Equipment Design: Mechanical Aspects
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Lecture 04
Terminologies

Welcome to the fourth lecture of week 1 and this lecture is based on terminologies. Whatever terminologies we will consider in designing that we will first discuss that how to select these terminologies or these parameters and then we will go for detailed design of the pressure vessel okay. So let us start the terminologies.

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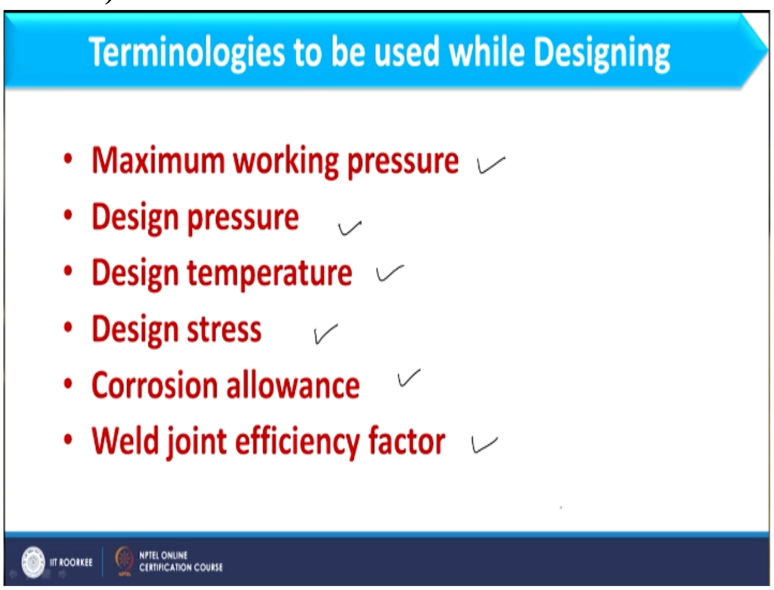

So, here I am having main terminology which to be used while designing. So the first one is the maximum working pressure, then design pressure, design temperature, and then design stress, corrosion allowance and weld joint efficiency factor. So, all these terminologies we use in designing, and therefore it will be good if we see how these terminologies should be selected in designing. So, let us start with the first one, which is on maximum working pressure.

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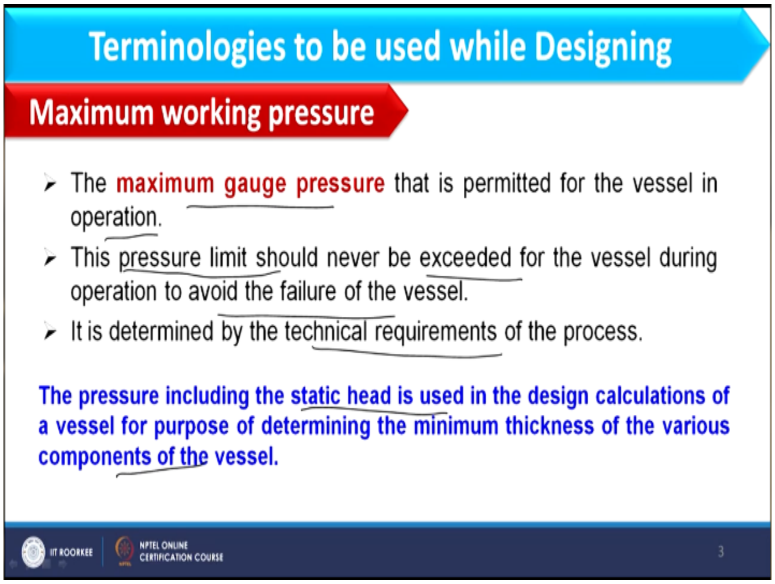

So, maximum working pressure is the maximum gauge pressure that is permitted for the vessel in operation, okay. So the maximum working pressure is the maximum operating pressure you can understand and that should be given in gauge, and why pressure is considered in gauge, that point we will discuss when we derive the expression for designing of pressure vessel okay. But here you should understand, what is the maximum working pressure is, that pressure which should never increase while operation.

So, maximum working pressure is that pressure, which is the maximum possible value of pressure which we can face during the operation. Now, for example, if I say that the system is being operated at 2 meganewton per meter square and some variation also may be found like 2.1, 2.05 like that, so the maximum possible value we can observe in the operation that should be considered as maximum working pressure, and if it is given in absolute, we should convert that first into gauge before using.

So, this pressure limit should never exceed for a vessel during the operation to avoid failure of the vessel. So failure of the vessel will occur when pressure exceeds the maximum allowable pressure value, and therefore we need to consider that value as the base for designing, and it is determined by the technical requirements of the process. It means for each process we already know what should be the pressure condition, what should be temperature condition, but in that pressure, further we will see how much variation I am observing during the operation because the value will not be fixed at one magnitude only. It will keep on changing.

So, what would be maximum possible pressure that we consider as maximum working pressure, okay. And the pressure including the static head is used in design calculation of a vessel for purpose of determining the minimum thickness of various components. So, along with operating pressure, we also need to focus on static head. I guess you understand, let us say up to certain height, liquid is filled and whatever rho gh for that, that we will consider as static head, so that should be added to operating pressure and that should be considered while designing also.

