Nature and Properties of Materials
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Lecture 31
Materials Selection-Connecting Rod

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Today we are going to take another example, which is the example of connecting rods, how to choose materials for connecting rods for high-performance engine. So this is a very practical problem as you can see here that these are the typical connecting rods. And the choice of material for such things for high-performance engines is highly critical. So what is the problem that is there for us?

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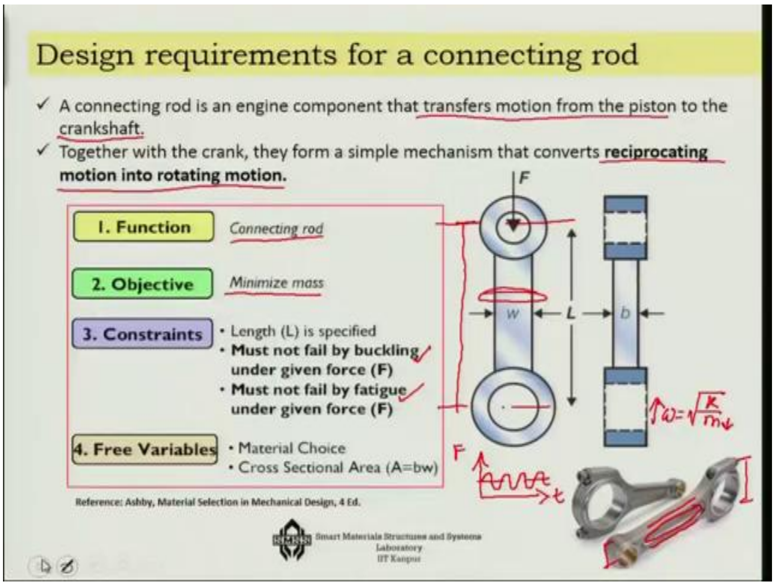

A connecting rod is an engine component that transfers motion from the piston to the crankshaft, so essentially as the piston is giving a reciprocating motion that it is putting that force to the crank shaft so that the crankshaft can actually go from reciprocating to rotating motion. So it is the other way round of a crank-slide mechanism that means the siding is coming from the piston and the crank in this case getting rotated by the connecting rod, the force that is transferred by the connecting rod. So the function here is that it is a connecting rod, it has to work that means it has to transmit force from one end to the other.

And objective is it has to minimise the mask okay it has to be as light as possible. Constraints will be that 1st of all the length is specified, you cannot arbitrarily choose the length okay, so this from centre to centre length will be specified okay. And it must not fail by buckling under given force because as you can see that the connecting rod is going to get a compressive kind of a load, so it must not fail by buckling under the given force that is one. And also because this F is repetitive in nature, so basically as the engine is getting fired, so in the ignition cycle so the F is going to vary in terms of maximum and minimum force F is going to vary.

So that is why in this case the fatigue we have to bring it into consideration, so it must not fail by fatigue, so must not fail by buckling, must not fail by fatigue. What will be the free variable for us? The free variable is the cross-sectional area of this part of the connecting rod. Now you may see that the actual connecting rod has couple of additional things for example, it is not exactly uniform okay.

And secondly, it may also happen that certain masses are scooped out from the system, these are the 2 strategies that are taken one is in terms of the natural frequency to control that, so I will not talk about it today but the resonating frequency is also a concern and hence if you reduce the mass, what you can do is that the natural frequency of the system which is square root of K by m and as you reduce the mass, the Omega goes up so this fellow would not resonate, so that is one of the strategy that they take. The other point is that depending on the piston part and the crank part so the sizes will be different here and here.

And as a result, there will be a kind of a gradient in the connecting rod, but again for today's analysis we are simplifying these factors and we are simply considering buckling load and fatigue load and uniform cross-section of today's analysis. Now let us go to the board and try to 1st find out that what is the performance index material performance index, and then we will come back to the discussion here.

