Welding Engineering
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Module - 5
Heat flow in welding
Lecture - 6
Residual Stress - II

So, this is the sixth lecture of the module 5 which is based on the heat flow in welding. And we know that for developing the weld joint when heat is applied onto the faying surfaces of the plates to be joined, very localized heating and cooling takes place during the welding. And this localized heating and cooling results in the differential expansion and contraction of the regions close to the fusion boundary of the plates being welded. And this in turn results in the residual stresses in the weld region as well as the, in the heat affected zone.

In the previous presentation we have seen that there are three different mechanisms that contribute significantly towards the development of the residual stresses. These are the thermal stresses which are which mainly develop, because of the differential heating and cooling. And the second mechanism was the quenched stresses and the and those stresses develop mainly due to the differential cooling rate experienced by the top and the bottom surfaces as compared to that of the core region of the plates being welded.

And the third mechanism was the transformation stresses which are developed basically due to the transformation of austenite into the other phases like the pearlite, bainite and the martensite. We have also observed that those transformation which occur at the higher temperature they lead to, they contribute marginally towards the development of the residual stresses, but the transformations occurring at the lower temperature, they contribute significantly towards the development of residual stresses. And under this category we have seen the transformation of the austenite into the martensite contributes towards the development of the residual stresses.

And the type and nature of these stresses are primarily governed by the location where this kind of the, this kind of transformation are taking place. In this presentation mainly we will try to see that what are the important effects of the residual stresses on the performance of weld joint and the how the, what are the factors that can affect the development of the residual stresses and what can be done in order to control the development of the residual stresses in the weld joint. And if at all any distortion is taking place during the welding or after the welding then what can be done to control the distortion in the weld joints which is mainly caused by the development of the residual stresses in the welds.

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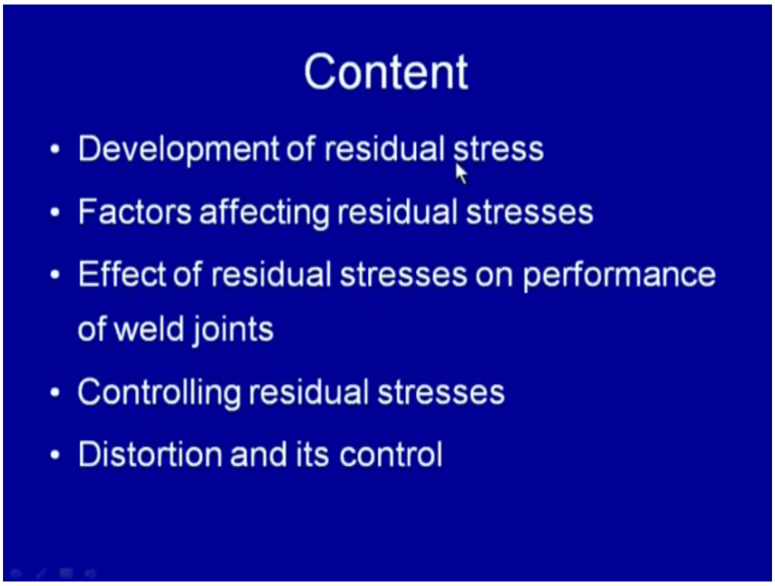

So, as far as content of this presentation is concerned we will be talking about the development of the residual stresses which mainly will be seen in that, in the way by which or the type of the stresses which develop in the different zones of the weld joint. Then we will see the factors affecting the residual stresses and the effect of residual stresses on the performance of weld joint. And then what can be done to control the residual stresses and if at all any distortion is taking place then how to control the distortion.

So, what are the common types of the distortions which are experienced by the weld joint during the welding and how we can control them? That will be taken up at the last part of this presentation. We know that weld joint is, weld joints during the welding we apply the heat in very localized manner and because of this very differential expansion and contraction is experienced by the metal near the fusion boundary and this in turn results in the significant residual stress development. So, if we have to see this, we can see this using this simple diagram.

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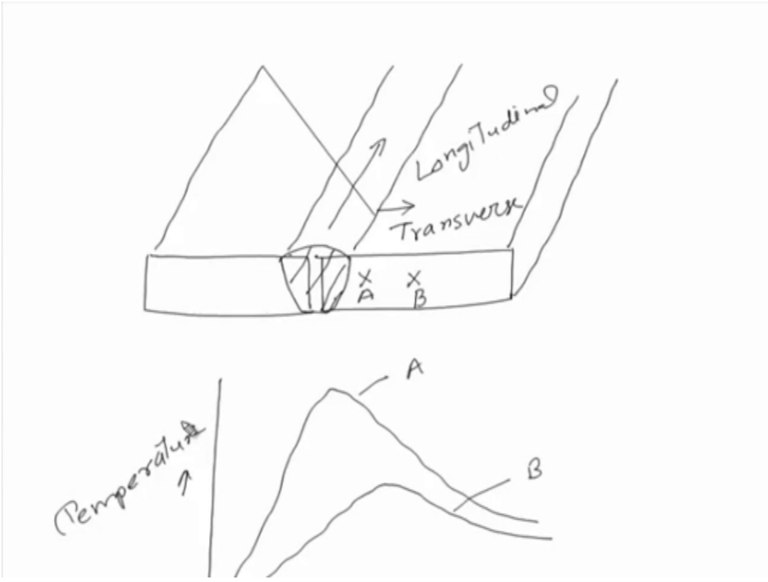

Like these are the plates being welded by and the heat is applied using the suitable heat source and the faying surfaces are brought to the molten state to develop the weld joint like this. And the different locations close to the fusion boundary are subjected to the different peak temperatures, and so the different peak temperatures for location A and different and location B.

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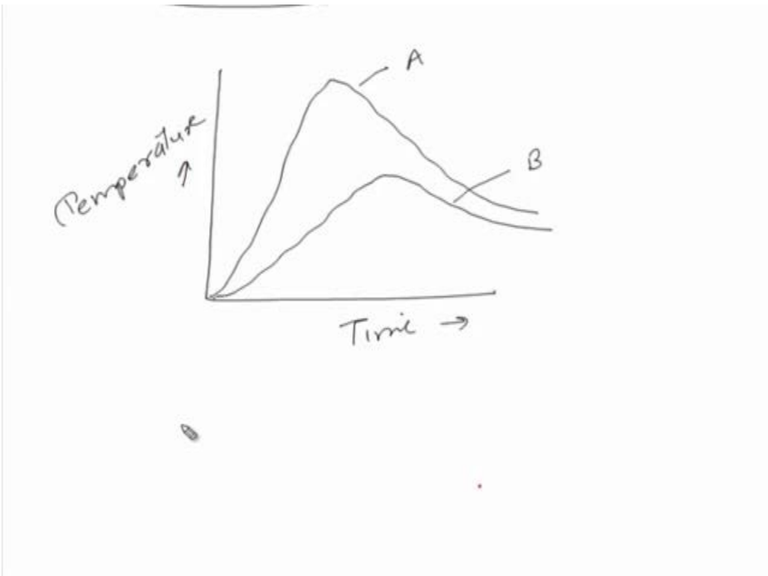

And respective weld thermal cycles will be of the different. The heating and cooling rates with the different peak temperatures say this is for the B location and this is for location A. So, location l will be experiencing higher the peak, higher peak temperature and the higher cooling rate. So, obviously because of the higher peak temperature location A will be subjected to the greater expansion and subsequently greater contraction while the location B will be subjected to the lesser expansion and the contraction. And because of this differential heating and cooling of the different locations especially close to the fusion boundary the residual stresses develop.

So, if we take up, this is the line along which the weld you can say this is the thickness of the plate, this is the direction in which the weld is being made. So, this is the, this direction is termed as the longitudinal which is in the direction of the welding. And the direction perpendicular to the direction of the welding is called as a transverse direction. So, the residual stresses develop in both the directions longitudinal as well as in the transverse directions. And the magnitude of these stresses is primarily governed by the amount of the heat which is being applied for development of the weld joint.

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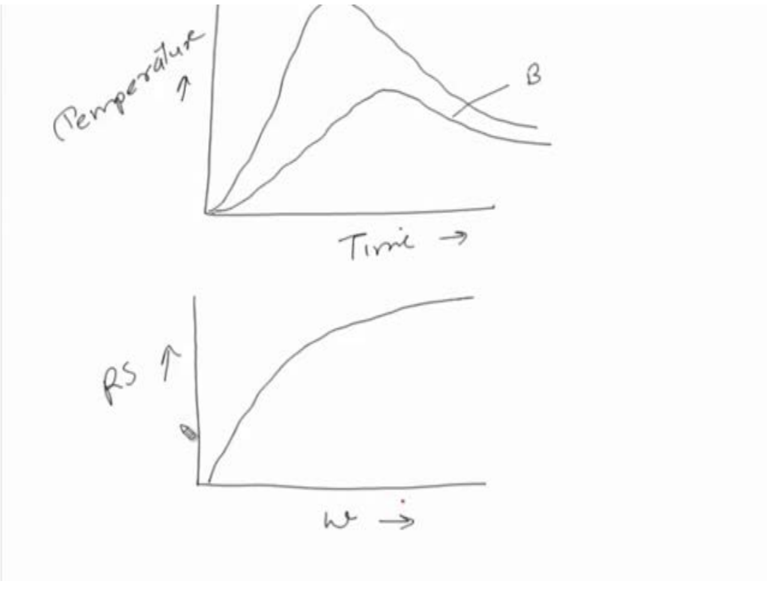

If the, if the more amount of the heat is supplied for melting the faying surfaces and the lot of weld metal is deposited then subsequently on contraction this results in the huge magnitude of the residual stresses in the weld joints. So, in order to avoid that kind of possibility efforts are always made to deposit the weld metal as less in quantity as possible. And with the help of the heat which is as less as possible. So, the weld joint must be designed in such a way that the weld can be made using the least amount of the weld metal and with the minimum amount of the heat input to the plates which are being welded.

