Basic Construction Materials
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Module No # 08
Lecture No # 38
Metals 3 – Part 2 (Iron, Iron products, and steel)

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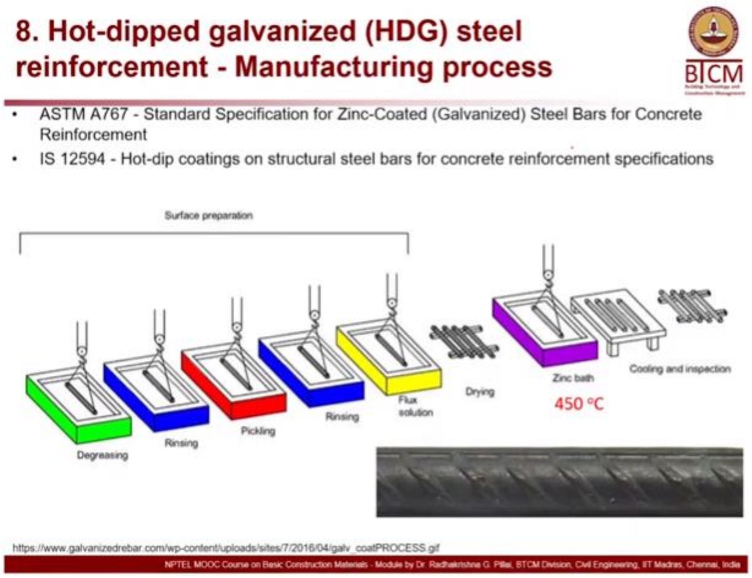

Now another type of (00:17) reinforcement, so until now, we were talking about item 6 and item 7 that is epoxy coated rebar and CPC coated rebar; they were non-metallic materials, which had much problem because; of the abrasion resistance. Here we are talking about hot-dipped galvanized or HDG steel reinforcement with very good abrasion resistance. It is a bit costlier, but the product is still good because we handle them roughly at the construction site.

So you will walk over it, you can drive vehicles over it or park vehicles over it with all sorts of things you can do to the rebars. So they have to sustain all those, and there should not be any scratches. So a non-metallic coating, in general, it is not a good idea for our typical construction sites. So metallic coating is what we need to go for.

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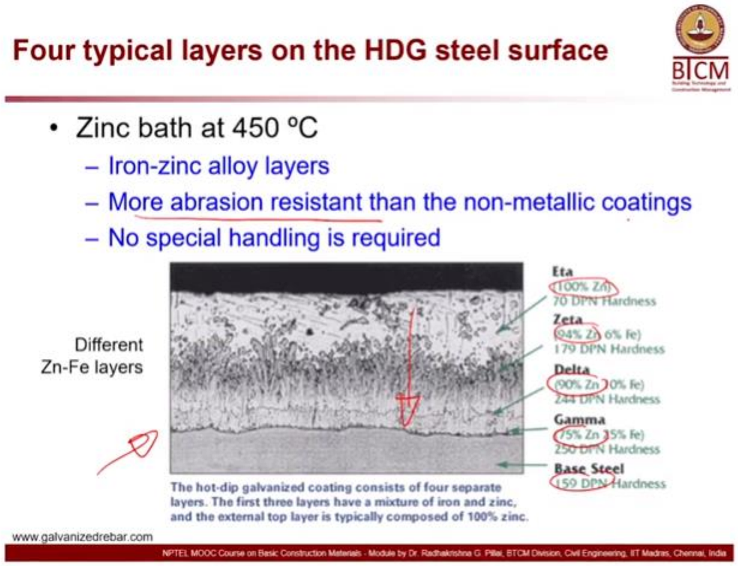

This is an example now zinc here galvanized steel; what essentially it is? It is a zinc bar at about 450 degrees Celsius. So the various processes are there, so basically you provide you dip the steel in a zinc bar at about temperature, which is for 450 degrees Celsius. What will happen is a hot dip you know what will happen is the zinc will adhere to the steel surface. And this is a microstructure for that you can see here zinc 94% zinc 100% zinc 100% then 94% then 90% then 75% and then the base Steel.

So as you move down, the concentration of zinc keeps reducing, so you have a layer as a whole it performs very well; you have much zinc there, which will protect the steel from corrosion. And more importantly, it protects the steel from corrosion, and also it has excellent abrasion resistance than non-metallic coatings like fusion bonded epoxy coating or CPC coating.

So metallic coating is better because it has abrasion resistance and corrosion resistance. After all, here, we use zinc as a metal. And zinc will corrode before the steel corrosion that is like a sacrificial thing that.

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But zinc will protect, and its corrosion resistance is better, and also you can see here in this picture is a white line around this is the cross-section of the rebar this white line around that. That indicates that even if there are sharp corners, they still have a good complete layer of a proper coating is there of the zinc coating is available even if you have rough edges. Imagine you have rebar here, you all rough edges, you know, very sharp corners etc.

So they are all in that corner region; also, you need to have a proper coating that is very clear from this picture on the top that is when you go for galvanized coating, you can have a very good coating, which is probably not that easy to provide when you talk about non-metallic material.

