Welding Metallurgy
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Lecture No. 43
Angular Distortion in Welds

Welcome to the lecture on angular distortion in welds. So, we talked about the longitudinal as well as transverse shrinkages, and now we will have some description about the angular distortion in the welds. So, angular distortion occurs in butt, lap, T, cruciform and other joints like corner joints as a result of single sided as well as symmetrical double sided welding.

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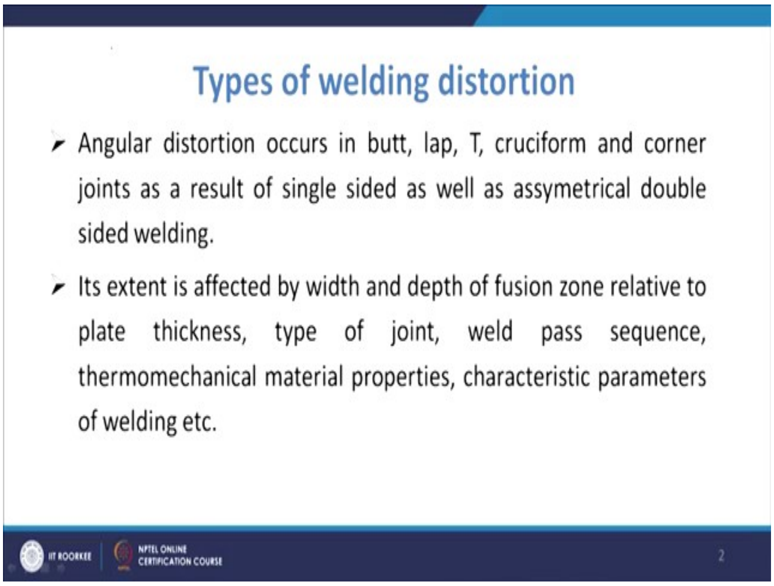

Types of welding distortion

- Angular distortion occurs in butt, lap, T, cruciform and corner joints as a result of single sided as well as assymetrical double sided welding.
- Its extent is affected by width and depth of fusion zone relative to plate thickness, type of joint, weld pass sequence, thermomechanical material properties, characteristic parameters of welding etc.

So, in those cases, you are likely to encounter the angular distortion. Now, the extent of these angular shrinkage will be depending upon many factors and they are like width and depth of the fusion zone relative to the plate thickness, then you have the type of joint, you have the weld pass sequence, thermomechanical material properties, and characteristic parameter of the welding processes just like you have heat input per unit length.

So depending upon the joint you have to calculate those things, and also the distribution of heat source density. So, that way, these factors basically will be affecting this angular distortion's extent. Now, the thing is that there are certain correlations which we will talk about, you know, the dependence of this angular shrinkage with the different factors, how they are varying. So, if suppose, you are changing the velocity or heat input per unit length, so that way there are variations.

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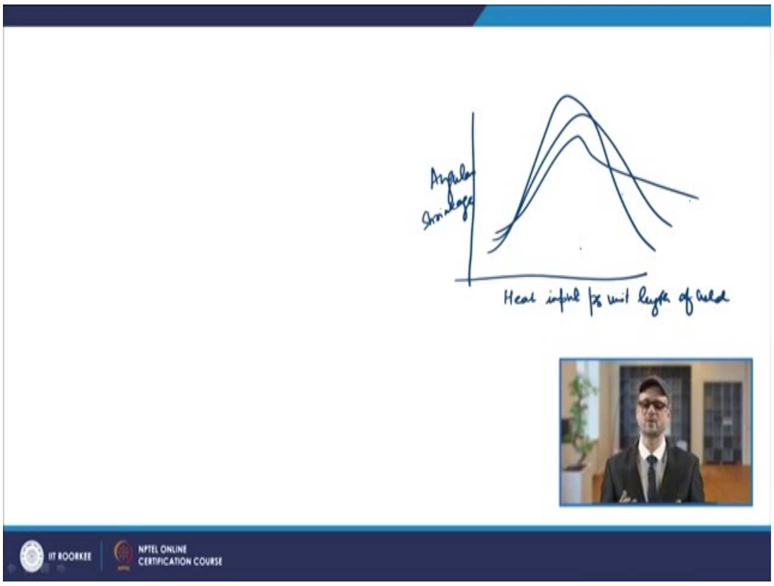