So, if we have to study at all anything then the, if we try to see the relationship the residual stresses that develop and the weld metal being deposited. So, amount of the weld metal being deposited and the residual stresses, these are very directly related and we can see that these increases with the increase of the weld metal. So, if we can see here in axis we have the amount of weld metal being deposited and in the y axis we have residual stresses being developed.

Then the, these; the, with the increase in the volume of amount of the weld metal being deposited per unit length there will be continuous increase in the residual stresses that are being developed. Further, if we try to see that then the how the residual stresses develop in the different directions. So, to understand this, the residual stresses being developed in the transverse as well as in the longitudinal directions we need to see this another diagram in the longitudinal directions.

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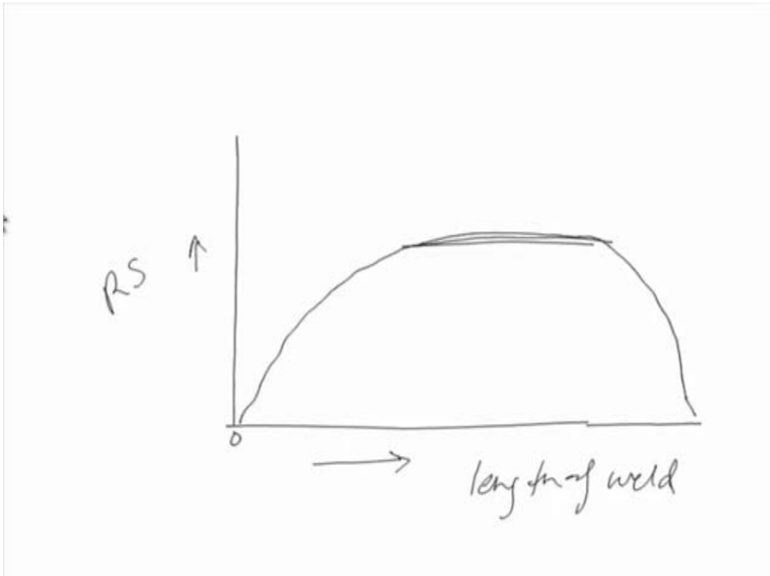

Residual stress mainly in the direction from the end of the plate if we consider the 0 distance and with the increase in distance from one side to the another along the weld centre line the magnitude of the residual stress increases gradually and it becomes maximum and then it tends to become 0 again. So, this is what we can see. At the ends, this is one end, and if say this is the another end of the weld. So, the residual stress magnitude will be maximum in the center of the weld, about the center of the weld and this is the length of the weld and here in y axis we have residual stress magnitude. So, the magnitude of residual stress increases with the distance from the ends of the plate and it becomes maximum at the centre of the weld. So, this is what we will see in this presentation starting with the…

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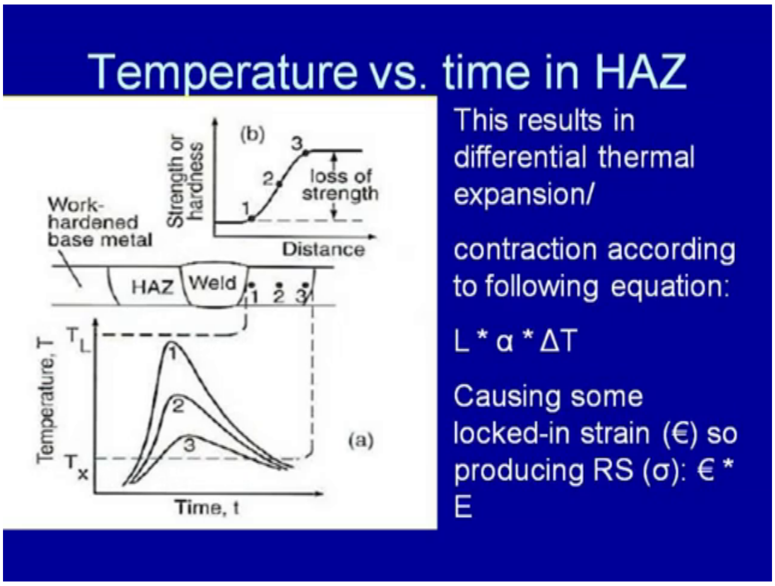

This is what I have made that if this is the weld joint which is being made then at different locations we will have different peak temperatures and corresponding the weld thermal cycles are shown here. So, because of this differential expansion and contraction some amount of the strain is always left. So, that amount of the strain which is left after cooling down to the room temperature if this is multiplied by the modulus of elasticity of the material we can get the amount of the residual stresses that are being locked in.

So, if this expansion and contraction during the welding is freely allowed then there would not be any residual stresses, but in actual practice since the heating and cooling takes place in very localized manner during the welding. That is why there is always some amount of the locked in strain which is left in the weld joint. And this locked in strain if it is multiplied by the modulus of elasticity then this results in the, this can be used to obtain the residual stress magnitude being developed at a particular location.

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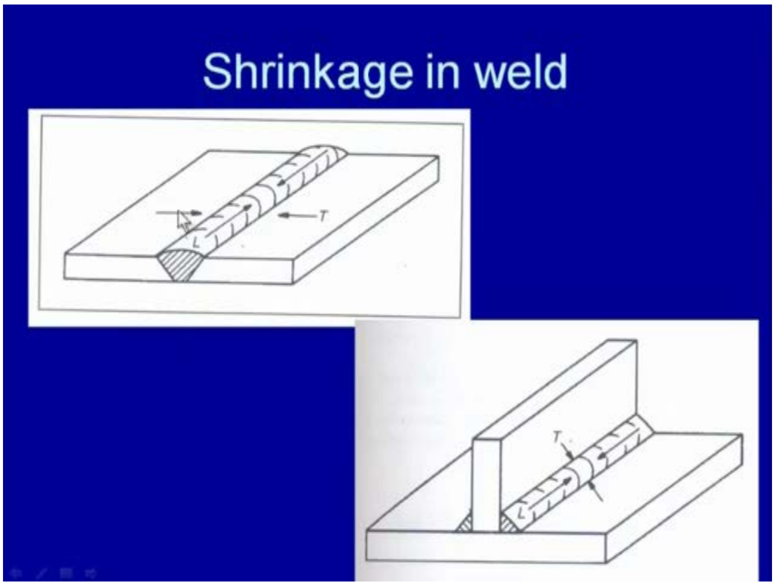

And the two kind of, the kind of because of this differential expansion and contraction we may, we mainly observe these are the two kind of phenomena. One is due to this shrinkage of the weld in the literal direction that is perpendicular to the longitudinal one in literal direction; the shrinkage of the weld metal reduces the width of the width of the plates with the weld joint because of the transverse shrinkage. So, transverse shrinkage will be occurring due to the shrinkage of the weld metal in the transverse direction that is this direction and the longitudinal shrinkage that that the shrinkage which will be occurring in the direction of the weld.

So, the two types of the shrinkages are observed in the weld joint. One, perpendicular to the direction of weld that is the transverse shrinkage and the another shrinkage which will be occurring in the direction of the weld that will be the longitudinal shrinkage. So, longitudinal shrinkage will be occurring along the length of the weld and the transverse shrinkage will be occurring perpendicular to the direction of the weld. Similarly, we can see in case of fillet welds the transverse shrinkage will be occurring in this direction and the longitudinal direction, longitudinal shrinkage will be occurring along the length of the fillet weld.

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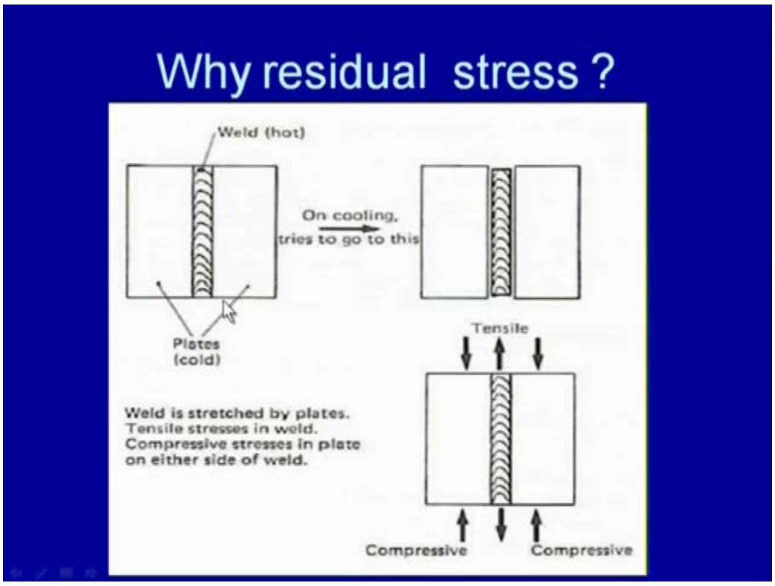

And when a since the weld metal is very rigidly attached with the plates being welded and because of this the longitudinal shrinkage is not allowed much. If it is allowed then there will be reduction in the length of this plate. Since, this reduction in the, reduction or in length or the contraction in the weld size is not permitted and because of this it results in the tensile residual stresses along the length of the weld.

