Joining Technologies of Commercial Importance
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Lecture - 38
Residual Stresses in Weld Joints

Hello, I welcome you all in this presentation. This presentation is based on the topic residual stresses in the weld joints. So in this presentation, we will see that the mechanism of the development of the residual stresses or the different ways by which the residual stresses develop in the weld joints, their effect on the joint performance, what are the factors that affect the residual stresses in the weld joints and what we can do to reduce the residual stresses in the weld joints.

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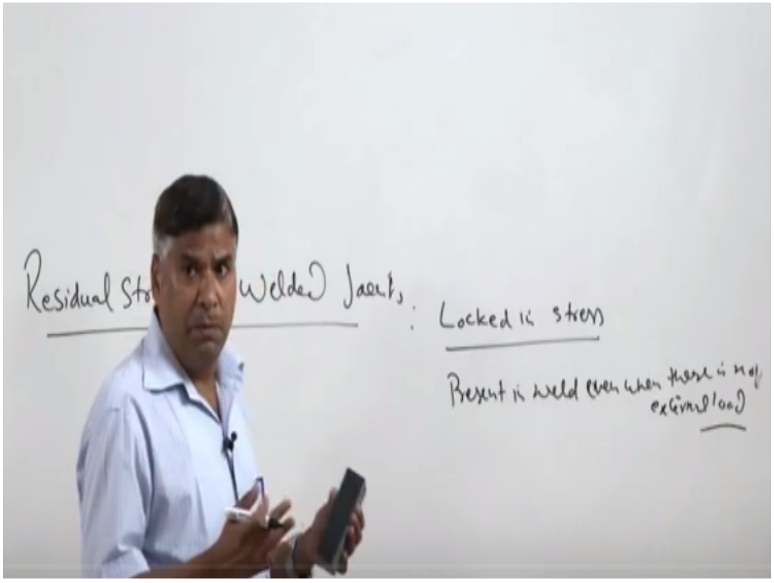

So the topic is residual stresses in welded joints. Basically, these are locked in stresses and these are present in weld even when there is no external loading. So these are inherent stresses, which are present in the weld without presence of external loads. So where from these come when weld joint is developed.

In the base metal, there may not be any residual stresses, but when weld joint is made, we find that there are some already stresses present even when there is no external load, such type of stresses are called residual stresses and there is one common reason for all the situations whenever residual stresses develop.

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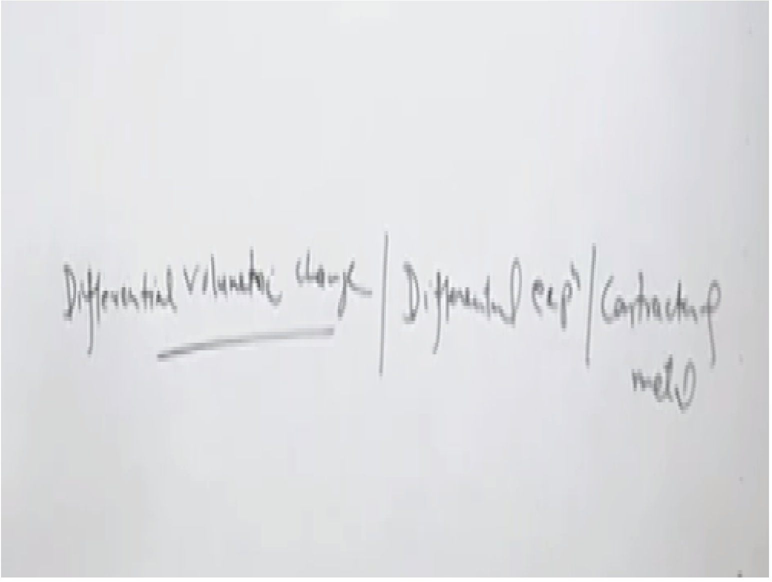

That is the differential volumetric change or differential expansion and contraction of metal where there it is machining or heat treatment or the welding or any other process. Wherever there is a differential change in the volume of the metal means one region is expanding, another region is less expanding, one region is contracting, another region is not contracting by the same amount or their expansion is different in the different zones or contraction is also different in the different zones.

So these situations in turn leads to the development of residual stresses, but how that is what we will be seeing.