So, if suppose, in this graph, if the ordinate is the angular shrinkage and if you take this abscissa as heat input per unit length of weld, that is for per unit length we want to have the heat input, and this is angular shrinkage. So, if you try to see for the different velocities, so this curve comes like, you know, this way it goes. This is in the term of radians. And as you see that when the velocity will be somewhat smaller, then it will go like that.

If suppose this is for the 12 metre per second, this is 10 metre per second, similarly this will be 7.5 metre per second, something like that. So, this variations talks that depending upon the velocity and also heat input per unit length of the weld how this angular shrinkage will vary. So, we will talk about the angular distortion in the butt welds.

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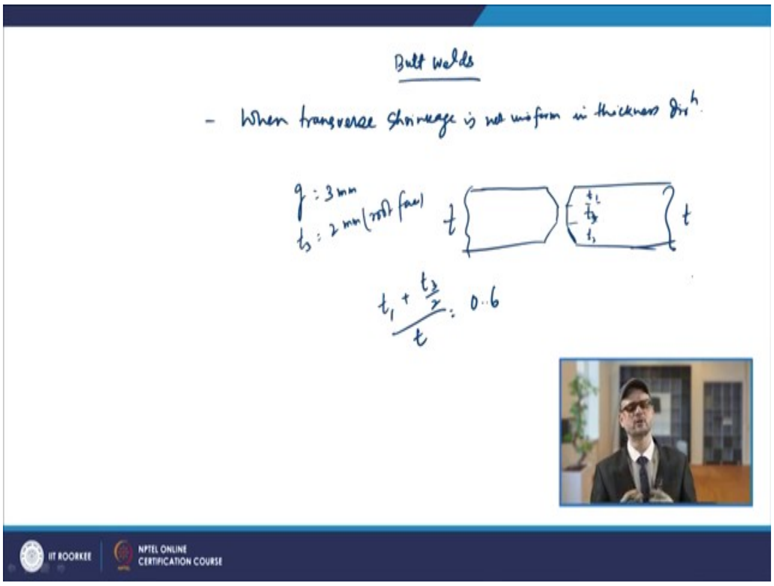
Butt welds

- When transverse shrinkage is not uniform in thickness dir^n.

g = 3 mm
t_3 = 2 mm (root face)

$$\frac{t_1 + \frac{t_3}{2}}{t} = 0.6$$

If we typically talk about angular distortion in butt welds, so angular shrinkage in butt weld is occurring when the transverse shrinkage is not uniform, when the transverse shrinkage is not uniform in thickness direction. So, in those cases when the transverse shrinkage which is there in the thickness direction is not uniform these angular deformations may result into and it can be reduced by taking a suitable type of joint.

Normally if you go for double V type of joint, then this can be minimised and even it can be almost zero. So, whatever is happening, if you take a typical double V type of joint, so you will have, this is your joint and this is your thickness on this side, so in this case if you take this as t_1 and this is your t_2, this is your t_3, and this is suppose t_2 you are taking, so t_1 and t_2 you can have similar values.

Now, in this case, we are taking for a root gap g, that is taken as suppose 3 mm, and if you take the root face t_3 also, t_3 is taken as 2 mm, so that is your root face. So, in this case, what is happening is that you can minimise this based on the condition that if you take $(t_1 + t_2/2)/t = 0.6$. So, for that you can minimise or you can even avoid any kind of angular shrinkage in such joints.

