Advanced Design of Steel Structures
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Lecture - 14
Load combinations

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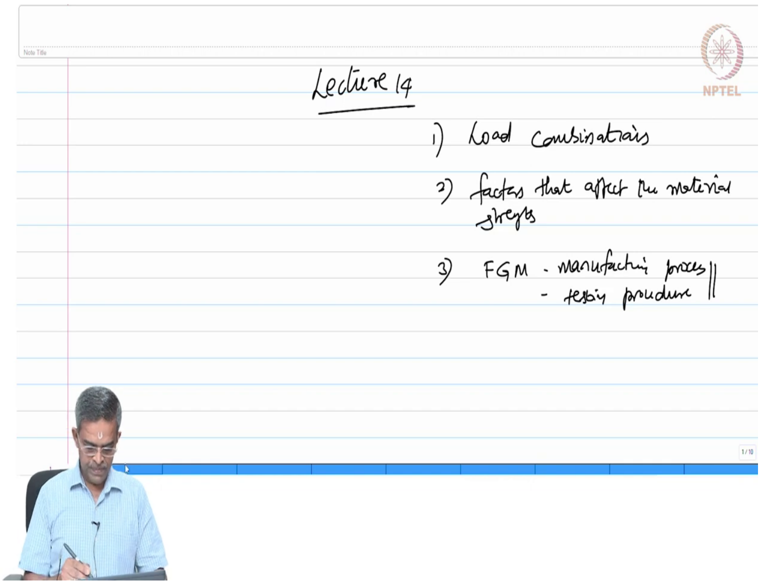

Friends, in this lecture 14 on Advanced Steel Design course, we are going to learn more about the Load Combinations in the design process. We are going to talk about the factors that affect the material strength and we also talk about the FGM manufacturing process and testing procedure as a part of the extended discussion we had in the previous lectures.

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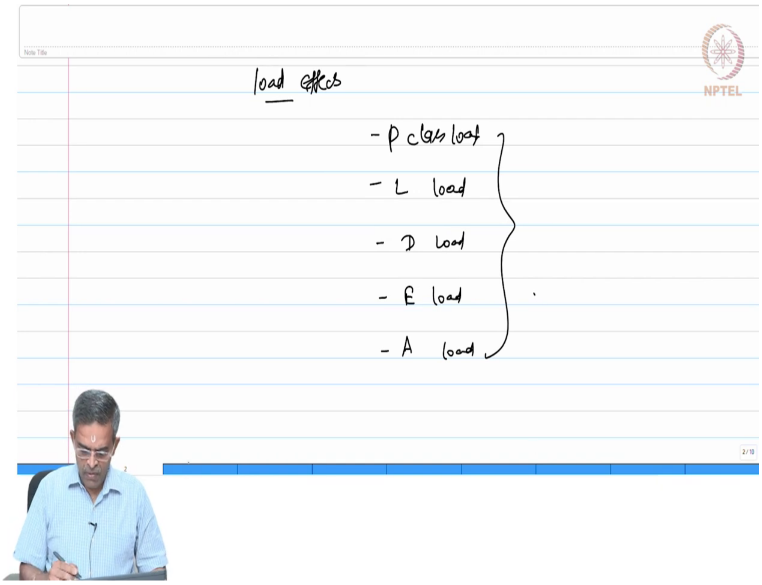

So, in the last lecture, we summarized of saying there are different class of loads which are called or classified based on load effects and they are classified as P class load, L class load, deformation load, environmental load, and accidental load is not; we discussed about this in detail in the last. We also discussed about the effect of environmental load in the context of return period and we learnt how this can be handled, .

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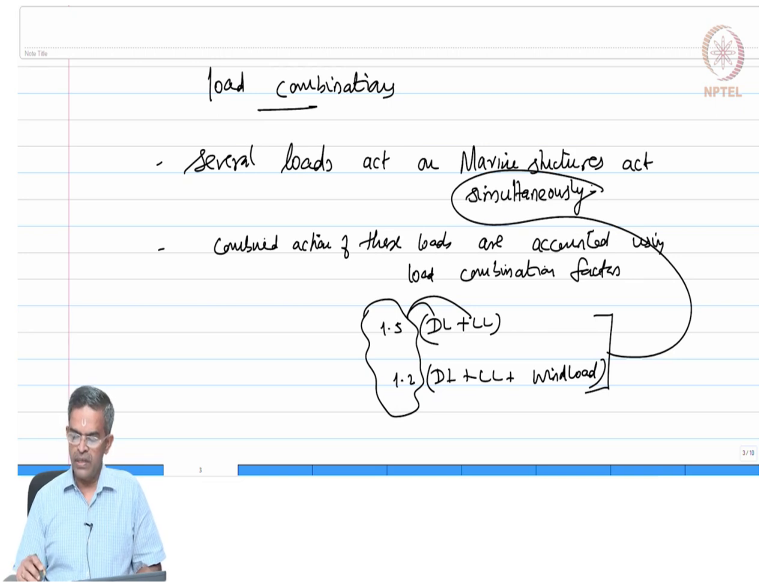

Now, we will discuss about the load combinations. Several loads actually act on marine structure simultaneously; not only marine structures, in general even land based structures they act simultaneously. So, generally the combined action of these loads are accounted using load combination factors; you must have seen and you have used in design.

