Advanced Design of Steel Structures
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Lecture - 08
Material properties - 3

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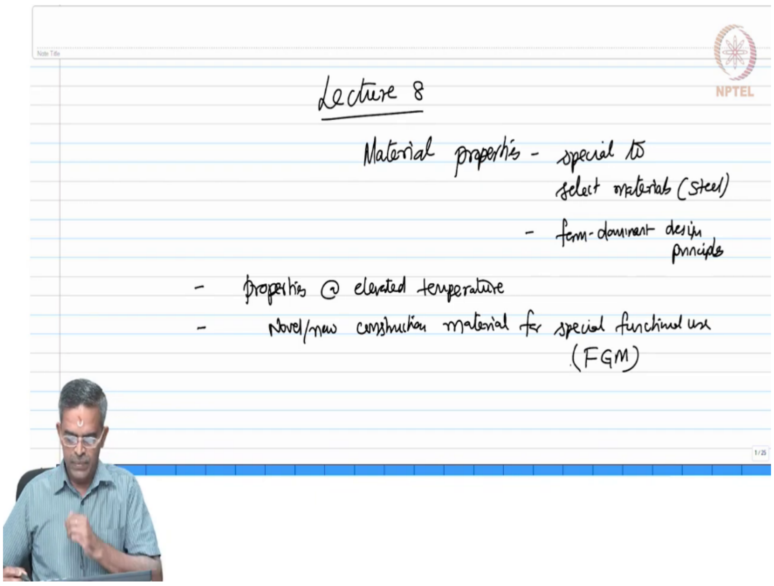

Let us continue to discuss something about the Material properties which are very special to select materials like steel which are applicable to form dominant design principles. Steel is the most preferred material for construction of conventional and special types of structures. Steel has got lot of advantages which we have been discussing in the previous lectures and we all agree on that the steel has gained an importance in the construction industry.

When it comes to special applications like industrial structures, strategic structures like nuclear power plants, large in type of industries cement industries tall buildings as well as offshore oil and gas exploration and production platforms, shipbuilding structures etcetera. So, we have also seen in the previous lectures that the how steel is classified what are the different international codes including Indian code that help us to classify steel based on certain special characteristics and properties that steel possess.

So, steel is not identified as an entity it has got lot of special characteristics, lot of subgroups, classifications, groups, etcetera. So, when you say I am using steel as a construction material in the present scenario it has no value. In fact, it does not make any sense you got to specifically say what grade of steel are you using, what chemical compositions that steel has and what are its mechanical and structural characteristics that make it as a desirable material for the construction process you have chosen.

So, steel is a large set within which there are lot of classifications which we discussed in the last lecture. We will now continue to do that and try to understand the properties of steel at elevated temperatures in this lecture. So, we will talk about special properties of steel at elevated temperatures. We will also talk about use of new novel construction material for special functional use which we are going to say as FGM.

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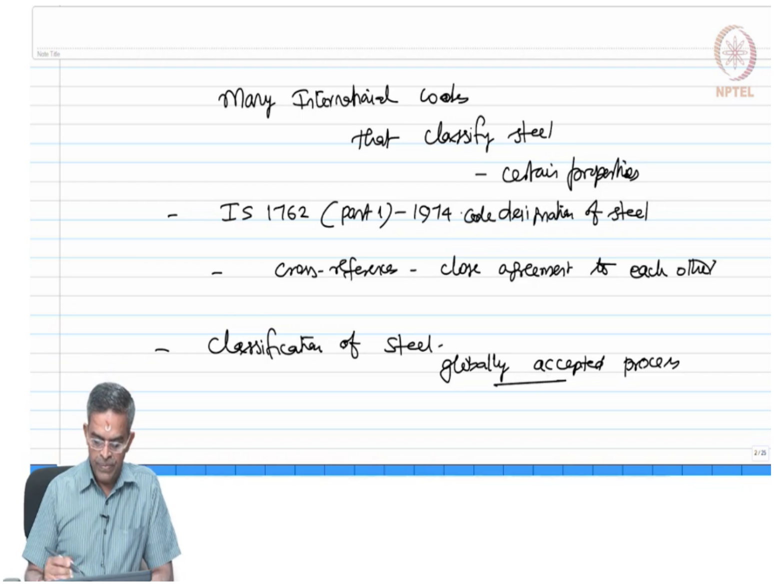

So, with the last note we had in the previous lecture we said there are many international codes that classify steel based on certain properties. In fact, to make a special emphasis Indian code 1762 (Part 1)-1974; also helps us to designate steel for construction purposes. It is important to note that these codes have lot of cross references and they are in very close agreement to each other. So, the classification of steel it is a globally accepted phenomena and many countries do follow this. Having said this apart from classification of steel; steel is also grouped.

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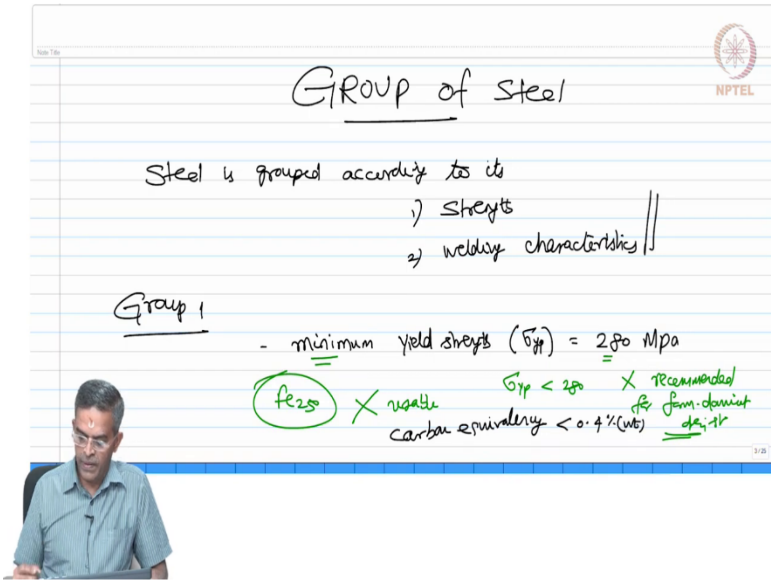

Now how are they grouped? Based on what parameters steel is grouped? Steel is grouped according to its strength and welding characteristics. Let us say how are they grouped? Group I states those steel which has got a minimum yield value as 280. So, friends it is very important that steel whose σ_{yp} is less than 280 is not recommended for form dominant design structures please note. Say Fe-250, the classical mild steel is not usable for special and strategic structures. The first requirement is σ_{yp} should be minimum of 280 and the carbon equivalency should be less than 0.4% by weight.