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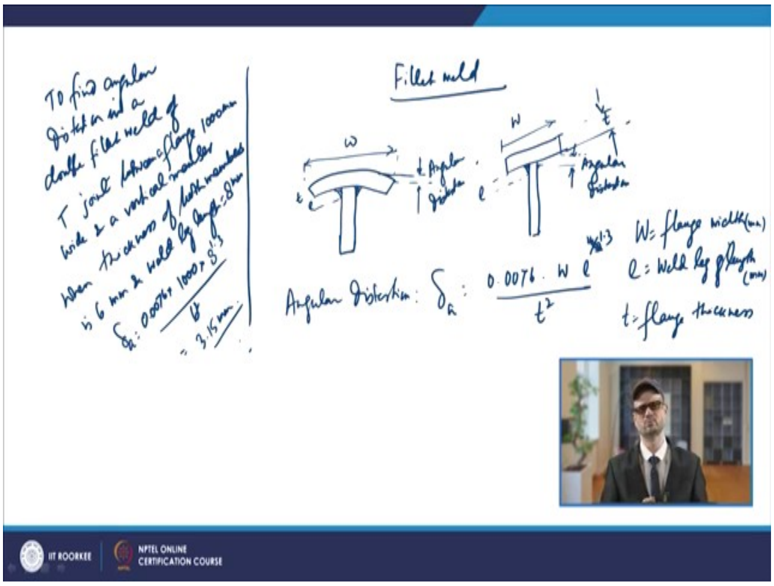

To find angular distortion in a double fillet weld of T joint between a flange 1000 mm wide & a vertical member when thickness of both members is 6 mm & weld leg length = 8 mm

$\delta_A = \frac{0.0076 \times 1000 \times 8^{1.3}}{6^2}$

$= 3.15$ mm

Fillet weld

Angular Distortion: $\delta_A = \frac{0.0076 \cdot W \cdot l^{1.3}}{t^2}$

W = flange width (mm)

l = weld leg length (mm)

t = flange thickness

Now, if you come to the fillet welds, if you go to a typical fillet weld, so in the case of fillet weld what happens is that, if suppose this is your, so this way you may have the distortion here. So, here, this is your fillet joint and here space is left here. So, if you look at this, this is your angular distortion. So, this becomes your angular distortion and this is the thickness of the structure which is to be welded and this is your leg length, so this is your l.

So, this is the amount which is known as angular distortion, that is δ. Similarly, for double fillet T joints you may have, you know, if you take the double one, so it goes like this one, and again we have seen that this is your fillet leg length. So, you will have this length l and then this is your thickness, that is t, this becomes your w. In this case also this is your w. So, in this case this becomes your angular distortion.

So, this way angular distortion is signified in the case of fillet weld. Now, in these cases, angular distortion is measured using a formula. So, we call it as δ_a and that becomes equal to $0.0076wl^{1/3}/t^2$. So, this way you measure this angular distortion. In these cases, we know these standard terminologies. So, your w becomes flange width, then your l becomes the weld leg length. Again this is in mm, this is also in mm, and then remains the t, so t will be your flange thickness.

So, this way you can calculate the value of the angular distortion. So, you can have, you know, many a times you can come across the numerical problems based on these type of weld geometries where you have to find the angular distortion. So, suppose you have to find the angular distortion in a double fillet weld of T joint, that is what has been shown, and between a flanges that is 1000 mm wide and a vertical member when the thickness of both members is 6 mm and weld leg length is given as 8 mm.

So, just like the cases we studied, so if you know, in this case also you know the thickness of the members that is 6 mm, then leg length that is l that is given as the value 8 mm, and your flange dimension also is given as 1000 mm, so you can have the value by putting these numerical values into the expression and accordingly you can find the angular distortion value, so, you will have, you know, that is 0.0076, that is the constant.

Then you have the value of w. So, w is your 1000 and then you have $l^4/3$, or better you can take 1.3. So, that will be your 8, then this $l^{1.3}/t^2$. So, t is already shown, thickness, is 6, so 6^2. So, that way you can have the calculation of these dimensions. And if you do it, you will get somewhere close to 3.15 mm.