For example, if dead load and live load are combined, we use generally a combination of 1.5; if dead load and live load and wind load are combined certain course advises 1.2 and so on. So, this factor affects for or accounts for the combination effects of these loads provided that there is an assumption that these loads act simultaneously. So, now, when we talk about the estimate of load factors, the combination effect should also be considered.

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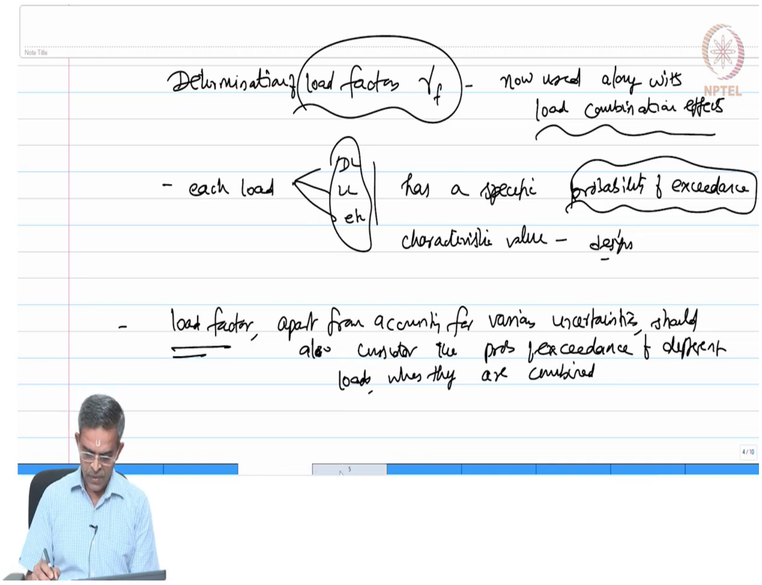

So, determination of load factors gamma f, in fact we already saw gamma f has got three different components which are actually not explicitly given in many codes; but still it are all inherent representation of different factors as we discussed in the last lecture. So, when you talk about the determination of this factor gamma f, which is to be now used along with load combination effects; then we will see how this is handled in the codes, .

So, now we know each load be it a dead load, be it a live load etcetera has a specific probability of exceedance; they also have a specific characteristic value to be used in the design, is not. And obviously, we all agree the probabilistic exceedance of these loads for example cannot be same right, they can vary; because some of them are environmental dependent, some of them are arising from the machinery equipments, some of them arise from the gravity loads of the structural system.

Therefore, the probability of exceedance of these loads need not be same. So, I have to account for the probability of exceedance of these forces or loads along with the combination effects and that should give me the appropriate load factor which I should use in the design is not. So, I should now say that the load factor apart from accounting for various uncertainties should also consider the probability of exceedance of different loads, when they are combined.

Now, the question is you do not have a choice whether to combine them or not, in nature they will act simultaneously; for example, in a marine structural system wind load, wave load, current load will always be there. You cannot imagine a situation where wave load is absent, wind load is absent, you cannot have a situation.

Because these loads are essentially arising from the environment; therefore they will be combined and they will act simultaneously. So, the load factor should account for this, correct.

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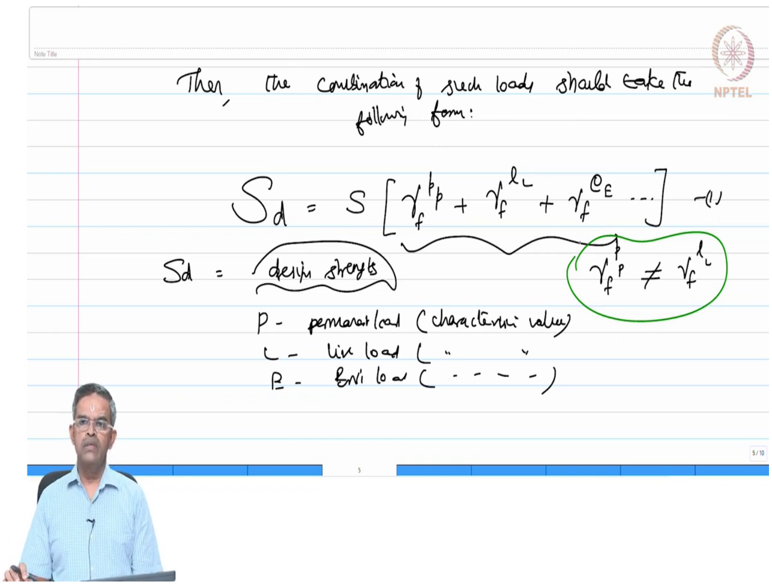

