Welding Metallurgy
Prof. Pradeep K. Jha
Department of Mechanical and Industrial Engineering
Indian Institute of Technology – Roorkee

Lecture - 37
Residual Stresses in Welding

Welcome to the lecture on residual stresses in welding. So we will talk about the welding stresses and typically about the residual stresses which is developing in the welding process. So as we have seen so far we discussed that during the welding you have you know welding specimen is subjected to thermal you know cycling and because of that, because of the development of temperature gradients.

So internal stresses are developed, so residual stresses you know are there inside the specimen and these stresses are you know many a times as we might have studied that some stresses are good also for the body and some stresses are not good for the component. So we will have some discussion about you know the definition and concept about the residual stress development and also we will talk about the type of you know stresses which are there inside the body.

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Introduction

- Inherent local non-uniform heating and cooling cycle associated with fusion welding processes result in complex thermal stresses and strain.
- These may develop residual stresses and distortions in welded structures.
- Residual stresses can reduce the service life of a structure or even lead to catastrophic failures.

So let us you know first of all see that when we have the inherent local non uniform heating and cooling cycle which is there in the case of fusion welding. So in those cases the welding process result in complex thermal stresses and strain. So you will have you know certainly you have the heating as well as the cooling and most of the time it is you know that it is non-uniform.

So in those cases you have basically the you know generation of thermal stresses and also strains because when you have heating then you will have you know the expansion will go on then you have cooling then you have contraction going on so that result into stresses development and all that. So now this is so that may develop the residual stresses and then these stresses also typically go and result into the distortions in the you know welded structures.

So why they are important because many a times you know these residual stresses they will be you know reducing the service life of the structure because once they are logged in you know and during the service you know there may be you know catastrophic failure or in normal case it will be decreasing the life of the you know specimen. So coming to the residual stresses.

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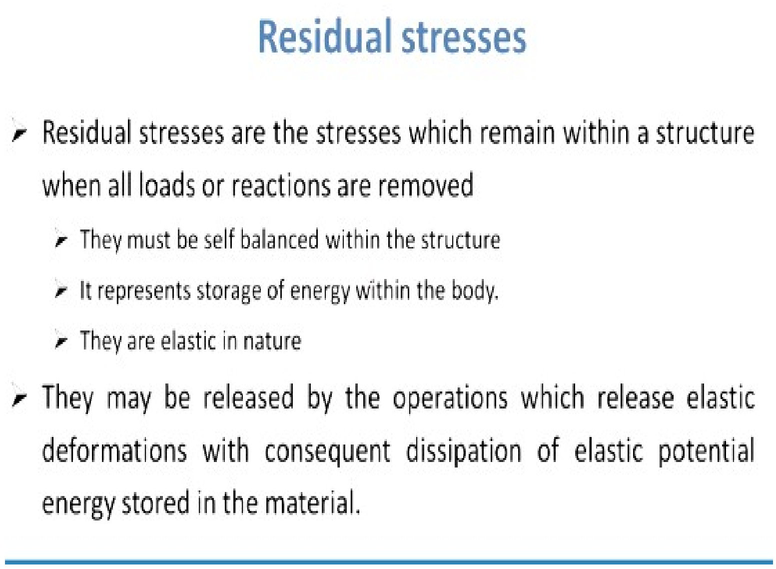

So basically as we see that residual stresses are the stresses which remain within a structure when all loads or reactions are removed. So basically you know what happens that you know the forces which are there so they are basically balanced within the body, so there must be self-balanced within the structure. So basically there are few points that it is in the absence of you know external forces which are causing them.

So these are those which are existing within the body and they are in the equilibrium within the body. So that also it will be representing the storage of energy within the body. So you know what happens that you know if and also they are elastic in nature. So what will be happening that you know when by some means you are trying to remove these you know stresses so it will go to different states.

So suppose you are subjecting the you know specimen to some heat treatment say annealing or so. So it will be coming to you know the different you know equilibrium state and the new equilibrium static equilibrium will be stored, you know, when you remove those external means so the stresses which are still there so that will be the residual stresses remaining.

So normally we try to remove them with certain means we have talked about you know few methods how to get rid of the adverse effects of the residual stresses. Then as we discussed that this is it will be representing the storage of energy within the body. So in the body you have there is storage of the energy and also they are you know elastic in nature. So although they are you know generated because of the plastic you know deformations.

But they are normally elastic in nature and they may be released you know by all the operations which you know they which release the elastic deformation with a consequent dissipation of elastic potential energy stored in the material. So in that you know you will again come to a new state and you will have the you know set of the new residual stresses in the material.

So that way you know this defines you know the residual stresses coming to the types of residual stresses. So residual stresses are defined you know as macro stresses as well as the micro stresses.

