Theory of Production Processes

Dr. Pradeep Kumar Jha
Department of Mechanical Engineering
Indian Institute of Technology, Roorkee

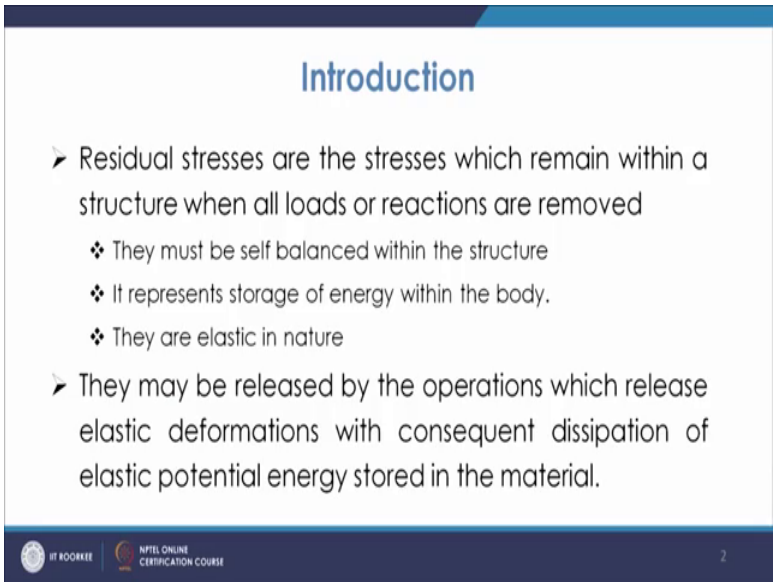
Lecture – 51
Residual Stresses in Welding

Welcome to the lecture on Residual Stresses in Welding. So, in this lecture we are going to discuss about the formation of residual stresses which are generated during the welding process. As we know that during the fusion welding process the temperature is reached to a very high level and from there you have a further a very fast cooling rate because of the presence of a metal all around because when we are doing the fusion welding of metallic plates so, you have on both the sides you have metallic plates and then you are also doing the welding so, by using the filler metal.

So, in the weld metal zone you have formation of weld metal pool so, that is in liquid state so, certainly you are increasing the temperature by a certain heat source. Now once the temperature is reached to the fusion point or the melting point more than that so, they melt the localized area and after that they are cooling. So, for cooling that is very small quantity of weld metal in the pool and the cooling is done very fast because it is exposed to atmosphere as well as on the sides is they have the metal in contact. So, that is fast cooling.

So, because of that and also there are a lot of other parameters there are other constraints. So, and so, because of the larger cooling rate because of the other constraints like you know restraint because of certain type of members or so. So the stresses are developed and these stresses are logged in inside the material. So, they are basically known as the residual stresses. So, residual stresses are the stresses which remain within a structure.

(Refer Slide Time: 02:31)



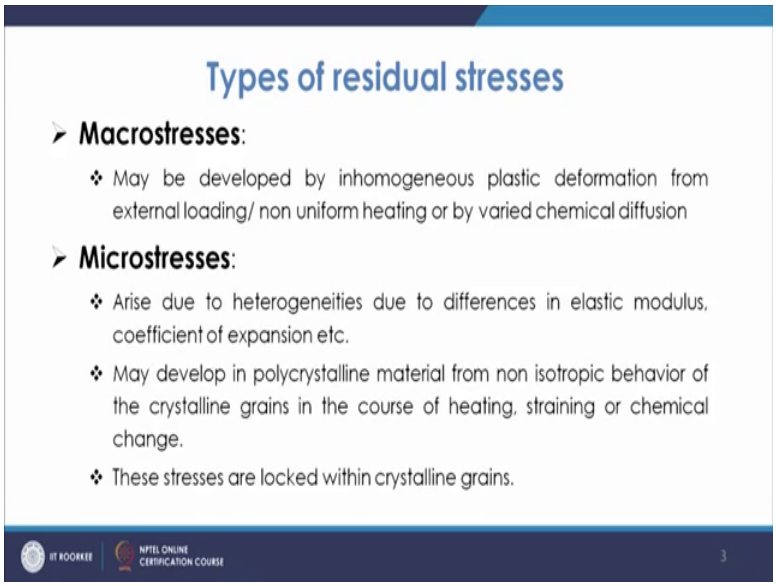
When all loads or reactions are removed means that when we do the welding then once we are removing the welded specimen then as it is there you know when it is removed from all the reactions or all the support or so.