So, if we agree on making this statement, then the combination of such loads should take the following form. Let us say S d is S times of gamma f of P capital P gamma f of l capital L plus gamma f of e capital E and so on. Let us try to explain what do we understand by the symbols. So, in this S d refers to the design strength, which we want to incorporate in the design.

S is actually a subset of these loads; let us say P in this case refers to permanent load, L refers to live load or I should say permanent load characteristic value, live load characteristic value and E refers to environmental load characteristic value etcetera, . So, now they all should be combined with different factors and these factors for example, gamma f should be a combination factor of permanent load, which need not be equal to gamma f of that of the live load.

So, you can have different combination effects of these loads and adding all of them together should give you the design strength.

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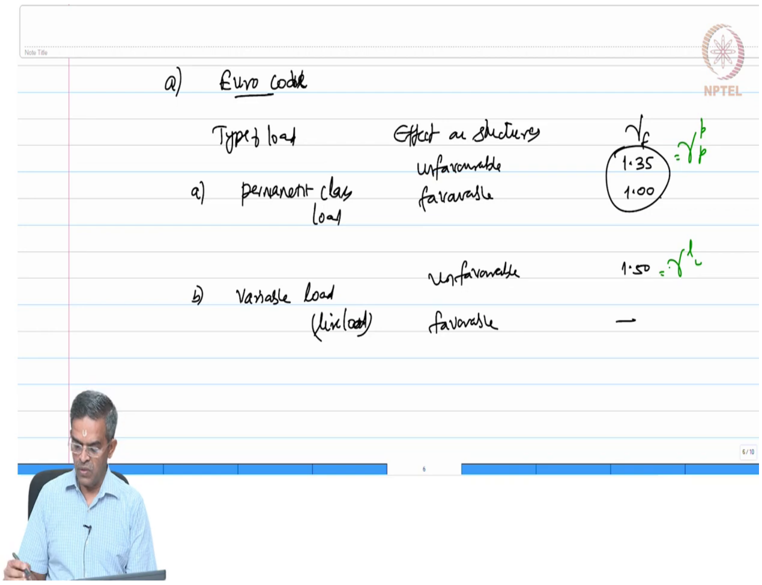

So, in this context let us see what international codes advise; let us take euro code for example, if you talk about the type of loading and the effect of this loading on structures and the appropriate gamma f advised by the euro code; if you say for permanent class of loads, there are two cases they say unfavourable condition and favourable condition. For the most unfavourable condition if you want to design the system, then use this value as 1.35; you want to design it for a most favorable condition, then use this factor as 1.0 for permanent loads.

Let us say for a variable load, it can be even the live load for example; then you look for the most unfavourable condition only for this kind of variable loads and the factor is 1.5 and for the favorable condition of design this is not suggested. So, friends looking back these values, now looking back this equation; now I can say gamma p p can be either 1.5 or 1.0, whereas gamma l L can be 1.5.

So, as I said they need not be equal. So, load factor cannot be equal to all kinds of loads when they act simultaneously. So, the combination effect of these loads also play a role in estimating the load factor, that is the point we want to emphasize.

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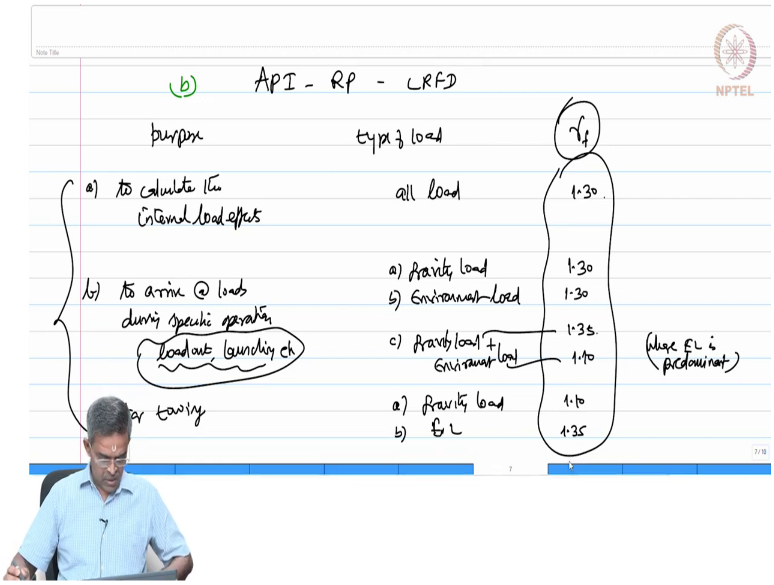

Let us see what AP RP code says, American Petroleum Institute recommended practice; LRFD load resistance factor design code, . So, go to the provision given by API. It indicates for the purpose, for the type of load and the load factor. If you say the purpose is to calculate the internal load effects, let us say that is the purpose and for all loads you can have a common factor as 1.3.