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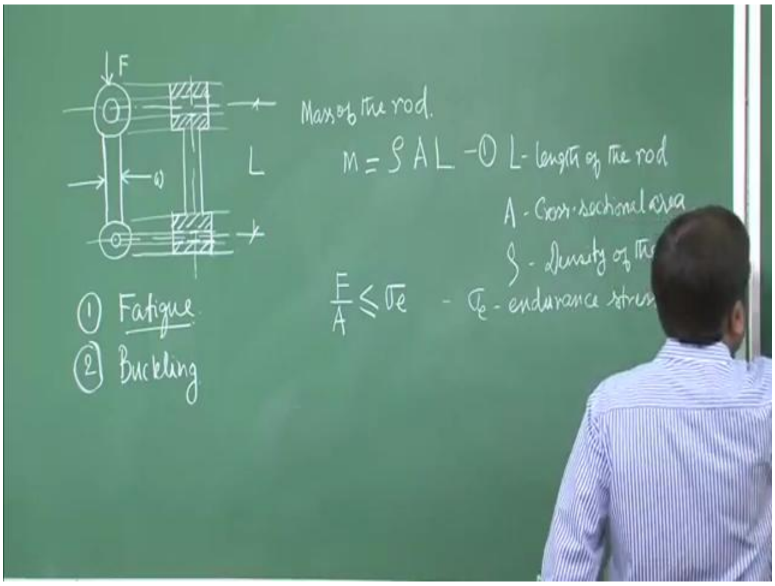

So we are 1st assuming that the shaft has a rectangular section, so let us 1st try to draw the connecting rod approximately here for our analysis, this is one part and then we have this is the simplified drawing of the connecting rod okay. It is thickness here and width here W, which is constant for us, it is getting the force F. But if you look at the other way round, it will look somewhat like this, so we are going to have a block like this right. And then we have blocks at this okay and we are going to have slots here; that is the solid part of the material, right.

And now this centre line to this centre line the distance is L this is what the approximate drawing of our connecting rod is okay. So what is the mass of it later say again if we neglect the two sides, then the mass of the rod m = simply Rho A L and here L is the length of the Rod, A is the cross-sectional area and Rho is the density of the material. Now we have 2 constraints in this case, what are the 2 constraints? Number 1 is fatigue and number 2 is buckling, so let us take up the 1st constraint that is the fatigue let us take it up. So from the fatigue point of view, F over A has to be less than or equal to Sigma e.

That means the maximum force the stress that will be happening on the connecting rod has to be less than the endurance stress okay Sigma e is actually called endurance stress, it is a new property, this property is important against fatigue. And as that there are various materials particularly say for example, metallic elements for which if you actually draw a diagram, you would see that with respect to the number of cycles versus the stress it is close something like this, so that there is a particular stress level Sigma E below which if the material remains and this is the failure line okay, this is the fatigue failure.

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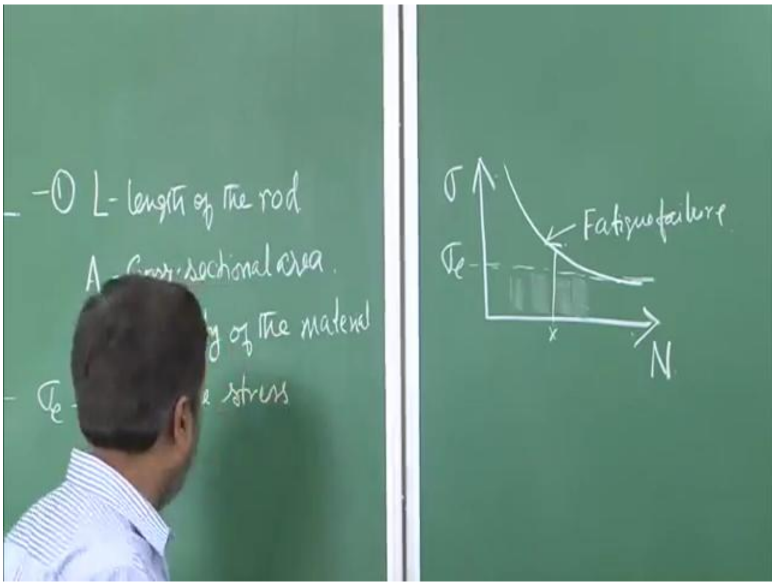

So suppose this is what is my number of cycle okay and then if the stress level goes beyond this point at this particular fatigue level okay something X number of cycles, 10,000, 20,000 or so, the moment stress goes beyond this the whole thing is going to fail. But if the stress remains below this sigma level, then it will never come across this line so that is the good part of it and hence we always try to keep the stress below the endurance stress level.