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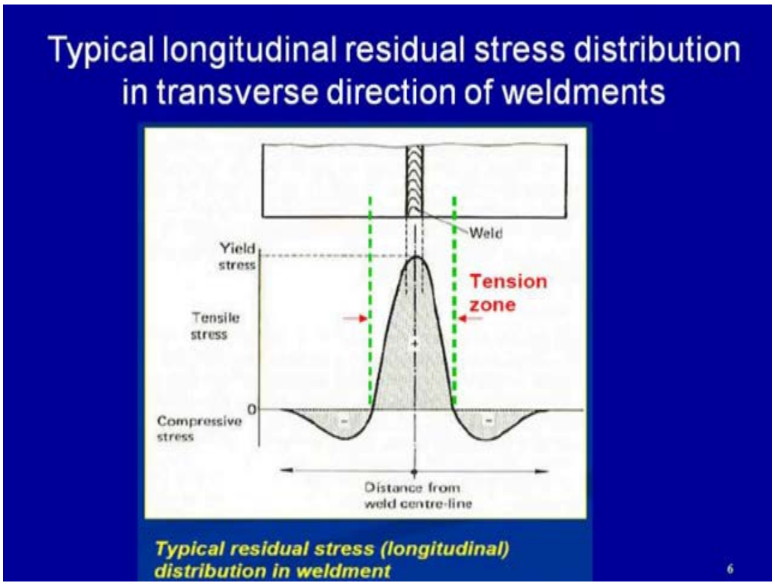

And the compress residual stresses in the region close to the weld region. And this in turn results in the very high tensile residual stresses along the weld line in the longitudinal direction and the compressive residual stresses in both the sides of the weld zone. So, this is what we can see if we consider the stress distribution in the longitudinal direction.

Then means along the direction the residual, longitudinal residual stresses and their distribution in transverse direction of the weld and the longitudinal residual stresses will be maximum along the weld centre line. And they are tensile in nature while in both the sides we have the compressive residual stresses. So, now we need to see what are the factors that can affect the magnitude of these stresses being developed in the different directions of the weld? So, to understand that we need to see the thermal properties.

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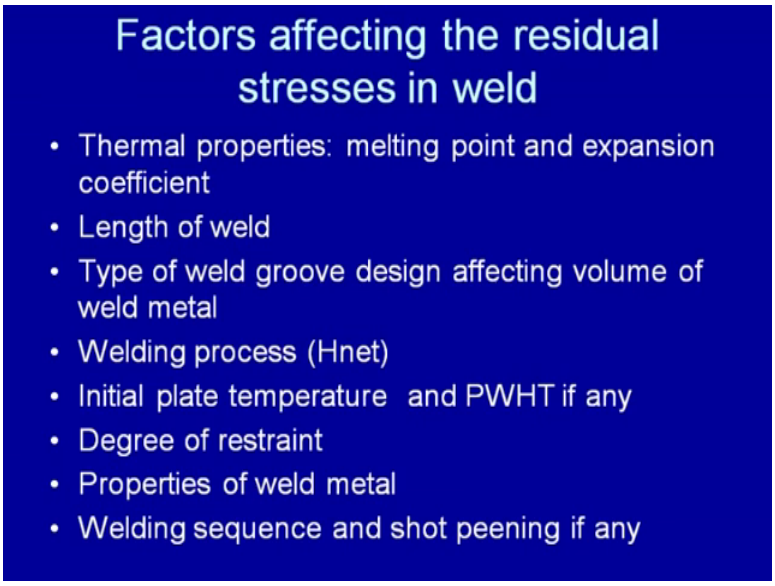

We know that the residual stress magnitude is primarily governed by the, governed by the thermal properties of the material like the melting point and the expansion coefficient. Because the locked in strain is found the function of the length of the weld which is being made and the expansion coefficient and the delta t that is the melting point minus the ambient temperature or the initial plate temperature. So, for a given length of the weld and given metal system higher the, if the temperature difference between the melting point and the ambient and the initial plate temperature increases then this will increase the extent of the contraction or the locked in strain which will be left in.

So, one is the thermal properties that will be effecting the residual stress magnitude because greater is the melting point and higher is the expansion coefficient greater will be the possibility to have in higher locked in strain. And which in turn will be resulting in the higher residual stresses. Similarly, length of the weld, in general the length of, increase in length of the weld increases the residual stress up to about 300 mm length and thereafter no major increase in the residual stress magnitude is observed.

This is what we will be seeing in the subsequent slide. The type of the weld groove design also affects the residual stress because it directly decides the volume of the weld metal to be deposited for developing the weld joint. And in general we know that the more is the volume of the metal to be deposited for developing a weld joint greater will be the magnitude of the residual stress that will be developed. Then the welding process, in general the welding process can be, effect of welding process on the residual stress can be understood from the fact that each welding process offers the different energy density.

So, those processes which are of the low energy density they will, they will be supplying more heat to the and the plates being welded and the increased amount of heat will have the larger area which will be subjected to the expansion and contraction during the welding. And which in turn will increase the possibility of having the larger residual stresses. So, the so the high energy density welding processes like the laser beam, electron beam and the plasma arc welding processes are having the higher energy density.

They will be supplying very less amount of the heat for developing the weld joint. And because of this the reduced amount of the heat input to the base metal will be resulting in the reduced amount of magnitude of the residual stresses that will be developed after the welding. Then the initial plate temperature and post weld heat treatment. Increase in initial plate temperature in general reduces the temperature gradient from the weld centre to the base plate and because of this largely the expansion and contraction, the extent of the differential expansion and contraction will be reduced.

Similarly, the post weld heat treatment, if the post weld heat treatment like annealing, normalizing, although a stress relieving is carried out then this will help in relieving the residual stress that are being developed. Then the degree of restraint, how firmly plates are being held in position during the welding that will also affect the magnitude of the residual stresses that are being developed. In general greater is the degree of the restraint then the more will be the residual stresses that will be developed. Because the expansion and the contraction means the contraction will be restricted which will be occurring during the cooling phase if the degree of restraint is too high.

Then the weld metal properties, the in general the weld metal of the lower yield strength results in the lower residual stresses because this residual stress magnitude which are higher than the yield strength of the weld metal, they will be eased out by the deformation of the weld metal. So, the weld metal of the higher strength will be developing the greater residual stresses as compared to the weld metal of the lower yield strength. And this approach is specifically used for controlling the cracking of the heat affected zone of the high strength steel weld joints by welding them using the austenitic stainless steel filler material which offers somewhat lower yield strength.

So, this approach is effectively used means for reducing the residual stresses for controlling the distortion and the cracking tendency of the weld joint, then the welding sequence and the shot peening also effects the residual stress development. Shot peening basically helps in developing the compressive residual stresses by localized deformation at the surface while the welding sequence this affects the extent of expansion and contraction which will be occurring during the welding. And which in turn will be affecting the magnitude of the residual stresses. These factors will be elaborated in the subsequent slides also.

So, the first this diagram schematically shows that if the a weld metal volume of the weld metal being deposited for developing weld joint is increased then there will be continuous increase in the kind of shrinkage which will be occurring after the welding. In general transverse shrinkage, transverse shrinkage increases with the increase in the weld metal being deposited. So, if we see the weld metal being deposited and its effect on the transverse shrinkage that the amount by which the plates will be coming closer after the welding that will be increasing with the increase of the weld metal being deposited. If the plates are kept in position with the high degree of restraint then this will be developing the higher residual stresses in the weld joint. Then the length of the weld…

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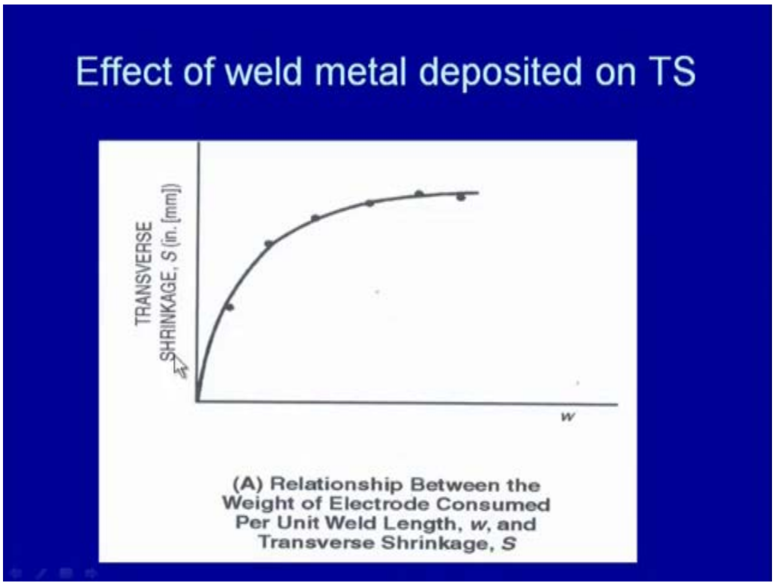

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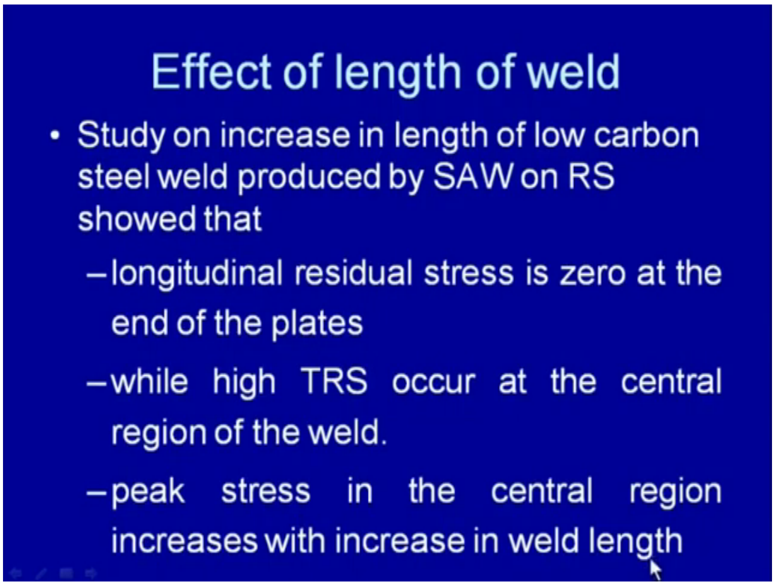

Study has shown that increase in length of the weld and being developed of the low carbon steel using the SAW then the residual stress shows that the longitudinal residual stress is 0 at the end of the plates. Both the ends experience the minimum residual stresses while the tensile residual stresses are found at the centre of the weld. And the peak stresses in the central region increases with the increase of the weld length. This is what we can see from this diagram.

