. So, which one has ABS or aluminium? Which one has the higher material index?

It is ABS. The ABS has the ABS has the higher material index. So, that is why we are selecting ABS. Now, once we have selected the material then for further mechanical calculations, we require other mechanical parameter. Like, what is maximum yield strength? For ABS it is falling between 29.6 Mpa to 48 Mpa, Mpa is nothing but mega pascal.

And then we also require Poisson’s ratio till the time we do the material index calculation. We do not require these materials. Once we have selected the material now we require those those further properties for that particular material. This Ashby methodology is nicely put up by Ashby itself in a material selection in mechanical design. If you want to further to have further information, you can look upon this book.

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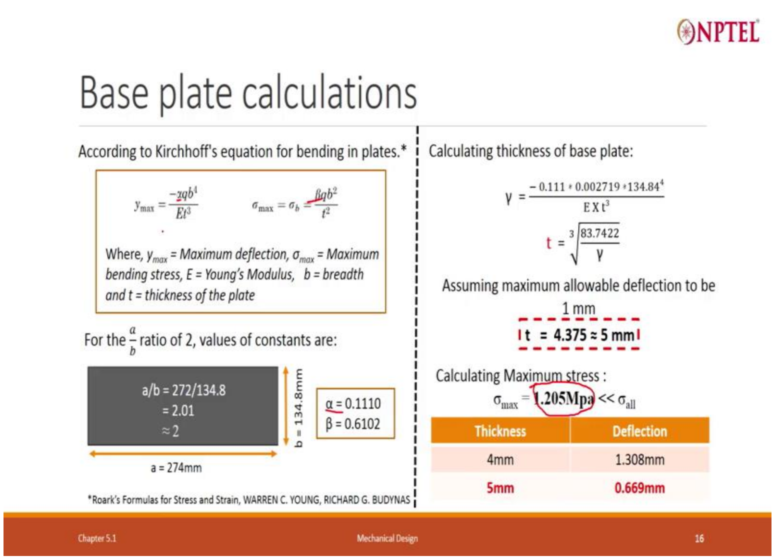

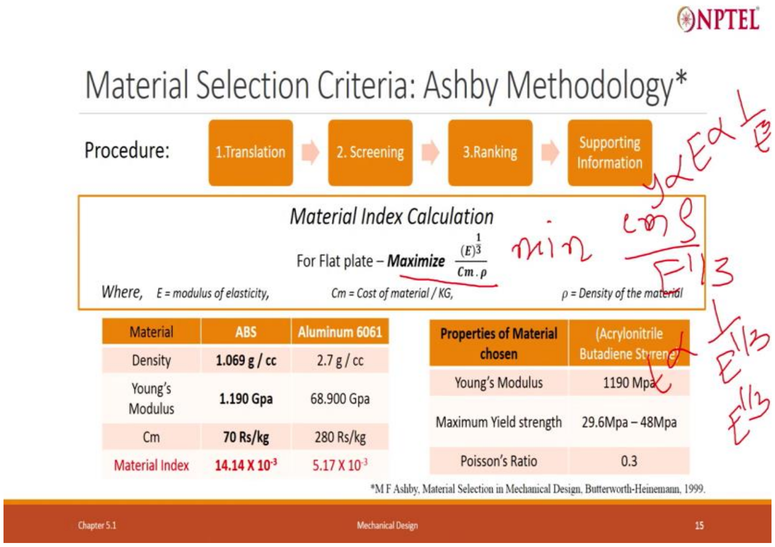

Now, we have a started base plate. So, what we have started that it has to take out weight of 10.24 kg of cell weight and then we decided let us go ahead what material we need to select for this particular. So, we have selected the material. Now let us start with base plate calculation. So, there is a equation Kirchhoff equation that is a fourth order differential equation partial differential equation.

Either we can solve with the boundary condition that or there is another way of doing that one. We use the direct formulas from design data book. One of the design data book what I have used is known as Roark's formula for stress and strain. For different boundary condition you get a direct formula there if we use that formula taken from that book or any other design data book you would be able to solve this type of problem very easily.