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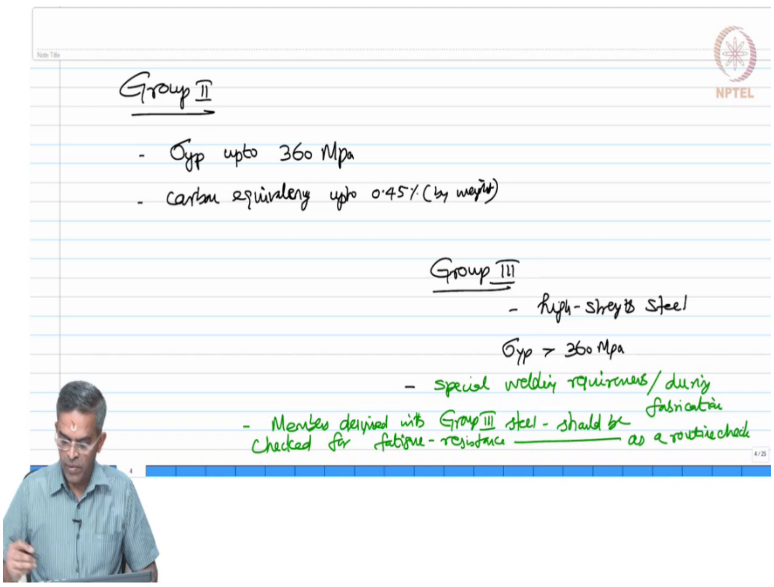

Group II is that steel whose yield value is up to 360 Mpa and carbon equivalency is up to 0.45% by weight. Group III steel it is also referred as high strength steel in the literature; this has yield value exceeding 360. Now this kind of steel has got special welding requirements which are emphasized during fabrication. We should also make a note that members design with group III should be investigated for fatigue resistance that is a condition as a routine design check.

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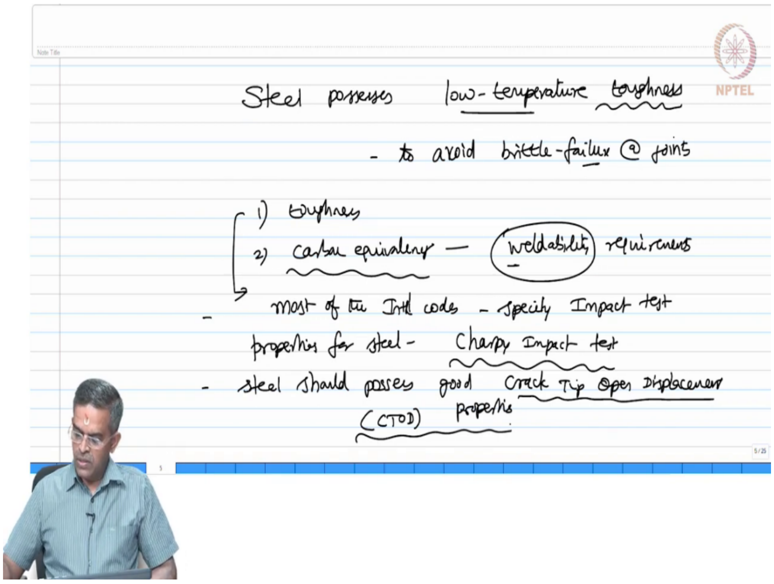

Another important property what steel possess which is also useful for us is steel possesses, low temperature toughness. This is helpful to avoid brittle failure at the joints. So, now I talk about toughness and we talk about carbon equivalency. We spoke about two things now toughness, carbon equivalency.

Carbon equivalency is a criteria which governs weldability requirements I will come to that. Toughness is a criteria which helps us to check the capability of the material under cyclic loads. So, now, most of the international codes specify impact test properties for steel using Charpy impact test. So, charpy impact test is considered as a standard procedure to qualify steel as a construction material when we talk about strategic and other important structures in the advanced scenario of design.

Furthermore, they also emphasize on a fact that steel should possess good crack tip open displacement properties. This test is briefly known as CTOD test. So, please be very careful in specifying steel or recommending steel as a construction material. The mechanical strength alone does not qualify this material for construction purposes in the present scenario of advanced steel design.

You have got to ensure that the material has good toughness the material possesses a carbon equivalency that makes it weldable comfortably and it should also have desirable CTOD properties as specified in the international codes. I will come to the specific details in the later part of this lecture.

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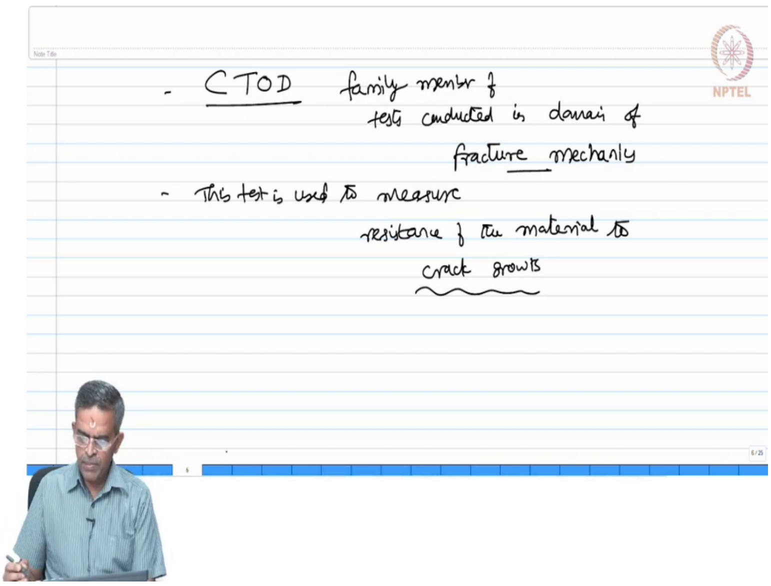

So, if you ask me a quick question what is CTOD test? Crack Tip Open Displacement test is a family member of test conducted in the domain of fracture mechanics. What does this test do? This test is used to measure resistance of the material to crack growth. Friends initiation of crack is a different scheme once the crack is initiated it propagates it grows. CTOD test is an index which will help you to qualify steel based on its resistance against growth of crack. So, you can very well see here we are imposing certain serviceability conditions not in the design scheme.