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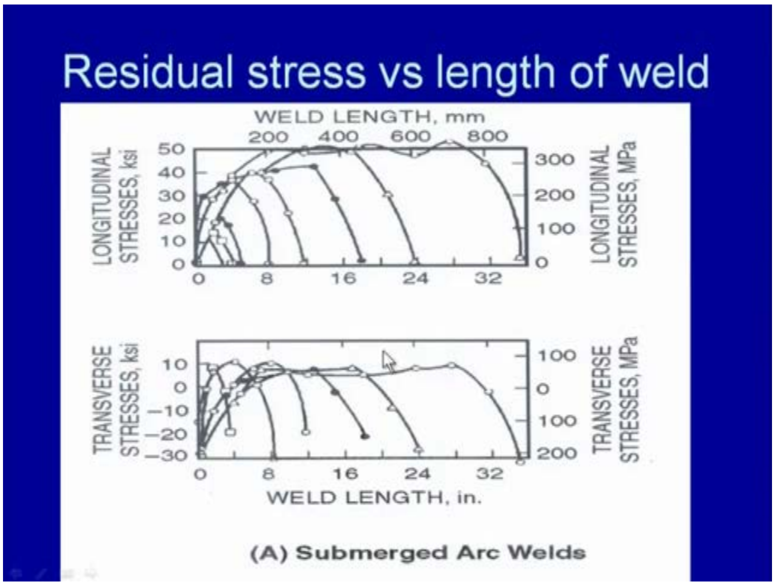

This diagram show, showing, is showing the weld joint made of the carbon steel using, developed using the submerged arc welding. The, it is showing that with the increase in the length of the weld there is increase in the magnitude of the maximum residual stresses that are developed. We can see that for a particular length of the weld say this one the initially residual longitudinal residual stress increases first and then starts decreasing. So, at both the ends we have minimum residual stresses while at the centre we have maximum longitudinal residual stress.

So, if we see that with the increase in the length of the weld the magnitude of the maximum residual stress is increasing while the, while the residual stresses at the end of the plate is 0. So, basically from this diagram we can say that the maximum magnitude of the residual stresses being developed is found to be function of the length of the weld and it will keep on increasing until the length of the weld is more than about 400 mm length. So, while the weld joints longer than the 400 mm length the residual stress magnitude is not affected at the centre of the weld.

Specifically, while at the ends the residual stress magnitude will be 0 in any case. Now, we can see the tensile, means the, in the transverse direction transverse stresses, this is the length of the weld. And here we can see the transverse residual stress also will have the maximum magnitude of the… At the ends we have one nature of the residual stress while at the centre we have another nature of the residual stresses. And it is positive at the centre of the weld and it is negative at the ends of the plate.

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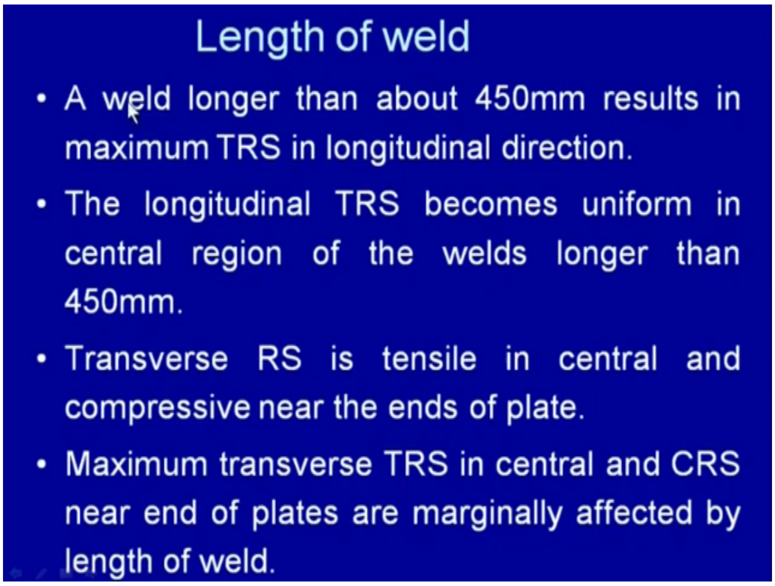

So, a weld longer than about 400 mm results in the maximum tensile residual stresses in the longitudinal direction and the longitudinal tensile stresses become uniform in the centre region of the weld longer than the 450 mm. And the transverse residual stresses is tensile in the central region and the compressive near the ends of the plates. So, and the maximum transverse stresses, transverse, maximum transverse tensile residual stresses in the central region and the compressive residual stresses near the end of the plates are marginally affected by the length of the plate.

So, in case of the transverse residual stresses tensile residual stresses are at the centre and the and a compressive residual stresses develop near the end of the plate. So, this is what we can see the variation in the longitudinal residual stresses as a function of the length of the weld. So, the magnitude of the maximum residual stresses in the direction, in the longitudinal direction that increases continuously with the increase in the length of the weld and it becomes a constant after about say 450 mm length of the weld or so.

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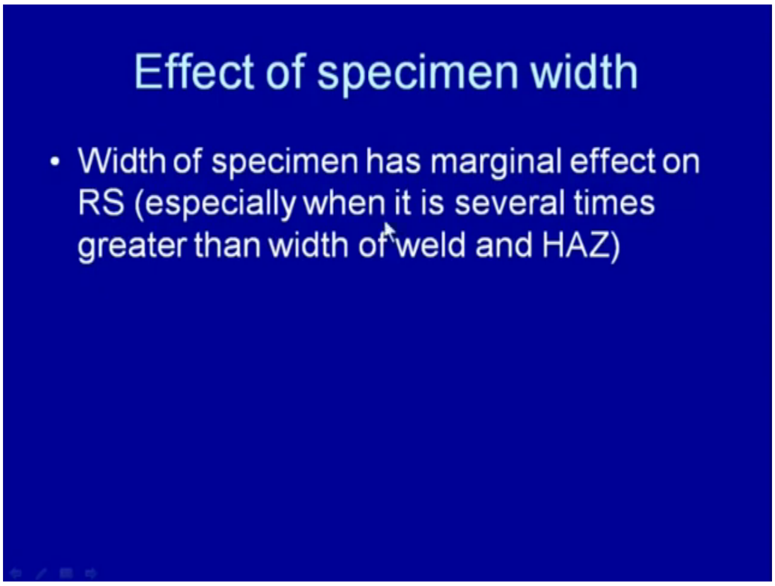

If we have to consider the effect of the specimen width then this width of the specimen has marginal effect on the residual stresses especially when it is, it is several times greater than the width of the weld and the HAZ.

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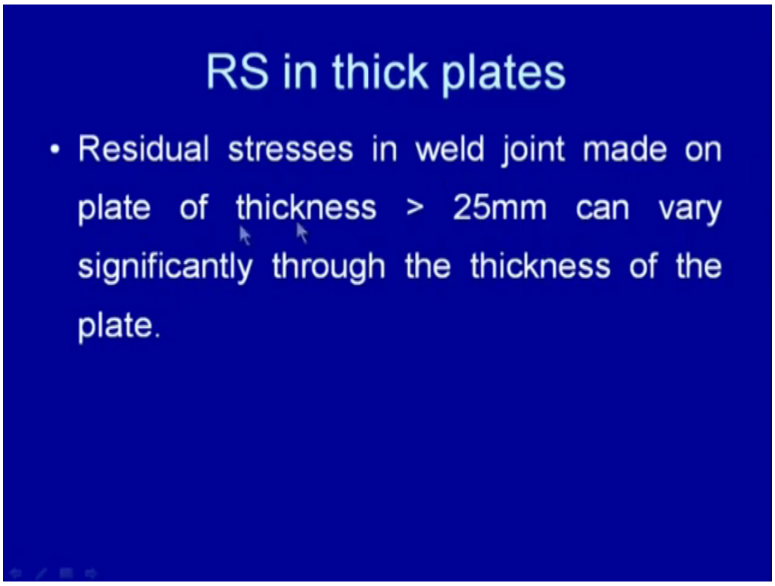

Then thickness residual stresses in the weld joint made on the plates having thickness greater than the 25 mm can vary significantly through the thickness of the plate. So, if the plates are thin then across the thickness means through the thickness the residual stress is largely uniform, but if for thicker plates it these can vary significantly.

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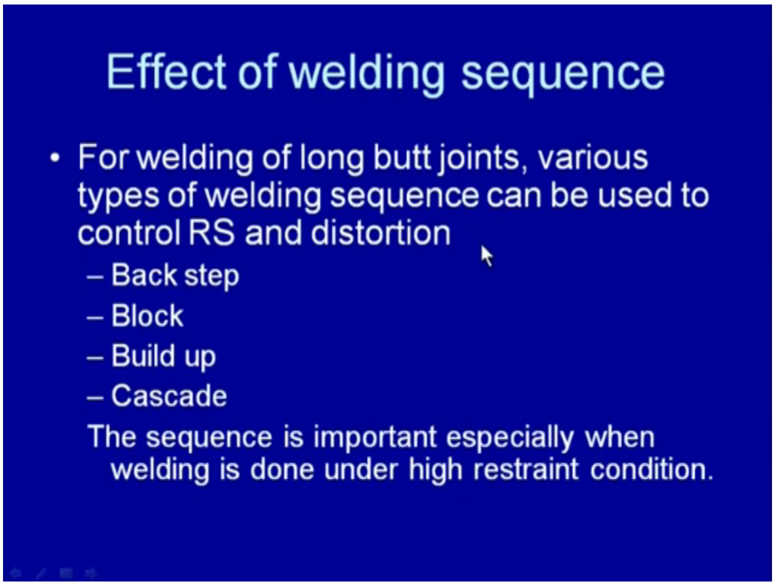

Then the welding sequence, the various types of welding sequence can be used for developing the weld joint. And each type of sequence offers one set of, one set of the residual stresses being developed. The sequence is important especially when the welding is done under the highly restraint conditions.