So, maximum deflection is minus alpha q b to the power 4 E t to the power cube, t is nothing but thickness is Young's modulus of elasticity Y max is maximum deflection. Now, the second one is maximum bending stress that is also we have to worry about because the maximum yield strength for this material is 29.6 Mpa I take a lower rank.

So, what is not known, b we know t we do not know all other things we know. So, we also know a is the length so there is some terminology known as aspect ratio maximum length by minimum length or length by breadth with that aspect ratio from the design data book or the formulas book we can get the values of alpha and beta we can get the value of alpha and beta directly.

We already know the q, q is nothing but the load, b we already know, E we already know, Y sorry sigma max we already know. Because of the so what is not known deflection also we can constrain I want not more than 1 mm or not more than 2 mm. My pack will support a deflection of 1 mm or 2 mm or 3mm so we can select this is what I want the deflection.

So, that deflection is also known what is not known is t. So, from this itself alpha now we know, q load we know, b we know, E we know, Y max also be know, deflection we know now I have selected a value 1 mm I do not want to go or deflection more than 1 mm. So, what is the unknown here t. So, we will find out the t from that.

For my value of t comes approximately 5 mm if I consider 1 mm deflection. The maximum deflection of 1 mm my thickness t comes 5 mm. Now, once my thickness t comes 5 mm does it also solve my sigma max problem that also we have to look upon. Sigma max should be less than, this my design criteria for that particular material. So, this t is equal to 5 mm thickness solve my both the problem its maximum allowable stress also it solved as well as it is also solved my problem of maximum deflection, which I have already selected 1 mm.

But sometime we may not need to go for or we may not like to go for a thick material up to 5 mm, no, how can we reduce? Is there any way? Yes, we can do, without increasing much weight and volume. In that case what we can do what we can do is we can provide the ribs. We can provide the stiffeners it is like a beam you are providing it would look like if it is my base plate, I can provide the stiffeners like this or rips like this.

For another 2 mm thick only at locations where ever I have put and this numbers again based upon that what is the thickness we wanted to go. We wanted to go for 3 mm or you we wanted to go to 2mm or we wanted to go for 1 mm. So, based upon that this stiffeners number of stiffeners you can calculate, again the similar formula only thing that we have used beam theory there.

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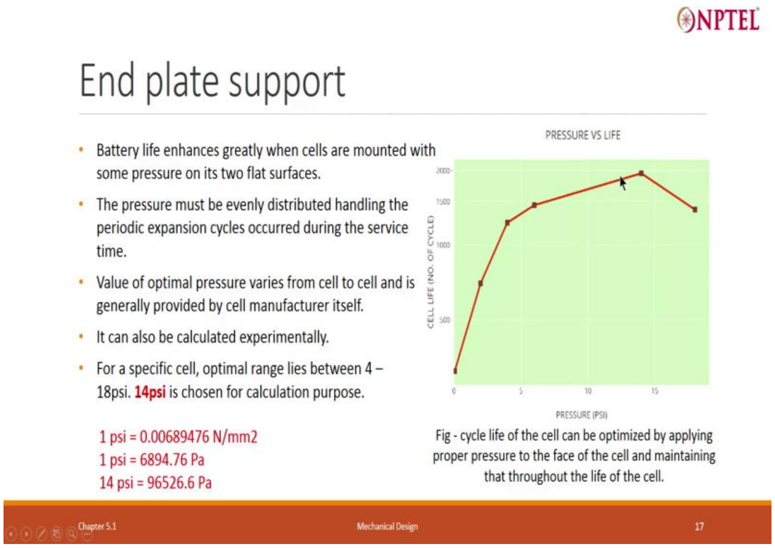