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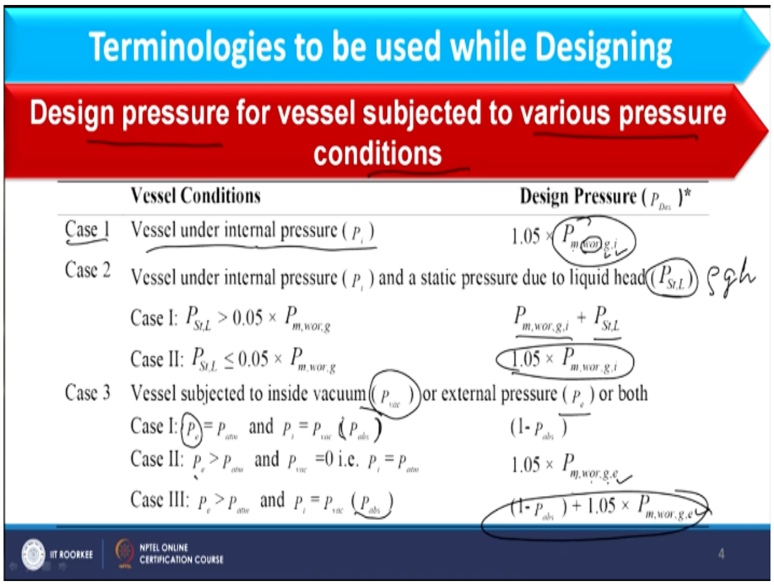

So, one is operating pressure, second is the static head, so both we need to consider. Now, here in this slide, we have design pressure for vessel subjected to various pressure conditions, okay. Now, why we have defined maximum working pressure, maximum working pressure is the maximum possible value of pressure found or observed in the process, okay, and then based on that we will calculate the design pressure. Design pressure value should be slightly more than the value we can obtain during working because we need to keep certain safety margin okay.

So, as far as design is concerned, we consider usually value higher than that at which we need to work, okay. So, here we have this table, where case 1 is basically whether vessel under internal pressure okay. So, internal pressure is PI, now what is the meaning of internal pressure and external pressure. This internal pressure we have already discussed in membrane stresses also, so basically internal pressure is when the pressure inside the equipment is higher than the atmospheric pressure or higher than the outside pressure that we can call as internal pressure condition.

If the system is being operated at vacuum, so obviously inner pressure would be lesser than the outside pressure, so in that case condition would be external pressure. So, this internal as well as external, these both are defined based on whichever pressure is higher, okay. So, case 1 is having vessel under internal pressure. So when I am having pressure, PI, inside the design pressure should be 1.05 * P m wor g i. So, 5%, then this, what is this, this is P that is pressure, maximum operating pressure or work is there, so maximum working pressure in gauge internal, getting.

So, considering this, whatever internal pressures are there, we need to consider that in gauge and then 5% extra I have to take as design pressure for case 1. Case 2 says that vessel under internal pressure PI and static pressure due to liquid head, P st L, P st is nothing but the rho gh. Here we have 2 cases, first is when static head is greater than 5% than maximum working gauge pressure. Gauge pressure is given basically internal pressure and if static head is 5% more than that, then design pressure should be maximum working gauge internal plus P st L. Static head will be added to maximum working gauge pressure internal.

If static head is less than 5%, then maximum working gauge, it should be 5% extra to maximum working gauge pressure internal. Now, we have case 3 where vessel subjected to inside vacuum and external pressure, P e or both. If this is the situation, case 1 is there, where P e is equal to P atm that is external pressure, e resembling to external, so P external will be equal to atmospheric pressure and inside is P vacuum, so inside if I am having vacuum and outside is atmospheric pressure, so obviously atmospheric pressure is more than the vacuum. So in that case, the condition would be of external pressure condition okay.

So, in that case, if P is equal to P vacuum and this vacuum corresponding to vacuum pressure, we consider pressure in absolute. So, 1-P absolute would be the design pressure. If external pressure is more than atmospheric pressure and vacuum is 0, it means internal pressure is atmospheric, but outside is more than atmospheric. So in that case we consider pressure as 5% extra than maximum working gauge pressure external.

And further, if I am having a condition like external pressure is greater than atmospheric pressure and P i is equal to vacuum, it means outer we have more than atmospheric and inside we have less than atmospheric that is vacuum and that vacuum we consider in absolute and that 1-P absolute plus 5% extra than maximum working gauge pressure external. This whole value we will consider as design pressure.

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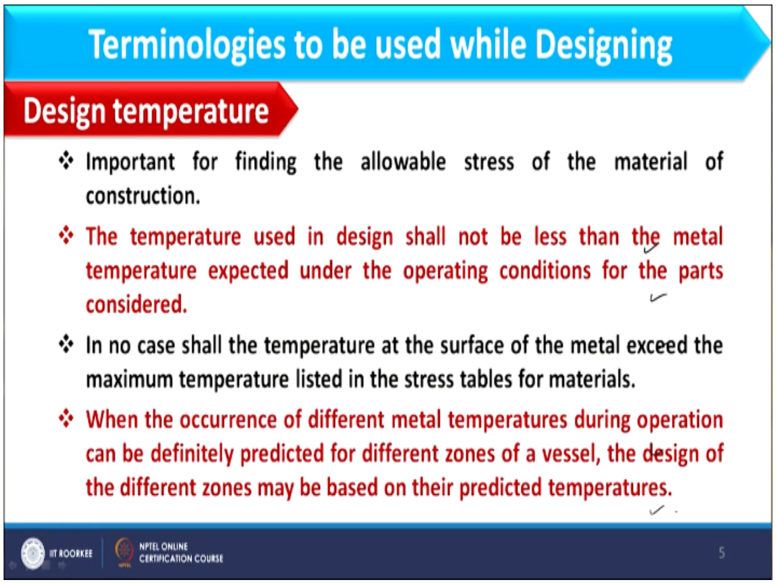

So, in this way, we select design pressure in different conditions, so this is very important terminology while designing. Now we have the design temperature. So, what should be design temperature, why is it required? It is required to find the allowable stress of the material. It is important to find the allowable stress of the material of construction. So, we need to choose the material of construction and then we have to see the value of allowable stress and allowable stress varies with temperature.

Therefore, it is important to first find out the temperature, so it is important to find out first the design temperature and then based on that we go for the allowable stress value. What is allowable stress that we will discuss in subsequent slides. So, what should be the design temperature, the temperature used in design shall not be less than the metal temperature expected under operating condition for part considered. What is the meaning of this.