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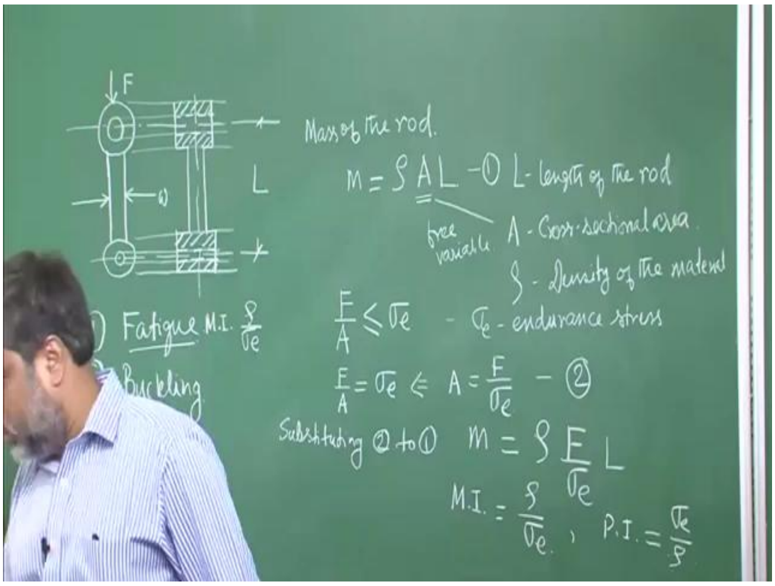

So for the maximum possibility I can keep actually let the force be such that F A is just equal to Sigma e, cannot be more than that. And keep in mind that the area here is the free variable, this is the free variable. So that means I can write this fellow here as area = F over Sigma e okay, so once I write that, this is what is my 2nd equation. So let us substitute that in the expression of mass, so substitute in 2 into 1, what we are going to get is that we are going to get m = Rho F over Sigma e times L right, then in that case what is the material property index?

Material index MI shortly is actually Rho over Sigma E, you can also keep the performance index which is the reverse of that that is Sigma e over Rho. In other words from the fatigue point of view, if you want to get a particular material then your Sigma e should be as high as possible and density should be as low as possible that is what should be your choice, so I can write the MI here which we have just find out that is Rho over Sigma e. And then let us move to the 2nd constraint that is the buckling, so let us erase this part now and let us think of the buckling.

Now from the buckling point of view, let us consider this to be a cylinder rod with a critical Euler or buckling load okay there is something called Euler or buckling load. So it is the 2, buckling that we will be now interested in and from the buckling point of view there is something called Euler buckling load, which is the 1st critical load when a compressive member suppose is subjected to a compressive force whatever is the boundary condition, it could be pint-pint and then it is subjected to and it deflects either this way or this way, so that is the 1st buckling load.

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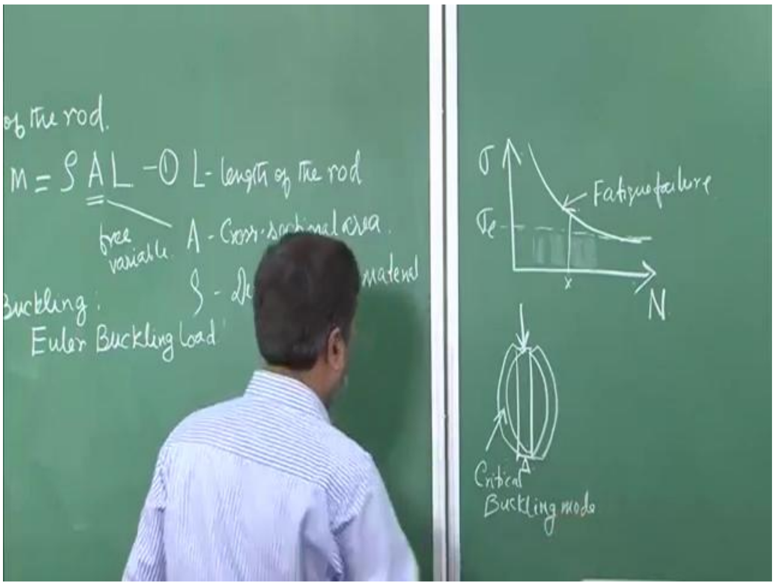