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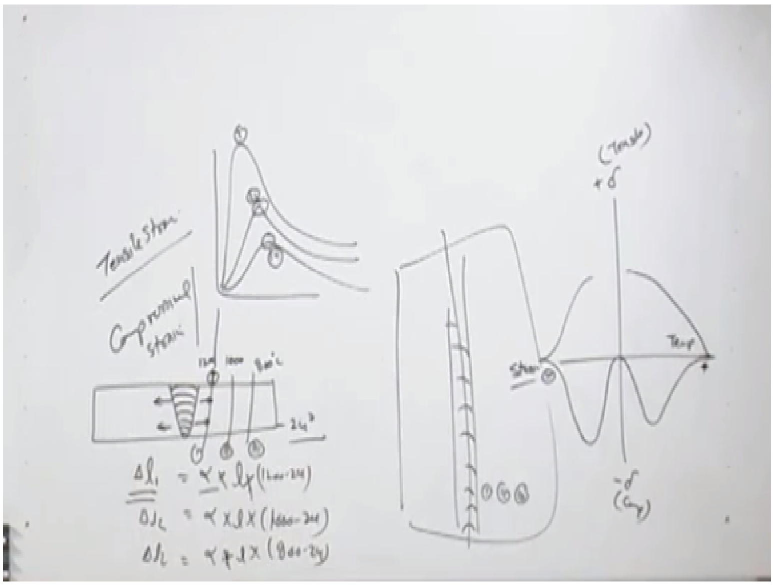

So for this what we need to see is that any welding process, any fusion welding process what we do we apply external heat to the suitable heat source for realizing the fusion of the faying surfaces or edges of the base metal. So in course of this, heat is dissipated to the base metal also. So the different regions are subjected to the different values of rise in temperature, say this one experiences temperature of 1200.

This one experiences temperature of 1000 and this one experiences temperature of 800 degree centigrade. So we know that if all are made of the same metal so alpha is same considering the unit length of each of the segment is l, so rise in temperature of this plate from 24 degree centigrade to the higher temperature will result in the different amounts of the expansion and then contraction.

So if you see here this one the alpha l delta t so 1200 minus 24, this multiplied by this. So the strain which should have happen means the change in length in this segment should have been by this much by alpha multiplied by length multiplied by that 1200 minus 24. If we talk of another segment when alpha is same, l segment is same, then temperature difference is of 1000 minus 24.

And then for another segment so l1 delta l2 delta l3 the kind of strain, kind of change it should have experienced so alpha into l into 800 minus 24. Since all these metals are integral part, all these zones are integral part of the metal system. So they will not be allowed to expand first and thereafter they will not be allowed to contract means this much strain is being restricted, this much expansion is being restricted in the zone 1 that is this, zone 2 that is this, and zone 3 this one.

So the maximum expansion is restricted to the zone 1 because it should have expanded much larger than the zone 1, zone 2 and zone 3. So since the zone 1 experiences the different thermal cycle as compared to the zone 2 and zone 3. The peak temperature experienced by the zone 3 is lower than the zone 2 and the zone 1. So because of this differential heating to the different temperatures, the different zones will be expanding to the different magnitudes.

This is one thing, so there is a differential expansion. And whatever expansion should have been there, but it actually will not be there because metal is integral part. So let us consider this case, where the plate is like this and we are applying heat like this so where is heat affected zone like one area, second area, third area. All these zones are being heated to the different temperatures.

But since these are integral part of the entire plate, so first their expansion will be restricted. So they will feel the compressive strain during the heating because their expansion has been restricted and once the things have been cooled, so they should shrink, that shrinkage is also restricted. So during the cooling they feel the tensile strain, initially they experience the compressive strain due to the heating and then they experience the tensile strain.

To understand this let us take any point here and the point 1 here.

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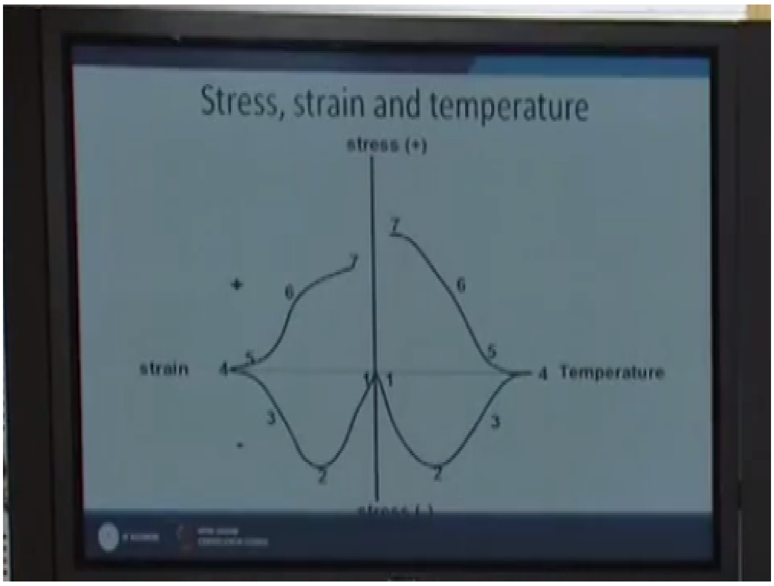

And if we try to study the way by which its temperature raises and how the strain and stress it experiences, here this side shows the strain, stress positive, stress negative and the temperature. So when there is increase in temperature, first the negative compressive strain is experienced. So initially the compressive strain due to the increase in temperature increases. Thereafter, softening starts.