So, this way we calculate the value of the angular distortion. Now, we will talk about the multiple restraint fillet welds. So, many a times we need to have because we have fillet welds and we have the restraint at many points. So, in those cases, how to find the angular distortion?

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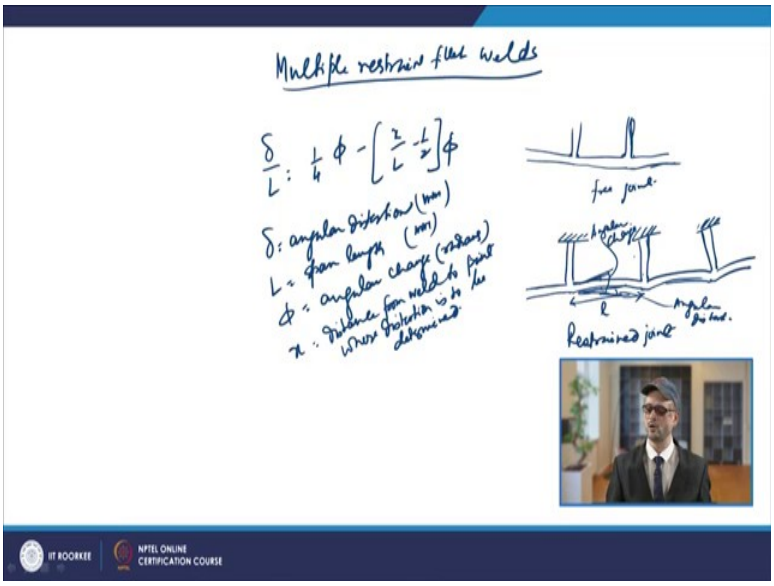

Multiple restrain fillet welds

$\frac{\delta}{L} = \frac{1}{4}\phi - \left[\frac{x}{L} - \frac{1}{2}\right]\phi$

δ = angular distortion (mm)

L = span length (mm)

φ = angular change (radians)

x = distance from weld to point where distortion is to be determined

So, for that, as we see in the case of multiple restraint fillet welds, because as you see you will have the weld and you have the restraint at many sites, so restraint will be in two points there, so what will be the angular deflection? So, angular distortion, in fact, that can be found out, and that is found out by using the formula $\frac{\delta}{L} = \frac{1}{4}\varnothing - \left(\frac{x}{L} - \frac{1}{2}\right)^2 \varnothing$.

So, what we do is, we have these terminologies, so in this case your δ is angular distortion, and then you have L as the span length, $\varnothing$ is the angular change that is in radians. So, these two are in mm. And x is the distance at which you have to find that angular distortion, so distance from weld to point where distortion is to be determined. So, you can have the example of, suppose, your weld when comes like this, so this way it goes, then you will have another fillet.

So, you have the fillet welds here. So, your fillet weld will go like this. So, you will have fillet welds. So, these are the examples of free joint. So, here you have the free joint and there is no constraint, whereas similarly in these cases you may have the constraint here. So, this, this, this comes. So, this way it will move and then you will have another constraint which is here, and after that suppose it goes like this.

So, you may have another fillet joint. So, this is the example of the restraint joints. Now, in this case, this is the value of L what we mean to say and we mean to calculate. And in this case the distortion which is there, so that is basically here, you get this you know. So, in fact, here, this is your angular distortion and now this is your, if you take from here, so this becomes your angular change in radians.

So, this way you have to have the value of the angular change and from there you can calculate the value of the angular distortion. So, that is how you are going to have the value of the angular distortion being calculated when you know all these parameters. So, we can solve a problem. Suppose, we are given a problem and in that problem we have to calculate this angular distortion.