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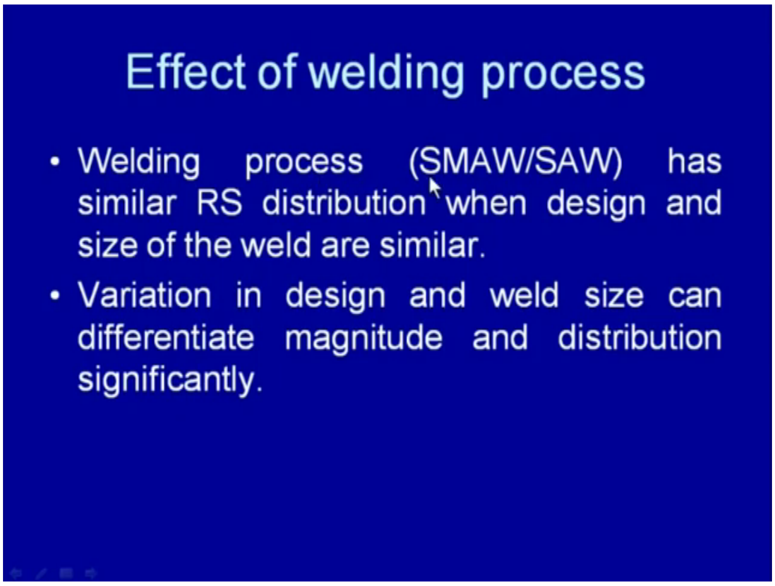

Welding sequence in case of the restraint butt or circular patch weld has the following effects like the welding sequence predominantly affects the transverse shrinkage, reaction stresses, elastic strain energy stored while it has the marginal effect on the longitudinal residual stresses. Block welding sequence generally results in the lesser shrinkage and the reduced strain energy stored and the reduced reaction stresses as compared to the multilayer a sequences. Then the welding process effect, the welding process like shield, high heat input process like submerged arc welding and the comparatively low heat input process like shielded metal arc welding process. The welding process has the similar residual stress distribution when the design of the weld and the size of the weld are largely same. So, when we are using the similar designs and the similar size of the weld then the distribution of the residual stresses is same, but the variation in design and weld size can differentiate the magnitude and the distribution of the stresses significantly.

Now, we will see that how performance of the weld can be affected by the residual stresses? The load carrying capacity of the weld joint can get improved or lower under both tensile or compressive loading depending upon the type of the residual stresses that are being a developed. So, means the residual stress development can increase or can decrease the load carrying capacity of the weld joint.

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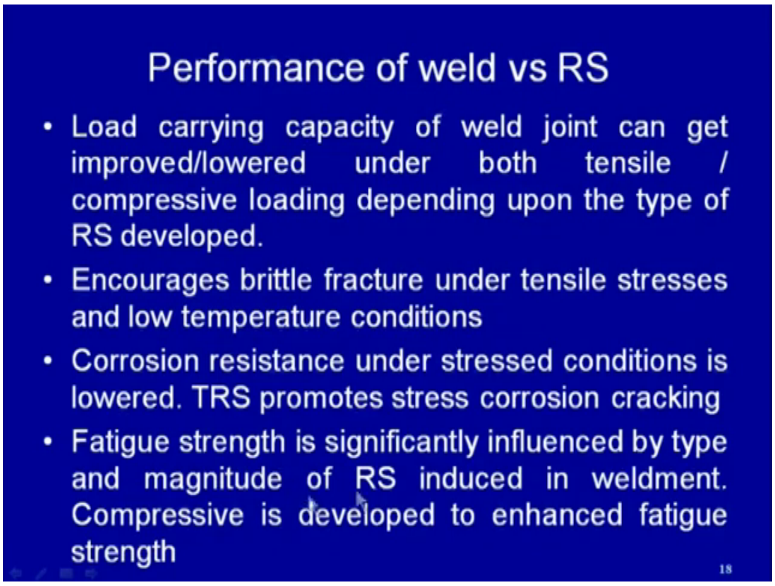

Further, presence of these residual stresses increase the brittle fracture under the tensile stress conditions; especially, under the load, under the tensile stresses and low temperature conditions. So, if the residual stresses are present in the weld joint then these will promote the brittle fracture under the tensile stress and the low temperature conditions. The corrosion resistance under the stress condition is also lowered and the tensile residual stresses promote their stress corrosion cracking tendency.

Further, the fatigue strength is significantly influenced by the type and magnitude of the stresses being induced in the weld joint. And the compressive stress is developed to enhance the fatigue performance. So, it is common to use the techniques which can help in developing the compressive residual stresses in the weld joint, so that the fatigue performance of the weld joint can be improved. Some of these effect we will be discussing in detail like the first one.

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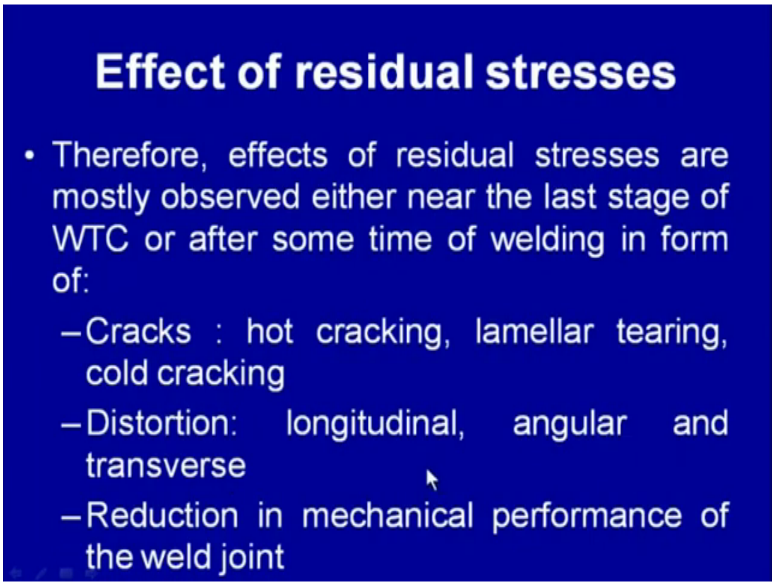

The effect of the residual stresses are mostly observed near the last stage of the weld thermal cycle or after sometime of the weld. This is because the residual stress magnitude is found maximum only after cooling down the entire system down to the room temperature. Once, the maximum magnitude of the residual stress is developed they will be resulting in the maximum effect on the, on the performance of weld joint in different ways. For example, cracks are developed because of the presence of excessive tensile residual stresses or the weld joint tends to distort from its shape in form of longitudinal, angular and the transverse directions. So, the distortion can be longitudinal or the angular or the transverse type. And further it affects the mechanical performance of the weld joint.

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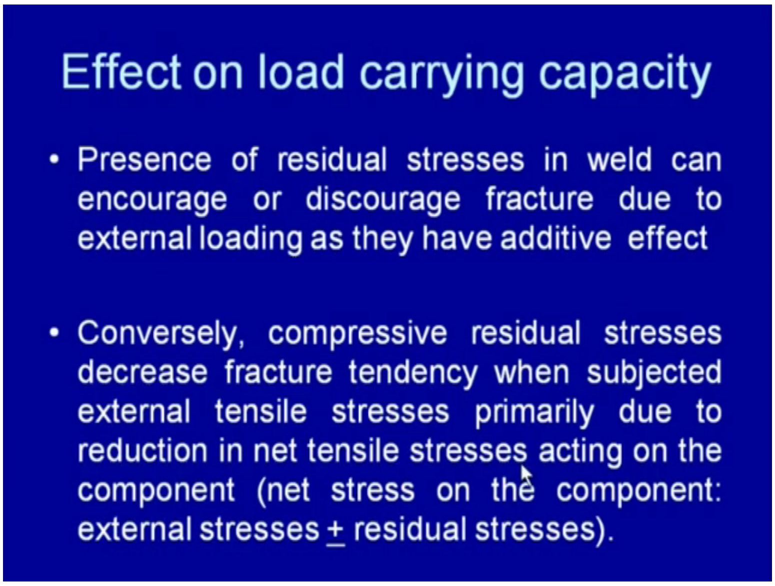

So, the first effect that the load carrying capacity of the weld joint is affected by the residual stresses. We know that the presence of residual stresses in the weld joint can increase or decrease the fracture due to the external loading as they have additive effect. Means the residual stresses of the tensile nature if present then the component will tend to fill earlier under the tensile external load conditions, but the performance of the component will improve under the compressive loading conditions because of their additive effect.

So, conversely the compressive residual stresses decrease the fracture tendency when the component is subjected to the tensile stresses primarily due to the reduction in net tensile stresses acting on the component. Because the net stress on the component is obtained from the external stresses plus minus residual stresses. For example, if we are applying the external tensile stresses of tensile type then the presence of the compressive residual stresses will decrease the net stresses while the presence of tensile residual stresses will increase the net stresses that are acting in the component.

So, depending upon the nature of the external applied stresses residual stresses can help or can deteriorate the mechanical load carrying capacity of the weld joint. Residual stresses of the same type as that of the external one increase the fracture tendency while the opposite type decreases the fracture tendency.