So the compressive strain with the further increase in temperature starts decreasing. So initially the compressive strain increases then it starts decreasing. This is the stage when metal is softened significantly and no compressive strain is left and thereafter after reaching to the point 4 cooling starts so the temperature starts decreasing and when the temperature starts decreasing it sets in the stress pattern changes.

So if we see here this side we have the strain and this side we have stress. So strain side it is with increase in temperature or the compressive strain increases then its magnitude decreases.

As the temperature starts decreasing the strain pattern becomes positive. So now the tensile strain comes into the picture and the strain, which is tensile in nature, becomes active with the further reduction in temperature.

So what we see here during the heating, there is increase in temperature, which sets in the compressive strain, it reaches the maximum. So compressive stresses are maximum and then it starts decreasing due to the softening of the metal. So as the softening of the metal takes place, compressive strain starts decreasing and becomes zero. This is the stage when it reaches to the melting point.

And once it is soft and significantly reaches to the molten state, its compressive strain becomes 0 and as soon as solidification starts and shrinking starts it sets in the tensile strain. So tensile strain sets in gradually. So here will see there is tensile strain increases rapidly with reduction in temperature, but as the metal starts gaining its strength, tensile strain magnitude increases gradually.

And then finally as soon as it reaches to the room temperature or after cooling some of the strain is left in the metal, which is the tensile in nature. So this is what explains that with the increase in temperature first compressive strain is set in then as soon as it is softened and reaches to the melting point, the compressive strain becomes 0 and then it sets in the tensile strain.

So accordingly stresses also varies initially compressive stresses then become zero, then tensile stress sets in. So at the end we are left with the tensile stress in the weld joint. So this is one typical thing, which shows that due to the differential heating and cooling, we find the tensile residual stresses in the weld joint and we can see this in more simplified way to understand the kind of residual stresses, which are set in the weld joint.

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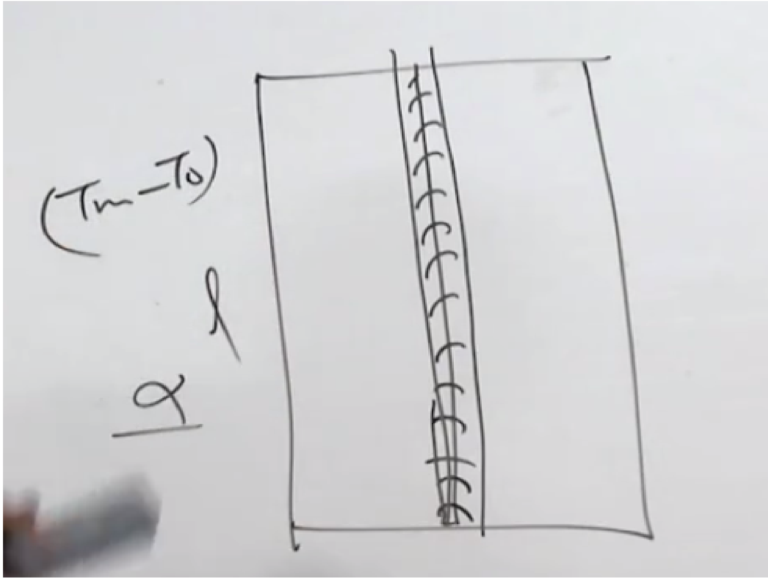

Let us take the two plates like this when the weld is made like say length is l and the temperature melting point to the room temperature T naught and alpha is the expansion coefficient and this is the length of the weld, which is made assuming that entire weld is made in one go which will be shrinking on cooling from melting point to the room temperature.

So the shrinkage of sample having length of the plate, shrinkage of the plate after the welding means weld length is l actually.

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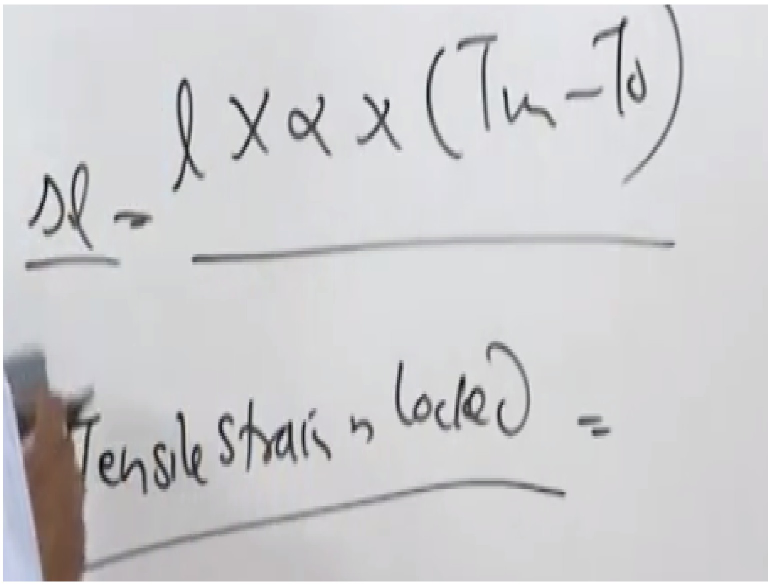

So the weld should shrink on cooling from the melting point to the room temperature by this much amount. Says the weld is connected with the base metal formally it is an integral part so this much shrinkage is not allowed under that is why lot of tensile strain is locked in. So this locked in tensile strain basically it accounts to the 1 mm per m and this is in case of typical steel.