For example, if the system is being operated, let us say at 300 degree Celsius and metal will acquire some of the temperature that may be slightly less than the operating temperature because of conductivity value, but design temperature should not be less than that temperature. Let us say 300 is the operating temperature and system is acquiring 290 and 280, so the temperature we will choose for design should not be less than 280 or 290 as the case may be.

And further, in no case shall the temperature at the surface of metal exceeds the maximum temperature listed in the stress table of the material okay. So, for each material we have permissible temperature value as you can see from this table for carbon, steel and other alloys.

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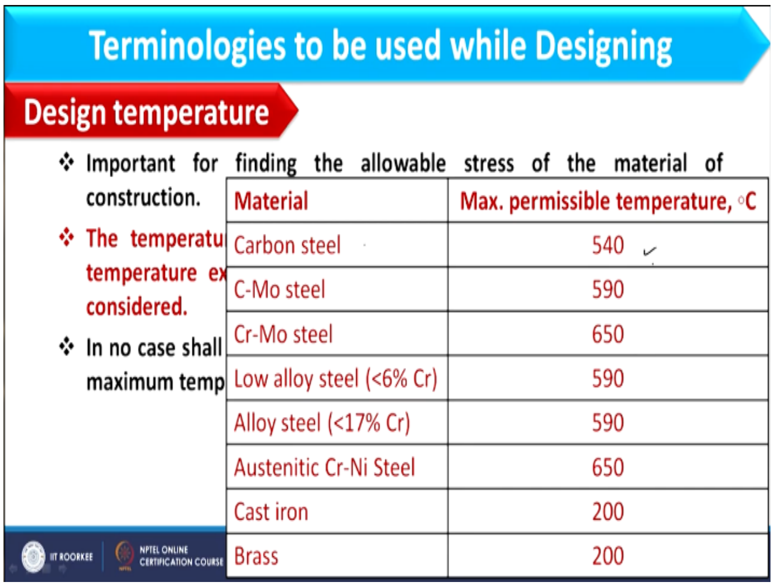

We have maximum permissible temperatures; these values are based on the melting temperature of the material, so these are the maximum possible values for material to be considered in designing. So, you understand. Here I am having 2 limits, first is the lowest possible limit. It means whatever temperature metal should observe, at least that temperature we will consider as design temperature or that design temperature should not exceed the maximum permissible temperature defined for that particular material.

So, considering these values, we have defined lower as well as upper limit of the temperature. And when the occurrence of different metal temperatures during operation can be definitely predicted for different zones of the vessel, the design of different zones may be based on their predicted temperature. What is the meaning of this. For example, different sections, different components of the pressure vessel may have different temperature experienced. So each component will be designed based on respective temperature and then we will consider that as final design of the pressure vessel.

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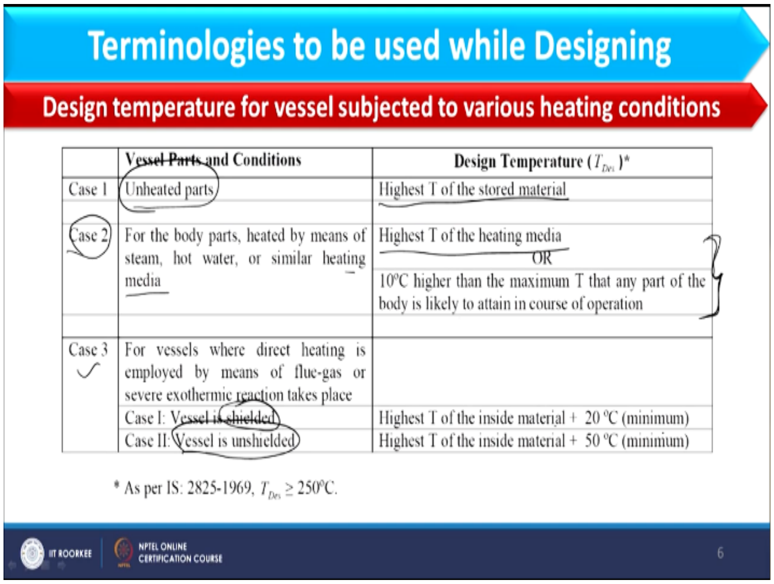

Here, I am having the table to choose the design temperature for different parts or different conditions. The case 1 should be unheated part. It means heating is not provided, material is available at a particular temperature. In that case, highest temperature of stored material can be taken as design temperature. Further, I am having case 2, which is basically used for body parts, heated by means of steam, hot water or similar heating media, okay. So if heating is involved in the system, then highest temperature of heating media, that is the maximum possible temperature in the system.

So that we will consider for designing, or 10 degree higher than the maximum temperature that any part of the body is likely to attain in course of operation. So, whatever would be higher among these that we will consider as design temperature for case 2. Case 3 is the vessel where direct heating is employed by means of flue gas or severe exothermic reaction. In this case, we have first case when vessel is heated. In that case, highest temperature of inside material plus 20 degree minimum we need to take as design temperature.

Now, what is the meaning of shielding? Shielding means when the vessel is insulated, in that case, highest T inside the material plus 20 degrees we will add as the minimum design temperature. And if vessel is unshielded or non-insulated, in that case highest temperature of inside material we need to choose plus 50 degrees we need to further add. So, in this way, we choose the design temperature, but in no case design temperature should be less than 250 degrees Celsius.

That is the guideline when temperature is coming less than 250, at least you take value of design temperature as 250 degrees Celsius, and this is because allowable stress value is started from 250 degree Celsius. That further we will discuss in detail when we will discuss the allowable stress as a terminology.

