Welding Metallurgy
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Lecture No. 41
Introduction to Welding Distortion

Welcome to the lecture on introduction to welding distortion. So, we studied about the residual stresses which are developed in welding and the associated topic which is further needed to discuss is the welding distortions. So, many a times we see that when we do welding the parts are distorted, the welded specimen is distorted. And there are different types of distortions. And there are reasons for these distortions to occur.

So, first of all, we will be acquainted with why this distortion occurs and what are the parameters which affect these distortions, and then slowly as we move towards the other portions to discuss the distortion we will talk about the different types of distortions, and how we do the quantitative analysis of the distortions which occur in welding and how to get rid of these distortions or how to control the distortion. So, that we will discuss.

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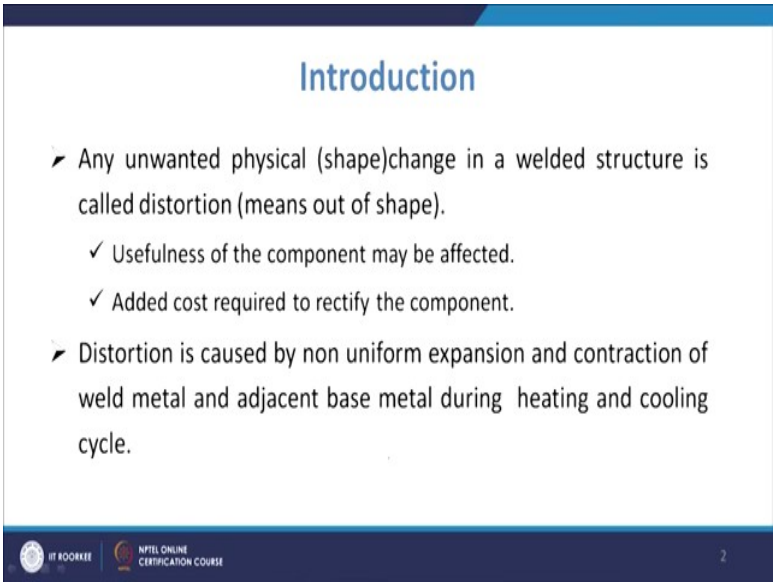

As we know, that distortion means any unwanted physical shape change in a welded structure, that is called distortion. Distortion means it is becoming out of shape, so no longer you can use them. So, basically, if the structure is distorted, its usefulness will be affected. You cannot have the same value of that component as it has been if it would have been undistorted or it would have been in a proper shape.

So, many a times what happens is that when you have the distorted shape, then you have to do some measures to rectify it, and that basically also involves certain costs you have to spend, resources for correcting it, what has been seen as the cost of correction or cost of making the shape in a proper manner. So, that is becoming quite high as compared to the original cost of the machine itself.

So, that basically adds to the ill effects of the distortion. So, basically, you must have the proper measures to minimise the welding distortion so that you have minimum effort required to rectify those distortions after welding. Now, distortion is caused by non-uniform expansion and contraction of weld metal and the adjacent base metal during the heating and cooling cycle of the welding process. So, what happens is that, as we know that, when your welding process is going on the heat will be dissipated towards the sides.

If you talk about the sides the heat will be increasing, so the heat when it is dissipating the temperature on the side will increase and so there will be expensive. Similarly, if you talk about the region or the portion which is along the line of welding, and if you take the position which is behind that welding spot, now, on those areas as we are moving away from the place, so that starts cooling, so that leads to basically the contraction.

So, basically you have a complex state of stress which is developed, you have somewhere expansion, somewhere contraction, so you will have compressive stress or tensile stress developing. Now, all these things if they are interacting, that many a times lead to the formation of these distortions. So, if you talk about the change in the volume of the material, what we see is that in three stages the volumetric change takes place.

So, if you recall, the change in the volume of the material, one is in that superheated state, so from there it is coming to liquidus temperature and the other will be during that solidification. And then, later on, you will have during the solid state, so you have three stages of expansion. If you recall, then what you see is that for every 100 °C you have about point 0.8% of volumetric expansion in that superheated states.

So, the super heat which will be extracted, so for extraction, by extraction of super heat you have about 0.8% of volumetric change. Similarly, when you do the solidification, if you talk

about mild steel, so in those cases during the solidification the volumetric change will be close to 3%. So, during the solid state it is about 7 to 7.5%.