Then, the stresses which are still remaining inside the body that is known as residual stresses; so the traits of these residual stresses are that they must be self balanced within the structure. So, structure is there and you have the stress values it may be different at different points which are generated at different points may be because of the different varying cooling conditions or different conditions so, but then they are all self balanced within the structure and the structure a structure is as it is. So, as we have supplied energy into the body so, that represents so, the presence of residual stresses they represent storage of energy within the body and they are elastic in nature.

So, being elastic in nature they can be released by the operations which release the elastic deformations with consequent dissipation of elastic potential energy stored in the material. So, you have a different type of you know methods by which you can release these stresses, but then that further may lead to formation of a different set of residual stresses. So, you can do suppose the heat treatment we can do for removing the residual stresses, sometimes you can apply the stresses of I mean forces also to remove the stress may be or we may use the application of heat to remove the residual stress in certain part.

So, this way we can control this residual stress or diminish the value of residual stresses, but then all these methods may also further generate the residual stresses in some other sense. So, this way the residual stresses are there in the material. Now, when we talk about the residual stresses then they can be classified.

(Refer Slide Time: 05:02)



Depending upon what is the magnitude or on what scale we are viewing that. So, we can view them as either macro stresses or micro stresses. So, as the name indicates macro stresses means they are developed by inhomogeneous plastic deformation from external loading or non uniform heating or by varied chemical diffusion.

So, basically when we talk about macro means maybe on the larger scale. So, when we talk about the larger scale not confined to the one grain or so, very small places when we talk on a larger scale then it is macro scale. So, basically when we do the plastic deformation, when there is plastic deformation even during the welding also we have um. So, this phenomena because we are heating and then ultimately the plastic deformation also takes place and then they are further cooling. So, all that so, because of that or you have non uniform heating or maybe you have also a chemical diffusion which is varied at different positions.

So, so, all these basically develop certain type of stress in a macro zone. So, it is basically evaluated for many grains all together in a certain means large number of grains all together and you are basically evaluating the value of a stresses. So, that is known as

macro stresses so, just like you have the in a hoop. So, if you find that from a bent wire so, the flexible stress which is developed that is the example of the macro stresses.

Now, these macro stresses they can be measured by the relaxation techniques. So, we use the strain gages and then depending upon the a strain which is being experienced by the strain gages we find the value of you know stresses. So, being elastic in nature you can find the value of the stress which is logged in so, that way we can find these stresses.

Next is the micro stresses so, micro stresses are you know developed due to the heterogeneities and due to differences in elastic modulus. So, you have if you look at the material it is a poly crystalline in nature. So, every phase or every part of the material does not have the same property. So, you have the difference in the properties from point to point and that is why you have the heterogeneity and it may be due to the difference in the elastic modulus because if you have 2 different materials or 2 different phases you have the different elastic modulus of the 2.

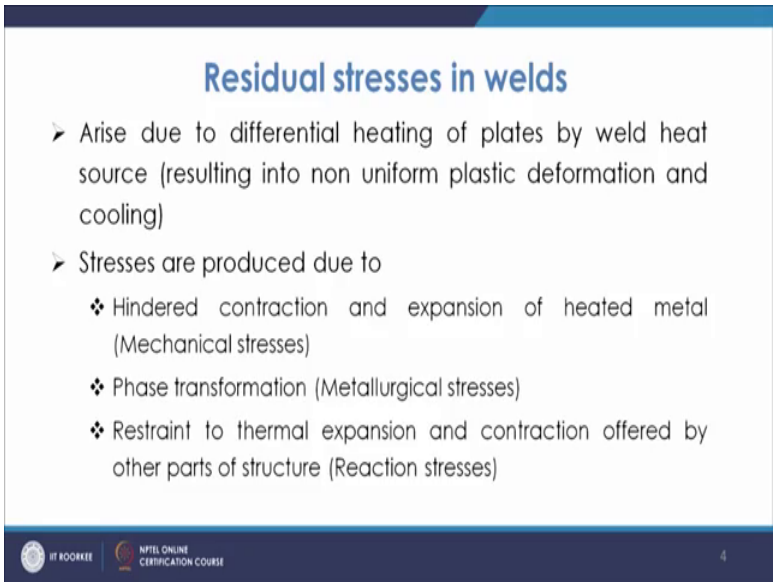
Similarly, the 2 will have a different coefficient of expansion like if you have suppose austenite and ferrite or austenite, martensite and all that or conversion from one to other. So, they have the different properties and because of that the stresses which develop so, that is known as the micro stresses. So, as we discussed that normally in the case of poly crystalline materials so, because of the non isotropic behavior of the crystalline grains in course of heating or straining or chemical change these type of stresses may develop that is micro stresses.