If the purpose is to arrive at loads during specific operations, such as load out, launching etcetera; these are all specific type of operational conditions which are in prevalence when you commission an offshore platform. My textbook on ocean structures and materials published along with Arvind Kumar Jain for CRC press; we will have more details about what are these kind of load conditions and how do they actually occur and what do they mean.

So, please refer to that text book for more information. So, what we learn here is these are all different specific operations happening during marine construction installation time. For that case if you have a gravity load arising during this operation, then your factor is 1.3; if you have an environmental load arising during this operation, then the factor suggested is again 1.3.

If I have a gravity load acting along with the environmental load, where environmental load is predominant ok; in that case for gravity load, the combination factor is 1.3 sorry 0.35 and for environmental load the value is 1.10.

For towing operation you want to calculate; then for a gravity load the factor suggested by the code is 1.10, for environmental load the factors suggest is 1.35. So, friends one can see here very clearly that gamma f is not a single number, it keeps on changing depending upon the combination, even depending upon the type of purpose what you want to compute.

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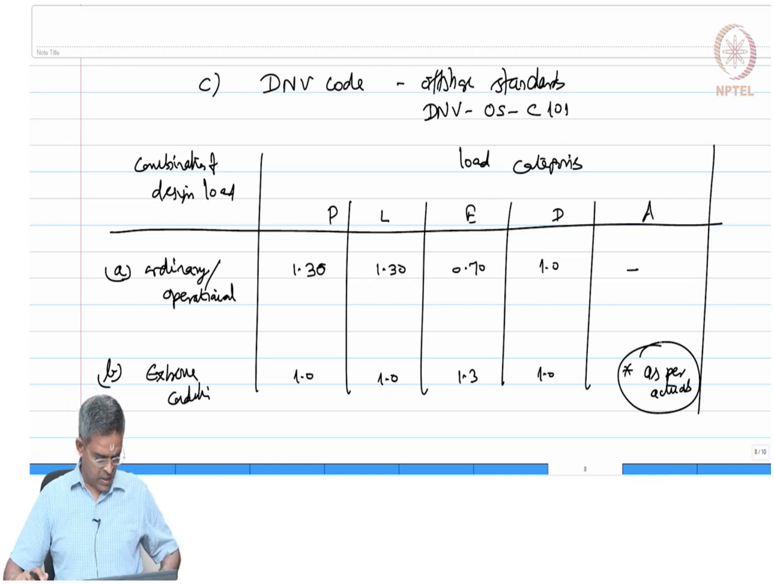

Let us look one more insight what we see in the DNV code, which is offshore standards which is DNV offshore standards c 1 0 1. In this case it clearly says, the combination of design loads and the load category and the categories are as we see permanent load, live load, environmental load, deformation load and accident load. And if it is an ordinary condition or ordinary or operating condition, then the factors for different class are indicated as you see here; obviously during operational conditions accidental loads are not present.

If it is extreme condition, then you reduce the combination from permanent live load and increase the combination from environmental load and accidental loads are to be computed as per actual,. So, you can see there are three different codes advice in different manner as the load factor, which is to be multiplied by the imposed load the characteristic value to compute the design load on a structural system.

So, we have seen in detail that the load factor accounts for the uncertainties present in estimating these loads, the probability of exceedance of these loads, different load classifications, their combination effects and their operational conditions with respect to their combination effects how these loads or factors are influenced, .