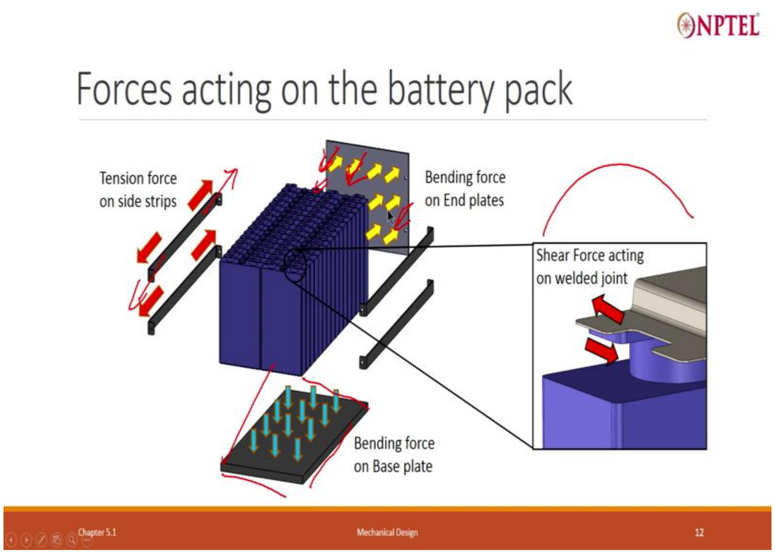

So, this is how we have calculated everything for the base plate. The Maximum bending stress and the maximum deflection this was two parameters for us and which we have solved. We got a particular thickness and we do not want if you do not want that particular if we did not like that thickness that is now this thickness is too much for my pack.

We also found that how can we reduce the thickness further by providing rips and the stiffeners. Again, we need to calculate by similar theory how many ribs or how many stiffeners we require. What would be thickness? What would be height of those rip? All those things we can calculate to similar formulation.

Now, the second thing what we have talked about the battery pack design is the end plate. Why end plate become necessary why end plate design becomes necessary because it provides a constant pressure on the cell surface. Why the constant pressure is required on the cell surface is because of the life of the cell.

Otherwise what will happen if you do not provide sufficient pressure on that cell surface the cell will bulge it will require more volume. The life cycle life cycle of the cell will come drastically down. Which you can see from this curve that if I do not provide any pressure on the cell surface if I do not provide any pressure on the cell surface, a cell which supposed to go for 2000 cycles approximately will work only 100 or 150 cycles.

So, it is important to provide some pressure some uniform pressure on the cell surfaces, what would be the pressure. Generally, it comes from the cell manufacturer that if you provide this much, this is the optimum pressure this is the optimum pressure range for the cell and then once we know from the manufacturer this much pressure we need to provide on that cell surface.

Accordingly, we design the end plate again to provide the to provide the pressure on the cell surface what will happen there would be a reaction force on the end plate. You see here if pressure will go there then there will be a reaction force on the endplate what this reaction force will do it is uniformly distributed force. What it will do? It will again try to bend the end plate.

So, for this particular this one particular cell what we found out that around 14 PSI pressure would be optimum pressure for the cell life to go up to 2000 cycle. The conversion factor is given 1 PSI is 6894.76 pascal. Now, sometime you may not get the information from the supplier or cell manufacturer what you will do in that case. You have to do simple long-time experiment.

You keep on charging and discharging put two plates put the pressure sensors keep on changing the pressure and you see the what is the life cycle of that cell. So, it is a tedious and long-time process, very simple but tedious and long-time experimental process. So, it is always good to get the information from the supplier or if you are using the same cell for different and we have a road map for next 5 years we will be using the same cell in that case we can also re-verify all those information given by the supplier.

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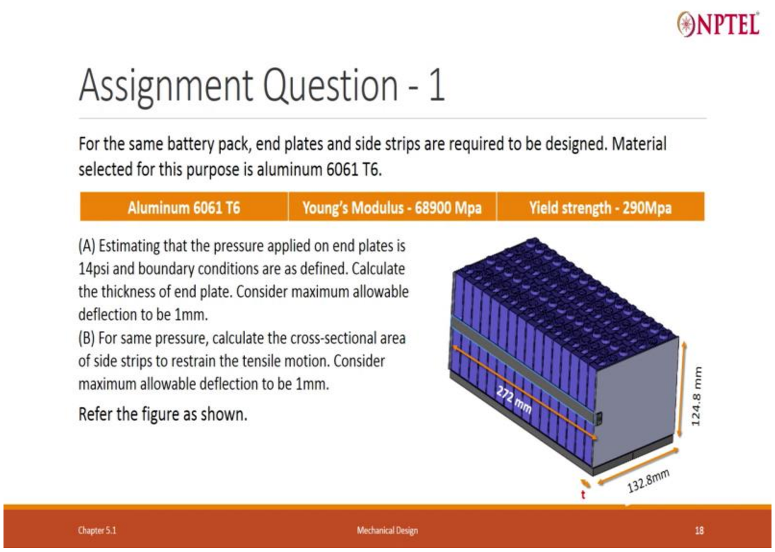

