Advances in Welding and Joining Technologies
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Lecture 13
Computational Welding Mechanics Part III

Good morning everybody. Today, we will start with the computational mechanics in specifically welding process. And we will specific to the topic the influence of the surface active elements, and we will try to see the other computational methods how to find out that velocity field, temperature field and distortion residual stress that is associated with mainly fusion welding processes.

So, we have the theoretical knowledge or we know about the there is a influence of the surface active elements during the welding process. And normally the surface active elements enhance the well depth of penetration and reduce the weld width if we use the optimum quantity of the surface active elements. But what is a in mathematical point of view, how we can this phenomena represents in true mathematical sense.

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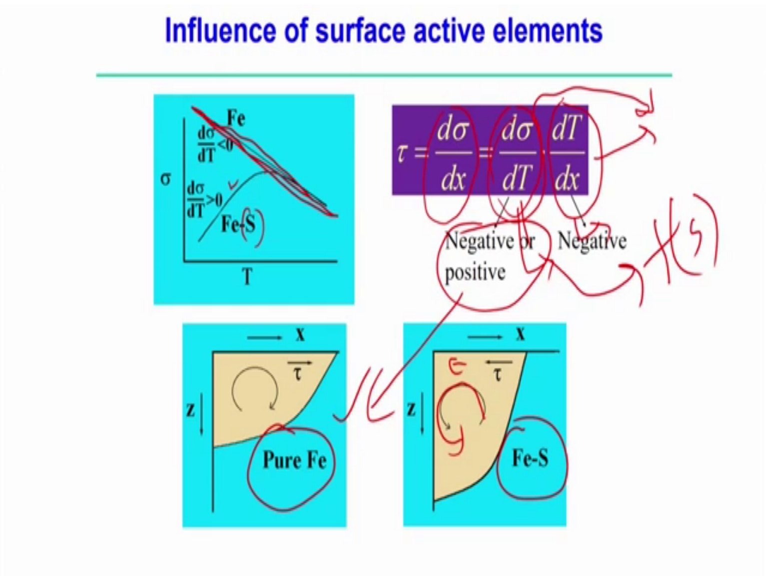

So, let us see that how it can be done. So, theoretically the when we use some surface active elements within the metal or during the welding process, so here you can see that temperature coefficients of the surface tension is plotted like that either it can be negative or reaches some optimum point or maybe it following the negative slope. So, that means in the if you see the first figure that temperature coefficient of the surface tension basically what this graph the gradient is greater than 0; that means, positive flow reaching towards the optimum point and then gradually decreasing. And then that other way also decreasing, but this generally happens in case of when the in presence of surface active elements for example, that sulphur presence in the steel that creates this kind of profile of the temperature coefficient of the surface.

And other cases when we consider pure element without any surface active elements, they generally flow this negative slope and that is the representation of the coefficient of the surface coefficient coefficients of the surface tensions as a function of the surface active elements. So, let us see that basically this modify the shear stress on the on the top surface of the weld pool that means, at the interface between the liquid medium and the gaseous medium so that shear stress can be represented by this d sigma by d x that can be represented thereby in as a function of temperature and d T by d x. That means, is the temperature this first one is called temperature coefficients of the surface tension and this is the temperature gradient.

So, by multiplying these two we can represent the what is the shear stress value on the surface so that means, in presence of surface active elements actually modify the shear stress value considering these two term; either modifying the temperature gradient or either modifying the coefficient of the surface tension. But if we assume that in a specific welding system, the temperature gradient which same, but there will be the radiation of the coefficients of the surface tension that can be a function of the surface active element.

For example, here sulphur or maybe some other surface active elements that actually modify this term that is that can be either negative or positive in the sense that if you look into this figure, and this is always a temperature gradient is always negative. So, if it is positive or negative depending upon there is a change of the sign that means shear stress or Marangoni shear stress actually acting depending upon the what sign convention we used for the coefficients of the temperature gradient.