But in the material scheme itself like the material should be non-corrosive, the material should sustain cyclic loads, the material should sustain or should oppose a crack growth and the material should be weldable and ductile which are all earlier considered to be the design properties, which are earlier considered to be nomenclature recommended in the structural design.

But in the latest trend the recent phenomena of structural design they have all moved to qualify the material for construction itself. So, one can say very well here we are slowly moving the design procedures from a conventional strength base to form base and to a larger extent material specific.

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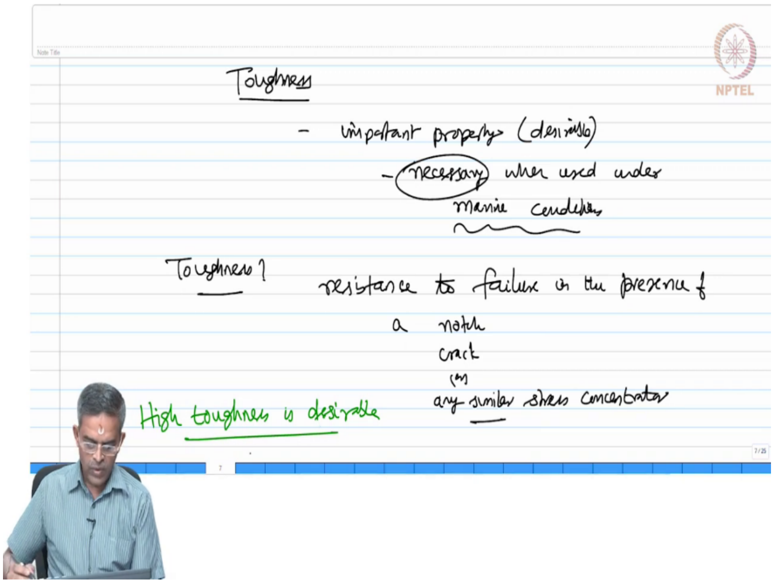

The next interesting property which steel is expected to possess is the toughness. Toughness is an important property which is considered to be necessary when you use under marine environment. It is a desirable property otherwise when used in marine environment this is compulsory.

One may then quickly recollect what is toughness? Toughness is described as resistance to failure in the presence of a notch a crack or any similar stress concentrator. So, in general what do we prefer? We prefer high toughness for the material.

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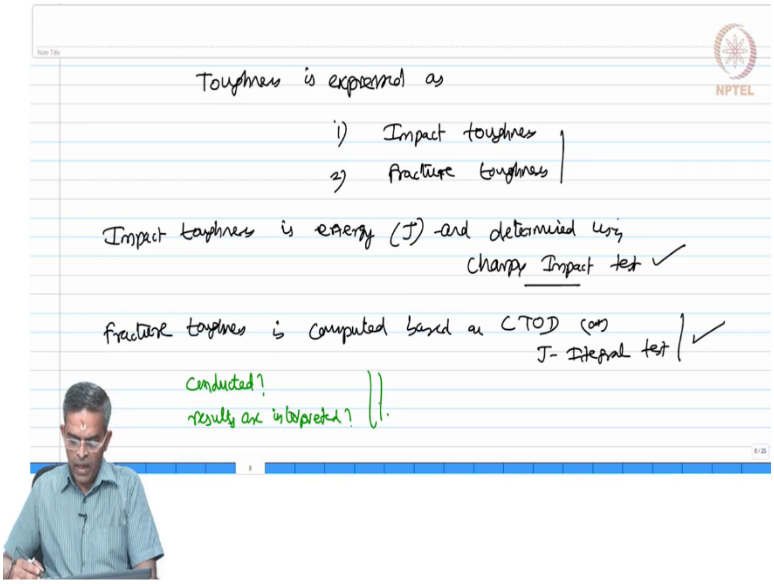

So, how toughness is expressed? Toughness is expressed as two ways impact toughness, 2, fracture toughness. Let us quickly also try to recollect the meaning of these two toughness. Impact toughness is the energy measured in joules and determined using charpy’s impact test.

I am not anyway describing the procedure of charpy impact test most of you may be knowing it or I would always request you to go to the website of leading institutions where there are live videos uploaded the institutes website about charpy’s impact test procedures. So, you could learn that separately I am not talking a believe that you know what is charpy’s impact test. Fracture toughness is computed based on the CTOD test or J integral test.

So, mechanical engineers may know both of the test procedures very clearly. However, does not mean that others may not be interested in knowing them can go through the open domain websites of these days available to explain these test procedures in a nice video for about a couple of minutes. How a charpy test is conducted and how the results of the charpy test are interpreted please learn both. How it is conducted? How the results are interpreted? Both are important for us.

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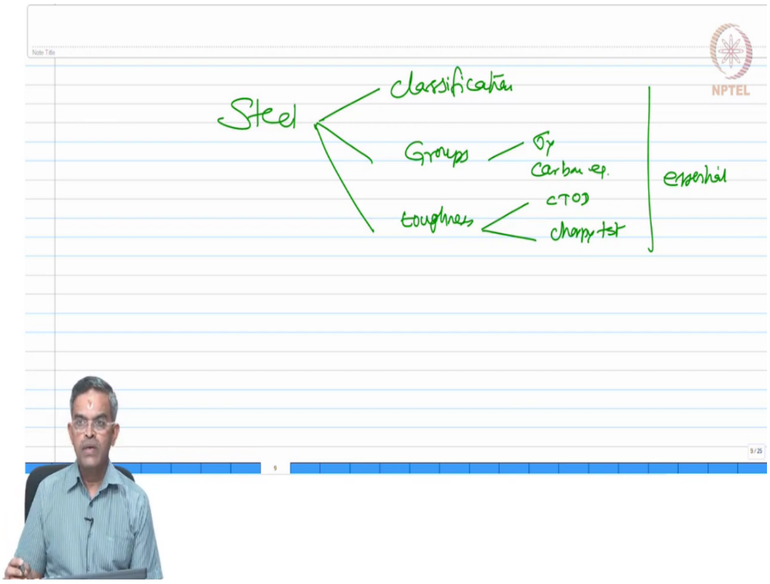

Having said this we have learnt the steel is classified based on certain properties by international codes. Steel is grouped based on σ_y and carbon equivalency. Steel has got special properties like toughness which need to be investigated either using CTOD or using charpy test.

These are all mandatory before you select steel as structural material for structural systems. In addition to that friends to add to more complication to your knowledge steel is also group based on notch toughness.