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Types of residual stresses

- **Macrostresses:**
  - May be developed by inhomogeneous plastic deformation from external loading/ non uniform heating or by varied chemical diffusion
- **Microstresses:**
  - Arise due to heterogeneities due to differences in elastic modulus, coefficient of expansion etc.
  - May develop in polycrystalline material from non isotropic behavior of the crystalline grains in the course of heating, straining or chemical change.
  - These stresses are locked within crystalline grains.

So macro stresses are developed by the inhomogeneous plastic deformation from external loading or non-uniform hitting or by varied chemical diffusion. So basically they are on the larger scale that is why they are known as the macro stresses because they are on the large scale and that is why we look at a larger perspective because of the inhomogeneous you know plastic deformation which occurs during the welding.

So you have melting and then you have the plastic deformation also you know at that particular high temperature. So you know that is because of the non-uniform heating and also because of the external loading you know also as we know that in the case of welding you have the you know varied chemical diffusion. So or alloying you can say especially you know in the surface zones you can see them.

So you know the example of these macro stresses is in the flexural stresses which you know which is developed in the hoop which is bent from the straight wire. So these are the macro stresses. Now these macro stresses can be relaxed. So you can you know they can be basically measured by the you know relaxation techniques using strain gauges. So whatever the you know macro stresses are there they can be measured from those techniques.

And so we have the you know strain gauges and then we measure, so we have there are many methods you know. So and they will be covering a large number of crystals that you are measuring over the area. So normally you calculate the average stresses which you know the stresses which you calculate they are the you know average stresses which we get in the case of the micro stresses.

Then comes the micro stresses. Now micro stresses basically arise due to the heterogeneities, due to differences in the you know elastic modulus coefficient of expansion etc. So basically they are the small scale you know stresses that is why it is known as the micro stresses. So they are the small scale you know internal stresses and they will be arising due to these heterogeneities due to the difference in the elastic modulus.

Because you have many components and they have the different properties you know like elastic modulus or the coefficient of expansion. So you have different phases which are there so and they all will be expanding and they all will be contracting, so as the temperature goes up or it comes down. So because of that there will be mismatch in these values of these you know coefficient of expansion or elastic modulus.

So you know because of that you know because of the difference in these macroscopic constituents of the material you know these micro stresses are developed. Now they also develop, they also are developing in the polycrystalline metal and that will be because of the nonisotropic behaviour okay. So you have the crystalline grains. So they are you know nonisotropic behaviour will be also developing these micro stresses.

So that is normally during the process of heating, so or you have the straining you know due to the chemical or due to the chemical change. So in these cases you have the development of these micro you know stresses in the poly crystalline metal. So you will have the interactions between the grains and accordingly these micro stresses are you know developed. Then they also are developed because of the you know metallurgical transformations.

So you know of the individual constituents, so that is may be by different processes like you have precipitation, you have phase change. So these are the you know examples of the micro stresses. So just as an example that when you are getting the you know ferrite cementite lamellae, so when you know that lamella is formed at that particular temperature that is in equilibrium you know with the matrix at that temperature.

But when it will be coming to the room temperature when the temperature will drop in that case you will have the large amount of stresses which are logged into. So that you know these type of stresses which are logged in they are the example of the micro stresses. Now coming to the residual stresses in the welds.

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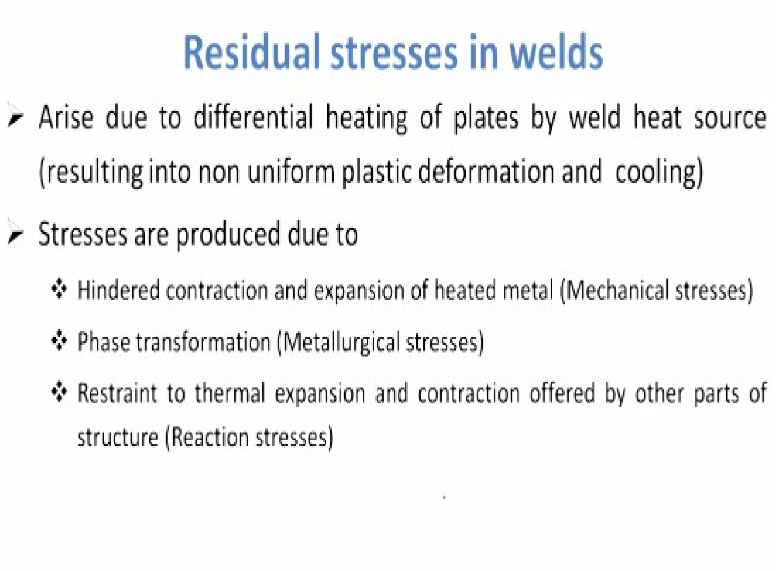

So you know that residual stresses in welding arise due to the differential heating of plates by the weld heat source. So you know that is because of the so that results into the non-uniform plastic deformation and you know cooling. So this way you know you have many reasons because you know you will have the non-uniform plastic deformation and then cooling, so that will be produced because of like hindered contraction and expansion of the heated metal.