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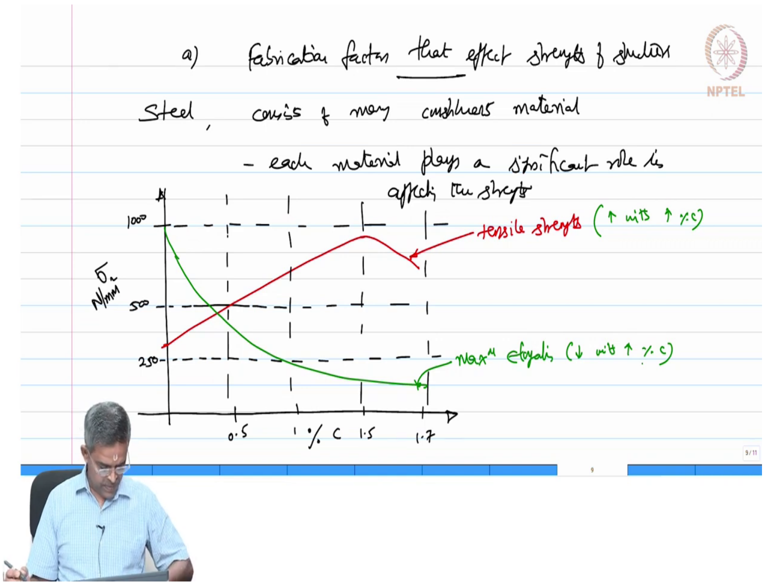

Having said this, let us now go one step ahead and discuss what will be the fabrication factors, fabrication factors that can affect the strength of structure. The strength of the structure can also be affected by various factors during fabrication. Now we all know steel consists of many constituents material and each constituent material plays a significant role in affecting the strength. Let us see how these factors affect the strength. Let us try to plot percentage carbon in x axis, we will plot the strength in megapascal.

So, let us say percentage carbon as 0.5, 1, 1.5 and 1.7; let us just to draw these grids for our learning. Let us have these as the control points. Let us say this is 250 megapascal and this is 500, let us say goes till 1000. So, let us try to plot the tensile strength variation starting from 275, it increases with the carbon content; it goes as high as 1000, close to 1000, then drops, this is the tensile strength.

Let us talk about the maximum strain or maximum elongation. The maximum elongation decreases from 1000 with the increase in carbon content. So, we can say we will say the tensile strength increases with increase in percentage carbon, maximum elongation decreases with increase in percentage carbon.

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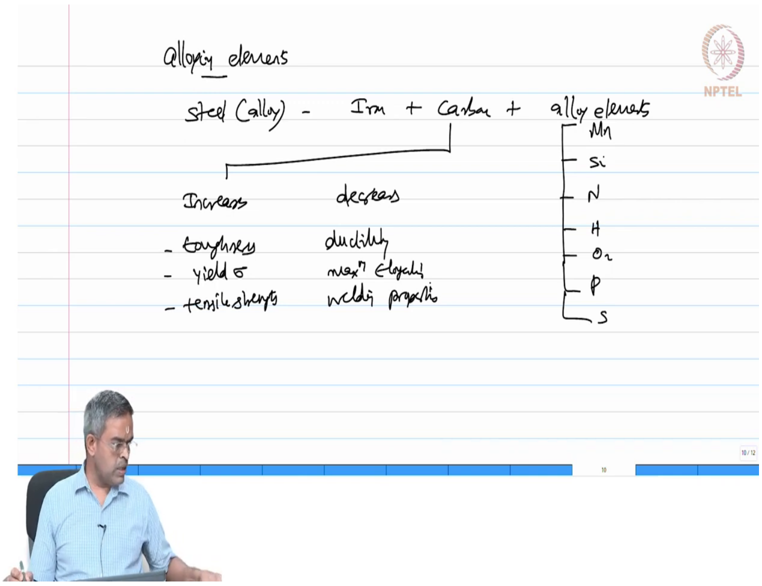

Apart from that, the alloy of steel also affects the strength. Let us say steel alloy has got a combination of iron, carbon; I am only writing the major components and various alloying elements. These alloying elements are essentially manganese, silicon, nitrogen, hydrogen, oxygen, etcetera phosphor, sulphur etcetera. Now, with respect to carbon, it increases toughness, yield strength; the presence of carbon increases toughness, yield strength and tensile strength.

We just now saw the figure, but it decreases ductility, maximum elongation and it also affects the welding properties.

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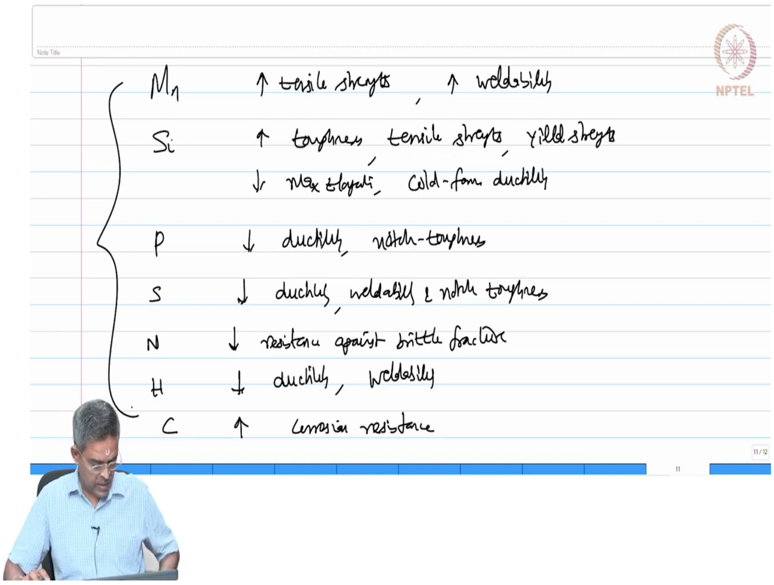