So, normally these stresses are logged within a grain. So, that is why they are known as micro stresses because you know they are measured for typically for one grain or 2 grain or so, on the grain basis. So, that is why they are known as micro stresses.

So, typically we have a basically 2 kinds of a stresses we have just developed that is a macro stresses and micro stresses. Macro stresses will be because of the inhomogeneous plastic deformation and macro stresses will be because of this mainly macro stresses resulting because of the transformation of phases from one to other during the as in the case of welding you have the transformation of phase from liquid to solid.

So, you have because of the because of the formation of transformational products you have the formation of these micro stresses.

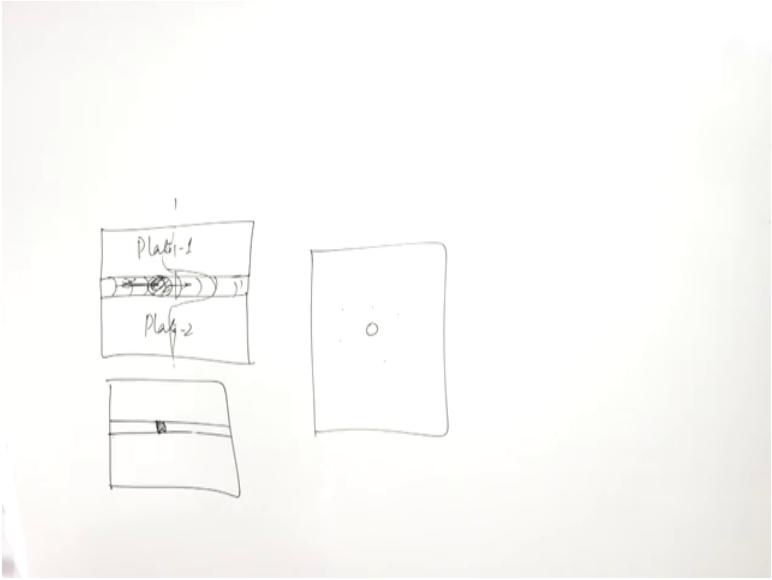
(Refer Slide Time: 10:12)



Coming to the residual stresses in the weld so, when we talk about the welding, the residual stresses are developed or they arise due to differential heating of the plates by weld heat source. So, you have a heat source and because of the differential heating of the plates they result and because of that they result into a non uniform plastic deformation and cooling also.

So, non uniformed plastic deformation and cooling is you know there that is the reason because of which the there is differential heating and then that is why these residual stresses are developed. So, now when the residual stresses are developed they are developed because of the following reasons, one is hindered contraction and expansion of heated metal. So, you know many a times what happens that you are heating in a localized area and it will try to so, once it is heated then it will try to expand.

(Refer Slide Time: 11:30)



So, for example, if you look at the members so, suppose you have a 2 members and this is the portion where you are doing the welding. So, these are plate 1 and this is plate 2 and here you are doing the welding suppose so, this is the welding. Now, what happens that when you are welding this when the heat source is in this you are heating in this region and this is the heat source. So, what happens this zone is becoming heating heated and once becoming heated, it will try to expand.