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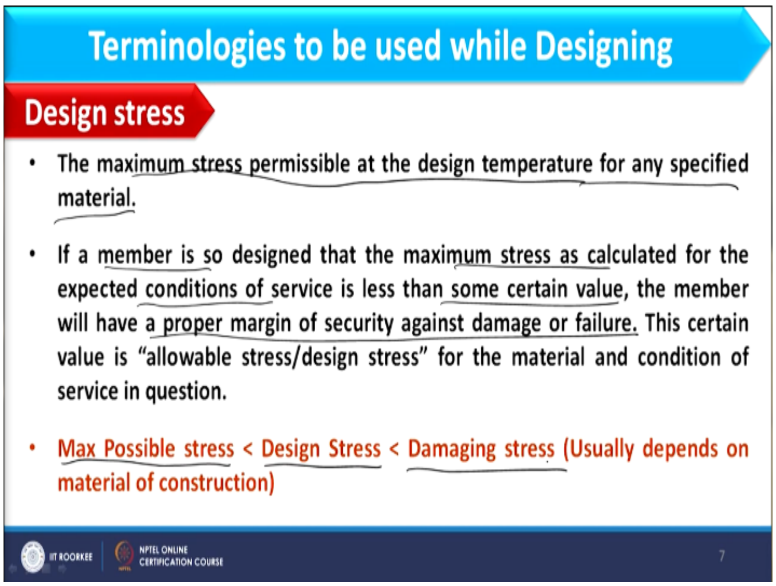

Now, next terminology we have is the design stress, so let us define this. The maximum stress permissible at the design temperature for any specified material, okay. So maximum stress permissible, what is the meaning of that. It means, when I am operating with any pressure it will create some stress in the material. So we should consider maximum possible stress that can be created in the system. That we have to consider as a reference point, okay.

Now, if a member is so designed that the maximum stress as calculated for expected condition of service is less than some certain value, the member have a proper margin of security against damage or failure. What is the meaning of that. If member is so designed, member means what. Member means the pressure vessel, the object which we need to design. So, if member is so designed that the stress whatever we are considering in design that should be slightly higher than the maximum permissible stress in the system. Are you getting this.

This is the maximum permissible stress in the system and we are considering this as a design stress okay. We are designing at this level. So, what I can say that, this much difference we can consider as proper safety margin, so failure will not occur in that case. So, this value, here I am operating, here I am designing, so this particular value will be known as design stress or allowable stress. Allowable stress we have discussed many times in previous lectures, but here I am defining it. It is slightly higher value of stress than the value at which system is operated.

And further you should keep in mind that this allowable stress should be less than the damaging stress. What is the damaging stress. Damaging stress is the stress where permanent failure will occur. So, allowable stress value would be slightly lower than the damaging stress and I am operating the system at this level. So this is the operating condition, this is design condition and this is the failure condition, so you have this much safety margin, okay. So you can consider here maximum possible stress during the operation. It is less than the designing stress or allowable stress, and this is further less than the damaging stress.

So, here, until unless the stress will not reach the damaging stress value, failure will not occur, and we are designing the system to sustain slightly lower value of stress, okay. So, here this is different than the temperature and pressure. In pressure, we have maximum operating pressure value or working pressure value and we have design at slightly higher value than that. And similar observation we have seen for temperature, but here, at which level it is damaged, we will design at this level, so that we can consider sufficient safety margin.

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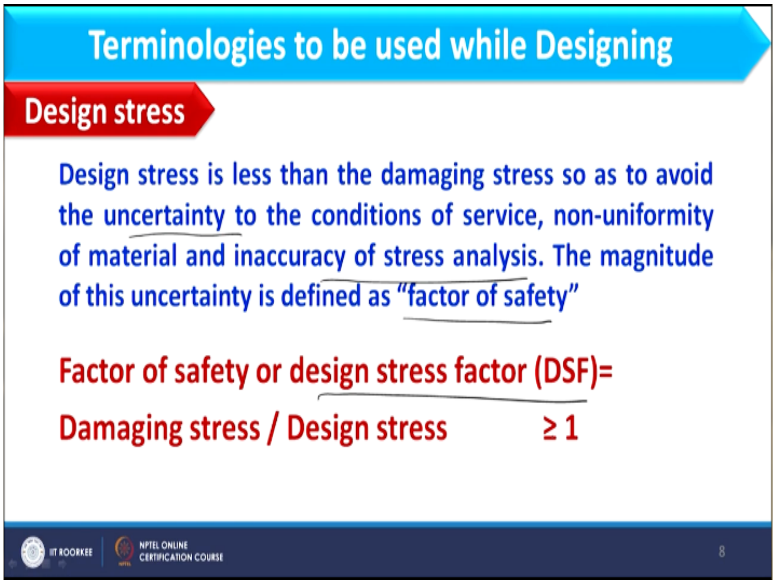

So, design stress is less than the damaging stress so as to avoid uncertainty to the conditions of the service, non-uniformity of the material and inaccuracy of stress analysis. So, considering that uncertainty, we have considered design stress lesser than the damaging stress and the ratio of these two will be defined as factor of safety. So, factor of safety or design stress factor will be defined as damaging stress divided by design stress and that should be greater than or equal to 1. So, in this way I choose the design value.