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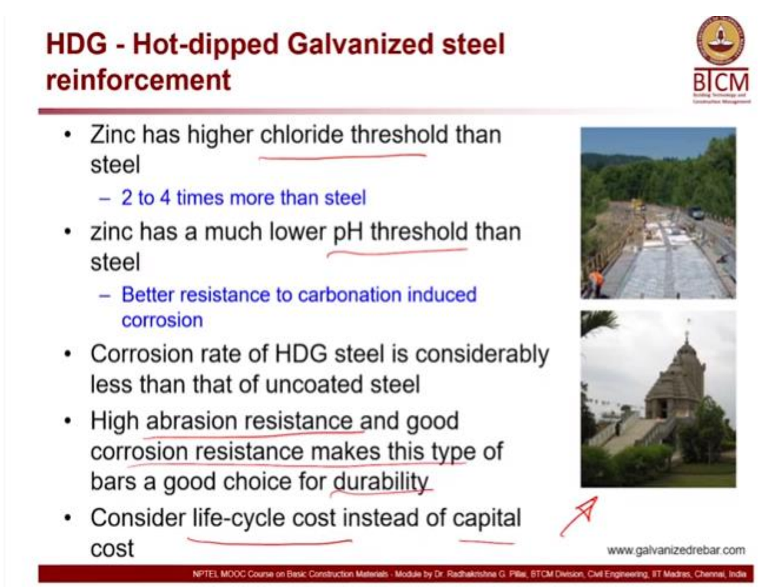

And also it has zinc has a very high chloride threshold; in other words, zinc will need two to four times more chloride contamination to corrode. So that means when you a galvanized steel concrete, it will need double the amount of chloride for that steel to start corroding. Because only after the zinc coating gets corroded, it will reach the steel. So if the zinc coating is preventing the corrosion, the steel inside is also getting protected.

Now when you talk about the carbonation-induced corrosion again pH threshold, you know the concrete gets exposed to carbon dioxide and chlorides and then. The carbon dioxide reacts with the concrete, and then the pH of the concrete will decrease. When; the pH of the concrete decreases, the steel inside starts corroding. When you put this galvanized coating, that amount of pH reduction is also significantly high, so you have again very good protection against carbonation.

So more things I am not going into detail you read about chloride in this corrosion and carbonation induced for corrosion if interested. But for you for this class, you need to remember that the chloride threshold of the amount of chloride required to initiate corrosion for galvanized steel is more than that for the uncoated steel. And the amount of pH reduction required is more for the galvanized steel than the uncoated steel.

So in both these two primary corrosion mechanisms, the galvanized steel performs better than uncoated steel. And also, because of the high abrasion resistance, the steels are excellent abrasion-resistant. Very high corrosion resistance makes this a good choice for durability. However, there is a consideration for the cost; it is sometimes twice that the cost because due to various factors, manufacturing is not that easy etc.

But if you look at life cycle cost instead of capital cost, you will see that this kind of bar is durable and beneficial in the long run. So these are some examples; this photograph is from a temple in Chennai where they are used galvanized steel, and this temple is about 50 to 100 meters from the seashore, very close to the seashore. So this was the only option to have a long-lasting structure.

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Steel Rebar Type	Ratio
Conventional uncoated steel	1
Epoxy-coated steel	1.33
Galvanized steel	2
Solid stainless steel	6 to 7
Stainless steel clad steel	2.5

Now, this comparison of the cost conventional steel of the cost is 1 unit for the epoxy-coated steel is about 33% more. For galvanized steel is about twice double the cost of stainless steel 6 to 7 times, and if it is flat stainless steel 2.5, I am not going to discuss much because these are the stainless steel rebar which you know used very earlier. It was not in much use that thin layers or stainless steel coating were provided on they used to do this, but not more I mean it is not widely used nowadays. Also known as clad steel.

Let us focus on these first four of them; you can look at the cost comparison, and then you can look at the life cycle cost. When you make choices, you have to look at life cycle costs, not just the very important capital cost.

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Until now, we were talking about steel rebars now; there is also a pre-stressing strand when we talk about very long bridges or high rise buildings with large spans; you know the span means the distance between column to column. You know, in the auditorium, etc., or a high-rise building, where roofs need to be very thin and long-span so that you get more space on the floor less the number of columns.

In such applications, bridges in such applications, we use something called a pre-stressing strand. These are the strands with about 4 to 5 times more strength than regular steel. So regular steel if you know the yield strength is about 415 or something, let us say 500 it has 1860 and all that this is the range you are talking about very high strength. So they come in typical, you know, seven wires you can see here seven wires of different diameters.

And there is also one with three wires; the bottom left will also see where these types of strands are used. So this is how the strand looks like top right you can see, and there are also sheathed strands. Sheathing means like a plastic pipe or can do it with round, and in between, they will put grease. So that strand gets very good corrosion protection so they will feel grease this coating there are also you know coating or grease is also used.