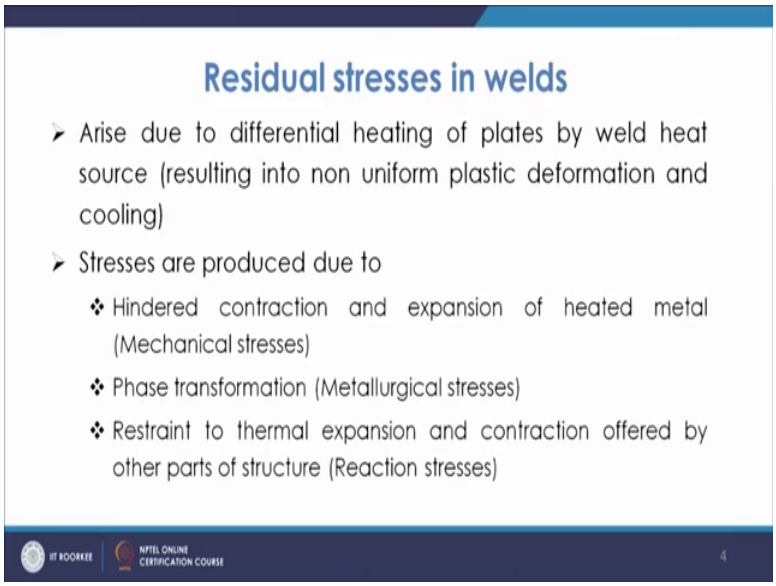
So, it will be experiencing a type of you know so, it will be expand it will try to expand on both the sides. Now, these plates are basically cooler as compared to this zone. So, it will try to restrain it from heating. So, this region will try to expand this region and this region will try to contract this reason. So, a type of so, because of the resistance which are offered by a one by each other so, this is trying to expand and it is trying to restrain it. So, it will be experiencing a type of compressive stress.

Similarly, this will be and this will be try, this will be subjected to a type of tensile stress because once it is heating then it will try to expand it. So, you have this plate this plate will be subjected to some kind of tensile stresses and this middle portion which is the heated one it will be subjected to the compressive stress during the heating cycle. Now suppose you are cooling so, once you are heating during that process that kind of the variation of stress occurs. Now when it is cooling at that time this portion will so, this is during the heating stage.

Now, when it is cooling the trend is opposite when you are cooling at that time this will be trying to you know contract because the temperature you know falls very rapidly and because of it is temperature high temperature these are all heated now. Now the thing is that it tries to get contracted and this being heated this will try to oppose it. So, there will be a tensile type of you know stress which will be subjected so, this portion will be subjected to a tensile type of a stress and this portion will be subjected to a compressive type of a stress.

So, this way you have 100 contraction and expansion of the heated metal and this way the stresses are developed. So, that is what the concept of the hindering of the contraction or expansion. So, one of the element is trying to expand another is trying to you know contract so, you will have the formation of the stresses and the stresses may be of a varying nature, it may be tensile or it may be compressive. So, that is so, the formation of such type of stresses they are known as mechanical stresses then you have the phase transformation.

(Refer Slide Time: 15:13)



Now, what happens that during the phase transformation when the different phases are formed then you have suppose in the case of a steel based castings or so, medium carbon steel or so, when there will be transformation from austenite. So, when there is electro transformation taking place, when austenite will be transforming to ferrite and cementite or austenite will be transforming to martensite. So, in those cases the there will be you

know because they have the different properties. So, because of that because and also there you know as we know that it have to be different c by a ratio or they have different you know you know crystal structure or so.

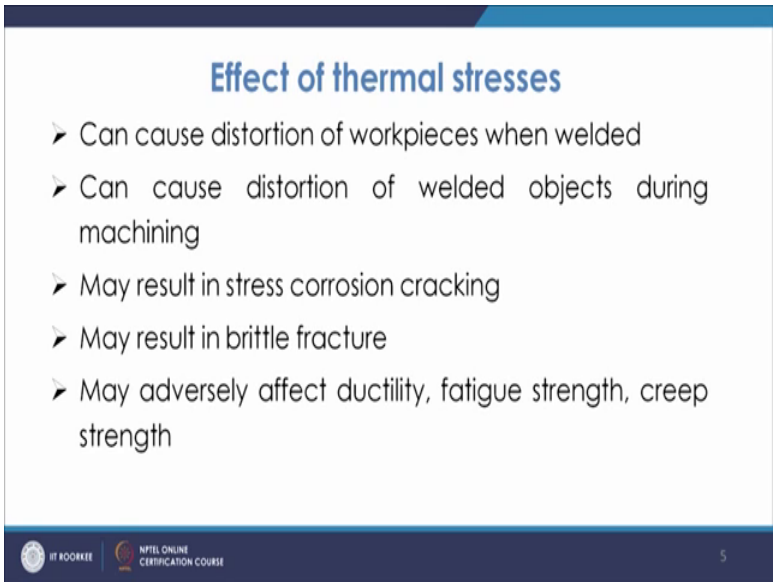
So, because of that when they are transformed as we know that because of the transformation from austenite to martensite you have a lot of stresses are developed and these stresses only are the reasons of very high strength of the martensitic phase, but then the stresses which are developed they are known as metallurgical stresses. So, these residual stresses it is not necessary that every time they are not desirable. So, they may be desirable also, but then suppose if you take the example of metallurgical stresses then in certain cases it may be beneficial and in certain cases it may be not if the stresses level are too high in that case it may be it may not be the beneficial one.