Now, with respect to the alloying elements, let us quickly see what are their contributions; manganese increases the tensile strength, the presence of manganese increases tensile strength, it also increases the weldability. Silicon increases toughness, tensile strength and yield strength; but it decreases the maximum elongation and cold form ductility. Phosphor decreases ductility and notch toughness; we have heard about this, we know how they are important in classifying steel.

Sulphur decreases ductility, weldability and notch toughness. Nitrogen presence decreases resistance against brittle fracture. Hydrogen decreases ductility, weldability; carbon increases corrosion resistance. So, varying alloying elements also influence the characteristics, mechanical and performance characteristics of steel in a different segment as you see on the screen just now.

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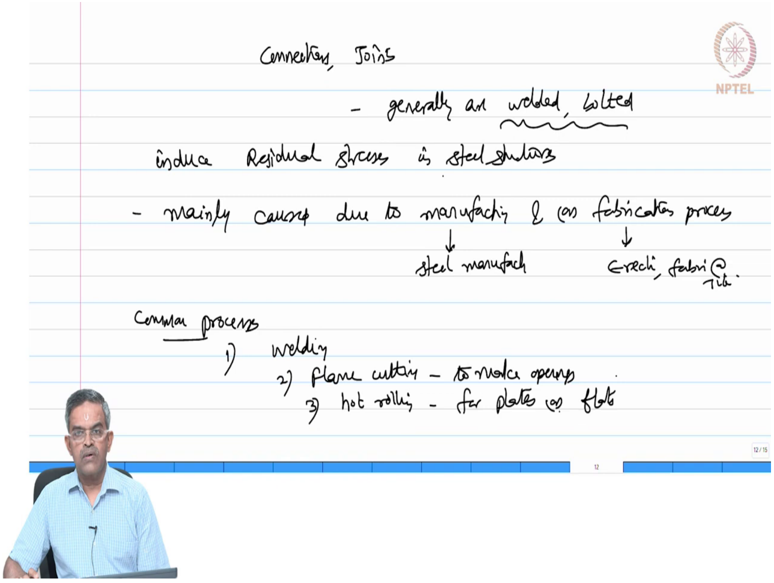

Now, friends when we start fabricating a structural system using steel as a construction material, we all know there will be connections; there will be joints which are in unavoidable, you cannot have a single piece for the entire system. So, these connections are joints generally are welded or sometimes they are bolted; riveting is of course not in practice because of various reasons, but welding and bolting is still in presence.

Now, these specific operations also induce something called residual stresses in steel structures. So, residual stresses are generally caused due to manufacturing and or fabrication process. Manufacturing is during the steel manufacturing itself; fabrication is during erection fabrication in the site, they are two different things.

So, what are those common processes which influence the strength, residual stresses? The common processes are 1 welding, which of course the most common process; 2 something called flame cutting, this is a proper process used to make openings. 3, hot rolling; this is a manufacturing process, this generally used for manufacturing plates or flats. So, they introduce residual stresses. Now, if you ask me a question, introduction of residual stresses causes what kind of problem?

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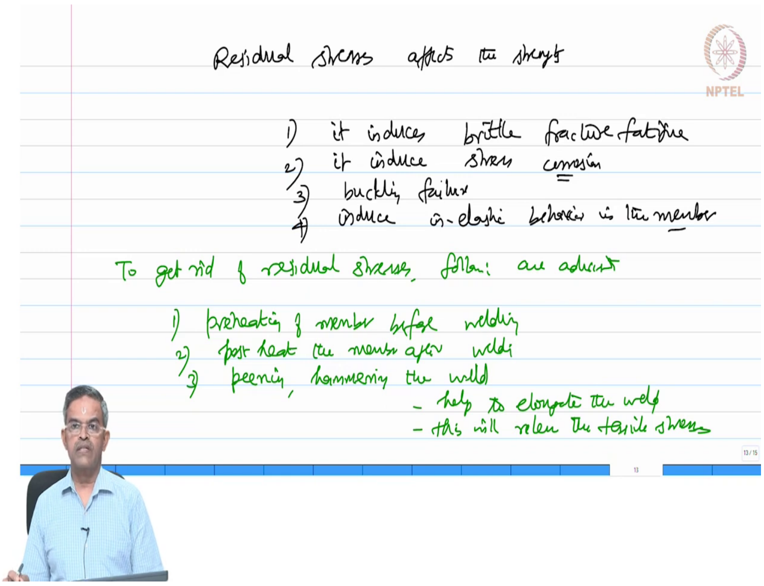

So, residual stresses affects the strength, it induces brittle fracture fatigue, it can induce stress corrosion. Stress corrosion is a induced corrosion caused because of high stress concentration at the connections; it can cause buckling failure, it can induce inelastic behaviour in the member, not on the material please understand.