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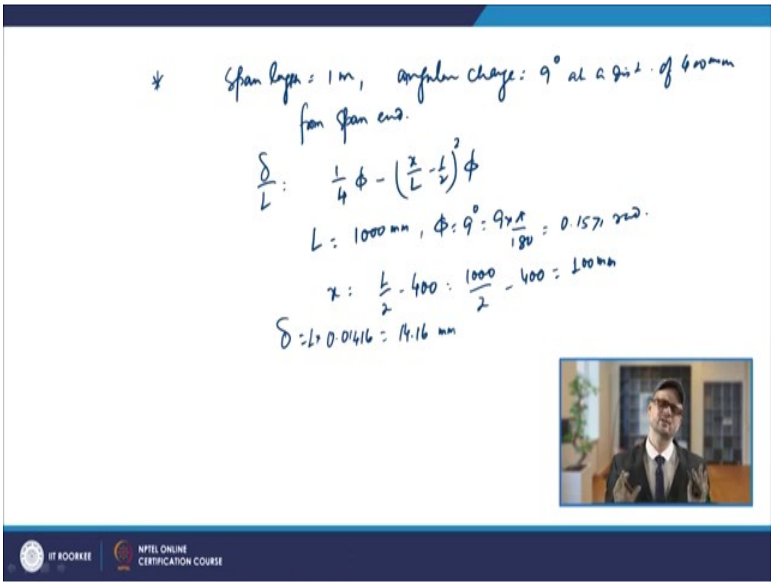

* Span length = 1 m, angular change = 9° at a dist. of 400mm from span end.

$$\frac{\delta}{L} = \frac{1}{4}\phi - \left(\frac{x}{L} - \frac{1}{2}\right)^2 \phi$$

$$L = 1000 \text{ mm}, \ \phi = 9^\circ = \frac{9 \times \pi}{180} = 0.1571 \text{ rad.}$$

$$x = \frac{L}{2} - 400 = \frac{1000}{2} - 400 = 100 \text{ mm}$$

$$\delta = L \times 0.01416 = 14.16 \text{ mm}$$

And for that what we do is that, to calculate in a multiple restraint fillet weld, so span length is given as, say, 1 metre and angular change is given as 9°, and that is given at a distance of 400 mm from span end. Now, what we need to know in this case? So, as we see that you have angular change is given as 9°, so you have to convert that into radians, so you will have δ/L.

So, if the $\frac{\delta}{4}=\frac{1}{4}\varnothing-\left(\frac{x}{L}-\frac{1}{2}\right)^2.\varnothing$. So, here it is raised to the power 2. So, that 2 was missing. So, this is the formula. So, we have to calculate δ. So, your L is given as 1000 mm and $\varnothing$is 9°, so 9° is to be converted into radians. We know that πradian is 180°. So, $9 \times \pi/180$, so it will be something like 0.1571 radians.

Then, x is to be calculated. So, you are doing it 400 metres from the span end. So, if you take the x, x will be basically (L/2) - 400. So, accordingly you will get this (1000/2) - 400. So, it will be 100 mm. So, in that case, you are going to have the calculation. Once you know all these values, you can have the calculation of δ. So, δ will be, you put those values, and then multiply it with the span length. So, L * 0.01416 is the value which is coming. So, if you put those values on $\varnothing$/4, phi you know that 4 minus this.

On this, everything knowing, you can calculate. So, it will be 14.16 mm. So, that way you will have the calculated angular deflection which is calculated for such cases. Now, the amount of angular change, that is $\varnothing$, in a restrained structure, that will be smaller than the amount of $\varnothing$which is there in a free joint basically, and that phi will also be depending upon the rigidity of the bottom plate. So, you can have the value of that rigidity calculation or amount of $\varnothing$ that is calculated.