So, altogether, if you look at, it is in the range of 11 to 12% or 11 to 15% which is the range in which these volumetric expansion is taking place. Now, what happens is that that may be taken care of by plastic deformation.

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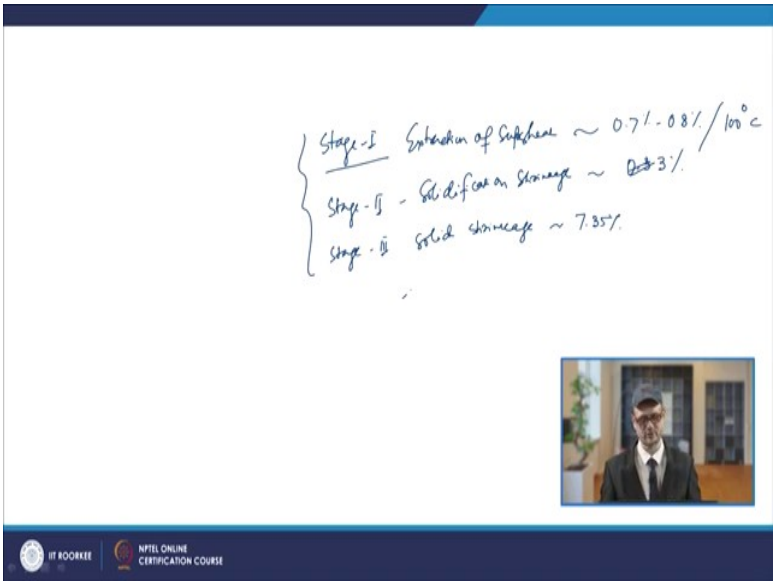

So, what you see is that in your stage one where you have the extraction of super heat, there it is of the order of 0.7% or 0.8% per 100 °C. Similarly, if you go to stage two where you have the solidification shrinkage or phase change, now, in that your shrinkage is about 3%. And if you go to stage three which is the solid shrinkage, that is taken care of by providing other type of allowances in case of casting, but here anyway it is taking place.

So, this solid shrinkage that is normally of the order of 7.35%. So, this way what you see is that you have altogether close to 11 to 12% or it may go even, for some materials, it may go even the order of 15%. So, now, if these are to be accommodated, what happens is that, that results in the development of internal stresses, so that will result in the plastic department if that exceeds that yield stress, and even that results into tearing of the material.

So, that is the effect of these changes which take place during that solidification of the material. So, what we do, we also give further treatment, thermal or mechanical treatment also. So, what we see is that that leads to the development of internal stresses and that may result into distortion of the welded specimen.

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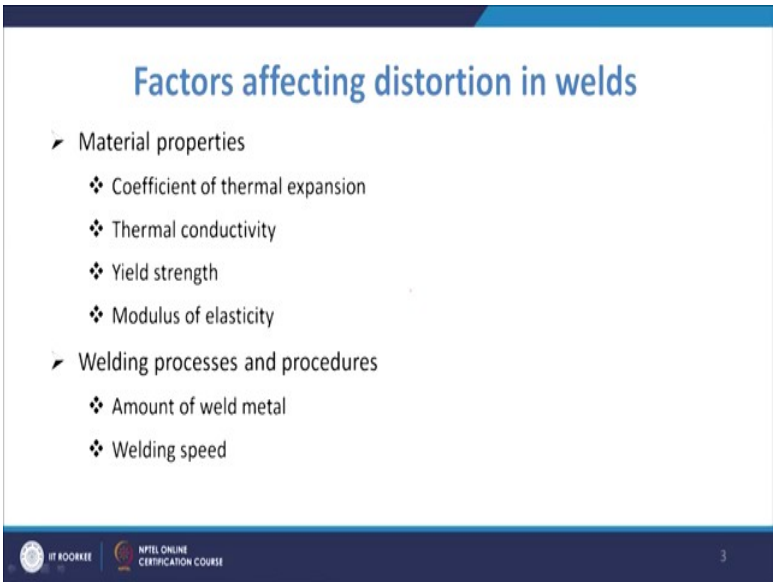

So, coming to the effect of or the factors which are affecting the distortion in the welds, so you have certain parameters which basically affect the distortion in the welds, and among those factors you have the material property. So, there are different material properties and each of the material property may have a positive or negative contribution towards the distortion which is caused in the welded specimen.