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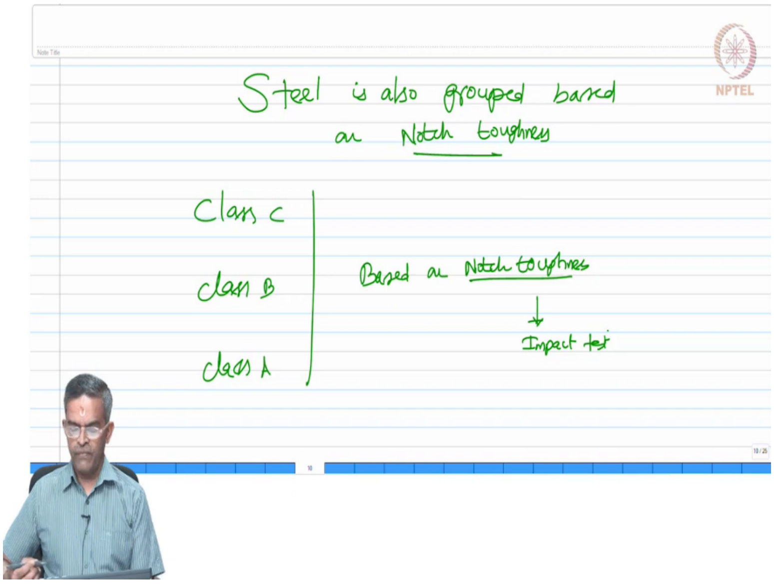

Based on notch toughness steel is grouped as class C, class B and class A. Now one may ask me a question how notch toughness is estimated? Notch toughness is also computed based on impact test by providing a notch in the specimen of a standard size using ASTM controls. You conduct the impact test and estimate the notch toughness. Based on the notch toughness obtained from the impact test can again group steel as class A B C.

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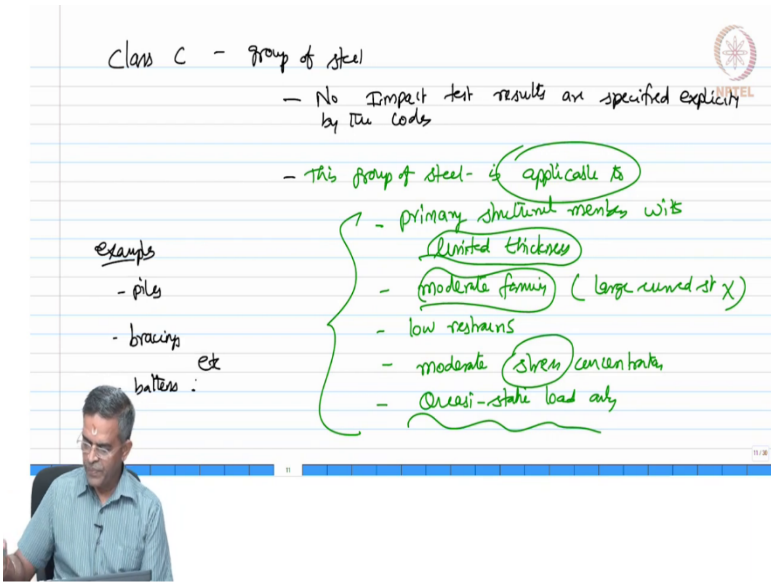

Let us see what is this class refers to? Class C refers to a specific group of steel where no impact test results are specified explicitly by the codes. Now where do we apply this? This group of steel is applicable to primary members, primary structural members with limited thickness that is very important here.

They can be also used in structural systems with moderate forming not large curved structures where you require low restraints you can use class C steel. When you have got moderate stress concentration, you can use this group of steel when the structure is subjected to quasi static loading, you can use this group of steel. So, friends please see here very carefully steel is grouped based upon the type of load, type of stress developed and also on the shape and cross-sectional dimensions.

So, far I think I am sure most of you would not know and would have not agreed that codes specify steel based on these conditions. We have been using steel as a simple material and find out the stresses and check whether this material and the cross section can sustain the bending stress, the shear stress and the torsion coming on to the cross section at the maximum sections and the declare the design as safe and check for its serviceability requirements. Those days of design have been gone friends.

We are looking for novelty in design advanced design procedures. So, we have to be very specific and we must know how steel is grouped, so intricately even for a specific choice of application.

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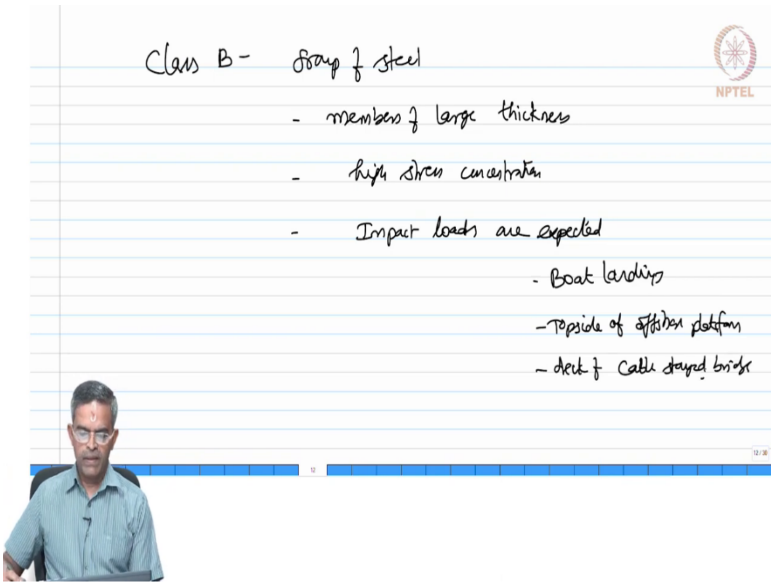

Continuing this argument class B group of steel is recommended for members of large thickness. You can also use this group of steel for members having high stress concentrations.

Now, getting back to this group class C examples could be piles, bracings, battens etcetera. Class B group of steel can be used on sections or members which are likely to attract large and higher stress concentrations. You can also use them where impact loads are expected example could be boat landings, top side of offshore platforms, deck of cable stayed bridge etcetera.