Of course there can be even higher buckling loads, but as far as our particular application is concerned, the moment this shape which is we considered to be a critical buckling load for our design, the 1st mode itself. And for that we can write the force has to be less than equal to pie square E I over A square. Again, L you know, E is the modulus of elasticity, and I is the area moment of inertia, so that is something like if you think of the cross-section here suppose the cross-section is actually this is W and this is b, then the area is b W.

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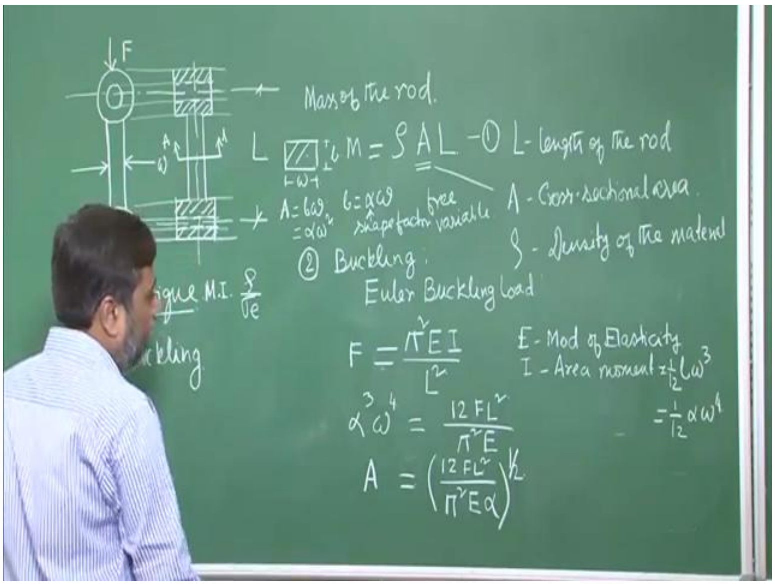

Of course there are many applications where b and W are related like b = Alpha W, where Alpha we call it to be a shape vector. So, area is b W and b is Alpha W, we can keep that in mind and then we can actually write it down again in terms of the W maybe fast we can find out that if you use this expression in this particular equation it will come out Alpha cube W to the power 4 = 12 F L square, so I in this case also let us write it down one twelfth b W cube. So in fact you can also write it as one twelfth Alpha W to the power 4. So thus if you apply all these things together, it will come out as 12 F L square over pie square E okay.

In fact, if you work it out a little more keeping in mind that area = actually Alpha W square, so if you substitute that here you will get the A area from this as 12 F L square divided by pie square E Alpha whole to the power square root that is what will become your area from this expression once I take the equality in this expression that means maximum possibility of F is pie square E I over L square, with that if I go ahead I am going to reach this value of area that I will get from this expression. Now what I can do? I know the area now from this buckling load point of view, I can put it back to this equation 1, so if I do that for equation 1, how would it look like?