So this is known as the mechanical stresses, so when you have the hindrance to the contraction and expansion of the heated metal because you know many a times you have the you know the equipments or the phases which are there. So you will have them as the different you know expansion as well as the contraction. So because of their you know hindering nature as they are attached to each other you will have the you know stress development inside and that is known as the you know mechanical stresses.

Then you have the phase transformation, so during the phase transformation also as there is you know transformation of one phase to other and the other phase has the different properties. It has different you know crystallographic you know parameters like it has different you know dimension of the unit cell. So that way you know in those cases due to the phase transformation you will have the development of stresses.

You know so that is normally you know happening because in most of the cases you have if you talk about the steel. So normally we are having all the processes above the you know in in the range of austenitizing temperature. So you have the austenite above certain temperature and then we are cooling it. So after cooling you have the formation of different phases like you know if you take the you know. If you take the example of say iron carbon diagram.

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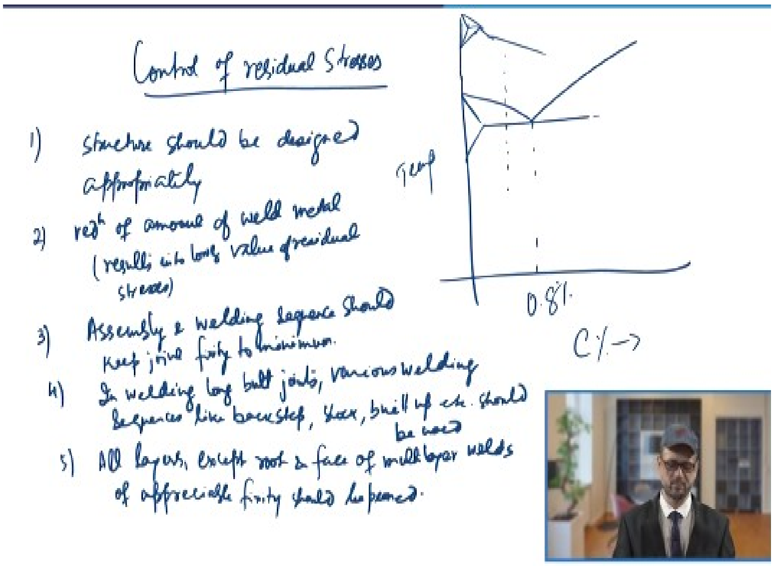

So in that case what we see so you have you know you go to you know so you are going to this zone, so at the top again you have the you know this is so this way it comes, so here that that will come so this zone so that way it will go there so it is along this scale. So now you are going into this zone. Now if you go into this size, so this is your you know 0.8% carbon so this is carbon percentage and this is your temperature.

So when you are on this side so basically what you see is you have this is the pearlite and this side you have the cementite. So that way you are you know the formation from this austenitic zone when it is coming below this temperature then you will have the formation of pearlite and the austenite even cementite on this side.

Similarly, when you are in the hypo zone, so in the hypo zone you have once you come below this temperature, then you will have the austenite which is here. So this is zone of austenite + ferrite. So you will have ferrite coming out and this side you will have the you know pearlite. So that way you will have on both side one side you have ferrite and another side you have pearlite.

So cementite again is precipitating out so that way you know these transformation which is occurring and both all these phases different phases have different properties. So because of these metallurgical transformations you know the stresses which are built in which are developed, so that is known as the metallurgical stresses. So that is because of the you know different type of metallurgical you know transformations or phase transformations.

Then you also have the development of stresses because of the restraint to the thermal expansion and contraction offered by other part of the structure. You know to which the piece is being welded is attached. So many a times we attach the pieces you know which we are welding to different you know to the sites. Now when we do the welding so as the temperature will increase.

So the temperature will increase so the material will try or the dimension of the specimen will try to increase because of you know the expansion properties of the material. So depending upon its expansion coefficient the material will try to increase in the length and when it will try to you know decrease while cooling again it will try to further decrease in length because of the you know decrease in the temperature.

Now if you are giving the constraint on the sides you are giving the restraint on the sides then that there will be stresses which will be you know generated inside the material you know because it is not getting the free hand to you know expand. So you will have you know the specimen will be subjected to some kind of you know tension or compression, because it will try to expand.

And it is you know it is stopped from there so it will be under the compression type of thing because it is going and so that way and similarly in some case it will try to come you know closer or length will be thinking of you know length will start decreasing, but then that is also restrained because of the restrain from of the 2 sides. So in those cases you know these restrain which is provided these restraints also result into the different kind of stresses.