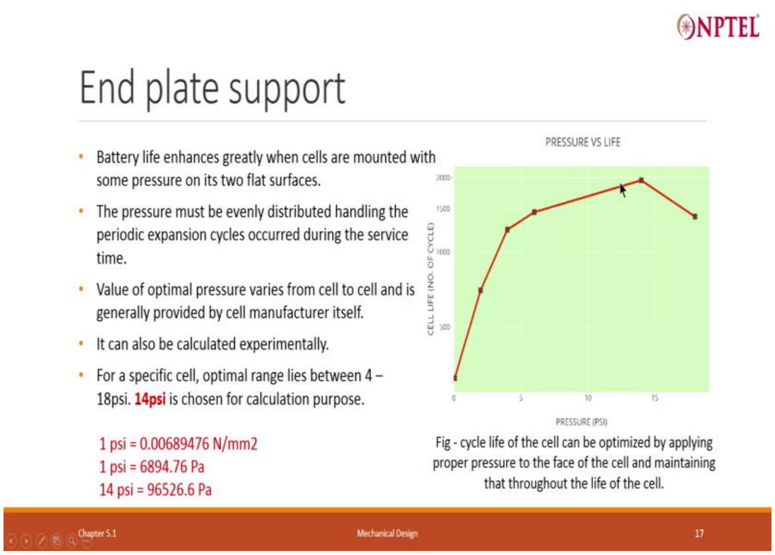

Now, I am not going to solve this end plates support problem I am going to give you an assignment on that. The battery pack what we have designed on the same battery pack end plates and side strip are required to be designed material selected for this purpose is aluminium base plate we have selected as ABS. But let us suppose we have selected aluminium for this end plate as well as side trips.

We know the length we also know the pressure value please find out the thickness of the end plate. Because again length and the width is we already know what we do not know is the thickness. Now, for the side strip this side strip would be holding this end plate for that particular pressure. So, there would be a tensile force on the side strip. So, what we wanted to know, what would be the cross-sectional area of side trip? Because force would be acting on that, since we are not giving you width so we want the cross-sectional area.

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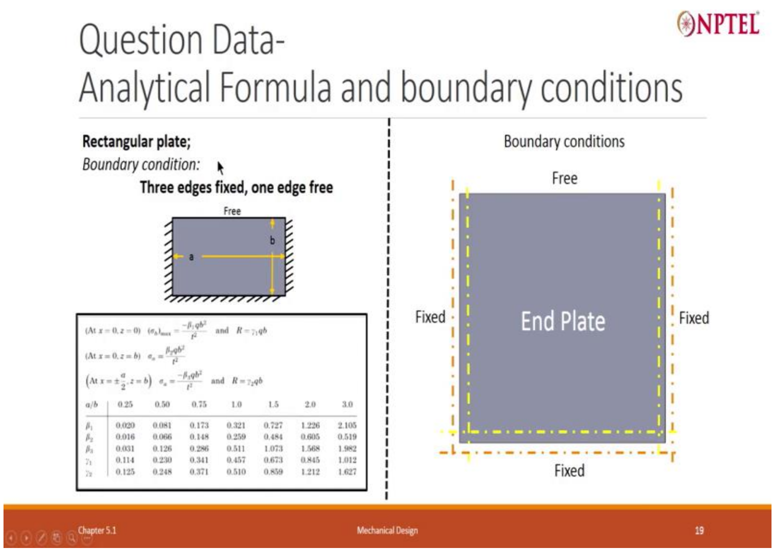

The boundary condition 3 is fixed length and width, you know one free and use the same formula book, which already we have given here for alpha and beta formulas here and solve this problem. It is a assignment question.