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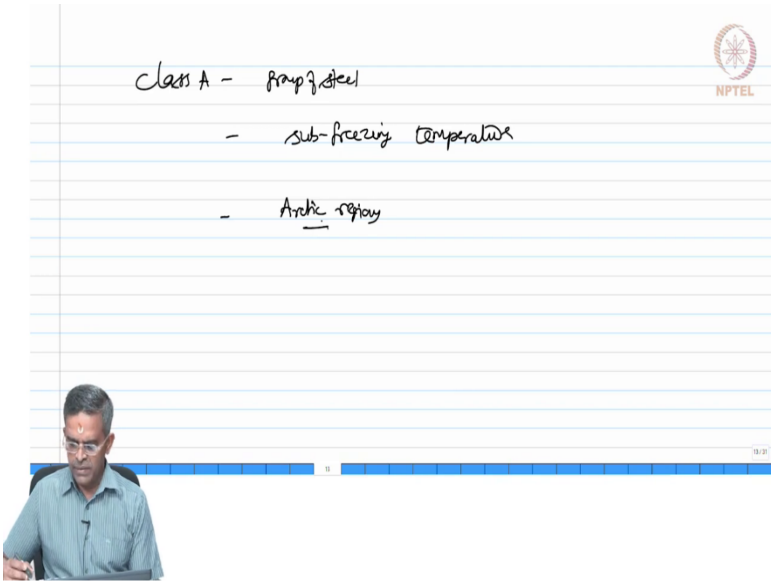

Now, let us talk about class A steel; Class A refers to a group of steel which is used in sub-freezing conditions. These are applicable to structures built in arctic regions. Friends we are slowly discussing the important mechanical and additional properties of steel which help to qualify it as a construction material.

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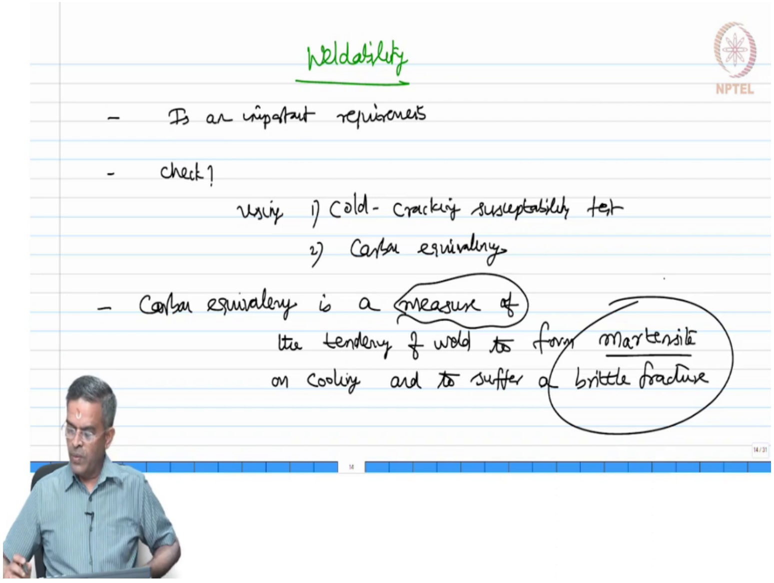

In that line we have one more important characteristic which is weldability as I said steel is grouped based on carbon equivalency and yield strength. Carbon equivalency helps to qualify steel for its welding characteristics. So, let us quickly see how this is approached in international design codes. friend’s weldability is an important requirement of any construction material steel it is very important because steel need to be welded or bolted.

They need to be connected the members need to be joined usually the joining is a welding, but people can go also for bolted connection specifically required if you do not want a welding connection at that particular location. So, weldability is essentially required.

Now how can you compute weldability? How can you check whether the steel is weldable or not? This can be checked using cold cracking susceptibility test. You can also do this by estimating the carbon equivalency from the chemical composition of steel. If you know the components present in steel each component by weight. If you know that percentage, based on that composition by weight one can compute carbon equivalency.

If you know the carbon equivalency value you already know how to group them. We discussed that in the previous slides. Now we want to see how based on carbon equivalency one can check its weldability. Let us be very specific about this objective at this moment. So, now we can say very well clear here that carbon equivalency is a measure of the tendency of the weld to form martensite on cooling and to suffer a brittle fracture. So, it is a measure to assess this property.

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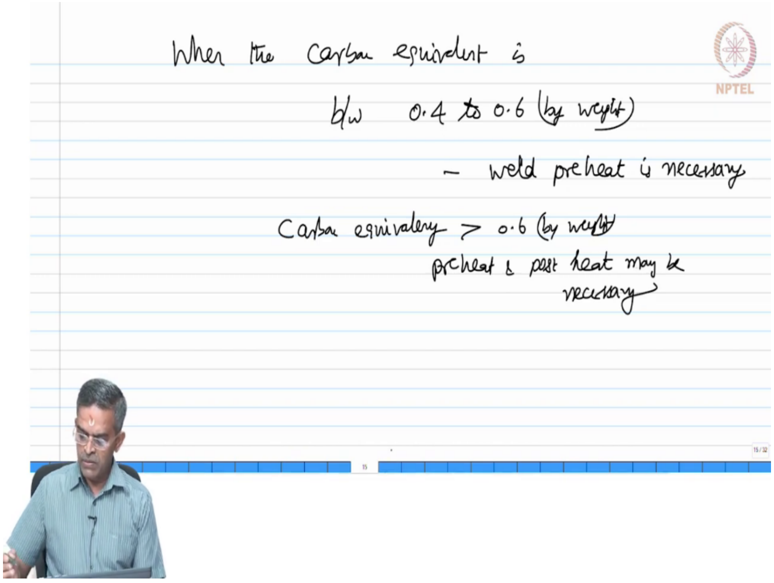

Now, in general if you ask me a thumb rule. Sir when can we say that steel is weldable? When the carbon equivalency or the carbon equivalent is between 0.4 to 0.6 by weight, then one can say a weld preheat is necessary. When the carbon equivalency is more than 0.6 by weight then preheat and post heat may be necessary.

I am talking about preheat and post heat of the member. So, we have a very interesting table recommended by the literature. You can refer to me list of references in detail to know more about this.