So, the properties which are of interest, which affect the distortion of the welded specimen are like coefficient of thermal expansion, thermal conductivity, yield strength, modulus of elasticity, and then you have other welding processes and procedures like you have amount of weld metal and then you have other parameters which we will be discussing.

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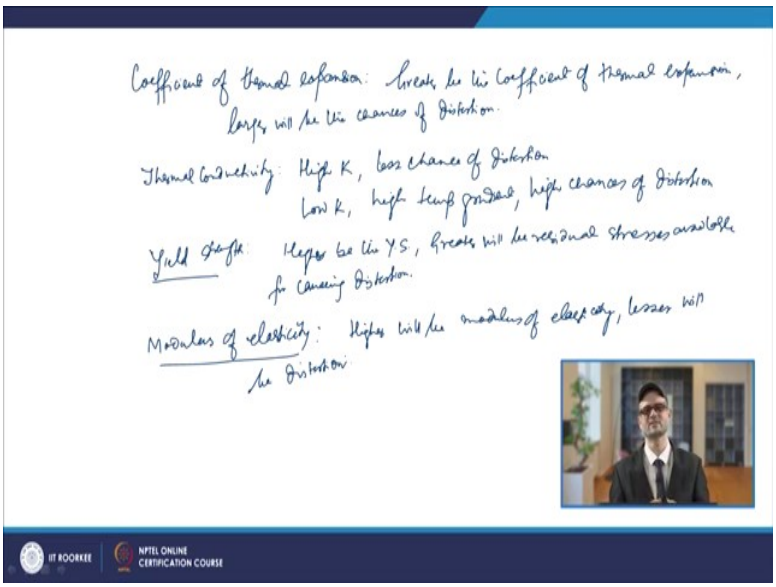

So, the effect of these parameters, material properties say, if suppose you have the coefficient of thermal expansion; if you recall, this is the property which talks about the change in the dimension of the material as the temperature is increased, so this will be the measure of expansion and contraction so that if it is more it will either expand more or it will contract more as per the change in the temperature.

If it is greater, if greater be the coefficient of thermal expansion, more likely you will have more distortion. So, if greater be the coefficient of thermal expansion of the material, so larger will be the chances of distortion. So, that is very obvious, as the coefficient of thermal expansion will be more there will be large amount of distortion in those cases. Next is your thermal conductivity. Thermal conductivity is the property of the material by which the heat is allowed to pass through it.

So, if the thermal conductivity will be more, more fast the heat will be allowed to pass through the material. So, how readily the heat will be allowed to spread through the material that will be indicated by the value of thermal conductivity of the material. So, if your thermal conductivity of the material is low, in that case there will be more thermal gradient, so it will take larger time to pass through, so there will be more thermal gradient.

If the thermal gradient is more it means that will be likely to produce more distortion. And if the thermal conductivity on the contrary is higher, in that case it will quickly allow the heat to pass through it, so thermal gradient will not be more in the material. So, accordingly, your distortion of the material will be smaller. So, what we see is that if you have high thermal conductivity of the material, there will be less chance of distortion, and certainly the case will be opposite if you have low K.

So, in that case, you have high temperature gradient, so you have high chances of distortion. So, that will be the effect of the thermal conductivity of the material. Next property is the yield strength. Now, if you talk about the yield strength, the higher will be the yield strength of the material the greater will be the residual stresses available for causing the deformation. So, higher the yield strength of the material, greater will be the residual stresses available for causing distortion because that much of stress it can accommodate, up to that stress.

So, that is available as the residual stresses and then your chance of distortion will be that way higher. If you talk about the modulus of elasticity, as we know that this property is also important because it talks about the rigidity or stiffness of the material. So, if the material has high modulus of elasticity or if it is more stiff, it will try to resist the deformation. So, higher will be the modulus of elasticity, more it will resisting the deformation and so less will be the deformation.

So, higher will be modulus of elasticity, lesser will be the distortion. So, these are the typical material properties which basically will be decisive and will tell you whether the distortion will be more or less. Now, coming to the influence of other parameters like you have welding process or the procedures.