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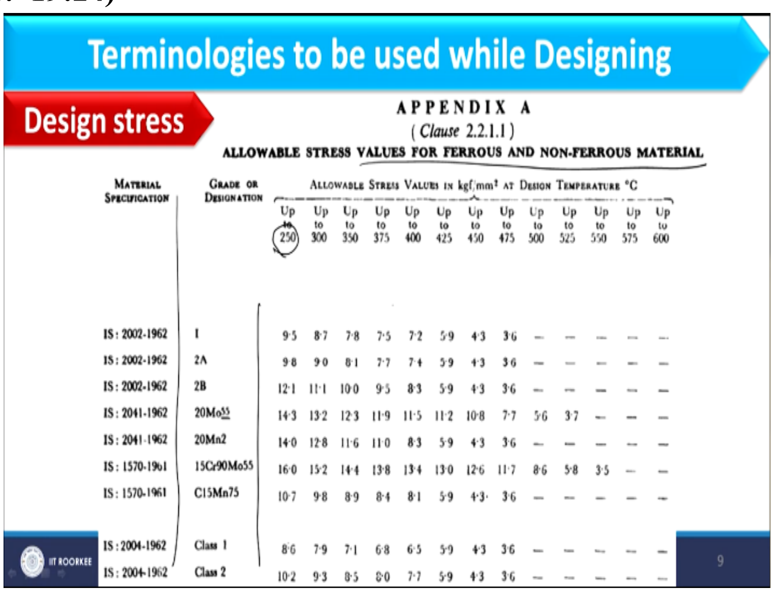

APPENDIX A

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ALLOWABLE STRESS VALUES FOR FERROUS AND NON-FERROUS MATERIAL

Material Specification	Grade or Designation	Allowable Stress Values in kgf/mm² at Design Temperature °C Up to 250	Up to 300	Up to 350	Up to 375	Up to 400	Up to 425	Up to 450	Up to 475	Up to 500	Up to 525	Up to 550	Up to 575	Up to 600
IS : 2002-1962	1	9·5	8·7	7·8	7·5	7·2	5·9	4·3	3·6	—	—	—	—	—
IS : 2002-1962	2A	9·8	9·0	8·1	7·7	7·4	5·9	4·3	3·6	—	—	—	—	—
IS : 2002-1962	2B	12·1	11·1	10·0	9·5	8·3	5·9	4·3	3·6	—	—	—	—	—
IS : 2041-1962	20Mo55	14·3	13·2	12·3	11·9	11·5	11·2	10·8	7·7	5·6	3·7	—	—	—
IS : 2041-1962	20Mn2	14·0	12·8	11·6	11·0	8·3	5·9	4·3	3·6	—	—	—	—	—
IS : 1570-1961	15Cr90Mo55	16·0	15·2	14·4	13·8	13·4	13·0	12·6	11·7	8·6	5·8	3·5	—	—
IS : 1570-1961	C15Mn75	10·7	9·8	8·9	8·4	8·1	5·9	4·3	3·6	—	—	—	—	—
IS : 2004-1962	Class 1	8·6	7·9	7·1	6·8	6·5	5·9	4·3	3·6	—	—	—	—	—
IS : 2004-1962	Class 2	10·2	9·3	8·5	8·0	7·7	5·9	4·3	3·6	—	—	—	—	—

And if you see, here we have allowable stress values for ferrous and nonferrous material. Here, the first column speaks about different material, IS stands for Indian standard and here we have different codes for different material, these are basically ferrous and nonferrous material. And according to this number and grade, material is specified, and here we have allowable stress value for different design temperature.

So, you see the minimum values available at 250, and therefore design temperature should not be less than 250. And as we can keep on moving towards higher temperature, you can see value of allowable stress will keep on decreasing, okay. Because when temperature exceeds, it is more prone to fail; therefore allowable stress value at higher temperature is less than in comparison to that value at lower temperature. So, you can choose allowable stress value based on such tables.

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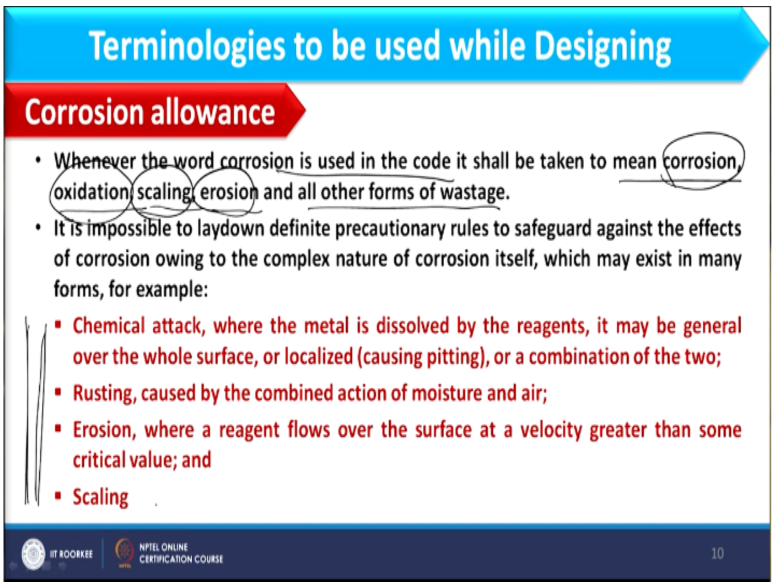

Now, next terminology we will discuss is corrosion allowance. Corrosion allowance, I guess yes you understand, that represent all type of damages occurring in a metal sheet that collectively called as corrosion allowance. So, whenever the word corrosion is used in the code, it shall be taken to mean corrosion, oxidation, scaling, erosion and all other forms of wasted. What is the meaning of corrosion. When system is being operated with the fluid, so continuous contact of fluid and metal takes place, so it makes some reaction with the metal surface and that reacted material, that material is deposited on the surface of the vessel and that is called as corrosion.

What is oxidation. When metal is coming into contact of the moisture or water, it reacts with that to make the iron oxide and that we call as oxidation. Next, we have the scaling. What is scaling. Scaling is also called as fouling where material deposited over the surface of the metal.

Now, why it happens because usually we have observed that solubility of a component in a solution increases when the temperature increases, okay.

But there are certain components like calcium iron, magnesium iron, and all these components have the tendency that after certain temperature, instead of increasing solubility, solubility will keep on decreasing with increasing temperature. So, once solubility will keep on decreasing, they form lumps and they deposit it over the surface of the metal and that forms a scale or that foul the system.