So because of that these stresses which are you know found so which are you know you know generated they are known as the reaction stresses. So basically you have 3 kind of the residual stresses, one is the mechanical you know stresses and other is the thermal stresses and you have the you know the reaction stresses which we come across in these cases. So we must have you know the way to control these residual stresses and there are many ways you know you have to have those precautions to control these you know residual stresses.

So for controlling of the residual stresses you know there are different you know points. So first is that you know you must be you know have appropriate type of design. So structure should be designed appropriately. So basically you will have you know you should have the appropriate type of joint so that you get the minimum amount of residual stresses. So basically what we do is you know a double V groove butt joint should be used instead of single V so that way we do the balancing.

So if you have to have the joint suppose you have the chance of single V and you have the chance of you know the case of having a double V. So if you look at these you know these 2 joints so in that case the double V joint will be having more you know balanced structure. So that way you can prefer for you know the proper design having the you know double V type of joint.

Then you know the second reason what we can do is we can have. So because these are caused because of the thermal strains. So you know so if you reduce the amount of weld metal. So many a times because if you have the weld metal is in a large volume in that case the thermal strain which is generated that will be larger. So you should try to have the weld metal you know so that there is reduction in the amount of the weld metal.

So that will also lead to the lower value of the residual stresses. So that is why you should have the reduction of amount of weld metal. So that results into the lower value of the residual stresses. So results into so what you can so for example you can have the use of U groove instead of the V groove. So you know that results in the reduction of the amount of the weld metal.

Then comes that you know the assembly and the welding sequence which is followed you know so it should be keeping the joint basically joint fixity to minimum. So the assembly and welding sequence should keep joint fixity to minimum. So you know this you know this proper welding sequence and assembly should be you know maintained, so that joint fixity is the minimum in those cases, the residual stress which is you know generated.

So that can be ensured that there will be lesser amount of the residual stresses. Then you can have you know like you have the different type of welding processes like if you have the longer you know butt joint so various type of welding sequences are there like you have the backstep welding is there then you have built up cascaded and all that all those phenomena are there.

So these are basically used to reduce the residual stresses. So you know in welding long butt joints so you have the various welding sequences like so you have the various welding sequences like backstep then you have block, you have built up all that you know, this would be you know used should be used. So this is used you know with an aim to reduce the residual you know stresses and then because we will also discuss about the effect of the residual stress because that also leads to the distortion of the workpiece.

So if that is reduced then the extent of distortion is also you know reduced. Then you know if we talk about you know the multi-layer welds. So you know what we do normally that you know in the case of multi-layer welds we have we normally adopt the practice of pinning. So basically when we go for the multi-layer welds. So you know in those cases all layers except you know the root and face of the multi-layer welds.

So of appreciable fixity should be basically pinned. So now you know what we do is that in those cases you know as we go on giving the layers one by one in those cases in the case of multi-layer welds. So there this is a common practice to have the pinning of the layers. So if you go to the next layer we do the pinning and then further we go to the next layer. So we deposit the next layer.

So that basically reduces the you know the residual stress to a large extent. Then we have also to see that so the next point will be so you have we have discussed about the five points.
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6. Introdn of bending stress in welding should be avoided.

7. Material of objects (specimen / electrode) should be selected carefully.

8. Cracked tack welds should be chipped or melted out before welding the work.

Then what happens that you know we should avoid you know while we are talking about the you know appropriate sequence of welding and all that we should also avoid you know in any case the bending stress which are likely to be formed. So basically you know the introduction of bending you know stress in welding should be avoided. So basically you should have you know while we talk about the assembly or while we talk about you know the sequence at that time we must have this thing in mind that the bending stress should not be developed.

Then you know also what is important is that the selection of the electrode you know and for the material which you are welding that also should be selected very carefully because you know if there is a change in the properties of the you know materials which is used for the you know electrode which is vastly different from that of the material which is to be welded in those cases there is a likelihood of the development of traces.

So material of objects you know so the specimen and electrode should be selected carefully. So because you know accordingly you know because if there will be changes in the properties of the materials you know so that way you have you must have the you know at the most possible the uniformity in the materials and then for also for the as far as the process is concerned.

So you know when you know cracked tack welds should be chipped or melted out before welding the work. So now you know if you have the cracked tack welds and the cracks are basically very much you know stress raiser so in those cases they will be chipped so that cracks should be you know chipped off.

Or else you know it should be melted that there should not be any cracks. So if the crack is there you know that leads to the development or the increase in the value of the stresses. So that is you know another way of decreasing or controlling the residual stress values. So this is about you know the residual stress and it is control. Thank you very much.