Now there are unsheathe or uncoated strands also and you can see the number of wires. So this is typically how these strands are supplied because these are used for long structure long spans, so you cannot have the 10-meter long piece of anything like that you have to have it in the spool or a this is called spool, so you have to have this circular. And then so that you can use the same wire starting from one column to another column far away. 35, 40, 50 meters long it is possible, so it is heavily used in metro construction.

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I will show some pictures where are; these types of strands are used, like the 3 wire strand shown in the previous slide in the bottom left corner two-wire, you know. So that is used for railway sleepers widely used for railway sleepers here. And all other things which you see here the typical type of wires they are the seven wire strands. When they become very tall, electric postures, you know very tall electric post typical rebars may not be sufficient.

You need to have very high strength strands so that one application and long strand bridges you can see here this is a bridge in Bandra Worli in Mumbai. And many of the flyovers which we see today are using pre-stressing strand; the use of prestressing strand is becoming very widely used in most high-rise buildings. So you can see the floor of this high-rise building; beams are also sometimes used with or made with the pre-stressing strand.

So this is the sheet strands which I said it has grease coating; you know you can see grease here. So it is a steel strand coating with grease and then put inside the plastic pipes flexible pipes. And then also nowadays we have this epoxy coated strand. So be very careful when we use this strand, and that is why they put the picture here. We know very well that epoxy-coated bars or rebars are not performing very well.

So let us not create other problems by inadequate providing you know epoxy coated strands. See, these are all technologies that are very good but provided the implementation is also done in a good manner. If you cannot have good protection and cannot fallow the good quality control measures at construction sites, you should not use that. So all coating materials, you have to ensure that you have not cracked, they are not exposed to sunlight they are not scratched.

All these are very important, and it is better that you provide an up-gradation resistant coating than a non-metallic coating which is bound to get scratch, you know, the way we handle things on the construction sites. So it all depends on how we use it, I am not against the technology but what I am saying is? When we use technology, we should use it with complete quality control measures also in place.

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And these are some examples where we use this kind of strands and cables, so this is a threaded rod. Pre-stressing and then these are the seven wire strand then; you can see here cables these are all cables. So one here I would like to mention one here so when I say seven wires so this wire each of this is wire, seven wires are put together to form one strand. So that is seven wires nows; in the things on the right side, you can see 1 set of wires are placed; you know they are placed in a co-axial manner.

So you can see here this is another round, so they are cables we can call them cables these are used as you see in these pictures here these are the cables used for that. So you can see these are the cables for cables (14:05) bridges. When you put the strand inside the concrete, we use these strands to see where a cable is used whereas strand is used. Or both are not the same; it is different things.

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I have told you earlier this example for the railway sleepers so you can sleepers are these concrete pieces on which the rail track is sleeping the two steel tracks which you see this rail track they are sleeping on the sleepers. So we can call it like that probably that is how the name came so you can see these little you know a black thing on the picture on the right hand these are pre-stressing strand. So these are those one with 3 wire strands.

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And then, we have threaded bars that are mainly used for geotechnical applications, such as slope stability. Or where you will have especially in tunnel construction where you will have rods that you know anchored into the, you have these steel rods anchored into the ground or rock strata. And then like a nail, and then you anchor it, then you tighten from the other end.

So for more detail, I would request you go and read out in the textbooks or internet. But you can look for anchor rods threaded bars are used so you can see these threads are here know you can see those threads over there and these bars. And then, with the nut and bolt system, they are tied.

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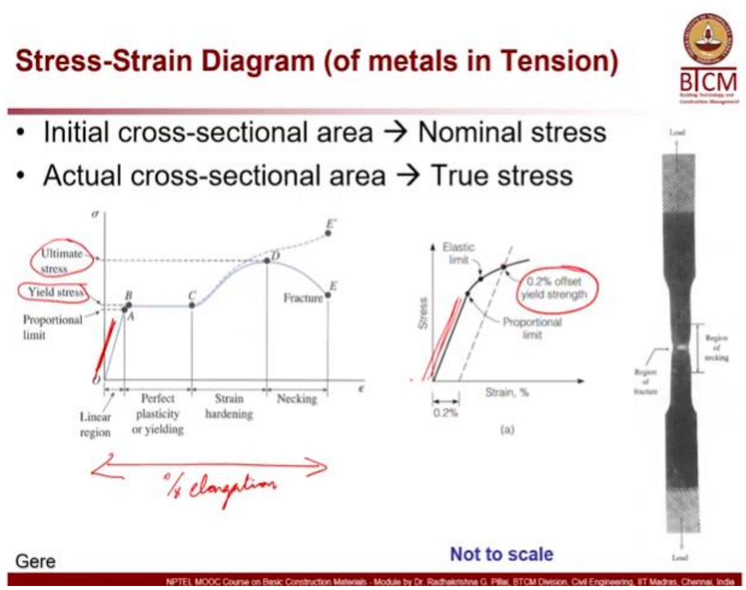

Now let us look at some of the properties we should be testing while selecting these rebars stands. So these are some of the images which you are already familiar with; we covered this earlier. Nominal stress, true stress, etc., but to other points, I am trying to make here is this parameter yield stress, ultimate stress, and the modulus over the slope. Yield stress, ultimate stress, and elongation are different things; we have to look at the length or percentage elongation you will calculate.