Next, we have the term erosion. Erosion means after continuous operation when high velocity fluid pass through a metal sheet continuously, then some of the metal part will mix with the solution and it will move with the solution. So it means removal of material from the metal surface is basically called as erosion. So, all these type of wastage we have considered in single term and that term is basically corrosion allowance, which we will use in designing. So, here you see all these factors we have already discussed to define the corrosion allowance.

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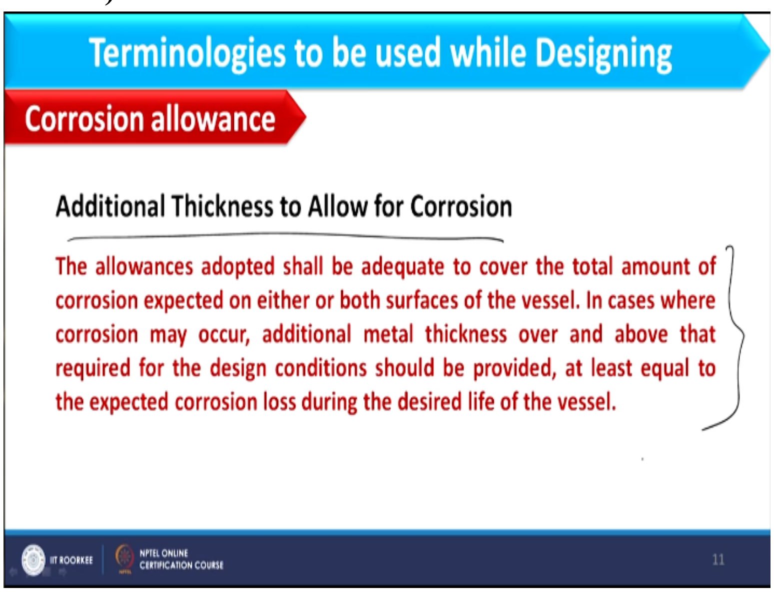

Now, additional thickness to allow for corrosion. Why this additional thickness is required. Because, when we design a system, okay, that you must have seen in membrane stress expression and you will see further in subsequent lectures also that whatever thickness we calculate from the expression that is the minimum possible thickness. It means to withstand that pressure that much thickness is required and that thickness should remain as it is throughout the life of the vessel.

However, when we consider corrosion and other type of wastage, after continuous operation, metal becomes weak, so we need some additional thickness to the thickness which we have considered from the expression and that additional thickness as called as corrosion allowance. Because after continuous operation, if damage will occur, damage will occur only in that particular thickness which we have added to the corrosion, and whatever is required for operation to carry out, that is the minimum possible thickness, it will remain as it is.

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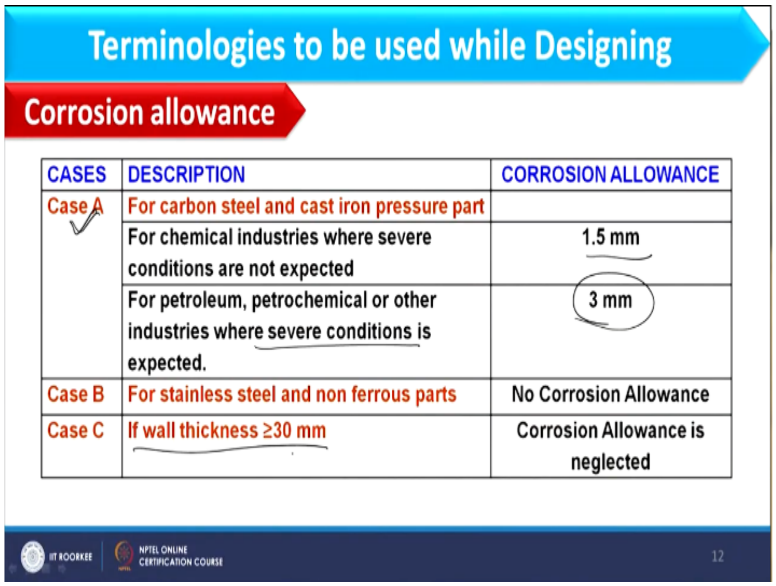

CASES	DESCRIPTION	CORROSION ALLOWANCE
Case A	For carbon steel and cast iron pressure part	
	For chemical industries where severe conditions are not expected	1.5 mm
	For petroleum, petrochemical or other industries where severe conditions is expected.	3 mm
Case B	For stainless steel and non ferrous parts	No Corrosion Allowance
Case C	If wall thickness ≥30 mm	Corrosion Allowance is neglected

So, that corrosion allowance we need to decide and then that corrosion allowance we will add to the minimum thickness. So, here whatever we have discussed is mentioned. Here, I am having a table to have the corrosion allowance for different cases. Case 1 says for carbon steel and cast iron pressure part. For chemical industry where severe conditions are not expected, corrosion allowance of 1.1 mm we consider.

Further, if we are considering petroleum or petrochemical industries where severe conditions of damage or wastage are expected, in that case, we consider 3 mm as the corrosion allowance. Case B is for stainless steel and nonferrous part. For this case, no corrosion allowance will be used because stainless steel will not have the tendency to form deposit or to have corrosion. Therefore, corrosion allowance is not required when we are preparing the vessel with stainless steel material and nonferrous.

Case C is when wall thickness is greater than 30 mm, then corrosion allowance is not required because that 30 mm is sufficient thickness and that is very huge thickness. So In that case, we do not add corrosion allowance because that thickness is sufficient enough to sustain for longer time. So, in this way, you find out the corrosion allowance.   And final terminology we have is the weld joint efficiency factor. So what is weld joint.