For example, if we look into this, it is a pure iron that means, without any surface active elements the shear stress is basically acting from centre to outward periphery. So, direction is given and that shear stress is basically because of the shear stress, the flow pattern normally happens from center to the outer periphery maybe we can say that it is the clockwise direction. And when, but this clockwise direction we follow when these temperature coefficient substance is negative; that means, we say for this negative slope this is the situation.

Now, if temperature coefficient surface tension is positive then shear stress is basically acting the other direction. So, that Marangoni shear stress is since it is acting towards the center of the weld pool that actually drive the liquid molten pool from outward periphery to the inward direction. This basically completely reversal of the flow direction happens in presence of the surface active elements that is this is a system for the iron and along with the pure iron along with the presence of the any surface active elements. And this way; it modify the direction of the flow pattern. Here it is looks like that it is a metal flow actually happens or the flow field is saying anti clockwise direction.

So, the in the very simply simplified way to incorporate the effect of the surface active elements in the simulation process, we can use this value that coefficients of the temperature gradient, this modifying this value. That means, whether it is positive or negative that means, for the positive slope and the negative slope based on that that actually impact on the material flow pattern and we can get either positive or negative value to different flow pattern one is clockwise direction; another anticlockwise direction.

And of course, we can see that if flow pattern is in this way; that means anticlockwise direction that actually enhance the weld pull tab, but the it actually reduces the width in other way also. In case of pure iron that means, in absence of any surface active elements that actually modify the flow pattern in such a that it actually the low depth of penetration, but with this very high. So, that is the typical impact of the surface active elements and we can represent mathematically in this way.

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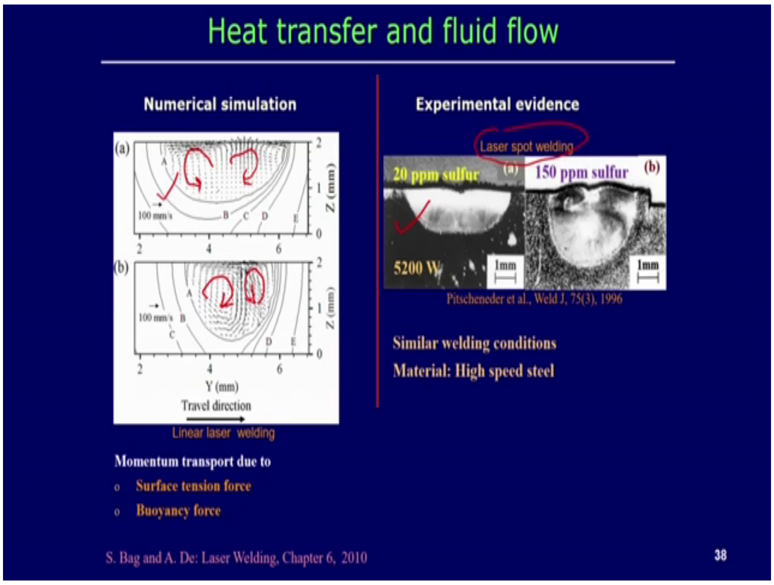

Now, we will try to see that the heat in general the heat transfer a fluid flow or how it happens in the small weld pool. Here to explain the effect of the surface active elements experimentally it was observed that as in a laser spot welding there are two picture that actually represents the weld dimension; that means, weld width and the well depth of penetration. And the first case it has been used that 20 ppm sulfur I think this is for the metal is the high speed steel.

So, in high speed steel 20 ppm sulfur we mixed up or presence of 20 ppm sulfur, this actually produce the this kind of profile ; that means, depth of penetration is not why or aspect is very low width is very high and depth of penetration is low. But in presence of 1 ppm 150 ppm sulfur that in rest for the similar material and the similar welding conditions that means similar powered laser power and all other laser spot diameter. In all the cases, there is a drastic change in the weld pool profile we can see that here in this case the penetration depth is very high and width is low.