Based on the strain you get, you can calculate the elongation of the rebar specimen. And the yield strength you can calculate by this 0.2% of set yield strength. And then the slope of this you can take for calculating the modulus. So just giving you some re-cap on what we have discussed in our earlier lectures. So these are things which we need to test.

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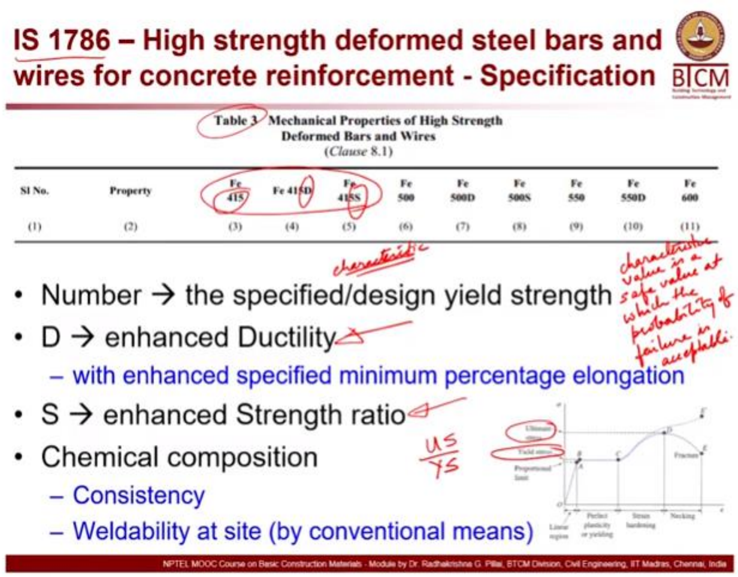

Now there is a specification which I have already mentioned IS 1786 is the IS standard or Indian standard specification published by the Bureau of Indian Standards BIS. And this standard, you know, is widely used, and for this standard provides both mechanical and chemical properties required for the steel reinforcement, in Table 3 in this standard where you have Fe 415, 415 D, 415 S, 500, 500 D, 500 S, 550 up to 600.

And there are you see these letters D and S also so first three are 415, so the yield strength is 415. That means yield stress here is 415 for this steel, but then you this D and S there what is D? D stands for enhanced Ductility and S stands for strength ratio, so what is that ratio? The ratio between ultimate stress and yield stress is the strength ratio; now, what is this number 415 that is the characteristic yield strength.

So I will call it characteristic yield strength, so we use that number for our design purposes. The characteristic value we already discussed earlier. So this characteristic value is something which kind of assures you that much will be the strength. So what is the characteristic value is a safe value at which the probability of failure is acceptable. So when I say the yield strength of a particular bar is 415, what that means is that at least 95 % chances are there that the strength would be greater than 415 N/mm^2.

So it is like a guaranteed value which you can get now also chemical composition there is a table.

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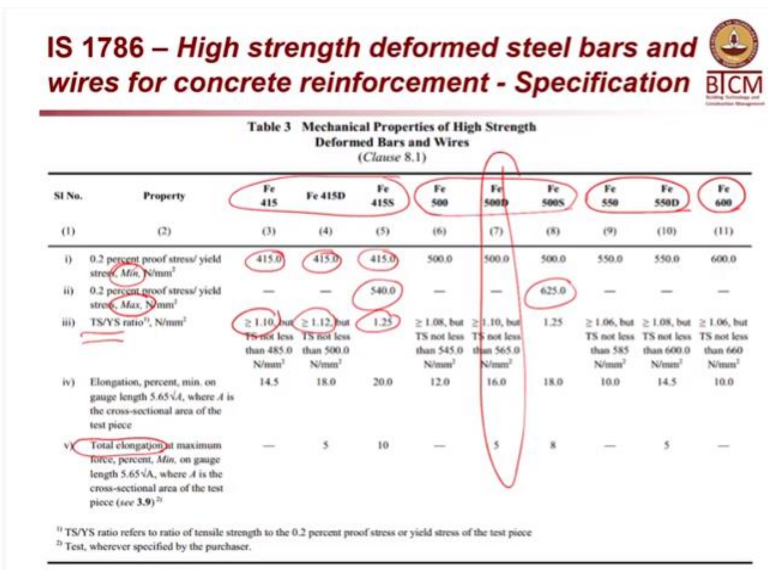

Table 3 Mechanical Properties of High Strength Deformed Bars and Wires
(*Clause* 8.1)