Now the question comes; if I want to get rid of this residual stresses, what should I do? Now, to get rid of residual stresses following are advised; 1, you can preheat the member before welding; 2, you can post heat the member after welding; 3, can also do something called peening, hammering the weld, this will help to elongate the weld and this will relieve the tensile stresses which are residual in the weight, . So, these are some of the aspects what we have, which I want to discuss about the factors affecting the strength.

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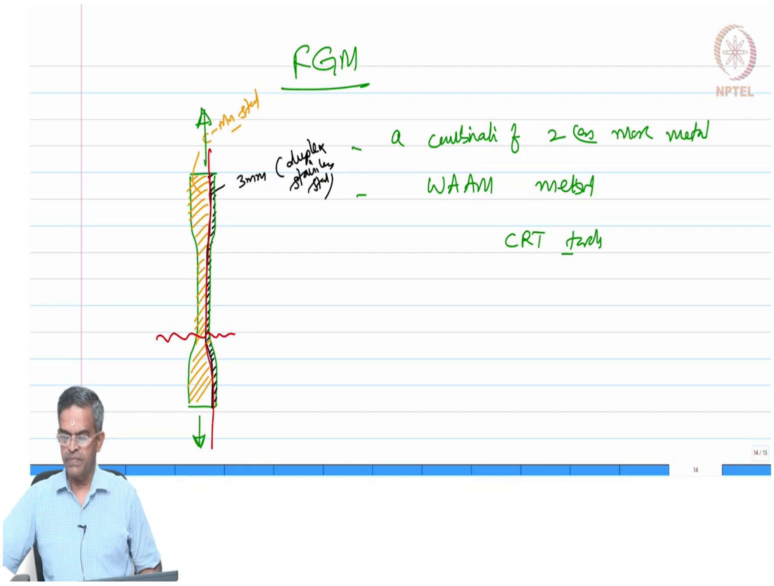

In continuation to this, we also said that functionally graded materials is a combination of 2 or more metal manufactured using wire or additive manufacturing method using CRT torch. So, we discussed this procedure very much in detail; we also shared the important research findings and experimental outcome of FGM fabricated in our lab at IIT Madras.

So, now I want to show you a quick video, to impart you or to impress upon you that this material manufacturing is very simple and the testing proves the data what we supported. So, recollect this, we have taken a specimen of this nature if you remember. And in this one portion which is our 3 mm thick is material A, which is approximately 3 mm thick in our study, which is duplex stainless steel. The remaining material about 14.5 millimeter is carbon manganese steel.

As I said very interestingly friends, the load is applied in tension along the boundary; this is the boundary right, this is the boundary between the two alloying metals, it is along and you will see there is no fracture notified along the boundary, but the fracture is happening here. So, I would like to show you a video at this moment and share this idea, just give me a minute; I will share the video, then come back to this.

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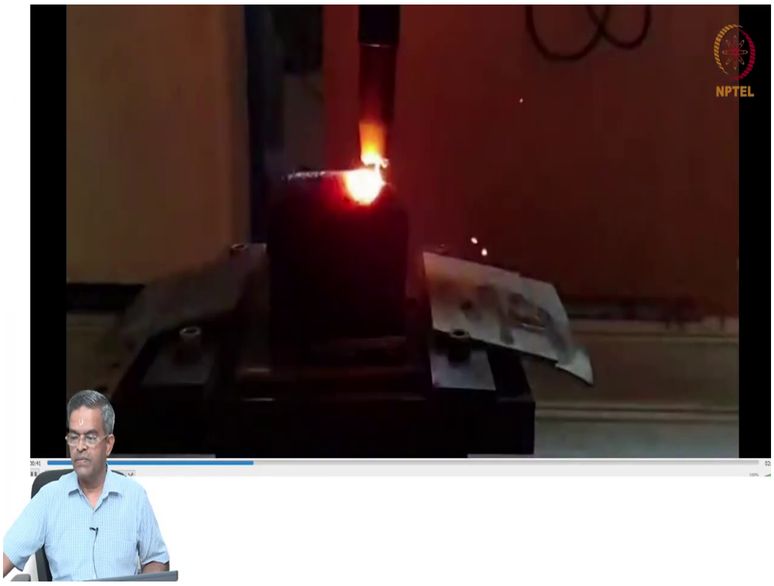

So, friends you can see the CMT torch is doing the wire feed on the stainless steel strata base strata, depending upon the x y coordinates laid for laying the wire and the wires are laid in layers and this is wire arc additive manufacturing method, which you see on the screen at this moment, . So, this is fabricated layer by layer and you get a specimen as we discussed in the last lecture.