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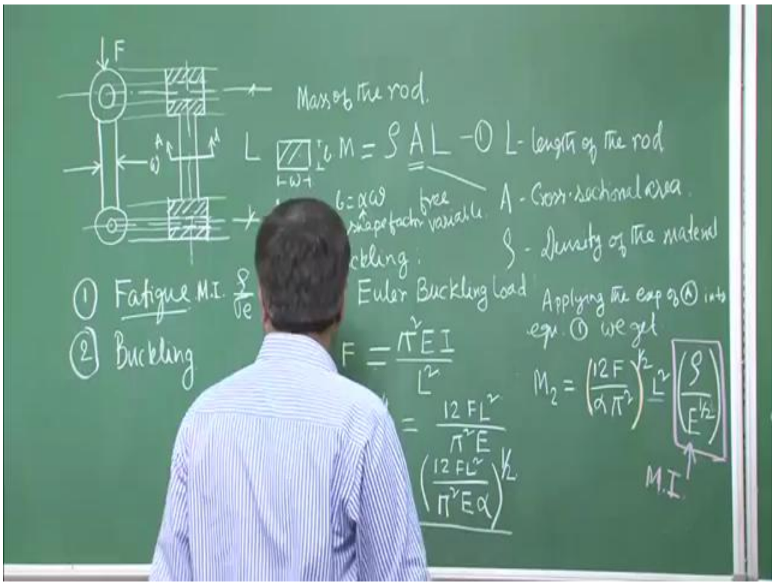

Let us just erase this little bit of it and just try to find it out that how will it look like. So if I apply this, applying the expression of A into equation 1 we get let us say in the 1st case the mass is M 1, then in this case the mass is we can call it as M 2 and that we can divide it into parts again, 12 F over Alpha pie square under square root L square and Rho over square root of E, so we have divided our system into 3 different parts okay in this case, this is the functional part and then of course the constants are also here and then we have what you call the geometry part and the last part is the material property index that is Rho over square root of E that is what is our material property index MI.

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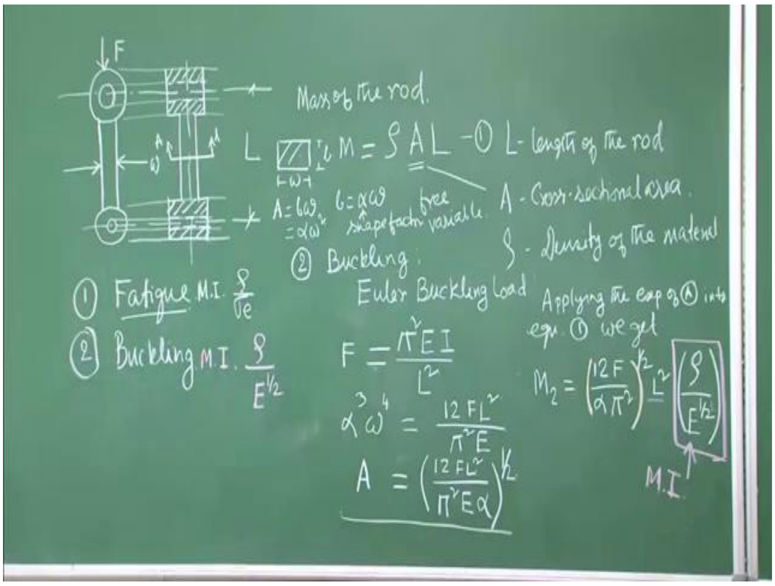

So we can write that that from here the material index that we are getting is Rho over E to the power half okay. So with this in background, now let us go and see that how are we going to tackle the problem? Now that we know the material indices, should I go for Rho over Sigma E, should I go for Rho over square root of E or should I try to do something better for this case?

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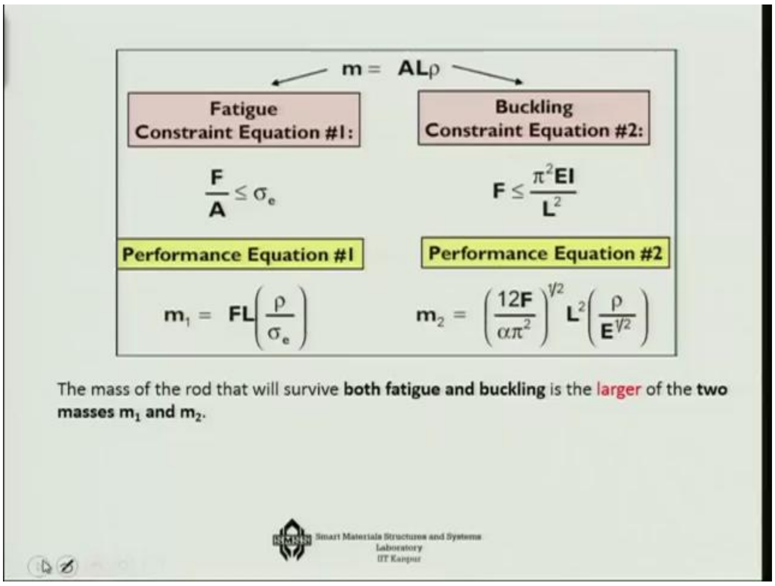