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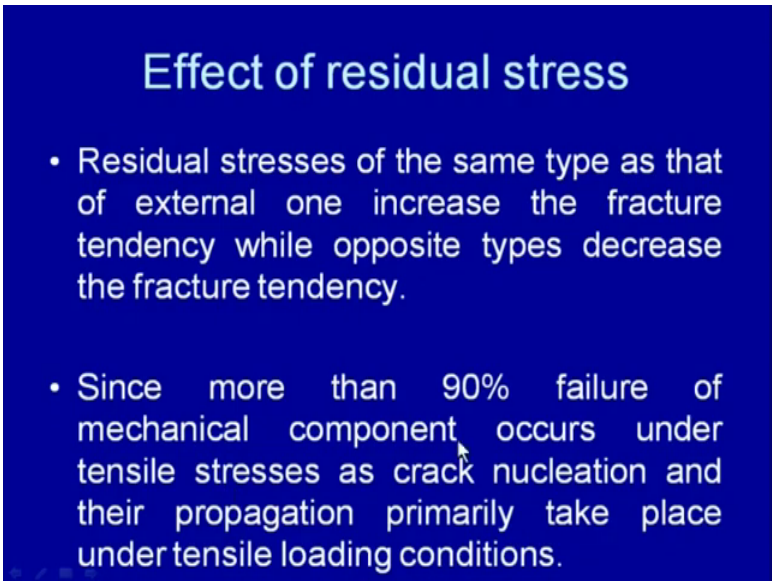

Since, the more than 90 percent of the failure of the component occurs under the tensile residual stresses because the tensile stresses promote the crack nucleation and their propagation tendency. And therefore, the mostly the failure of the component occurs under the tensile load conditions while under the compressive conditions these cracks or the discontinuities even if they are present in the material they will be closed. While in case of the, and tensile loading conditions they will be propagated easily under the tensile stress conditions.

Therefore, the presence of the tensile residual stresses in combination with the tensile external loading, adversely affect the performance of the mechanical component. While the compressive residual stresses under the similar loading conditions reduce the net stress and so discourage the fracture tendency and increase the tensile load carrying capacity. So, to, for enhancing the tensile load carrying capacity it is favorable to have the compressive residual stresses in the weld joint, so that the net stresses acting in the component or in the weld joint can be reduced.

Hence, the tensile compressive residual stresses are intentionally induced to enhance the tensile and the fatigue performance of the mechanical component. And efforts are made to reduce the tensile residual stresses using the various approaches such as the post weld heat treatment, shot peening and the spot heating. So, our, mostly our target is to control the residual stresses magnitude, tensile residual stress magnitude using the various approaches while the compressive residual stresses are intentionally induced in order to enhance the tensile and the fatigue load carrying capacity of the component. We can see the presence of the tensile residual stresses in the weld joint frequently causes the cracking may be at high temperature or of the low temperature.

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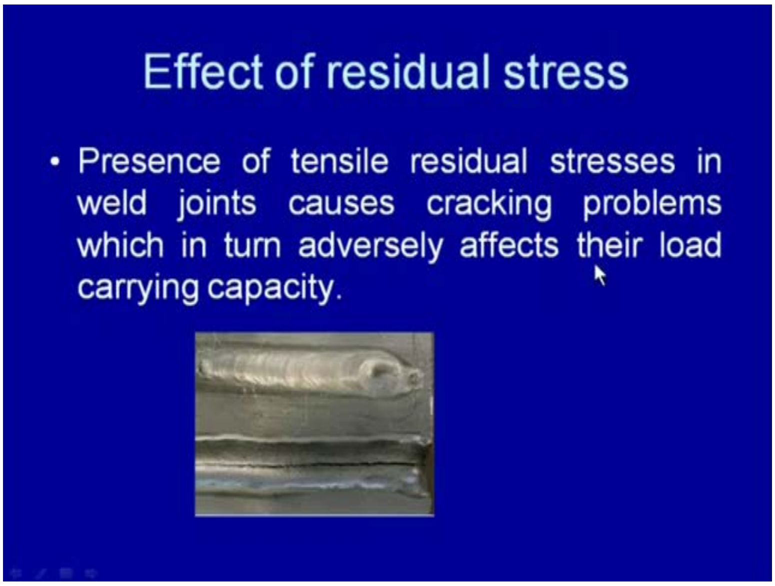

The cracking occurring at the high temperature is commonly known as the hard cracking. And it is mostly encountered in the weld joints of the metal systems having the higher solidification range. So, this typical photograph showing the solidification crack being developed along the length of the, along the weld centre line. And these kind of the stresses, these kind of the cracks primarily developed due to the presence of the tensile residual stresses along the weld zone. And presence of these residual stresses reduce the cracking, reduce the, increase the cracking tendency and further these increase their load carrying capacity, because the, no mechanical component with the cracks can survive for long under the tensile residual stress under the tensile load conditions.

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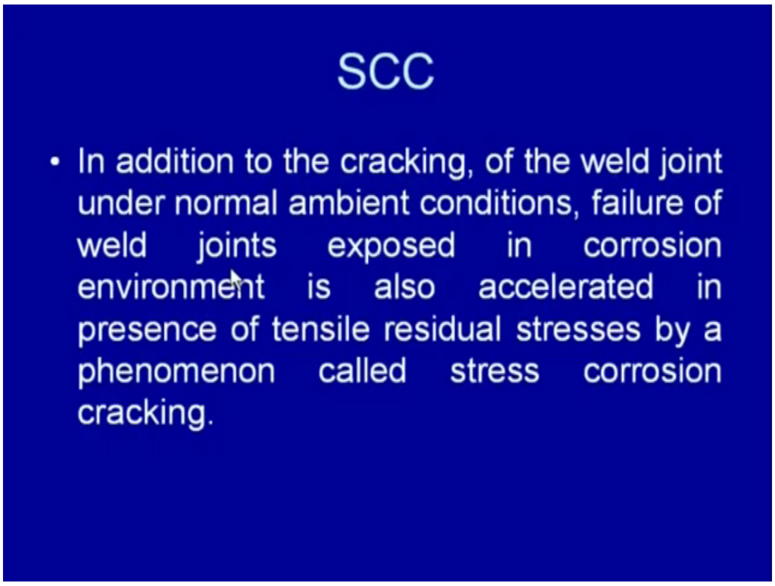

Another important effect which is noticed in the presence of the tensile residual stresses is the stress corrosion cracking. Stress corrosion cracking is the cracking which is experienced by the weld joints under the normal ambient condition or in the special environment, especially when the joint is exposed in the corrosion environment and the, and it is subjected to the tensile stresses. In, even in some of the cases when the, there is no external tensile load the presence of the tensile residual stresses in the weld joint and exposure of the weld joint into the corrosive atmosphere causes the cracking even with the, without the presence of the external load.

So, this kind of cracking which occurs mainly due to the presence of their tensile residual stresses in the weld joint in the specific corrosive environment, this is called the stress corrosion cracking. And in stress corrosion cracking corrosive, corrosion rate and the tensile residual stresses, both these act together and provides synergic effect in crack growth. And when this, both these are present these reduce the performance of the component very badly. And the life of the component is reduced drastically and many times it leads to the premature failure of the component.

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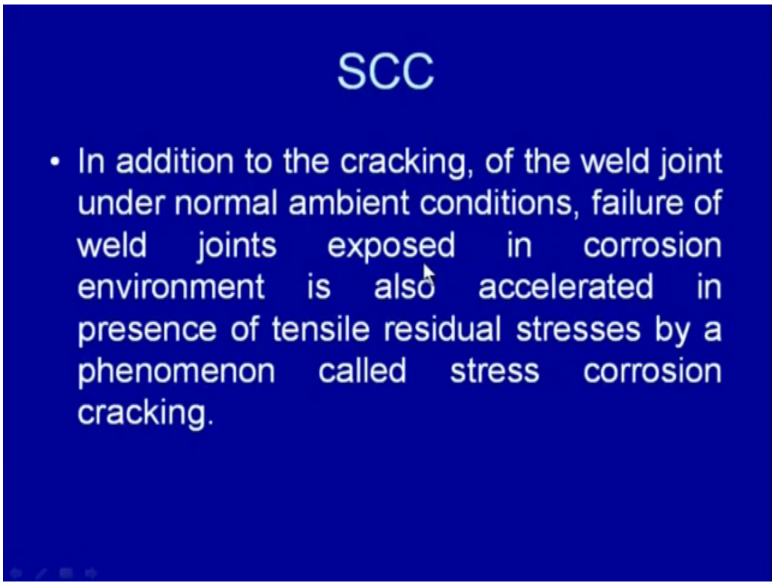

So in order to avoid the stress corrosion cracking, first the tensile residual stresses are reduced using suitable treatment of the weld joint and the, further the weld joint is exposure of the weld joint to the environment which is corrosive and the weld joint is sensitive to the particular environment that is isolated. So, the corrosion is prevented and the residual stress magnitude is the reduced in order to avoid the stress corrosion cracking tendency. I will see since the presence of residual stresses is not favorable for the performance of the component especially from the mechanical performance point of view.