So, such type of a stresses which are formed because of the phase transformation they are known as the metallurgical stresses. Then comes another type of a stress which are developed is the reaction stresses. So, what happens that many a times when we are welding suppose we are welding you have a some type of a structure where we have the 2 and this is we are doing the welding here if you are doing the welding here. Now, once you are doing the welding the stresses are developed into this and it will try to expand or contract depending upon the temperature conditions or the cooling conditions.

Now, since it has a restraint from the sides, it cannot freely move to any place because it is either fixed at these ends or in whatever way there they may be having a certain kind of a joint. So, in that case the since they are not free to move and since there is expansion or a contraction taking place because of the change in the temperature, because once you have the welding going on it will be leading to increase in temperature. So, once they are trying to expand or contract and there is restraint from the sides then that will lead to the formation of stresses inside the body.

And this is because of this restraining action and such you know stresses when they are you know generated they are known as reaction stresses. So, you have basically the mechanical stresses, metallurgical stresses and also the reaction stresses which are formed in this these are the 3 types of a stresses. Now, let us discuss about the effect of these thermal stresses. So, the thermal stresses was developed they can cause distortion of the workpieces when welded.

(Refer Slide Time: 19:01)



So, when you are doing the welding at that time because of the development of these thermal stresses, because of the temperature you know at which it is subjected to at the large temperature which is it is it is subjected to that can lead to the formation of residual stress and because of that even the material can be distorted, it can be out of it is shape.

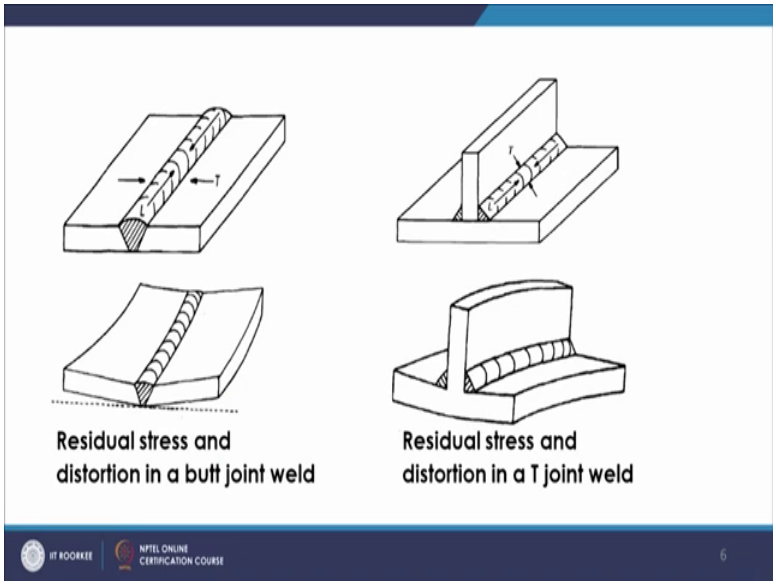
So, if the residual stress level becomes of larger value then that may distort the material, that can cause also the distortion of welded object during machining. Many a times what happens that when you are taking the welded material out and when you are doing the machining so, in that case the stresses may be released from certain point. And maybe because of that because we know that it is it has to be self balanced in itself. So, many a times we can see that because of the imbalancement of stresses or because of the improper value of stresses are different points, it may so, happen that there may be the distortion of these welded objects during the machining process itself.

So, that result that job may be out of it is shape. Because of the temperature because of the formation of a different type of undesirable you know constituents at inappropriate places inside the grain, there may also be the problem of stress corrosion cracking. So, so, in that case you may have the cracking developed and mostly what happens that that affects the type of a fracture it is subjected to many a times.

So, it may be a ductile fracture in normal case mainly may you know may convert to a brittle fracture type of mode. So, that is there in the case of the formation of these thermal stresses.

it may also adversely affect the a ductility, fatigue strength and creep strength. So, this basically they decrease the value of these ductility or fatigue strength or creep strength.