If I now consider both of them, so if I summarize it that we get in one hand Rho over Sigma E and our mass expression in the 1st case is M 1 = F L times Rho over Sigma E. In the 2nd case it was Rho over square root over E and the 2nd case gives us the mass which is of this particular expression. So when the rod has to survive both fatigue and buckling, then it has to survive the mass should be larger of the 2 masses, right because if M 1 gives smaller mass, then M 2 then M 2 becomes critical for us because otherwise it is going to fail in buckling and vice versa that means if M 2 becomes smaller than M 1, then M 1 becomes critical for us otherwise it is going to fall in fatigue.

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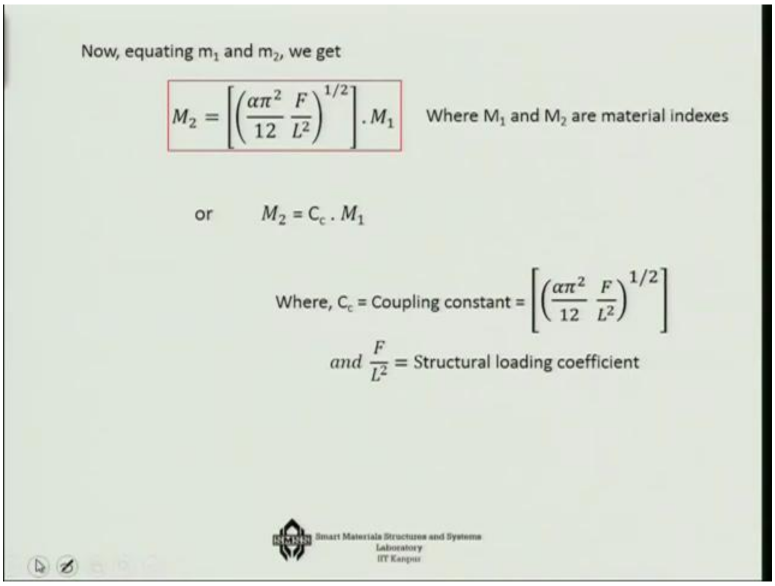

So the best solution for us so that almost both of them get violated at the single point is if I equate M 1 = M 2. And if I do that, then I am going to get this particular expression corresponding to M 1 = M 2 that is the force part of it okay, so you see that is the coupling constant okay. Now in the coupling constant if you look at it that F by L square would become a very critical term in the coupling constant which is the structural loading coefficient and that actually comes from the pressure in the piston, so we can denote it in terms of MPa.

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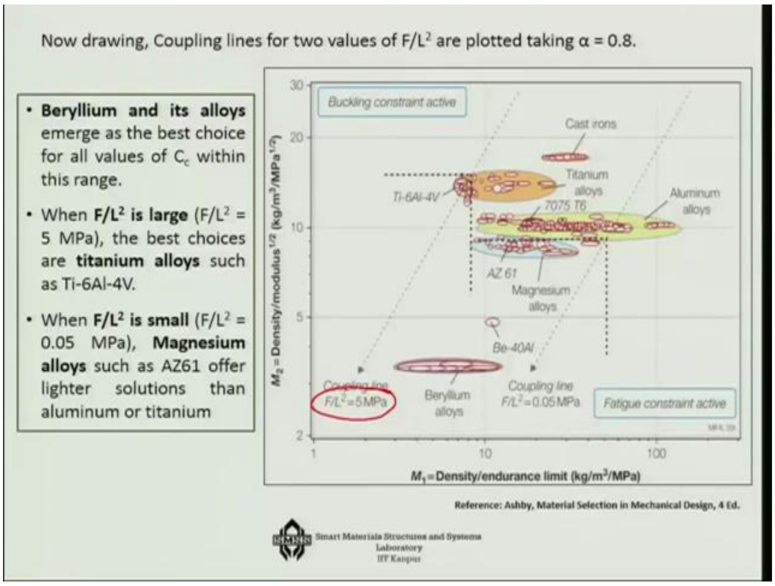