So this locked in strain basically, which is tensile in nature leads to the tensile residual stresses in the weld joint. So if the entire system is free then of course there will not be any residual stresses.

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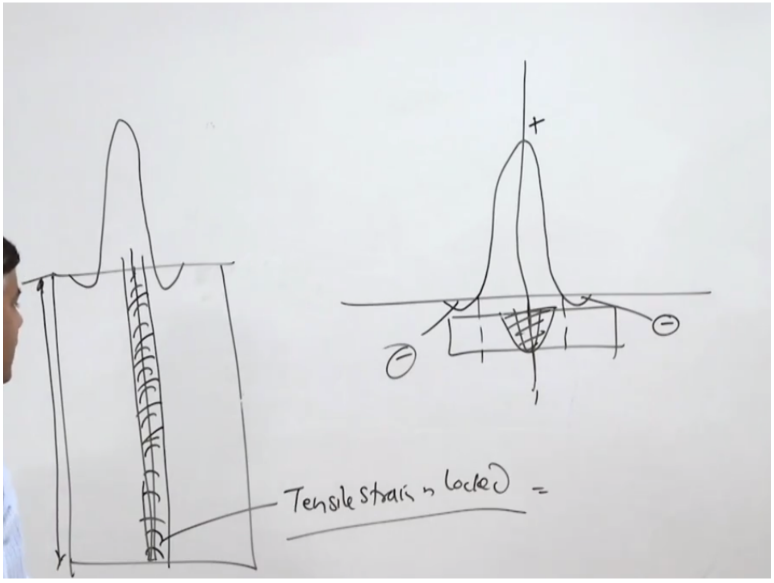

So if we try to plot the residual stress pattern like this. This is the weld like this then the distribution of the residual stresses is found like it is compressive away from the fusion boundary and tensile at the center line of the weld. So it goes in like this, this at the center of the weld metal and next to the fusion boundary zone experiences the tensile residual stresses, but the zones away from the fusion boundary they experience the compressive residual stresses, which will be balancing in nature.

So in the longitudinal direction in the direction of the weld what we see that the stresses are compressive in the heat affected zone or away from the fusion boundary and they are actually tensile in the weld area. So tensile residual stresses basically develop along the weld center line. Another thing or another way to understand the way by which residual stresses develop in the weld joint is like this.

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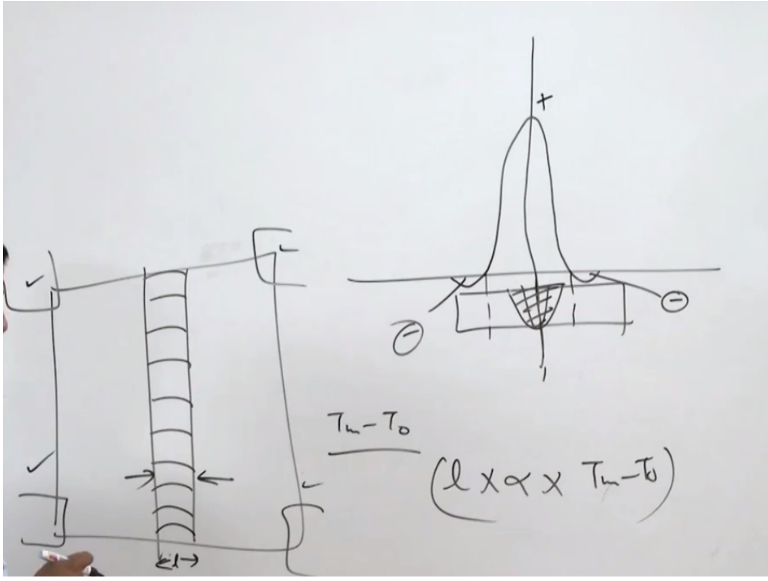

Like the two plates being welded under the restraint conditions with both the ends, all four corners and the weld joint is made between these. So obviously they will be expanding during the heating and contracting during the cooling. So this expansion and contraction will be leading to the development of the residual stresses. So this is the length of the weld, which will be shrinking from the melting point to the room temperature.

So l multiplied by alpha into this Tm - T0. This will be setting in the tensile shrinkage in transverse direction. So if the restraints or the plates are kept or held in position formally then this transverse shrinkage will be stopped or will not be allowed to happen and this in turn will lead to the development of the again tensile stresses in the weld joint. So this kind of shrinkage if it is stopped then it also causes the tensile residual stresses.