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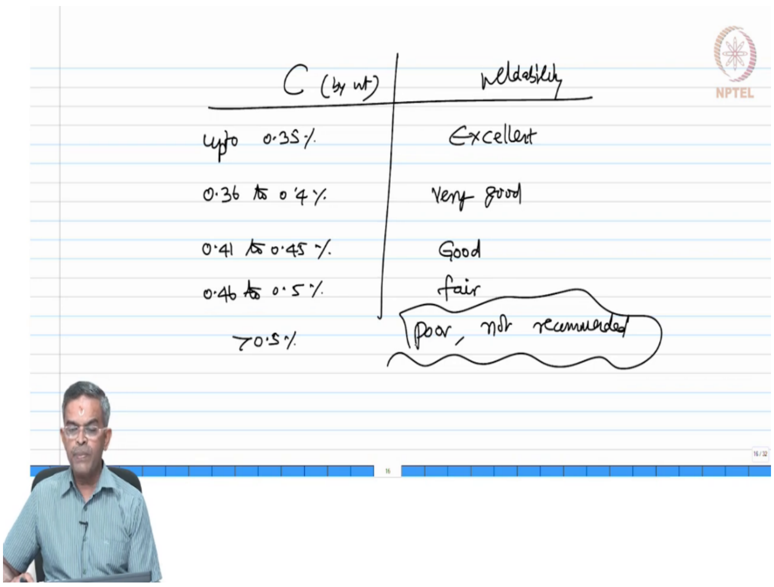

Let us open up a table carbon equivalency and weldability. If it is up to 0.35% by weight these all by weight. Then we declare this the weldability is excellent. If it is between 0.36 to 0.4% by weight we call the weldability as very good. If it is between 0.41 to 0.45% by weight, we call it is having a good weldability characteristic.

If it is between 0.46 to 0.5% by weight, we call the weldability as fair. If it exceeds 0.5 then we say it is poor and not usable or not recommended. So, before you check the material for construction especially steel look into the chemical composition of that product work out the equivalency of carbon by weight and see whether the code recommends it or not. Blindly you cannot use all grade of steel for construction.

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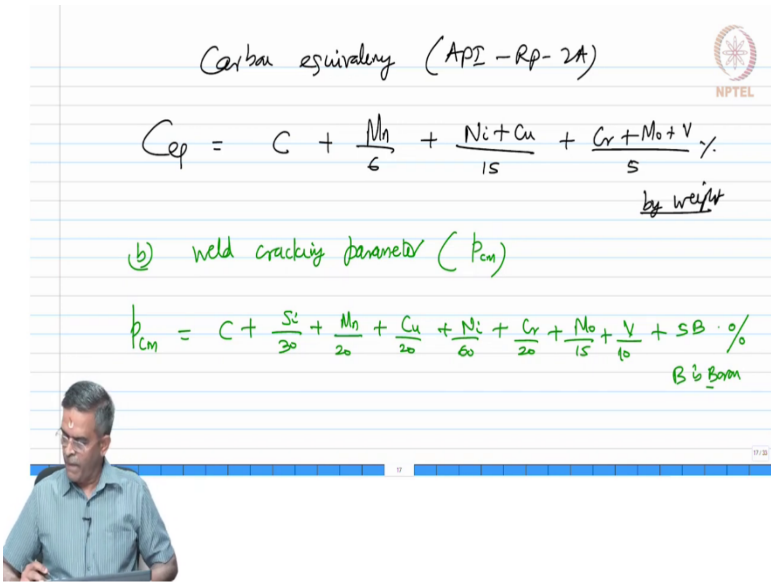

Now, the question interestingly comes how do we compute the carbon equivalency? Carbon equivalency as per API RP 2 A can be computed using the following relationship. Carbon equivalency is equal to carbon plus manganese by 6 plus nickel and copper by 15 plus chromium, molybdenum and vanadium by 5% by weight.

$$C_{eq} = C + \frac{Mn}{6} + \frac{Ni+Cu}{15} + \frac{Cr+Mo+V}{5} \; \% \; by \; weight.$$

The other parameter which is also used to check the weldability is a weld cracking parameter which is called as P_{CM}. P_{CM} can be obtained from the chemical composition relationship as you see here carbon plus silicon by 30 plus manganese by 20 plus copper by 20 plus nickel by 60 plus chromium by 20 plus molybdenum by 15 plus vanadium by 10 plus 5 times of B; where B is the Boron is all again in percentage. For your curiosity if you really want to know what the chemical composition of mild steel has for our knowledge sake.

$$P_{CM} = C + \frac{Si}{30} + \frac{Mn}{20} + \frac{Cu}{20} + \frac{Ni}{60} + \frac{Cr}{20} + \frac{Mo}{15} + \frac{V}{10} + 5B\,\%$$

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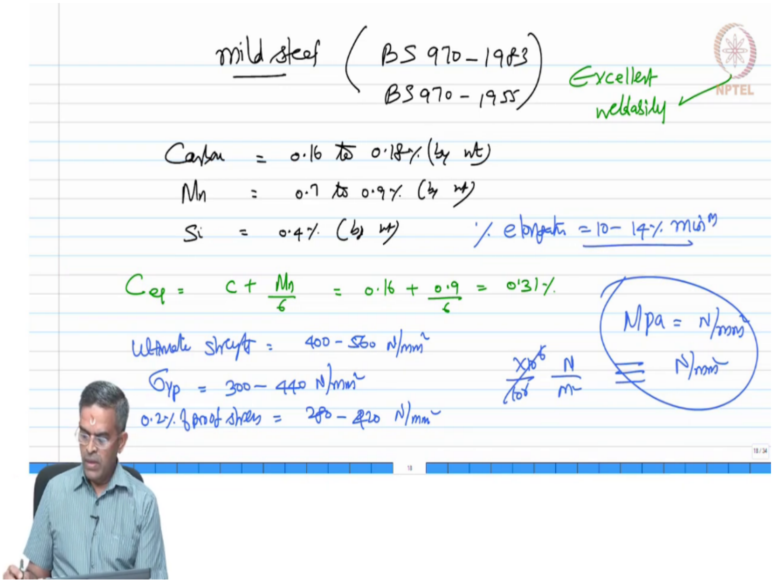

Let us say ask this question what a chemical composition mild steel has? Let us take mild steel mild steel should be designated by grade. We will not talk about steel as it is as mild, hard, beautiful, no adjectives.

So, let us say mild steel is specify as per BS 970-1983 or as per BS 970-1955 grades. So, this has the following composition. It has carbon as 0.16 to 0.18% by weight; it has manganese 0.7 to 0.9% by weight, it has silicon 0.4% by weight. Let us quickly compute the carbon equivalency for this which will be C plus manganese by 6.

This is what I know because other compositions are not involved in contributing to the carbon equivalency. So, we can quickly find out this as 0.6 plus let us say 0.9 by 6 which is 0.31% looking into this table up to 0.35 it is considered to be excellent. So, I can declare that mild steel is having excellent weldability. For our additional information mild steel has ultimate stress an ultimate strength let us be like specific is 400 to 560 Mpa.