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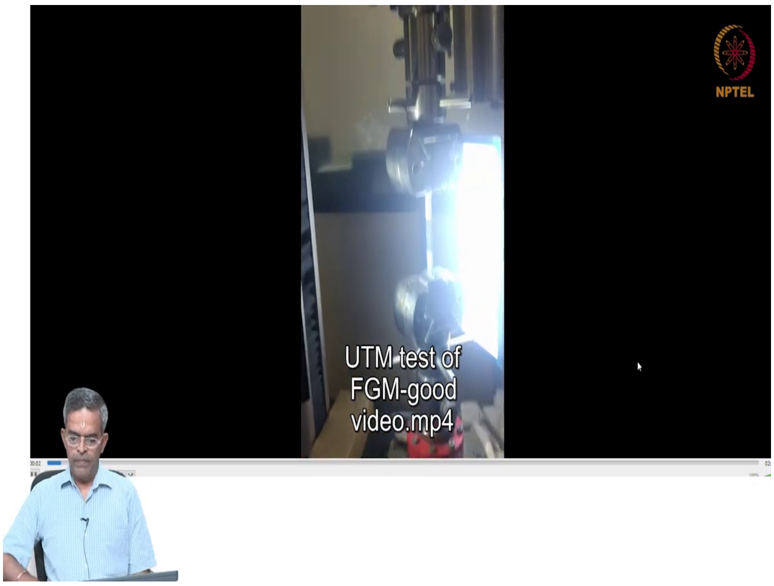

Where the specimen is placed in the UTM under axial tension; there are two pivotal points which are placed along the longitudinal direction and two along the lateral direction, there are four points you can see. So, these are the gauge points where you are measuring the elongation and computing the percentage elongation. So, it is a high speed camera which is recording this, the system is being loaded now; you can see the specimen very close at this moment.

So, the system is applying an axial pull; now you can closely see the boundary, you can closely see the boundary of the material. The edge is duplex stainless steel, the major part is carbon manganese steel; there are two dots which are going to measure the elongation along the longitudinal direction and there are two normal to this, which will measure the elongation along the lateral direction.

Please look at how this material fractures. Can you see the fracturing happening here; it is not fracturing along the boundary of this, but is fracturing like a simple tensile bar made out of homogeneous material. So, this is a very interesting exhibit which we wanted to show you, where we have learnt the fabrication method, the constituents of FGM and of course the testing procedure.

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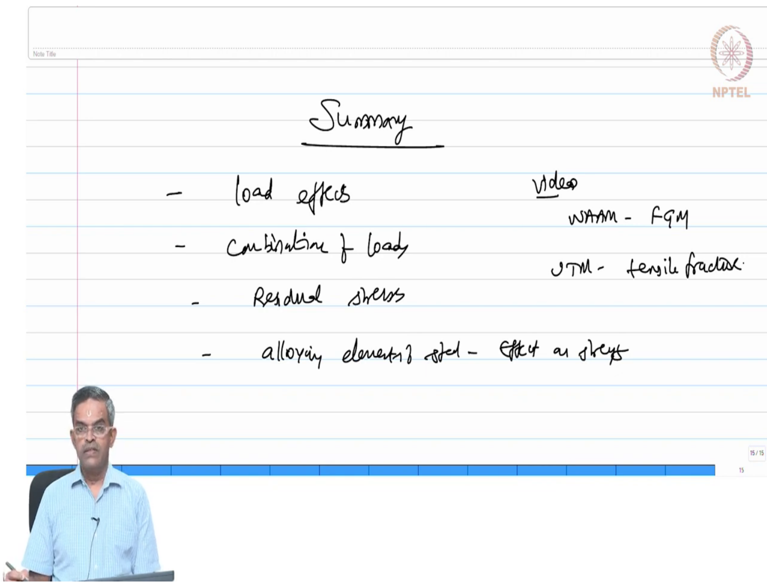

So, friends as a summary in this lecture, we learnt about the load effects, about the combination of loads, about the residual stresses and also we learnt about the alloying elements of steel and their effect on strength. We have also seen a video, which shows the wire arc additive manufacturing of FGM and we also saw how the FGM breaks in UTM, which is a tensile fracture similar to a homogeneous material like mild steel. So, friends this is what we wanted to add at this particular point of time in this lecture.

Thank you very much, have a good day.