So both residual stresses in the longitudinal direction and the transverse direction need to be seen. So what we have seen is that tensile residual stresses basically develop along the weld center line and when the transfer shrinkage takes place due to the shrinkage of the weld metal and if the plates are kept in very restraint conditions that also develops the tensile residual stresses in the weld.

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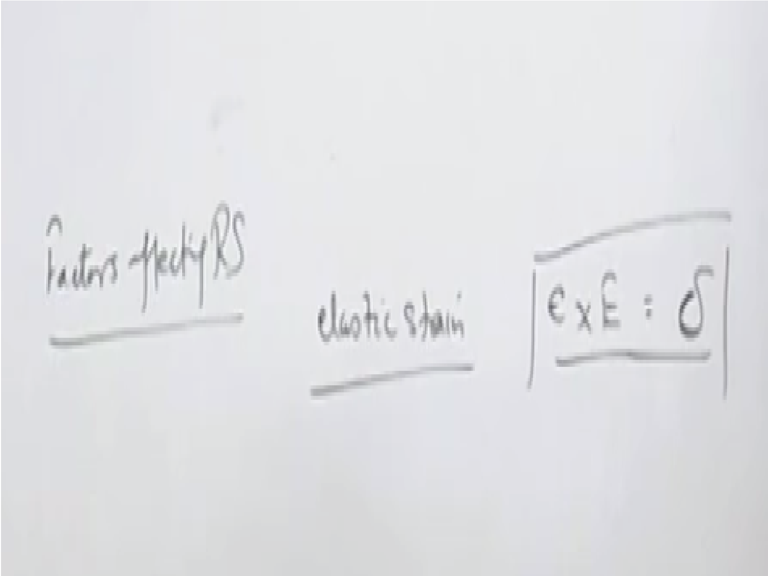

So now will see that how these factors affecting the residual stresses. The one thing is important that residual stresses happen due to the locked in strain and the locked in strain magnitude can be maximum up to the elastic strain, maximum elastic strain value. So maximum elastic strain, maximum strain that can be locked in is up to the elastic limit and if it is multiplied by the modulus of elasticity.

We can find for the given material of the weld metal or of the base metal we can find the residual stresses that will be the maximum magnitude of the residual stresses. So maximum magnitude of the residual stresses is equal to the elastic stress magnitude and above that if the stress is more than that, then it will cause the yield stress value and the material will be subjected to the plastic deformation.

So considering this point only sometimes filler metal is intentionally selected in such a way that the yield strength of the base metal is low or elastic limit of the metal is low so that residual stresses magnitude can be reduced.

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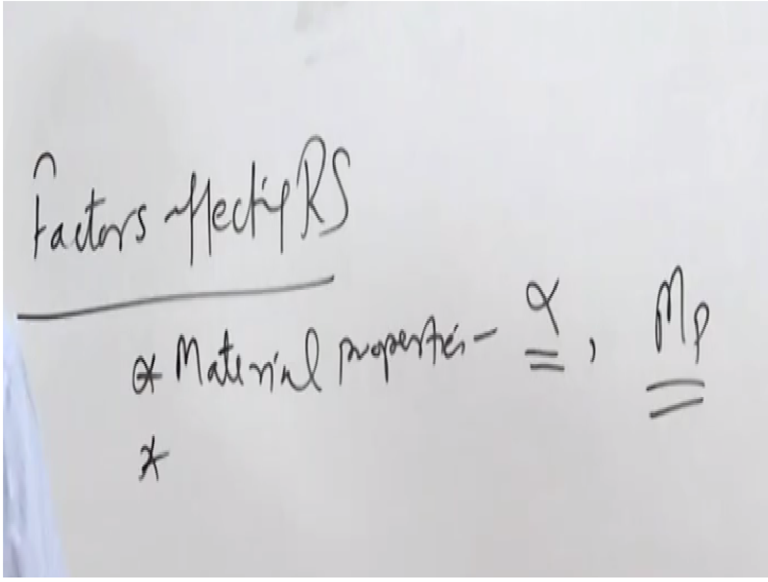

Now will see the different factors that affect the residual stresses, so one is the material properties, which is especially the alpha, thermal expansion coefficient. So if the filler metal or the weld or the expansion coefficient of the base metal is high, then there will be more expansion and contraction, which will be leading to the higher locked in strain and that in turn will be causing the higher residual stress value.

Then solidification temperature range STR that means it is solidification temperature or the melting point.