Although for the same material same welding condition only difference is the one cases is having low amount of the sulphur presence. Another cases is the relatively more amount of the sulphur presence in the second case and that that means, experimental it is also observed that there is a tremendous effect of the presence of the surface active elements that actually influence the material flow pattern and finally, it actually changes the weld pool geometry. So, therefore, it is very important to analyze the significant effect of the surface active elements. Most of the cases we generally neglect or we overlook the presence of the surface active elements in the weld pool.

But in computational mechanics point of view how we can do the simulation here also can see that a laser spot welding that similar conditions we have tried to do some simulation. And here we can see the fluid flow pattern. In case of the low sulphur content, this is the profile. And here the in this profile we can see that the material flow pattern is in this way that means, and other case if we see that when there is a presence of the surface active elements, the metal flow pattern is in this direction and it is this direction. So, in these two cases, all those similar welding conditions, but there is a significant difference of in the weld pool shape, weld pool shape and size because of the presence of the surface active elements within the material itself.

But when you try to do the simulation, this material flow and then we need to consider the positive or negative value of the coefficients of the surface tension that we just we had discussed. And by changing this value and we can or changing the sign of the coefficient of the surface tension that actually able to incorporate the effect of the metal flow pattern. And finally, we will be able to predict the weld pool shape and size in when you do the thermo fluid analysis in case of the welding process; but this kind of phenomena not possible to capture when you do the simple heat conduction analysis in welding process.

So, here the importance of the metal flow consideration in case of the weld pool simulation that means, temperature field as well as fluid flow field in fusion welding process.

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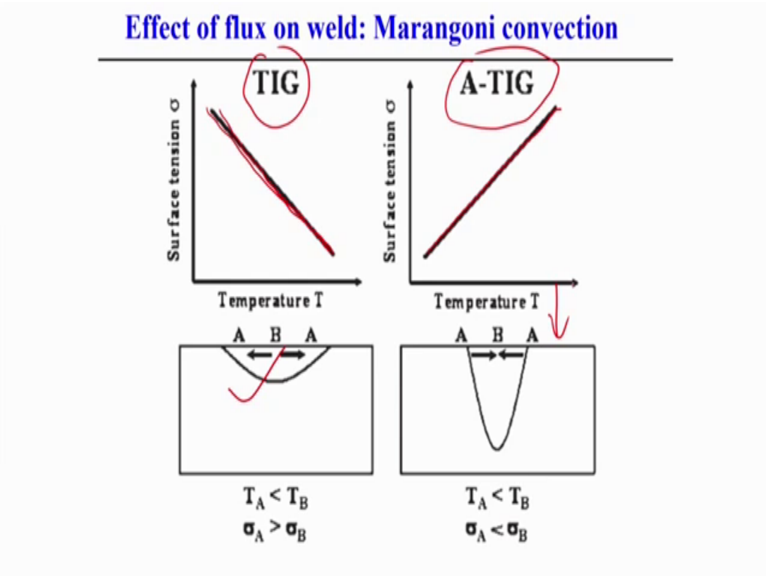

We have done some experimental also. And we can see that not on the earlier case we can we can we can see that in case of the laser welding, and the surface active elements actually present in the within the material itself. Now, there is the other way also the in case of TIG welding, but modifying the TIG welding process that is called activated TIG welding process or tungsten inert gas welding process.

So, in this case also normal TIG welding process this is the surface tension gradient on this. And here if the gradient is like this that means, negative gradient then flow pattern can be like this ; that means, metal flow from centre to outward periphery and that actually brings the white depth and low penetration. But other way in A-TIG process, so that means activated TIG that means, if by any means if it is possible to add some surface active elements within the base material in the different way either the surface active elements is already present in the base material, this is the one way or we can add the this active elements by putting some on the surface by putting some coating of the surface active elements. Or if we it is possible to mix the that elements within the shielding gas also.