Sl No.	Property	Fe 415	Fe 415D	Fe 415S	Fe 500	Fe 500D	Fe 500S	Fe 550	Fe 550D	Fe 600
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
i)	0.2 percent proof stress/ yield stress, *Min*, N/mm^2	415.0	415.0	415.0	500.0	500.0	500.0	550.0	550.0	600.0
ii)	0.2 percent proof stress/ yield stress, *Max*, N/mm^2	—	—	540.0	—	—	625.0	—	—	—
iii)	TS/YS ratio[1], N/mm^2	≥ 1.10, but TS not less than 485.0 N/mm^2	≥ 1.12, but TS not less than 500.0 N/mm^2	1.25	≥ 1.08, but TS not less than 545.0 N/mm^2	≥ 1.10, but TS not less than 565.0 N/mm^2	1.25	≥ 1.06, but TS not less than 585 N/mm^2	≥ 1.08, but TS not less than 600.0 N/mm^2	≥ 1.06, but TS not less than 660 N/mm^2
iv)	Elongation, percent, min. on gauge length $5.65\sqrt{A}$, where A is the cross-sectional area of the test piece	14.5	18.0	20.0	12.0	16.0	18.0	10.0	14.5	10.0
v)	Total elongation at maximum force, percent, *Min*, on gauge length $5.65\sqrt{A}$, where A is the cross-sectional area of the test piece (*see* **3.9**)[2]	—	5	10	—	5	8	—	5	—

[1] TS/YS ratio refers to ratio of tensile strength to the 0.2 percent proof stress or yield stress of the test piece
[2] Test, wherever specified by the purchaser.

So this is the extension of the same table which I just showed you in the previous slide. You can see what the limits are 0.2% proof stress should be 415 for all these three stresses. I am trying to show you how to read this table? Do not try to memorize any numbers in this table because you have this table all the time, but you need to know how to read the table? We do not want to memorize things for any of this code, but we should know where to look for what information?

In the 500-grade steel, the characteristic yield strength is 500, and in 550 grade and 600-grade steel, the characteristic yield strength is 550 and 600, respectively. So these are all the numbers that indicate the characteristic yield strength. And then you also have an upper limit for that, so item row 1 is a lower limit right the minimum value. Now row 2 shows the maximum value and upper limit for that.

But it is not for all the grades you notice that here it is missing only here it is provided, so only in cases where the strength S grade steel there is an upper grade for the yield strength. And then, you have the tensile strength or ultimate strength divided by the yield strength rate ratio. So you can see that it should be greater than this, so there are these specifications. So if you are looking into the market and then try to buy particular rebar, and somebody says it is a Fe 500 D grade steel.

Then you have to look at this column and see whether that is matching all those requirements or not. So that is how we use this table, and then also you have for the ductility part we look a total elongation how much? When you pull rebar, how much it gets elongated by percentage? So these are all different things which you have to look at.

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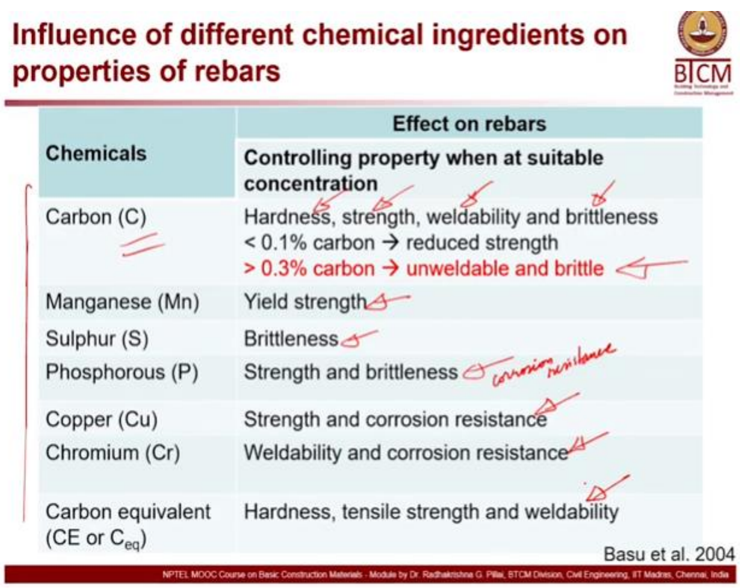

Chemicals	Effect on rebars: Controlling property when at suitable concentration
Carbon (C)	Hardness, strength, weldability and brittleness < 0.1% carbon → reduced strength > 0.3% carbon → unweldable and brittle
Manganese (Mn)	Yield strength
Sulphur (S)	Brittleness
Phosphorous (P)	Strength and brittleness
Copper (Cu)	Strength and corrosion resistance
Chromium (Cr)	Weldability and corrosion resistance
Carbon equivalent (CE or C_{eq})	Hardness, tensile strength and weldability

And also, in terms of so the previous table more on mechanical properties this is more on chemical properties. Where you look at the chemical, what are the different chemicals present in the steel or how much there should be? Because each chemical influences various properties, you can see here that carbon affects the hardness if it affects the strength, it affects the weldability, brittleness, etc. And the different range of carbon if the carbon content is more than 0.3, then it becomes unweldable.

Or it becomes brittle, and then Manganese affects the yield strength sulfur affects the brittleness Phosphorous affects the strength, and it also affects corrosion resistance; also copper resists corrosion resistance, Phosphorous also resists corrosion resistance then chromium also weldability and corrosion resistance. So carbonic equivalent so different chemicals can influence the various properties of the steel.