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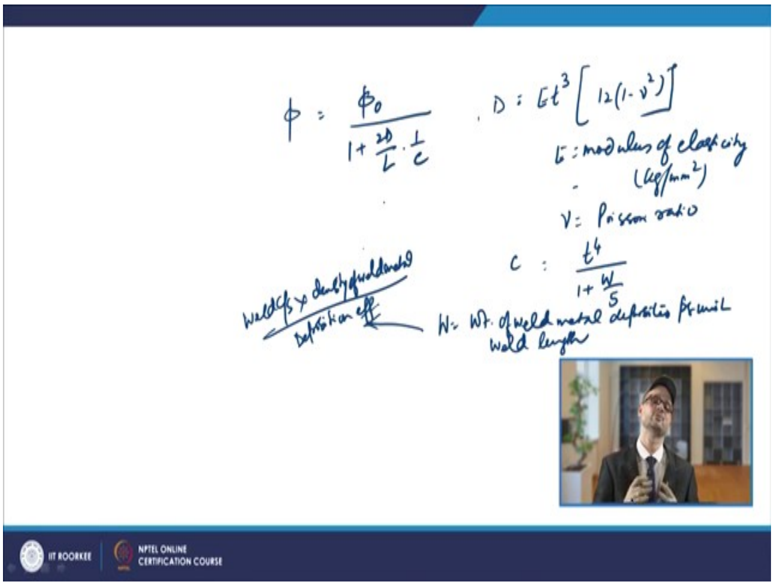

$$\phi = \frac{\phi_0}{1+\frac{2D}{L}\cdot\frac{1}{C}} \quad , D = Et^3\left[12(1-\nu^2)\right]$$

E : modulus of elasticity (kg/mm²)

ν = Poisson ratio

$$C = \frac{t^4}{1+\frac{W}{5}}$$

W = Wt. of weld metal deposited per unit weld length

weld CS × density of weld deposited / Deposition eff

So, $\varnothing$in those cases, you know, relation between the free and the restrained angular distortion, that can be found out by $\varnothing = \frac{\varnothing_0}{1+\frac{2D}{L}\cdot\frac{1}{C}}$. So, phi is the distortion in a constrained design. So, you have the restrained structure that is $\varnothing$, and when you have no restraint, so that is your $\varnothing_0$. So, in that case their correlation is found like this.

$D=Et^3\left[12\left(1-\nu^2\right)\right]$. So, that way, in this case, we know that this E is the modulus of elasticity, so that is taken in terms of kg/mm^2, and other things like t will be your thickness, and nu is basically the Poisson ratio. So, basically, you can find this. And in this expression we have another constant that is C. So, C is basically a constant which is determined based on the welding conditions and the plate thickness.

So, that C is basically a function of, so that will be $t_4/(1 + w/5)$. So, basically, again, your t is the plate thickness and w is the weight of weld deposited, weld matter that is deposited, so that is per unit weld length. So, accordingly, you can find. So, that will be your weld cross section, and then you have to multiply that with the density of the weld metal, and then you are further dividing it with the deposition efficiency. So, that can be computed using the formula.

So, that will be weld cross section, and then that will be multiplied by the density of weld metal and that will be divided by deposition efficiency. So, accordingly, you can calculate. So, from here, if you put all these values, you can have the value of $\varnothing$. So, if you try to have the plot of the free angular distortion, it has been found that if you do it for the shielded metal arc welding where there is a 5 mm electrode is taken, so a result can be drawn. And it can be seen how this angular change for the free end will be varying.

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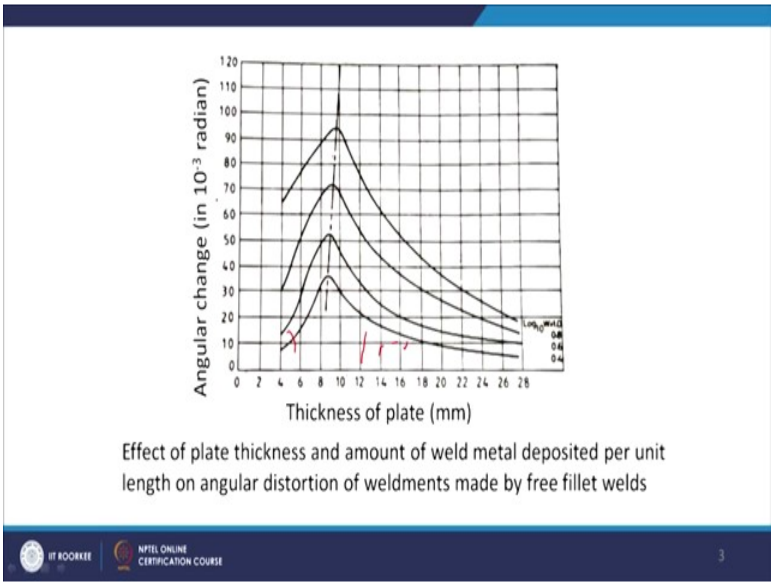