And that by these three means it is possible to incorporate the surface active elements through the weld zone. And then there is a that call is the activated TIG welding process. So, in that case it simply changes the slope of the surface tension gradient and that actually brings this kind of profile that means, low width and the high depth of penetration.

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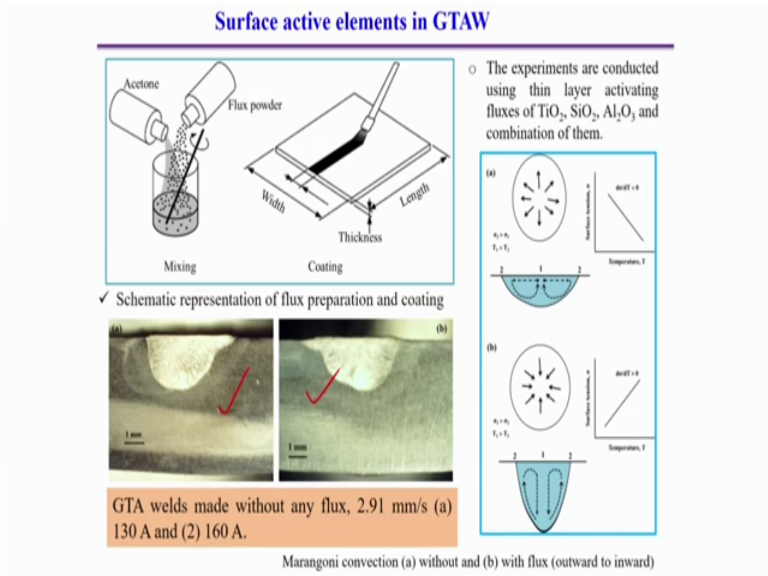

Let us see that in the first figure there is one way the surface active elements in t welding or gas tungsten arc welding process. So, in this process it is possible to mix the flux powder and that flux after mixing this thing with the acetone mixing we just simply put the coating on the surface and then if we conduct the welding process we can find out there is a different profile although with a for the similar parameters or maybe which change the other parameter. So, this is the one way to add the surface active elements within the weld. So, experiments are conducted you can see that the Ti O 2, Si O 2, Al 2 O 3, all can be used. And then all these three flux are used actually added and make some coating on these things. And we can find out there is a difference in the weld pool profile.

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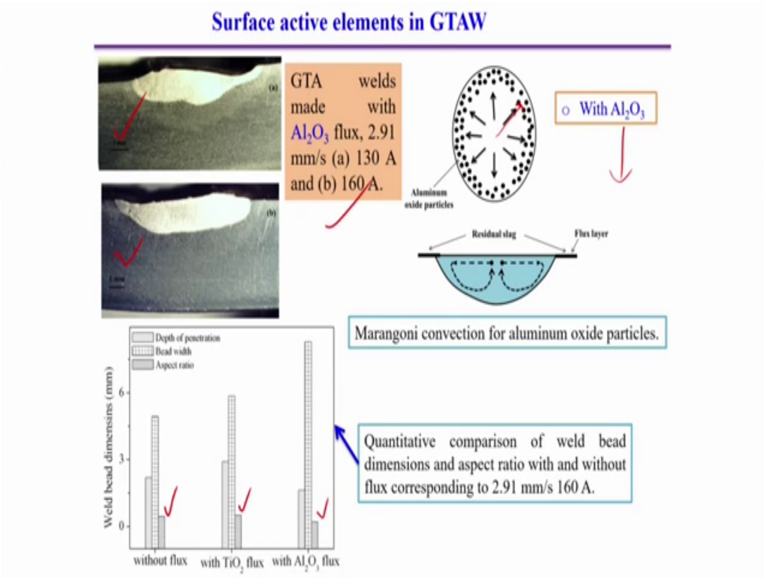

So, here simply that if optimum quantity of surface active elements is added, then actually it is clear well the from center points to the outward periphery with the presence of the in case of Al 2 O 3, but this from center of the output of periphery when it is happening the liquid metal flow from this direction that actually indicates that there is no effect of the surface active elements here that means, it is not necessary all the surface active elements and any quantity actually always enhance the well penetration and reduces the weld with not like that. There is a optimum quantity is required first thing.