Friends Mpa is as same as newton per mm square because mega is 10 power 6 and it is newton by meter square I divide by 10 power 6. So, is as same as Newton per mm square. So, 400 to 560 Mpa yield strength of this is 300 to 440 there is a range, 0.2 % of proof stress.

I believe most of you would know what is the proof stress and what is 0.2% and this stress is 280 to 420 Mpa and percentage elongation. Let me write it here of mile steel is 10 to 14% minimum.

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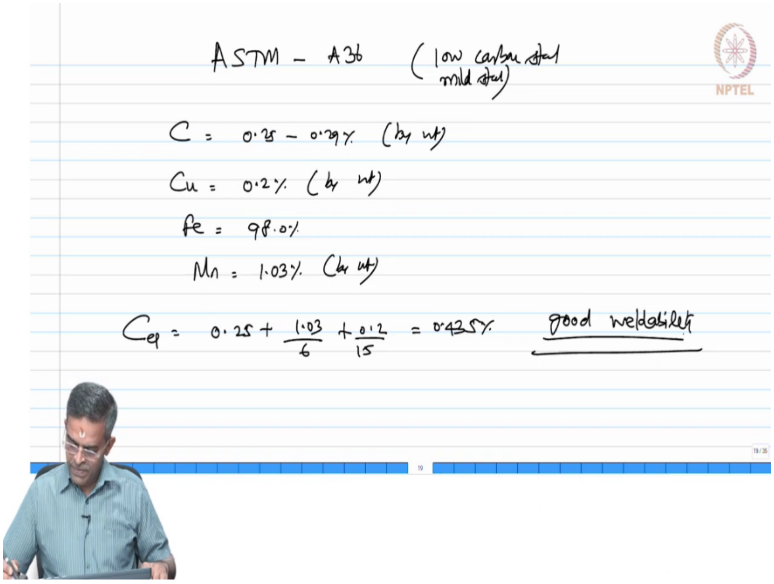

Let us take one more grade of steel which specified by ASTM, A 36. They call this as low carbon steel it is also referred as mild steel. This has carbon 0.25 to 0.29% by weight, it has copper 0.2% by weight, it has iron 98% by weight, it has manganese 1.03% by weight.

When I try to work out the carbon equivalency of this I get this as 0.25 plus 1.03 by 6 plus 0.2 by 15 like what the equation. You will get this as 0.435. when you look back the table I fall here. So, I can say this has got a good weldability. So, based on the chemical composition of steel one will be able to declare easily about the weldability characteristics.

I think it is clear enough for you to understand how this is done. I am not getting into more metallurgical part of it because I am not a metallurgist and I want you to know structural oriented characteristics only. This course is focused thoroughly only on structure engineering perspectives though we have to touch upon the material properties, but still I urge you to focus only on those things which are essentially required to know not beyond that.

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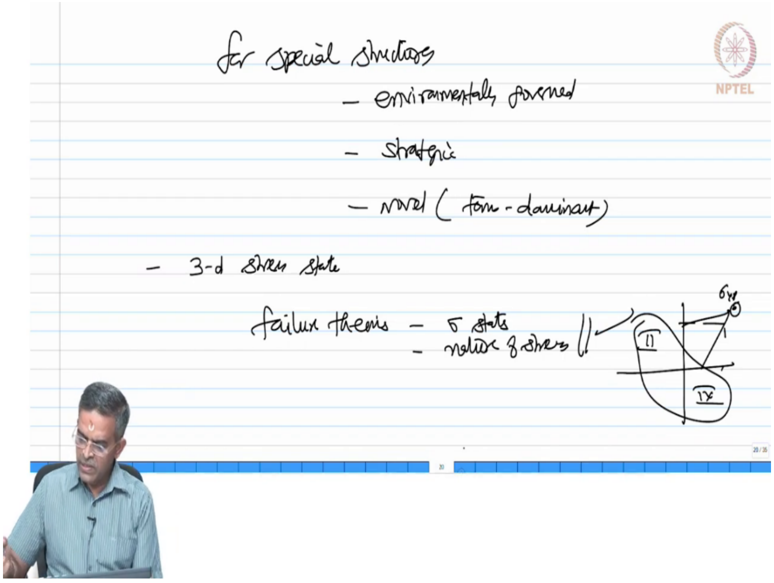

Now, friends we have learnt that for special application structures which are environmentally governed, which are strategic which are novel in terms of form dominant. They are usually subjected to a 3-dimensional stress state is it not? We have already said in a 2 dimensional or 3-dimensional stress state how complex it is to estimate the failure load. Because we have seen the failure theories and failure theories disagree on different stress states, on different nature of stresses etcetera is it not?

We have very clearly saw that and in the four quadrants the second and fourth quadrant the disagreement is very severe. And in this one of the theories says even beyond σ_{yp}. The failure does not happen is it not? Please recollect those the lectures what we had and you will really appreciate that how we are correlating the growth of understanding gradually to build your knowledge level on advanced steel design.

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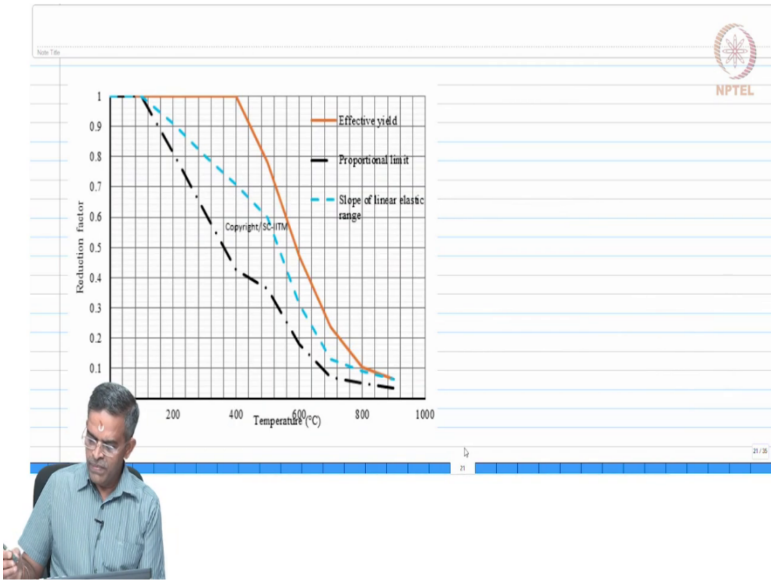