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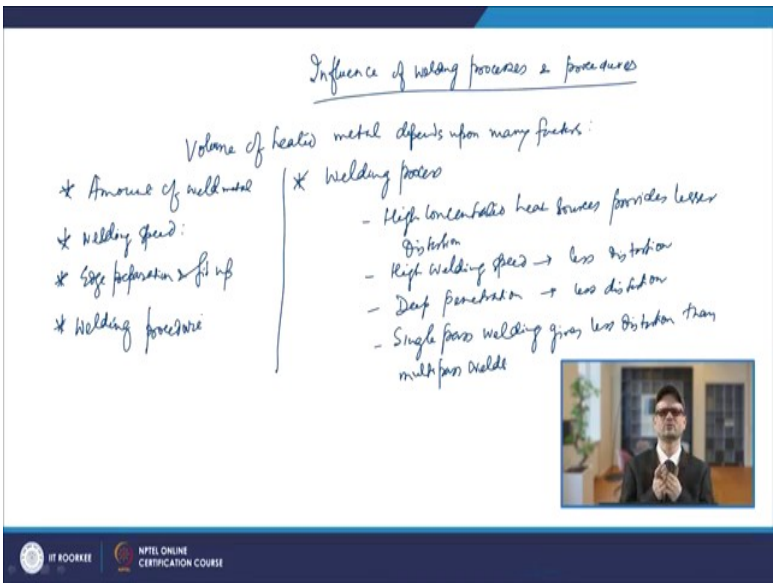

So, if you talk about the influence of welding processes and procedures, other than these physical properties of the material, other factors are also important which determine the extent of distortion in the welded specimen. Now, what are the types of welding processes, what are the procedures of doing the welding?

Ultimately, when we talk about the welding processes or procedures, basically we are dealing with the hot metal which is accumulated at a place and design of that weld pool, how the weld pool is, so that is a concentrated basically heat source, and then how you are moving, how much it is affecting, how long its effect is there. So, for more time its effect will be there, more will be the effect on distortion.

So, that way it affects those distortion which is going to come on the material. So, basically, overall, the amount of welding distortion it will be depending upon the volume of the heated metal. So, what is the volume of the heated metal and how its distribution is there, how the bead shape is there. So, the bead shape will also be important on the distortion which is occurring during that welding.

Many a times you may have, with certain types of bead shape or the joint which you are making, you may have uniform shrinkage and you may have either non-uniform heating and cooling also, so that will lead to different values of the distortion, different ways the distortion may be coming up. So, the volume of the heated metal, that way, volume of heated metal is a very prominent factor which will be talking about the extent of distortion in welding.

So, volume of heated metal will be depending upon many factors. So, those factors are basically the type of welding process which you choose. So, if you talk about the welding process, what happens is what kind of welding process you are choosing, whether it is a very concentrated heat source or you have a distributed heat source sort of thing, so whether it is concentrate or not very concentrated, so this is important that if you have a concentrated heat source, in those cases it is likely that it will give you lesser amount of distortion.

So, if you talk about the welding process, if you have a high concentrated heat source, that will provide you lesser amount of distortion. Then, if you take the welding speed higher, that also gives you less distortion because if the speed is higher spread will be less, and in that case the distortion will be less. So, similarly, if you have deep penetration, in that case, the distortion will be less, that gives you less distortion.

Now, many a times we go either for one-pass weld or multi pass. So, the single pass weld will give you less distortion than the multi run weld. So, this is the effect of the welding process. This way these parameters will be affecting the extent of the welding distortion. Then, comes to the next is the amount of weld metal. Normally we should try to have the weld metal amount to be minimum because that basically is the heat source or the content of the heat which is there.

So, minimum is the weld metal if it is which basically should be sufficient to do the satisfactory welding process and satisfactory quality of the weld bead, so if the amount is smaller or kept minimum, so that is basically better for lesser distortion. So, that way mostly we should try to have the minimum amount of weld metal. Coming to the welding speed, we have already seen that welding speed should be higher so that your distortion is smaller, but then you must have that also in mind because the process of solidification is also going on.

So, the solidification has to be in the proper orientation and you must have the proper care to avoid any kind of defect because of these high welding speeds, I mean more than required, because if it is more, in that case, because shrinkage is taking place, so that should not create any kind of defects such as center line shrinkage or weakness of the material. So, the welding speed although should be high, but then that also has to be taken into consideration.

Then edge preparation and fit up is also important because it has to be such that your amount of weld metal should be minimum and it should be uniform so that you have uniform shrinkage or you have consistent shrinkage around the joint. So, that way, your edge preparation and fit up that should be designed in such a manner that there is uniform shrinkage as well as you have consistent shrinkage around the joint.