Effect of plate thickness and amount of weld metal deposited per unit length on angular distortion of weldments made by free fillet welds

And that comes like you have such kind of graph you get where this is your angular change in the radian and on the x axis you have the thickness of the plate, that is in mm. And if you look at this, this is your $\log_{10}w$, and that is taken as 1, 0.8, 0.6, and 0.4. So, for the different values you have different graphs which can be seen. So, that way you can take the value of the $\varnothing_0$ from here.

So, this graph can be interpreted in the way that you can say that if you are using the 5 mm electrode, so the maximum angular distortion which is being seen here, now that is observed for the plate thickness of 9 mm here. So, you see that you have this plate thickness. So, here you are getting the maximum angular distortion that is found for that imension. Now, if your plate thickness is thinner than this 9 mm, then that angular distortion is reduced due to more even heating of the plate when the thickness is less.

And when the thickness is more, in that case, it has reduced because of the increased rigidity because once the thickness is becoming more the rigidity of the joint becomes more. So, that way your angular distortion further reduces. So, that may be the justification for the change in the value of the angular distortion.

Now, if you talk about the angular distortion in the butt welds, there also you have, you know, in the form of buckling and warping also that occurs, and that is happening because of the two halves which are trying to move relative to each other and also you have the non-uniform temperature development.

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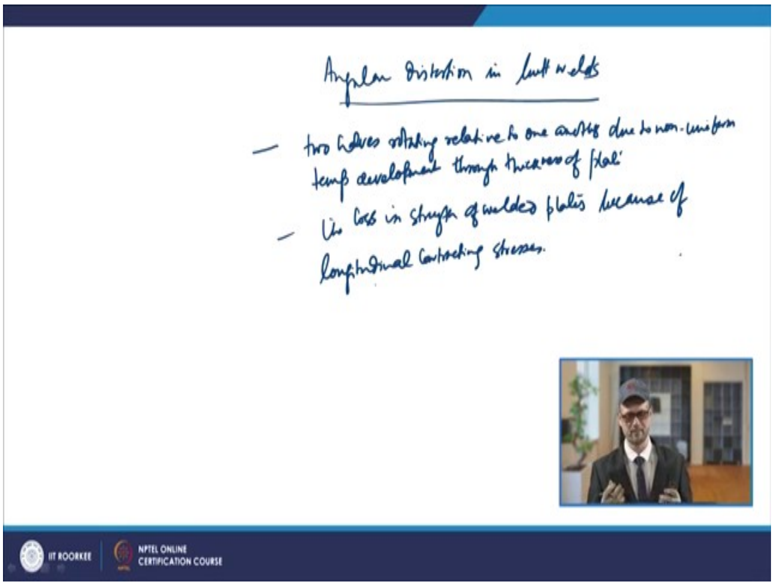

Angular Distortion in butt welds

- two halves rotating relative to one another due to non-uniform temp development through thickness of plate
- the loss in strength of welded plates because of longitudinal contracting stresses.

So, angular deformation in butt welds, so in those cases, as you see that you have these local deformities will be occurring in terms of buckling and warping, and the reasons may be, you know, because of the two halves rotating relative to each other. So, that is due to non-uniform temperature development through thickness. So, that is the basic reason for the angular distortion in the butt welds, and also the second reason is the loss is strength of welded plates.

So, this is because of the longitudinal contracting stresses. So, these are the reasons because of which angular distortion in the butt welds occur and you can have the ways to basically reduce them. So, you have seen that in the expression increase in the thickness or so, or increase in the rigidity. So, that way you can have control on these angular distortions in the butt welds. Thank you very much.