(Refer Slide Time: 21:31)

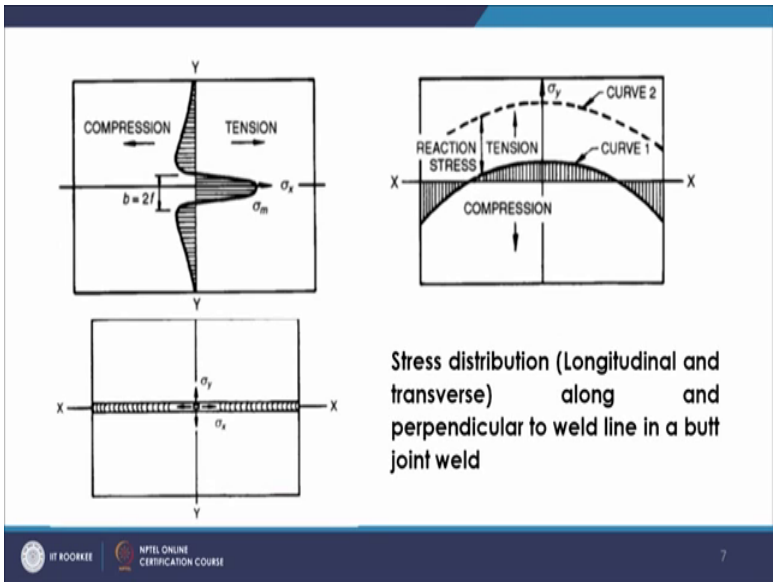


Coming to the different kind of a residual stresses which are formed and then how their distortion is produced if you look at so, as we see that you have you know in a butt joint weld you can have the stress formation and then further you may have the distortion in the so, this is the longitudinal stress.

Similarly so, that is so, denoted by L and the T denotes the transverse stresses so, transfer direction it is. So, when you have a stress formation in that in that direction when we talk about this is longitudinal stress and this is the transverse stress and because of that you can see that you may have the shape getting out of the normal one. So, this could have been flatter one and it becomes something like the moving one. So, that is in the butt joint weld typically it is seen.

Similarly, if you look at a T joint weld if we are also you have the formation of the longitudinal stress as well as a transverse stress and because of that you can see that how it is a shape is distorted. So, that leads to the distortion in a T joint weld.

(Refer Slide Time: 22:55)



So, this is because of the formation of this residual stresses, now what we discussed earlier that when we see that how this is a longitudinal and transverse a stresses basically vary.

So, what you see is if you look at this figure what you see is that as we discussed that in this case while heating while heating this will expand and the this will be subjected to the tensile and it will try to you know stop the expansion. So, it will be subjected to compressive force, while when it cools finally so, when because finally, it has to cool and come to the original temperature.

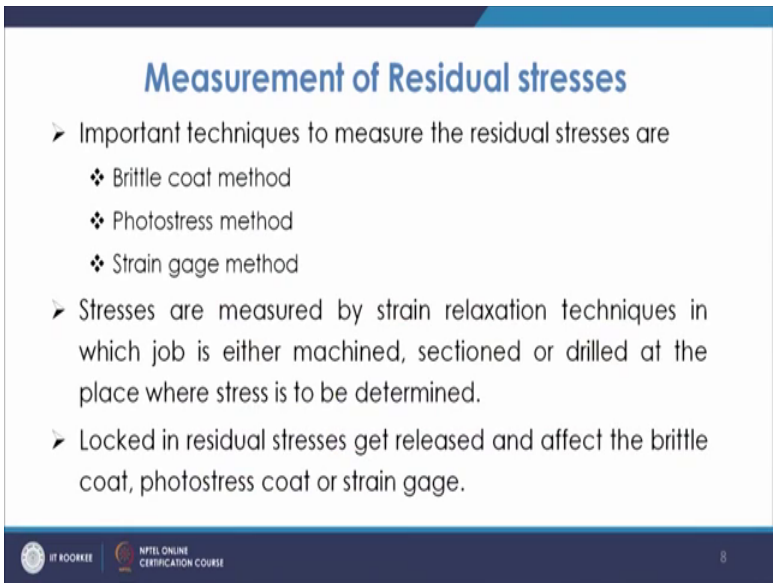
So, while cooling it will try to expand and this portion will try so, to put a restraint on that. So, basically this will be subjected to a tensile type of a stress. So, that is why you see that in this middle portion if you look at in this middle portion you will have the this tensile stress.