And then if you look at it that we can actually draw several lines for suppose F by L square = 5MPa, which is a high-pressure line, F by L square = 0 points 05MPa we can do it. And now the plot is such that for us, instead of working on each individual plot we are now plotting M 1 against M 2 okay, so M 1 and M 2 are coming into picture now, the material property indices directly. So that means M 1 = some constant times the M 2 and that constant for 2 values of F by L square are plotted considering Alpha = 0 points 8.

Now then when in this coupling line, when you are towards the lower border you can see that beryllium and its alloys this part actually is coming out as the best choice for all values of cc within this high-pressure to the low-pressure range because you are satisfying M 1 and M 2 both. But when F by L square is large suppose something like 5MPa, then the best choice is somewhere close to this line that is the titanium alloy, Ti-6Al-4V, V is the vanadium.

And when the pressure is low and you may also consider the magnesium alloys here of course, you have to keep in mind that if you choose the magnesium alloy, you will satisfy M 1 more and M 2 less, if you choose beryllium you can satisfy both the conditions, 50-50. And corresponding to the case of high-pressure, you have only titanium alloy as your choice in this case in terms of the material, so thus we get a very good idea of which material to choose corresponding to the applications.

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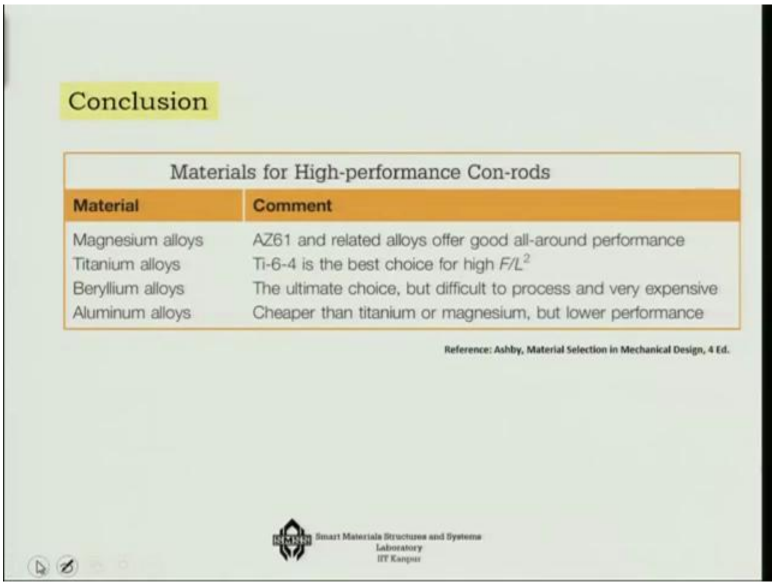

So thus our conclusion is that many shell alloys like AZ61 and related alloys, they offer good all-round performance. Titanium alloy is the best choice for high-pressure value, beryllium is a good choice a good trade off, but it is difficult to process and very expensive and also beryllium has a problem sometimes it is corrosive also, so we normally try to avoid beryllium. And the other thing is the aluminium alloy, which is cheaper than titanium or magnesium but it has a lower performance.

Let us look back the aluminium alloy's position one is more. So as you can see here that aluminium alloys are somewhere in this region okay, so they are for the low-pressure values they are not bad because some good quality aluminium alloys can indeed satisfy our criteria, but of course aluminium is expensive, but in comparison to titanium and magnesium they could be cheaper and their performance is lower performance. Titanium gives you the best performance at least in terms of the buckling parameter. So this is what our final conclusion is and we can discuss on some more problems in the next materials selection, thank you.