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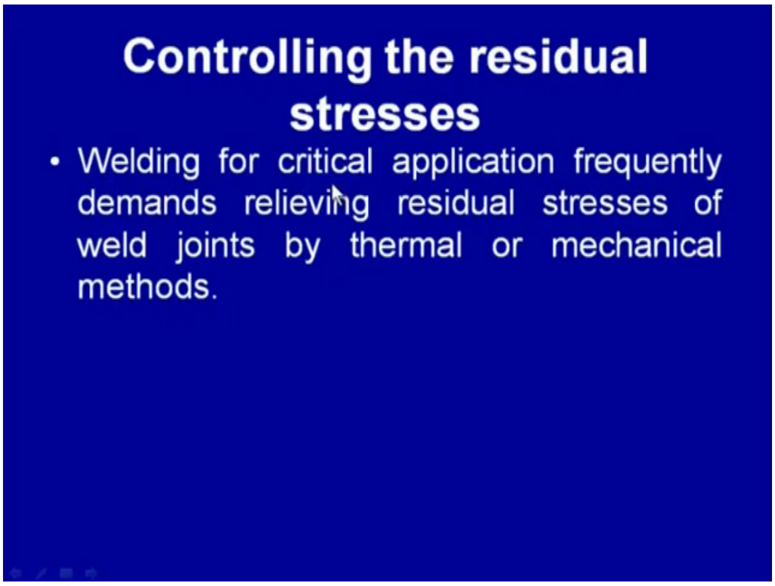

And therefore, the weld joints or which are to be used for the critical applications must be relieved from the residual stresses. And this relieving is mostly done using the mechanical and thermal methods.

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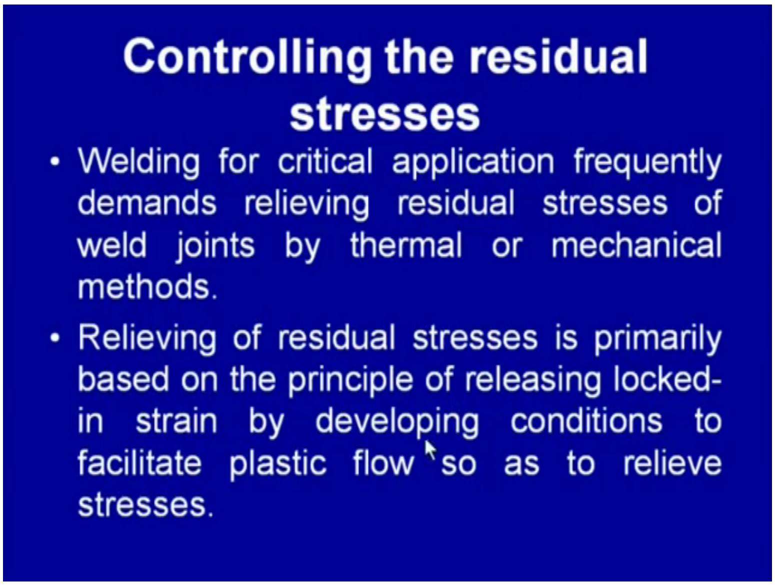

The relieving of the residual stresses is primarily based on the principle of releasing the locked in strain by developing the conditions that can facilitate the plastic flow, so as to relieve the residual stresses. We know that residual stresses are primarily induced because of the presence of locked in strain. And due to the lack of either due to the high degree of restraint or due to, due to the, not due to the poor contraction or not permission for the contraction to take place of the weld joint or of the heat affected zone during the cooling stage.

So, the contraction which should have taken place if it is not permitted then this leads to the locked in strain. And if somehow, we can release this locked in strain in the weld joint then that can help in; us in reducing the residual stress magnitude. And for relieving this locked in strain various approaches are used which are mainly based on thermal and mechanical methods. And wherever locked, wherever strain is locked in that zone is a heated in thermal method, so that the yield strength of the material can be reduced.

And so whatever locked in strain is there that can be eased out. While in case of the mechanical methods, we apply the excessive mechanical force in that area wherever strain is locked in, so that the plastic deformation can be used to ease out the locked in strain and relieve the residual stresses which are present due to the presence of the residual locked in strain in the component which has been welded.

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Some of the common approaches which are used for reducing the residual stresses are like use of the proper welding sequence like continuous welding sequence offers the greater residual stress as compared to the skip and the back step sequencing. Then the post weld heat treatment after the welding, the weld, the weld joint is exposed to the higher temperature, so that the, so that the stresses and the locked in strain can be relieved. And for this purpose the treatments like annealing, normalizing and the stress leaving are commonly used.

Then use of the mechanical force to relieve the residual stresses is also used using the shot peening where the localized surface deformation is used to produce the compressive residual stresses and the relieved in locked in tensile strain. Then mechanical methods we have vibratory stresses, vibratory forces are applied to the welded joint or the component in which the residual stresses are present to ease out the locked in strain. Further, the design considerations are also used for reducing the residual stress magnitude that is the groove design.

So, design of the groove should be such that it reduces the volume of the weld metal to be deposited. Because the greater increase in volume of the weld metal to be deposited increases the residual stress magnitude that are developed after the welding. Material considerations like the low yield strength metal, metal having the lower melting point and the lower thermal coefficient that will help in reducing the residual stress magnitude. And the increase in all these parameters, material parameters of the plate being welded will increase the residual stress magnitude.

So, efforts for selecting the weld metal and the base metal having the lower yield strength, lower melting point and the lower thermal expansion coefficient that will help in reducing the residual stress magnitude that are developed during the welding. Then preheating will help in reducing the temperature gradient and reducing the extent of differential expansion and contraction which is taking place and so the preheating will help in reducing the residual stress magnitude that are developed.

Then the welding procedure like processes, parameters and which is effecting the net heat input. So, all the procedural aspects that help in reducing the net heat input to develop the weld joint, they will be reducing the residual stresses magnitude. So, efforts are made in such a way that where the process is selected and the parameters are selected in such a way that the net heat input is reduced for developing a sound weld joint, so that the residual stress magnitude can be reduced.

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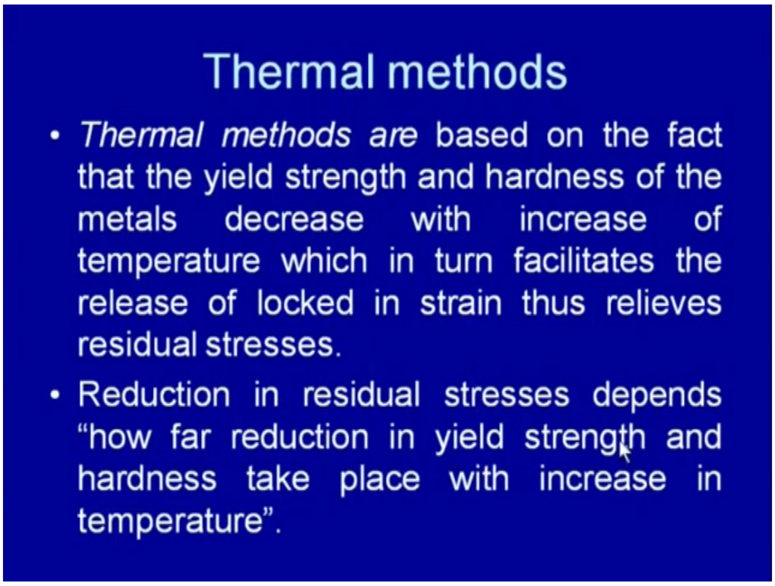

Now, we will see the thermal methods which are used for controlling the residual stresses. Like thermal methods are based on the fact that yield strength of the material and the hardness of the metal, decreases with the increase in the temperature when the exposure is given to the weld joint at high temperature. And the reduction in the yield strength and the hardness of the metal with the exposure at high temperature facilitates the release of the locked in strain and thus relieves the residual stresses.

The reduction in residual stresses depends how far reduction in the yield strength and the hardness takes place with the increase in temperature. So, if with the exposure greater is the reduction in yield strength and hardness, then the greater will be the extent of relieving of the residual stresses. So, greater is the softening due to the exposure at a high temperature more will be the relieving of the residual stresses.

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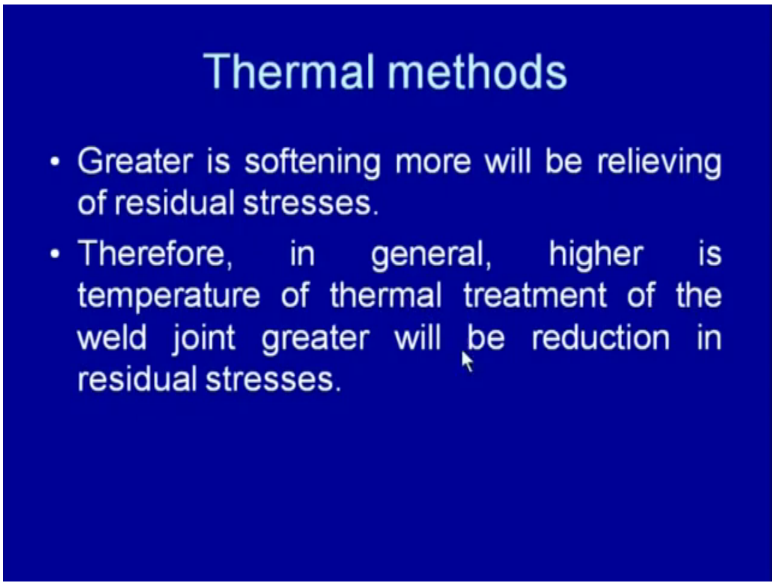

Therefore, in general higher is the temperature of the thermal treatment of the weld joint, greater will be the reduction in the residual stresses. This is what we can see from this diagram.