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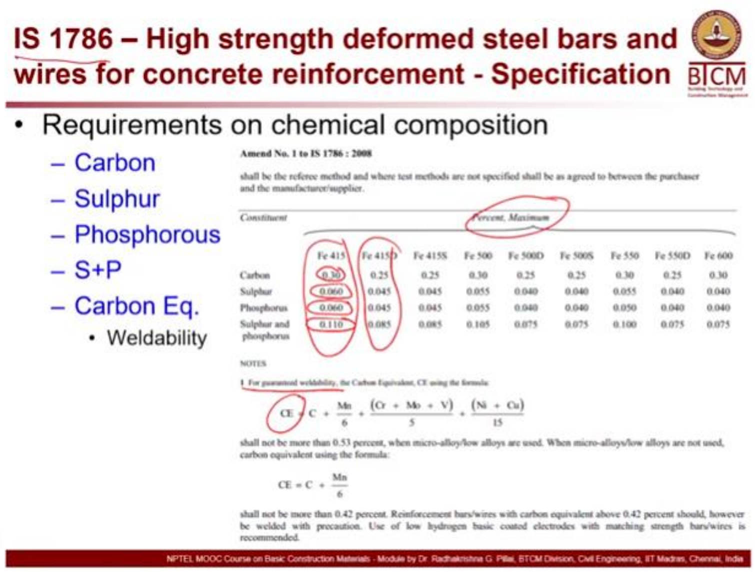

Now for this again IS 1786 as some specifications they say for Fe 415 steel this should be the maximum or upper limit for various composition various chemicals. If you have a carbon content of more than 0.3%, then you cannot call it Fe415 Steel; it is not Fe 415 steel in that case. So you have to make sure that this carbon content is less than 0.3, this sulphur content is less than 0.06, Phosphorous is 0.06, sulphur plus Phosphorous is less than 0.11.

So all these for each of the grade steel each of the designation you have to make sure that these steel is actually meeting this requirement. And they do test all the manufactured steels when they sell out when they ship the steel out there is also a test report which comes along with that you should ask for that. So when you get the test report and test it in a third party, somebody else can do the test thing. Once the steel comes to the side or before that, you should routinely check all this.

And carbon equivalent, you know, mainly affects the weldability; you can use this formula on different chemicals to influence weldability mainly to guarantee weldability. Because if this carbonic equivalent goes higher, then; you cannot weld that steel. So these are all different things that we very commonly or routinely tested in the construction steel industry.

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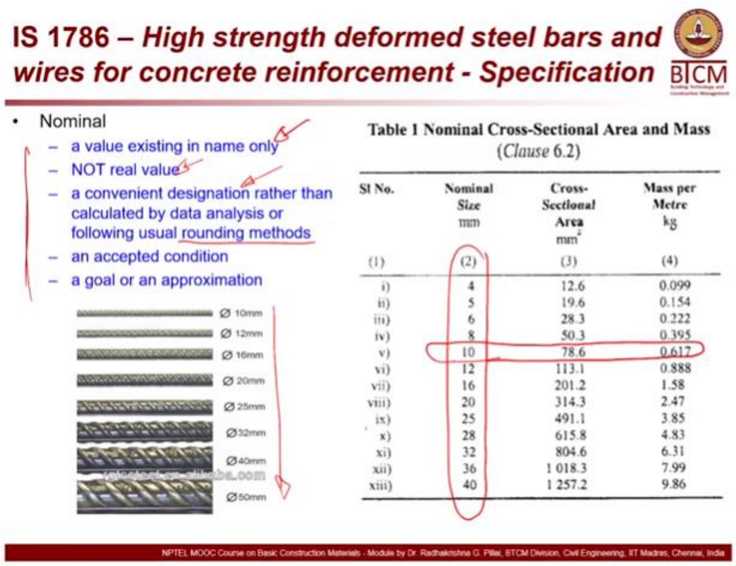

Now diameters that are also we say different diameters it is not you know if you do a calculation you say that I want steel, which is 10.56 milli meter diameter you cannot get. So you have to go for the standard sizes available and then accordingly you have to design. So typical sizes which are available or nominal sizes available are this, so what is the nominal diameter? So it is a value difference definitions are I just looked at the dictionary and found these different meanings for nominal.

It is a value existing in the name; it is not an absolute value if you actually take a 10mm diameter bar, and then you try to measure the diameter of the bar. It may not be 10 mm at all, but it will be minimal, at least 10 mm but slightly more than that. So what those numbers are essentially is just a convenience designation it is easy to call you to know for naming purpose, etc. Usually, they use round figures.

And it is accepted or goal or an approximation, so when I say a 10mm bar or a 12mm bar, I have roughly about at least 10mm I will get. So but these are the typical you know it is not at least means at least an about that number. So if I have a 10mm bar, I will know what is a cross-sectional area is and what the unit weight of that rebars? So I can calculate how much will be the right of the structure if I use that so many things you can calculate.