And the second thing is that that surface active elements that for example, Al 2 O 3, Ti O 2, Si O 2. So, all oxides may not act as a surface active elements during the welding process. For example, experimental time observed then in GTAW as trances arc welding process and the surface act will flux was used as Al 2 O 3, and we can find out that not there is a not increment of the a penetration actually so with actually increases and for this specific condition.

But overall if we see that there is a quantitative comparison of the weld for example, weld bead dimension and aspect ratio with and without the flux corresponding to that that aspect ratio these two cases is moderately increase, but with the aluminum Al 2 O 3 there is not much increment; that means, it is not effective as a surface active elements during the welding process.

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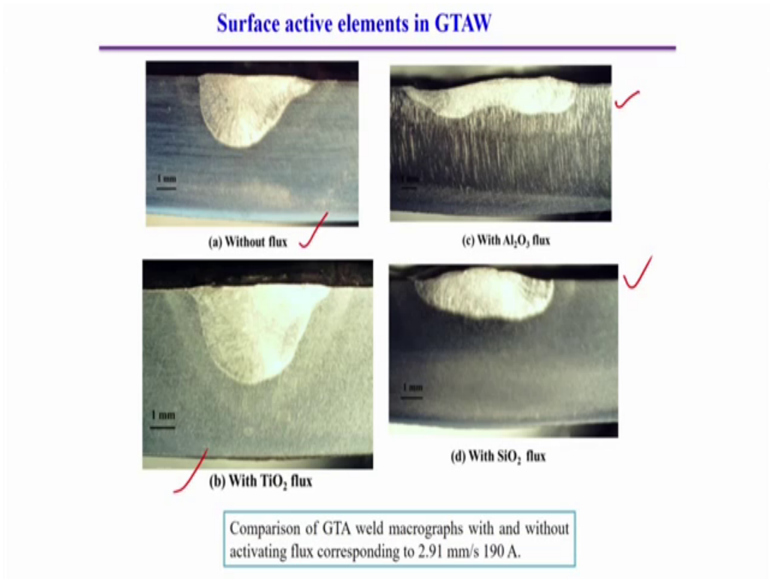

But if we look into that there is a Ti O 2 flux here you can see and you can see there is a marginal improvement in the weld bead weld penetration, but Si O 2 also we can see that also some marginal improvement that means, with reduces and actually depth of penetration increases. So, in this case, out of Al 2 O 3, Ti O 2 and Si O 2 or this all this fluxes, the Ti O 2 is the most effective active elements in the present system of the welding that means, with the present conditions of the welding.

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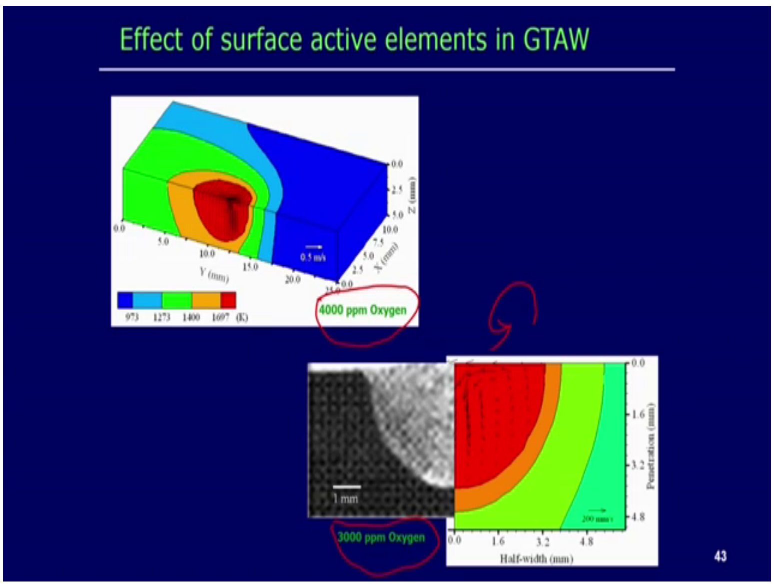