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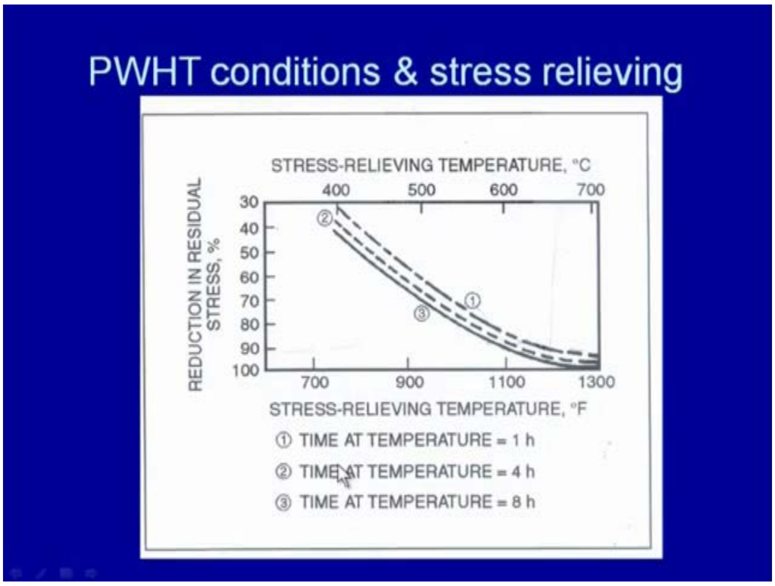

The typical residual stress temperatures, means the stress relieving temperatures and the effect of the time or the exposure which is being given. So, we can see the residual stress magnitude, this is the kind of extent of reduction in the residual stresses. Residual stresses, extent of reduction with the exposure at a high temperature say that and this is the stress relieving temperature in degree centigrade. So, if the exposure is being given say at 400 degree centigrade for the, for say 4 hours, the top line shows for 1 hour and the second one dotted line shows exposure for 4 hours.

And the bottom line shows the exposure for 8 hours. So, if we see a 1 hour exposure at 400 degree centigrade reduces the residual stress by say 30 percent, but if the exposure is given at say 700 degree centigrade for 1 hour then it will be reducing more than 90 percent of the residual stresses. Further, if we see this diagram at exposure at a given temperature for longer duration reduces the, increases the relieving of the residual stresses. So, we can see here if the at 8, 400 degree centigrade exposure is being given for 8 hours, then it will be decreasing the residual stresses by say 50 percent.

While at for 1 hour the extent of reduction is just 30 percent. Further we can see the increase in the exposure; increase in temperature of the exposure continuously decreases the extent of relieving of the residual stresses which is possible for a given period of the exposure. Higher is the temperature and greater, for longer duration we will be relieving the residual stresses to the greater extent. If we can see more than 90 percent of the stresses are relieved with the exposure at 700 degree centigrade for a duration of varying from 1 hour to 8 hours. Almost, all the residual stresses are relieved with the exposure at 700 degrees for 8 hours.

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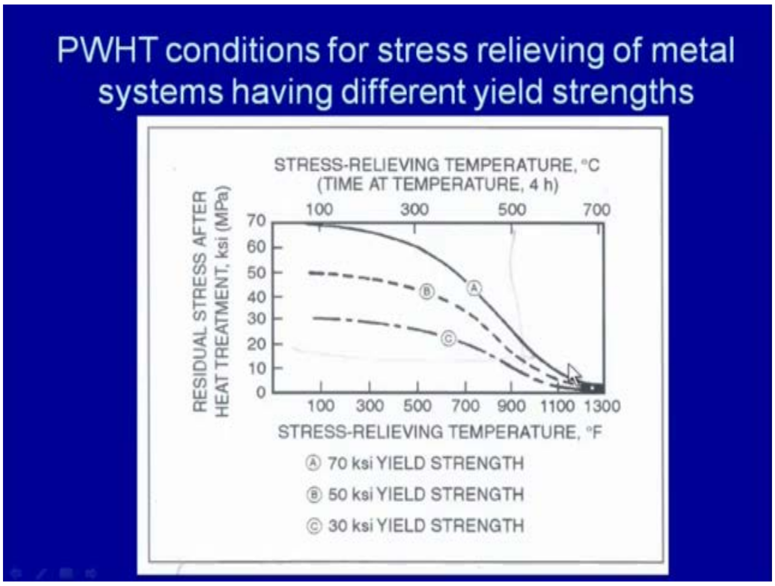

This is the another diagram showing the kind of the residual stresses after the heat treatment which are left in. So, the residual stresses left in after the heat treatment are almost nil, are almost nil after the exposure at 800 degree centigrade, 700 degree centigrade and 8 hours of the exposure here, this is for 4 hours. This diagram is corresponding to the 4 hours. So, this diagram is basically showing the relationship between the residual stresses that are left in after the exposure at the defined temperature for 4 hours.

So, if the exposure is, exposure is given for 100 degree centigrade then the residual stresses left in 70 MPa and with the, with the increase in exposure temperature for 4 hours there will be a continuous decrease in the residual stresses that are left in. Further, we can see these are the two other diagrams corresponding to the different magnitude of the residual stresses that are left in. So, now we will see the mechanical methods.

The mechanical method is based on the principle of the relieving residual stresses by applying the external load beyond the yield strength level, so as to cause the plastic deformation in order to release the locked in strain. So, in this, in this method, in the mechanical methods mainly we will try to apply the forces in the area where locked in strain is present, so as to cause the plastic deformation and the plastic. And the plastic deformation will be releasing the residual stress, residual strain which is locked in.

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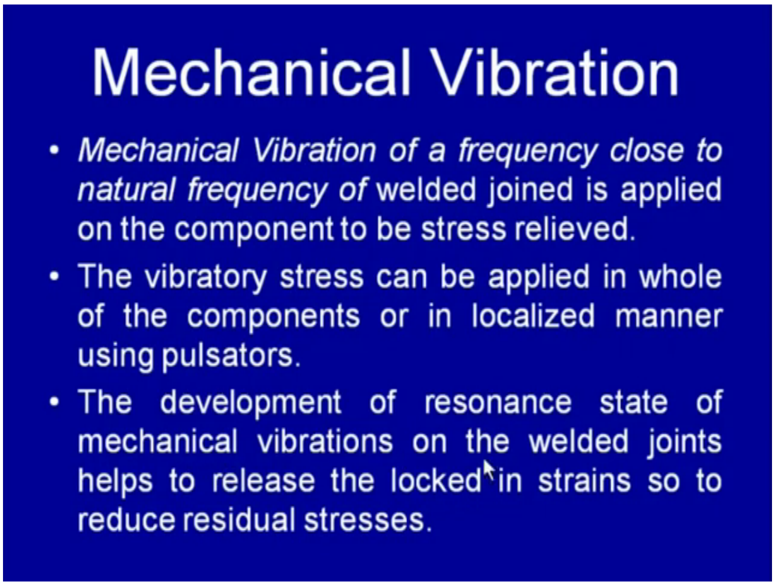

And the releasing of the locked in strain will be relieving the residual stresses. And for this purpose external load is applied in the area which is expected to have the peak stresses. Mechanical vibrations is one of the another mechanical method which is used for relieving the residual stresses. In this method exposure to the, exposure to the welded joint is given at such a frequency, so that the natural frequency of the weld joint matches with the frequency being applied. And when the mechanical vibrations are applied or using a frequency which is close to the natural frequency of the weld joint, which weld joint is applied the component is subjected to the situation of the resonance.

And the vibratory stresses can be applied in the component in very whole component or in very localized manner using the suitable pulsator. So, means these vibrations can be given to the whole component or in a localized manner using suitable pulsators and the development of the resonance state of the mechanical vibrations on the weld joint helps in release of the locked in strain, so that residual stresses can be reduced. So, in a mechanical method basically we try to apply the mechanical vibrations of the frequency close to the natural frequency of the weld joint. So, that the resonant, resonance state can be achieved in order to relieve the residual stresses.

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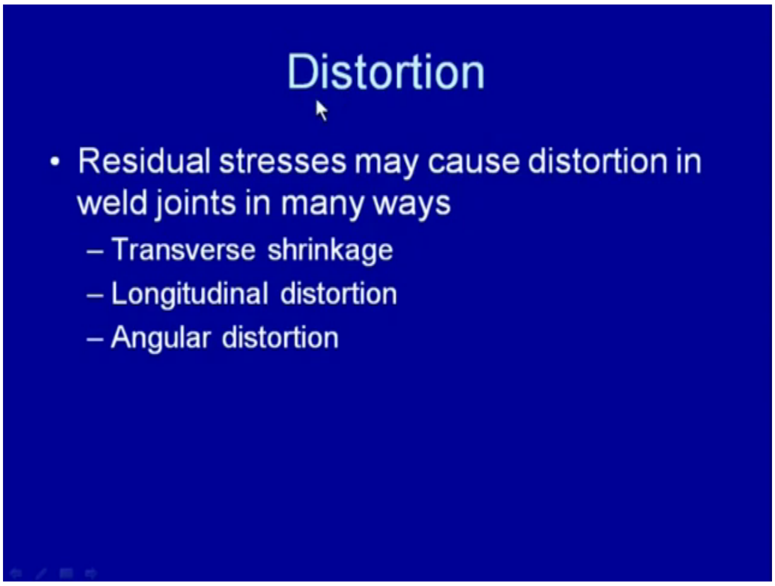

And see the residual stresses frequently lead to the distortion, if these are not relieved properly before taking the welded component out of the clamps. The residual stresses may cause the distortion in many ways. One is transverse distortion, longitudinal distortion and the angular distortion. There are specific approaches for controlling these distortions during the welding and these approaches basically involve nullifying the effect of the distortion which is taking place during the welding or holding the plates during the welding firmly. And thereafter, residual stresses are relieved using the suitable heat treatment.

So, now I would like to summarize this presentation which was based on the residual stresses. In this presentation mainly we have observed that the factors that affect the residual stress development and the methods which can be used for controlling the residual stresses apart from the effect of the residual stresses on the performance of the weld joint. Now, in the next presentation we will be starting a new chapter that will be based on the design of the weld joint. And we will be try, we will be focusing on the design of the weld joint for the static as well as the dynamic loading. So, the various aspects related with the design of weldment will be taken up in the next presentation. Thank you for your attention.