So, this region if you look at so, that is why if you look at this what you see is that you get such kind of a such kind of a distribution. So, that is what it is seen that in the middle portion when you are talking about this a longitudinal side we are looking at this section. In that section the this portion is subjected to the a compressive stress because in the end it tries to be remaining in the expanded state and this is trying to contract it. So, this is basically developed this is leads to development of a 10 a compressive type of stress in this region.

Similarly, this region tries to get contracted and these 2 regions try to get it pulling. So, you have tensile type of stresses development is developed and that is why in this zone you have the development of the tensile stress and that is how it goes. Now, if you look at the transverse one if you look at this section. So, in this section you have such kind of so, you have a tensile in the middle and here you will have the a reaction stresses and then you have tension in these this portion. So, this way you have a tension as well as compression stresses which are developed in the case of the in the in the case of this transverse. So, transverse stresses are developed and it is distribution is like this one.

So, this way and we have to be careful that these stresses value should not reach larger than the yield point. So, basically when the these values rich then more than the yield point of the material that may lead to some kind of deformation plastic deformation or so. So, that is what the you have to be you know aware off. Now, the thing is that you have a certain methods of the measurement of residual stresses.

(Refer Slide Time: 26:25)



So, you need to know the different methods of measuring the residual stresses and the residual method stresses are measured based on 3 important techniques are there, there are although few more. But these are the 3 important methods brittle coat method, photostress method and strain gage method and mostly strain gage method is the most popular among them where we use the strain gage or resets to find the stress value.

So, the concept is that when you have a specimen and you feel that it has the residual stresses you know in the specimen then you have to locate that region where you have to find the residual stresses and you have try you try to relax this material by doing certain technique. So, that is strain relaxation so, what you do is by you normally drill at that point a hole so, once you dry drill the hole the strain stress will be relaxed so, a stress will be released.

And in fact, what happens that that will lead to the change in the strain suppose at this point you are doing a drilling. So, the strain gages or a rest of raw sets which are there at different point, that may lead to that may have the there may be some a displacement in them or there will be some strain because the stress being released. So, that may lead to those a value of a strains at these points.

Now, these a strains at those different points that may be calculated that may be measured using the strain gages and then using the so, depending upon the in what you know you are doing the biaxial or a uniaxial or triaxial state. So, you can find further you can find from there using the property of a elasticity, you can have the calculation of a stress value at this point.

So, that is the main concept of measuring the residual stresses. Now, in that you have the brittle coat method so, in the brittle coat method you have basically having a brittle coat on the surface and we also apply you know you know you apply polish with aluminum. So, that surface is quite shiny and then when the drilling is done and the in that case that there will be cracks develop. So, when the residual stresses are released the cracks develop because of the brittle coat which is there on the surface.

So, and these cracks which are also developed, normally the cracks also have you know a certain say they show that from where the crack is developing. So, in this case certainly whether where we are drilling from there you will see that the cracks are developed. So, in that case and depending upon these positions of the how these cracks are developing and you have a calibrated cities there. So, based on that do you know you can have the calculation of the residual stresses by comparing the results of the stress coat on job with that of the calibration strip.

So, that is done in the case of these brittle coat method and then you have similarly you have the photostress method where so, in the case of a photostress method you have the

basically the use of a photo elasticity which is there in that case. And in this case you know photo stresses are acting as basically the infinite number of strain gages. So, which are practically of 0 gage length and then they are uniformly distributed over the surface. So, you have this on the surface of a welded object and they are applied on the coated surface that is a aluminum spread surface and there will be polymerizing first on that.

And then against in that case also the hole will be drilled and the strains will be relaxed so, a stresses was relaxed. So, from the removed material that will affect the photostress coating. So, again the there will be affect effect on the photostress coating and it will be becoming the by so, the there will be basically you know refracting because once there will be cracks there will be refracting and that basically you will have the plane polarized light.

So, that will affect this photostress material and then you can you know further that will material will be changed into to the 2 components and that will be mutually perpendicular rays and then in the direction of a stress you can calculate the stresses.

So, that you can further study and you can have a more idea about the these methods, another method is the strain gage method where you have the surface again you have the drilling at one point and your formation of strain resides or a strain gages at the points. And then the value of strain will be calculated after drilling and based on that you can have the calculation of these stresses. So, this way you can calculate these residual stresses from the specimen.

Thank you very much.