Then you have other defect which is also important, that is the welding procedure. Now, if you talk about the welding procedures, so in that case, you have single pass or multi-pass or you have high speed weld. So, this is the welding process, but apart from that you have other welding procedure like, we have talked about the back step welding or you have the skip welding procedure.

So, these basically are used to, so we have talked about in earlier lectures about the back-step welding or the skip welding, so these are the ways to minimise the residual stresses. So, basically, we should try to see that these procedures should be adopted to minimise the residual stresses and basically that only will create the distortions. So, that also plays an important role, these welding procedures, to minimise that distortion in the weld.

So, basically, in that the precaution which has to be taken is normally that you should always start the welding from a clamped end and move towards the free end. It is not that you should start from a free end and then go towards the clamp end, because then there we have

the restraint. So, basically, that restraint will create large amount of stresses and that stresses may create distortion in the work piece.

So, basically, what you see is what kind of process you are taking. We do in the case of skip welding where we are skipping the welds. We do in some region and then we leave one or two and then further we are doing that welding. So, that also is done. So, basically, these processes which are adopted they are with an aim to reduce the stresses, and so once the stresses will be reduced, accordingly, the distortion will also be less. So, this is about the distortion or introduction to the distortion.

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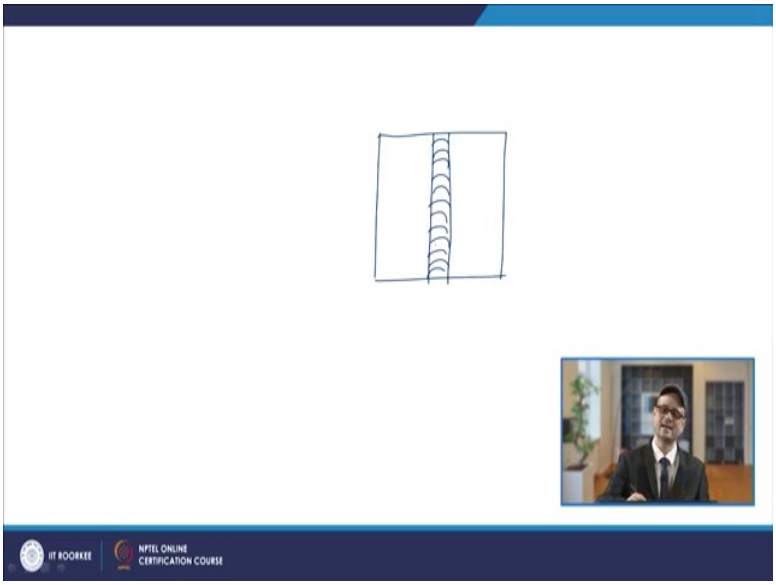

If we talk about the different types of distortion in welding, if you talk about a particular weld, what happens is that, suppose you have a butt weld which is going on, if suppose this is the bead, this is your weld bead which is there on this seat, so what happens is that there may be distortion in different way on this specimen and that will be mainly in terms of shrinkage or in terms of the angular distortions or it may be bowing or it may be twisting.

So, these are the different kinds of distortions which take place because, as you know, along the longitudinal direction if you look at, you have the stress pattern goes like this and then it will be coming in the negative direction here. So, this way will be going. Now, what happens is that, as we know that since the weld metal which is there, so it is in liquid state and it has to solidify.

So, you have the shrinkage with take place either along the longitudinal direction or along the transverse direction. So, the shrinkage which take place along the longitudinal direction that will be termed as the longitudinal shrinkage. Similarly, you will have the shrinkage also in the transverse direction, so that will be your transverse shrinkage. Then you have distortions, you know, going out of shape.

So, they are there. So, you have angular distortions which take place. You have different types of welds, so you have the angular destruction at some angle it will be going, it will be bending or so. So, the distortion which is there normally in the case or fillet welds or so, or anywhere you have the angular distortion taking place in terms of angles also you measure. So, we call it as the angular distortion.

You have the bowing or bending also which is there, that is also a type of distortion which take place in this welding. Then, the other kind of distortion is the twisting or buckling. So, that also is one of the distortion. You might have seen that many a times we do the welding on the thin seats or so, so they buckle or they twist. So, basically, that also depends upon the thickness of the parent material many a times.

So, many a times that kind of distortion is taking place that is your buckling or twisting. So, we will have the introduction about the different types of welding distortion, how it looks like and how quantitatively we can discuss about those distortions. So, we will have the discussing on these topics in our coming lectures. Thank you very much.