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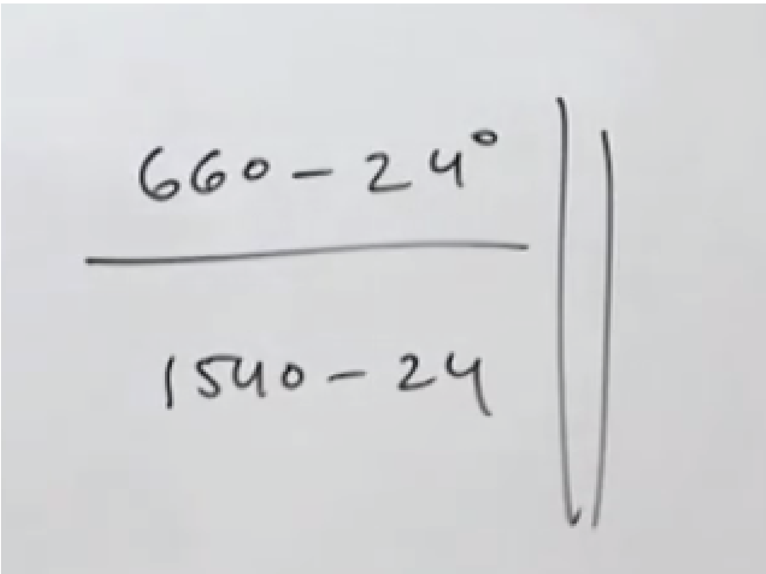

So if the melting point is high then it will be having the much wider range of the temperature drop like aluminium will be shrinking from say 660 to the 24 degree centigrade, while the steel will be shrinking from say 1540 to 24. So if there is much wider range of the temperature through which shrinkage will be occurring in case of the iron as compared to the aluminium.

So it is the temperature actually where from the solidification will complete and then shrinkage in the solid state will be occurring.

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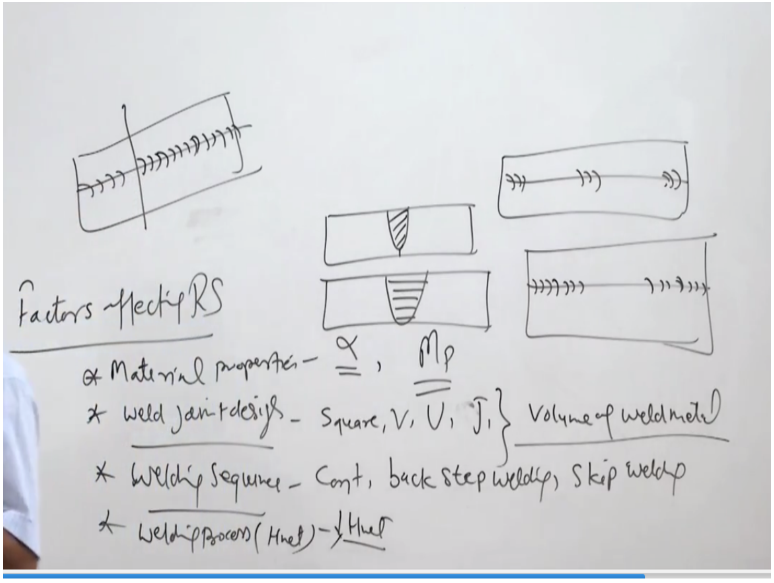

Another is the weld joint design, this factor is basically related to the kind of groove, which is being used. It is the square or V, U or J or the double V, double U, J (()) (21:14) etc. There are various types of groove geometry and purpose of all this is to see that because the groove geometry affects the volume of the weld metal. So any geometry, which is increasing the volume of the weld metal.

Volume of the weld metal is this much or the volume of the weld metal for the same one is larger. So in this case, shrinkage will be much larger, expansion and contraction will be much larger means the contraction of the weld metal will be much more as compared to the case when the weld metal is less or of the smaller in volume. So all those groove geometries, which will result in the smaller weld metal volume.

They will be causing the lesser residual stresses as compared to the geometries that will be causing the greater magnitude as compared to the groove designs that will be causing the higher weld volume so they will be increasing the residual stresses magnitude. Then another is welding sequence, if the weld is made continuously then it builds up lot of residual stresses, one is the continuous, starting from the beginning to the end weld is made in one go.

Then, this is continuous and sets in the maximum stresses as compared to the case if the weld is made in steps it is just like sequential welding, we make weld for one portion then we leave a gap then weld another location then gap is left, then fill the earlier portion whatever is left and then fill the remaining portion. So there can be various sequences which can be like step welding or back step welding.

There can be different sequences, which can be used for reducing the residual stress magnitude back step welding or skip welding where intentionally in step we leave initially weld is made here, then will be making the weld here, in meantime things will cool down so continuity of the weld metal is broken then weld is made here then weld is made here like this.

So or in back step the weld is made first along the weld line it is made here, then it is here, then it is here so like this different sequences can be used and these sequences always help in reducing the residual stress magnitude. So these are the various factors apart from this the welding process. The welding process means what is the energy density of the welding processes, for high energy density processes they will be supplying very less heat.