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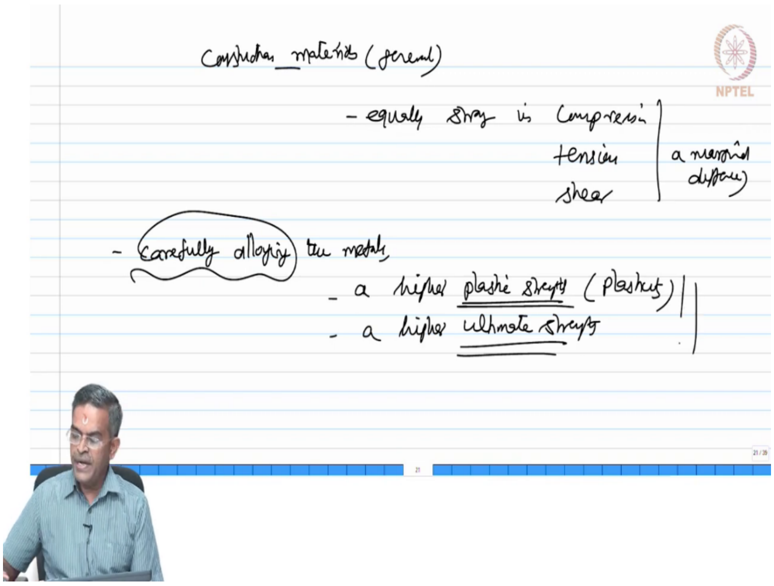

So, now interestingly friends, steel has got desirable properties in different perspectives. So, we talk about construction materials in general most of them are equally strong in compression, tension and shear showing a marginal difference. Most of them are strong in all these aspects. Now by carefully allowing them the metals we can achieve a good or higher plastic strength or plasticity and a higher ultimate strength.

We can be able to do that you have to work on the alloying part. Metallurgists will strongly agree and mechanical engineers to a larger extent will agree on my statement by changing the chemical composition and manufacturing processes. Fabrication procedures of making steel or manufacturing steel you will be able to achieve the better strength and plasticity of steel.

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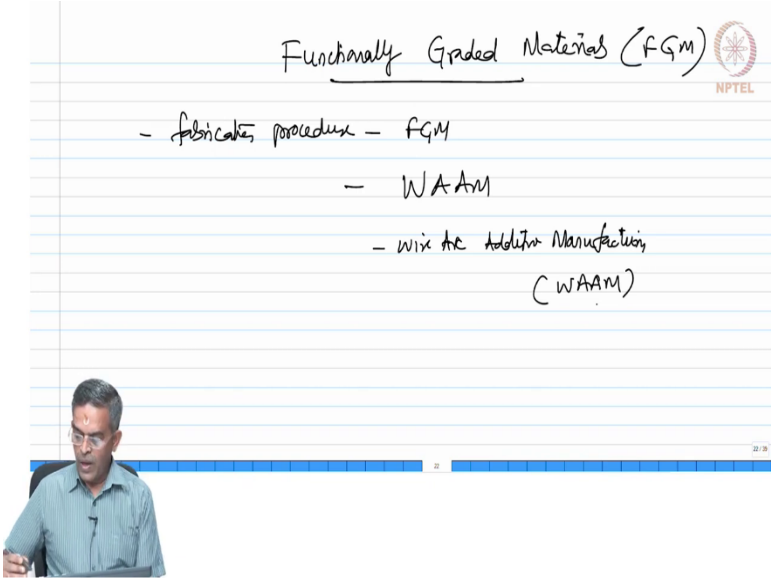

With this idea in mind in the literature in the very recent past about 2, 3 years back. People have introduced what is called functionally graded materials for strategic structures. FGM is not a new concept because this is being used in aerospace industry and special application systems very long back. But when it comes to structural applications when it comes to functional applications like anti corrosive etcetera it is a very very recent application friends.

So, now, FGM we will discuss in detail in the next lecture. One of the important fabrication procedure to manufacture FGM, which is widely used is WAAM which is Wire Arc Additive Manufacturing. We have a very strong and rich laboratory expertise in WAAM in the department of metallurgy in IIT Madras.

So, those who are interested those who want to inspect and see how WAAM actually is powerful in manufacturing FGM. You can email me we can arrange a short visit to the lab when the experiments are conducted and fabrication is going on we will help you how FGM can be fabricated using a WAAM process.

I will give you some more videos and some more lecture connectivity's in the coming lectures for you to know more about it, but keep your knowledge growth horizontal. So, that you keep on learning more and more as you go ahead. So, WAAM is one important manufacturing method which is very useful in manufacturing FGM. Now we will talk about WAAM much in detail later.

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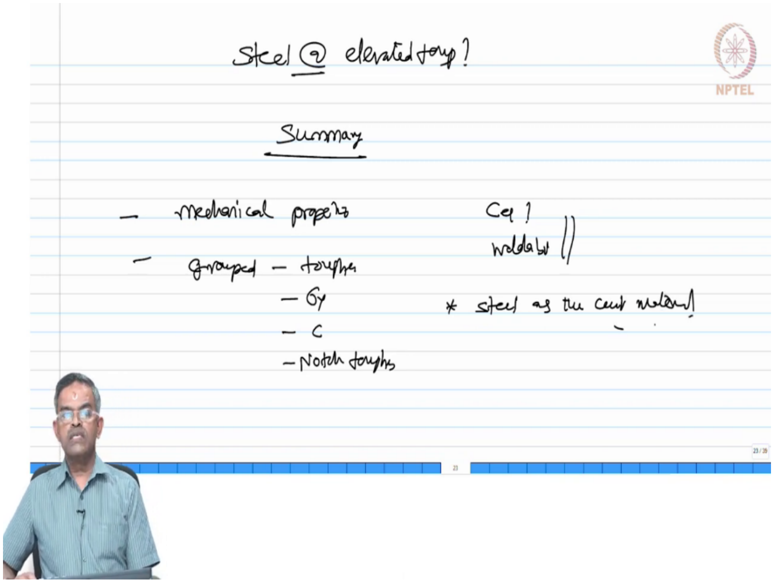

Let us quickly go through specific properties of steel at elevated temperatures. We will pay attention to this in the next lecture. But now we will write quickly the summary of this lecture. We have learnt a few mechanical properties of steel which are important, we have learnt how steel is grouped based on toughness, based on σ_y and carbon equivalency, also based on notch toughness.

We also learnt how to work out the carbon equivalency and how to check the weldability of steel. And we have also seen what are those special requirements for steel as a construction material. So, we close the lecture here have a good day bye.