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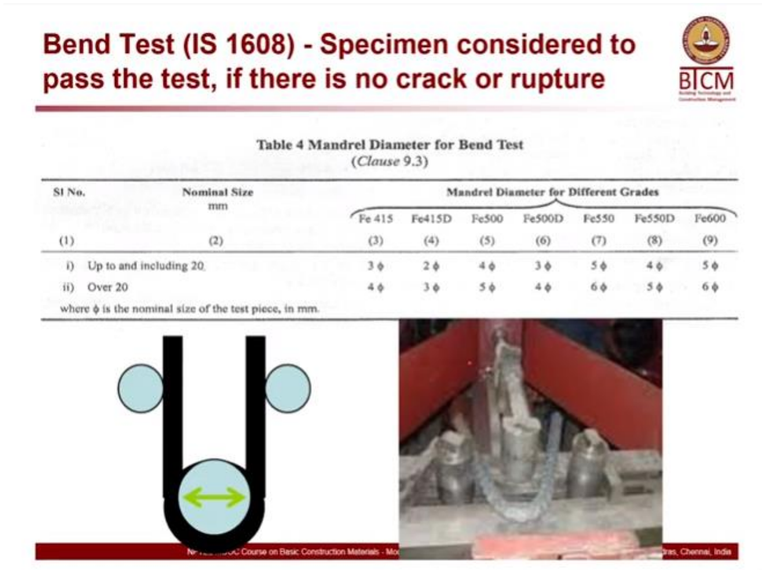

Sl No.	Nominal Size mm	Mandrel Diameter for Different Grades						
		Fe 415	Fe415D	Fe500	Fe500D	Fe550	Fe550D	Fe600
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	Up to and including 20	3 ϕ	2 ϕ	4 ϕ	3 ϕ	5 ϕ	4 ϕ	5 ϕ
ii)	Over 20	4 ϕ	3 ϕ	5 ϕ	4 ϕ	6 ϕ	5 ϕ	6 ϕ

where ϕ is the nominal size of the test piece, in mm.

Another test we have to do is, so I talked about the chemical test and mechanical properties epically the tensile. So we also should do a bending test on the site; you will always bend the rebar for ductility requirements; you will have stirrups which is the bar that goes as around and bends, you know. And those bars, when you bend it should not crack if it cracks, then it is not suitable we discussed in the previous lecture on TMT steel. If the coating is not good, then it will crack.

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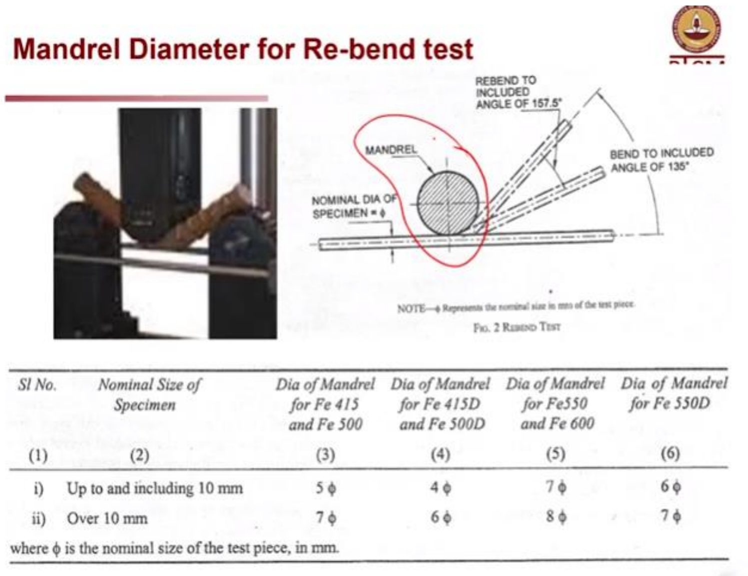

Sl No.	Nominal Size of Specimen	Dia of Mandrel for Fe 415 and Fe 500	Dia of Mandrel for Fe 415D and Fe 500D	Dia of Mandrel for Fe550 and Fe 600	Dia of Mandrel for Fe 550D
(1)	(2)	(3)	(4)	(5)	(6)
i)	Up to and including 10 mm	5 ϕ	4 ϕ	7 ϕ	6 ϕ
ii)	Over 10 mm	7 ϕ	6 ϕ	8 ϕ	7 ϕ

where ϕ is the nominal size of the test piece, in mm.

And then people actually do this bending test and then see whether it cracks or not; this is an example of how the test should be done? But also, when you bend it, this is something called a mandrel. So you but this bar and then try to bend it around that mandrel so, why am I showing this here is? I have seen many places where they bend the bar with a very small mandrel. So what will happen is? The bending will be very sharp, and when you have very sharp, the bars will crack.

So there are recommended mandrels; as you know, when you bend the bar, you should also use sufficiently diameter for bending purposes.