So very less volume of the weld metal and very less volume of the heat affected zone will be there. So the volume of the metal expanding and contracting that will be limited in the case of high energy density processes like laser and electron beam as compared to the arc welding process. So Hnet matters a lot so the low Hnet always help to reduce the residual stresses because it will be reducing the volume of the weld metal.

Volume of the metal, which will be expanding and contraction during the welding. Then degree of restraint if we allow the somewhat movement of the plates in course of the welding then the residual stresses will be reduced. Then initial plate temperature and post weld heat treatment. Initial plate temperature is important because if we preheat the plate.

Then, there will be more uniformity in the temperature as compared to the case when there is no preheat. So improved uniformity in the temperature will be leading to the uniform means somewhat less differential expansion and contraction and that in turn will be reducing the magnitude of the residual stresses.

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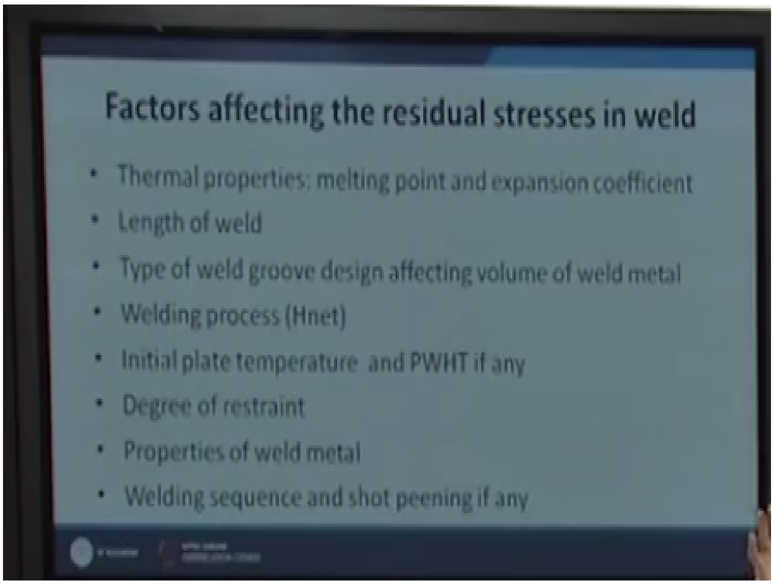

And then the properties of the weld metal lowly strength weld metal is always favorable from the residual stress point of view because that will help in reducing the residual stress magnitude, post weld heat treatment like stress relieving and the shot peening helps in reducing the residual stress magnitude. Apart from these there are other various factors that will be determining the residual stress magnitude.

But in addition to this will try to see that how the residual stresses affect the weld joint and how we can take care of the residual stresses.

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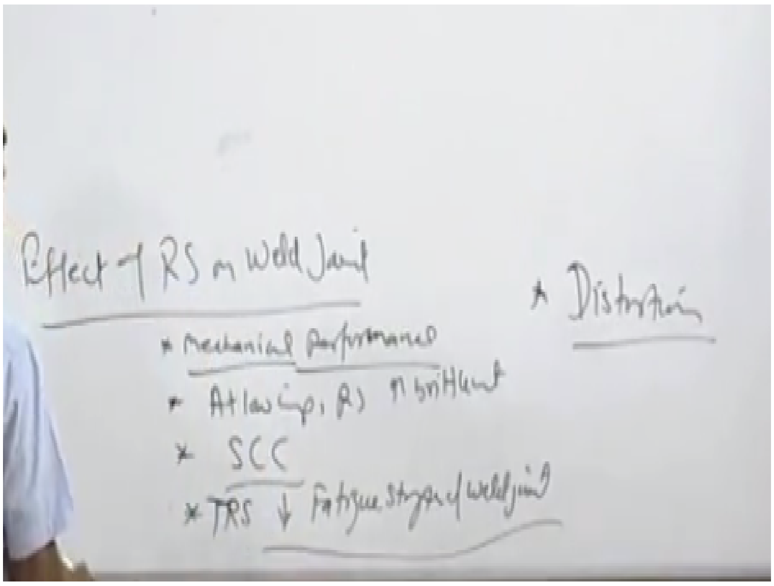

So here the effect of the residual stresses on the weld joints. So we can see the performance wise the mechanical performance. In general, when the residual stresses in the weld joints we have both tensile and compressive residual stresses. So they basically lower the load carrying capability of the weld joints and whenever the residual stresses are present at low temperature residual stresses increase the brittlement or ductile to brittle transition behavior.

Further it increases the stress corrosion cracking tendency in corrosive environment, presence of the tensile residual stresses promotes the cracking tendency and the tensile residual stresses low down the fatigue strength of the weld joint; however, development of the compressive residual stresses improves the fatigue performance of the weld joints. So sometimes intentionally the compressive residual stresses are induced in the weld joints.

So that fatigue performance of the weld joint can be reduced. Apart from that if the residual stresses are present in the weld joints, so they increase the distortion tendency means the weld joint will have the shape something else then what we expect from it. So apart from these effects will see the methodologies, which can be used to reduce the residual stresses and considering the methodology to reduce the residual stresses or the approaches, which can be used.