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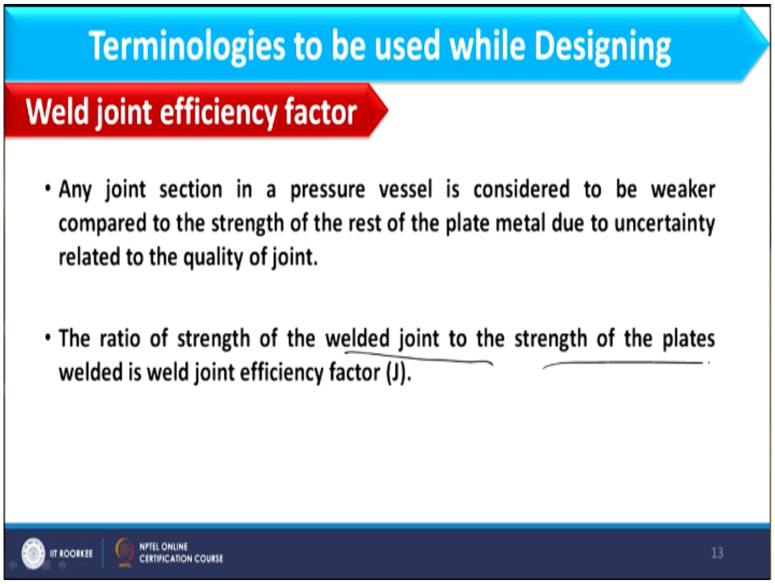

When we prepare any vessel, it is prepared with metal sheet. So what happens. Usually metal sheet is basically rolled if I am preparing for cylindrical vessel, vessel sheet we found in rectangle form. It is rolled and then we weld at one point, so wherever I am welding the metal sheet that joint becomes weaker in comparison to continuous sheet because that joint will face or will go through very high temperature with welding, which makes the material of that joint very weak.

So, the ratio of the strength of weld joint to the strength of the plates welded is weld joint efficiency factor. As we have already discussed that wherever welding will occur, that material at that particular section or particular location becomes weak in comparison to material available in sheet where welding is not done. So, the ratio of these two will be defined as joint efficiency factor. Now, before defining this joint efficiency factor, let us have a look on how many types of joints occur in a pressure vessel.

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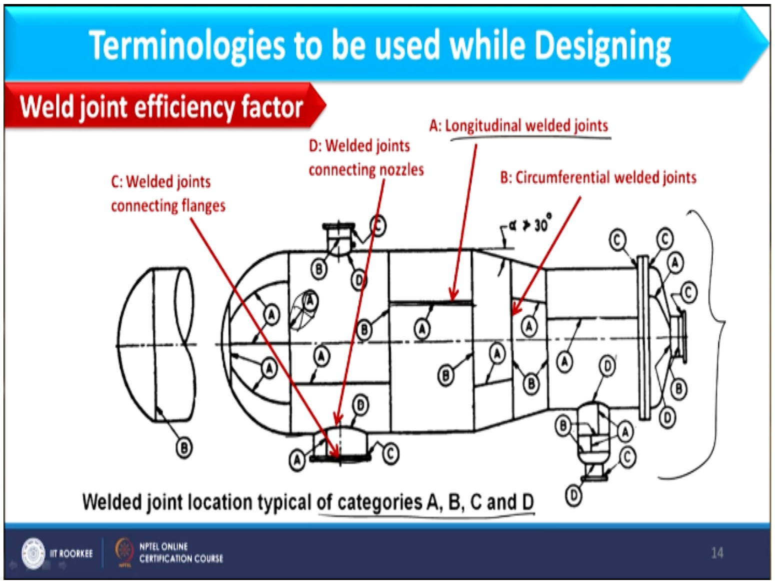

So, here you see in this diagram, we have the pressure vessel, okay, and here we have welded joint location typical for categories A, B, C, D. We have 4 categories and through these categories we define different types of welded joints. So, let us start with first one that is A and it is used for longitudinal welded joint okay and this is basically the longitudinal welded joint. It means when I roll the sheet and then weld along the length, it will be called as longitudinal weld joint and denoted by A.

And in this diagram, if you see here, A is given, this is wrong, this is not correct, okay. So, A is this. B is basically defined as the circumferential welded joint. If the length of vessel is very high, we need to prepare the vessel into 3 connections. So, if I am having one cylinder, second cylinder we need to add through circumferential joint, so that will be called as point B. Now, I am having point C, where welded joint connecting flanges. This is basically the flange where we cover the mouth of the nozzle using flange.

So connection of this vessel with the nozzle, it called as connection C or joint C. And when nozzle is connected to the head, you see, so all these A, B, C, D are different types of connections used in pressure vessel manufacturing.

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Terminologies to be used while Designing

Weld joint efficiency factor

	J Values		
CLASS OF VESSEL	CLASS I	CLASS II	CLASS III
Type of Welding	• Vessels do contain lethal or toxic substances or to be operated under severe conditions • Fully radiographed joints are needed • Minor defects also not allowed	• Medium duty operation • Most of the chemical equipments • All longitudinal and circumferential joints are spot radiographed • Thickness (including Corrosion allowance) ≤ 38 mm	• Light duty operation • Thickness (including Corrosion allowance) ≤ 16 mm
Double welded butt joint with full penetration	1.0	0.85	0.7
Single welded butt joints with backing strip	0.9	0.8	0.65
Single welded butt joints without backing strip	NA	NA	0.55
Single full lap joints	NA	NA	0.5

Now, I am having a table which speaks about joint efficiency factor for different conditions. So, if you see this table, here we have class of vessel, class of vessel will be class 1, class 2 and class 3, and for these classes we have J values in this table. And if you see this first column, it will speak about different types of welding, okay. So, let us discuss first different types of welding and then we will discuss different types of classes for vessels.

So first one is double welded butt joint with full penetration. So as far as joint during welding are concerned, there are certain standard joints. The first joint is the butt joint means, when I am having 2 metal sheets, I am placing these 2 metal sheets side by side and I weld it, okay. So, this is basically called butt joint when the sheets are kept side by side, okay. Now, here I am having double welded butt joint with full penetration.