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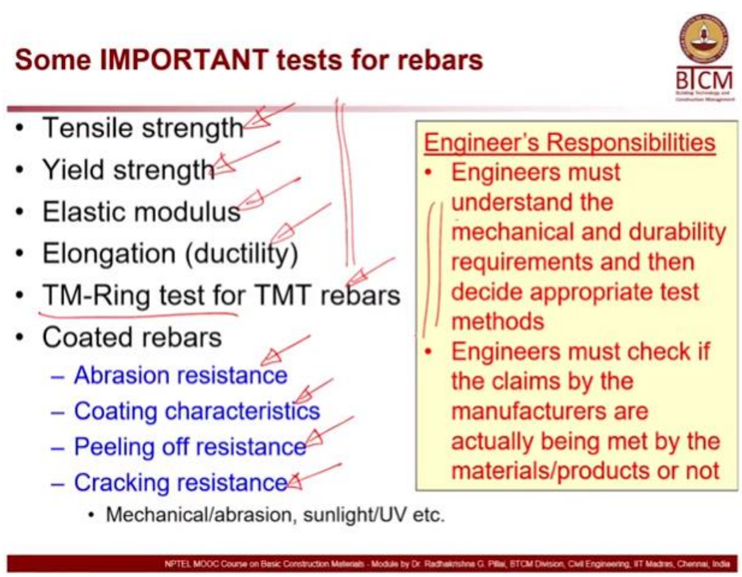

So these are important tests for various rebars; we should do tensile strength to find the yield strength? What is the elastic modulus? What is elongation? You know tensile strength, yield strength, elastic modulus, elongation, which indicates ductility. These are all mechanical things right now also corrosion resistance is very important. Of course, chemical testing is there corrosion resistance, especially when you go for TMT you should go for TM ring test.

A very simple test I showed a video in the previous lecture very you know you can just very easy to do the test. Now coated rebars, if you are using coated rebars, they claim that you will have corrosion resistance. But that high corrosion resistance is only possible if we are good quality coating. So you have to look for abrasion resistance characteristics of the coating itself. All these have to test peeling; the coating should not peel off very easily.

They should not crack very easily; not scratch gets scratched, you know, under exposure to sunlight etc. All these have to be tested, so the main message here is that we have some responsibilities as engineers when we use materials for construction. One responsibility is this is not this is two responsibilities; there are so many responsibilities.

But two such responsibilities are that we must understand the mechanical and durability requirements for that particular application. And then decided appropriate test methods, we will have to think about what the exposure condition is? What is the load condition, which is coming? So accordingly, you have to decide on the mechanical properties required; these are the durability properties or corrosion resistance, or something like that.

Now, this is the design of its will still these are the, which you have to do, and then we also must check if the claims made by the manufacturers are being met by the products they supply. So that is why we must also test them very routinely; we should test if you are buying like thousands of you know truck let us say lot of material you cannot just do one test and say that all the materials are of the same quality.

So you have to take samples from here and there, and then like in the case of concrete, will say every truck you should have so many cubes made and tested. Like that steel, also you should take every lot you should take one or couple of samples and then a lot is like the bundle of steel. And then you should do the testing for mechanical chemical corrosion resistance etc. These are very important as an engineer we must practice we should not just believe what the manufacturers are telling.

We should be able to test that our responsibility and make sure that the products we use in construction are of good quality.

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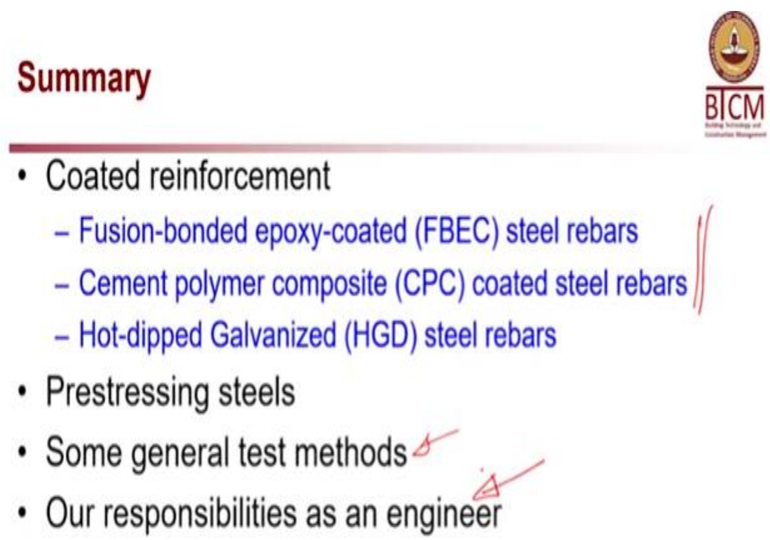

Just to summarize today's lecture, we looked at coated reinforcement. We discussed the challenges associated with the non-metallically coated rebars like fusion bonded epoxy coated and CPC coated rebars. And then, we also talked about how better the galvanized steel rebars are, especially because of their better abrasion resistance and galvanic protection properties.

Then we talked about pre-stressing steels and some test methods we talked about and then however most important thing our responsibility as an engineer. I think with that we will close today. Thank you.