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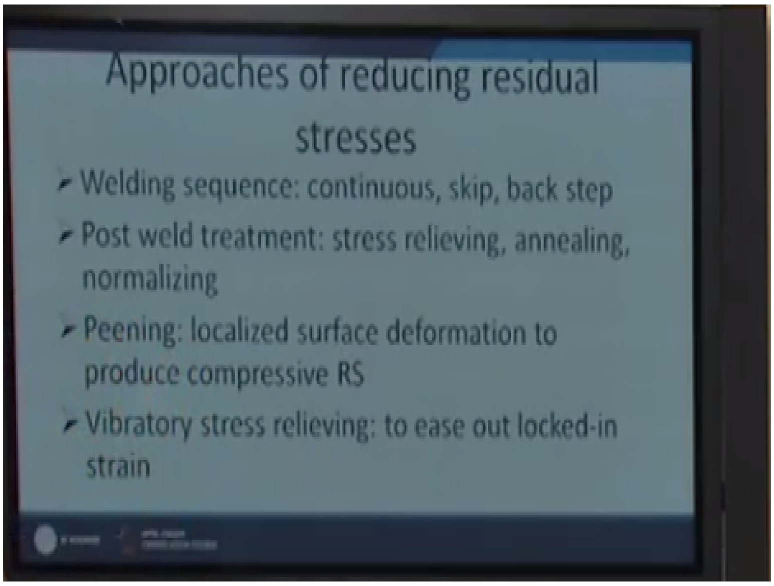

There are certain points, which can be used to reduce the residual stresses, which we can see. Approaches for reducing the residual stresses like sequence of the welding may be chosen properly instead of the continuous, skip welding and back step welding both help in reducing the residual stresses. Then we can do the post weld heat treatment because whenever heating is done at higher temperature it helps to soften the base metal.

And once the base metal or the weld metal is softened it relieves the locked in strain and thereby it will help to reduce the residual stresses. Shot peening also through the localized surface deformation produces the compressive residual stresses, which helps in improving the fatigue resistance of the weld joint and relieves the residual tensile stresses. Vibratory stress relieving system, in this case either in very localized manner or entire part is exposed to the vibration.

So that under the conditions of resonance, all locked in strains are relieved and that in turn helps to reduce the residual stresses.

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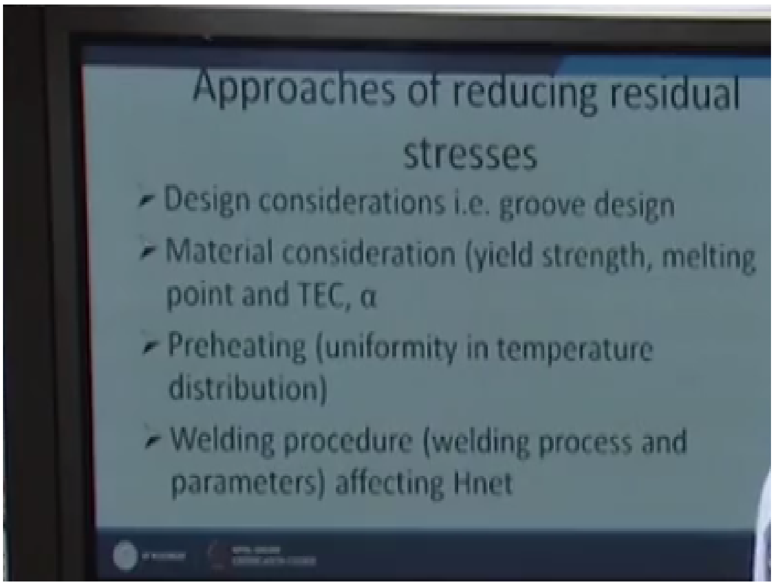

Design considerations, we try to select the weld joint groove geometry in such a way that the volume of the weld metal can be reduced so the residual stress development can be reduced. The filler metal is selected in such a way the yield strength is low, expansion coefficient is also low. So that the related expansion and contraction can be reduced and the maximum magnitude of the residual stress can also be reduced.

Preheating helps in uniformity of the temperature distribution, which is turn helps to have more uniform expansion and contraction in the different zones of the weld metal as well as heat affected zone and that in turn helps to reduce the residual stresses. Welding process, so will try to use the high energy density processes so that Hnet can be reduced that will help in reducing the volume of the weld metal and the base metal, which will be heated in course of the welding.

So here now I will summarize this presentation. In this presentation, I have talked that how the residual stresses develop in the weld joints due to the differential expansion and contraction and what are the factors that affect the residual stresses and what is the effect of the residual stresses on the weld joint performance and also what can be done in order to relieve the residual stresses or approaches which can tried in order to have the weld joints.

So that the low residual stress weld joints can be developed. Thank you for your attention.