So here side by side I am keeping, here I am welding, and from bottom also I am welding, and I will ensure that whatever material through welding is depositing over here that should penetrate fully. Next, we have the single welded butt joint with backing strip. Butt joint is what, these 2 metal plates are kept side by side, from one side we weld, and from bottom we put a metal strip, so that we call as the backing strip.

Next, I am having is single welded butt joint without backing strip, so that would be butt joint with welding at 1 side only, so that would be single welded. And then, we have the single full lap joint. So lap joint is basically when this is metal sheet, this is metal sheet, when we overlap metal sheets slightly and weld from this and weld from this, so this is basically lap joint. This is butt joint, this is lap joint, this is T joint, and this is edge joint.

In this way, different types of joints in welding are defined. Now, what is class 1 vessel. These vessels do contain lethal or toxic substance or to be operated under severe condition. If conditions are very severe, we go for class 1 vessel and it has fully radiograph joints. Minor defects are also not allowed. So what is fully radiograph joint. That I can make you understand if you consider this as my hand, and when I am passing through x-ray from this hand, how you can see the x-ray, wherever I am having the bone, okay, there I am getting white section.

White section will be resembling to solid part, however, where I am having the mass, which is not as solid as bone, there we have some blackish printing, okay. So, fully radiograph joint means, we make the joint okay and then we pass x-ray through this and we see the image. If that image will have all white lines, it means the joint is fully radiographed. Otherwise, if it is having minor defects or the welding is not done properly, it will show black sections along the welding. So, if that happens, it means it has minor defects.

So, for class 1, where minor defects are not allowed, we go for double welded butt joint with backing strip with J value 1 and single welded butt joint with backing strip can also be used where J factor is 0.9. These 2 joints are not allowed for class 1, and similarly class 2 is used for medium duty operation. Most of the chemical equipments are involved in this category. All longitudinal and circumferential joints are spot radiographed. Spot radiographed means where I am having a few black spots in x-ray, so that may be considered with minor defects.

The thickness should be less than 38 mm, if that is there, J factor for these 2 joints are given as 0.85 and 0.8. And then we have class 3 vessel where light duty operation is carried out and thickness should be less than 16 mm, and here we use all types of joints and respective J values are given in this table. So, here we have discussed different terminologies and these terminologies we will further use in designing. And these values of joint efficiency factor, you can also see from table 1.1 in code IS: 2825-1969.

I will speak when we solve the problem that how you need to use table B1 or how you need to choose other terminology, that we will discuss when time comes.

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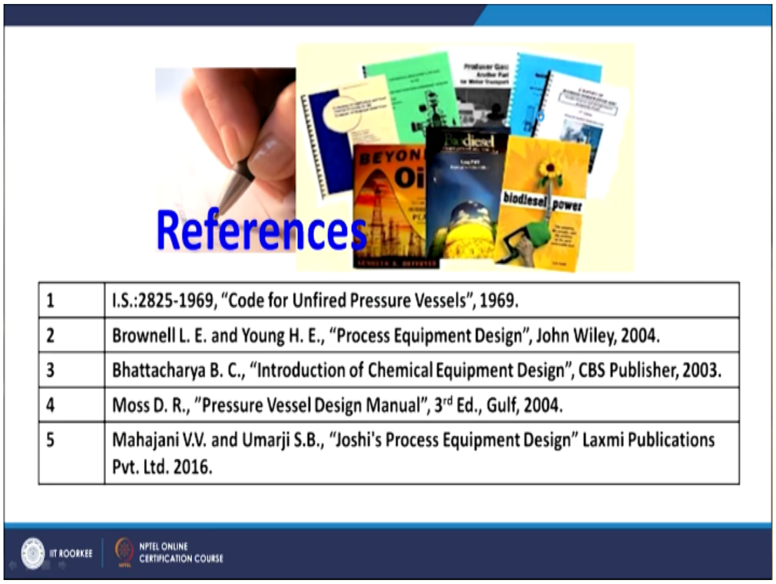
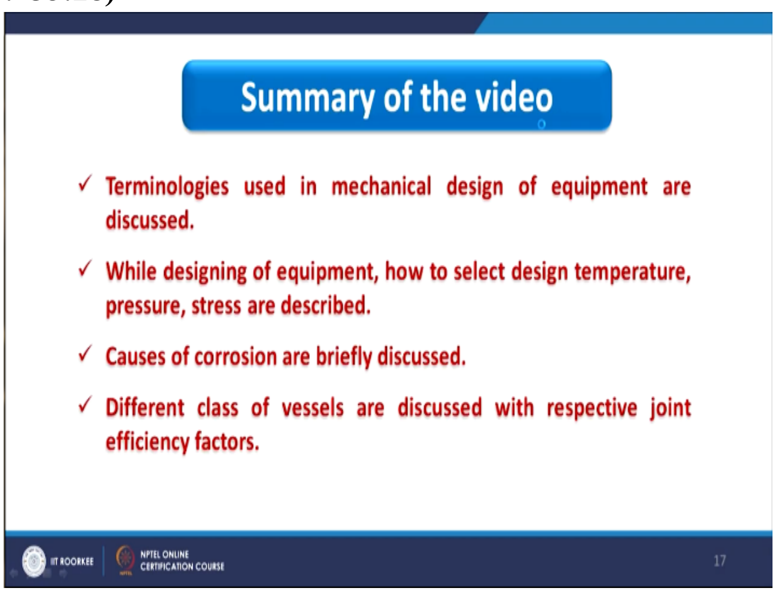


And here, I am having some of the reference books that you can follow for these terminologies and here we have the summary of the video.

(Refer Slide Time: 35:28)



In this video, in this lecture, terminologies used in mechanical design of equipment are discussed. While designing of equipment, how to select design temperature, design pressure, allowable stress, these are described. Causes of corrosion are briefly discussed and different classes of vessels are discussed with respective joint efficiency factor. So, using these four points, I am completing this lecture. So, that is all for now, thank you.