But if we look into that also in the other way that effect up the surface active element in gas trances arc welding process, but here just I mentioned the supply surface active; that means, presence of 4000 ppm oxygen and that oxygen has been mixed with the shielding gas that actually that actually acts as a surface active elements and that actually influence the material flow pattern in during the welding process. Here you can see that it is a flow pattern is in this direction that material flow pattern is over; that means, there is a effect of the surface active elements and then we can see that even for the gas trances arc welding process the it possible to achieve the quite high depth of penetration or that means, quite a high aspect ratio.

So; that means, as compared to the laser welding process this is the other way that where it is possible to achieve the high depth of penetration just simply using some the active elements adding to the welding system the that active elements can be added in terms of the flux. And that flux can be put as a coating on the surface or already the active elements presence in the base material all or these active elements can be added with the sealing gas.

So, based on that we can find out there is a profile, so 3 ppm oxygen that actually produce this kind of profile. Of course, the amount of the oxygen presents in this case that actually decides not necessary that each and each say this limits is too low that may not be effective to produce increase that depth of penetration even if it is too high and that is also not effective to produce the high depth of penetration. So, there is an optimum quantity is required that optimum quantity actually we can get the optimum value that means, maximum value of the weld penetration in case of the fusion welding process.

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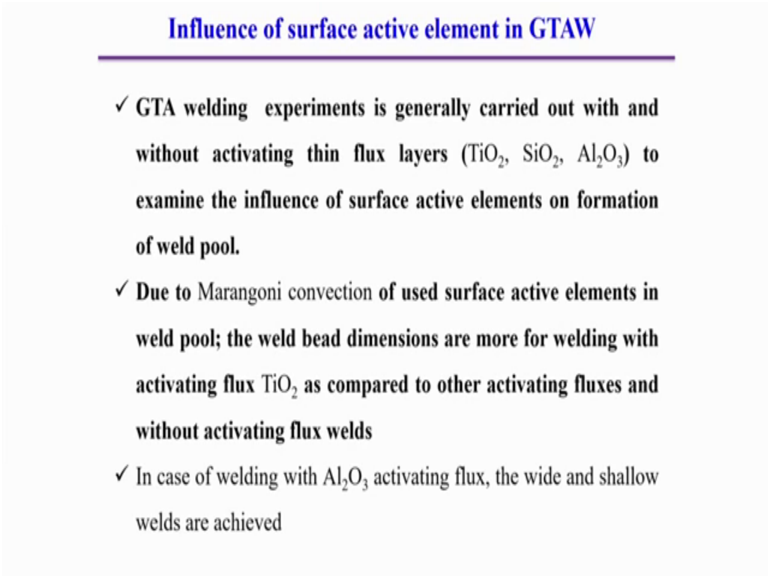

So, therefore, if we look into that GTA welding process experiments is generally carried out with the three different flux layers. And then we can find out the therefore, due to the Marangoni convection of the surface active elements in the weld pool in the weld bead dimension or may be changes or there may be significant we can possible to modify, but Ti O 2 is the most effective as compared to the other surface active elements.

But in case of Al 2 O 3 who did not find any kind of this thing effect of the active elements such that it will produce the high depth of penetration in this case in all in all this case; possibly it is need to optimize the quantity or maybe its needs to optimize the other process parameter. So, that we can get the benefit of the active elements and that actually influences the weld dimensions.

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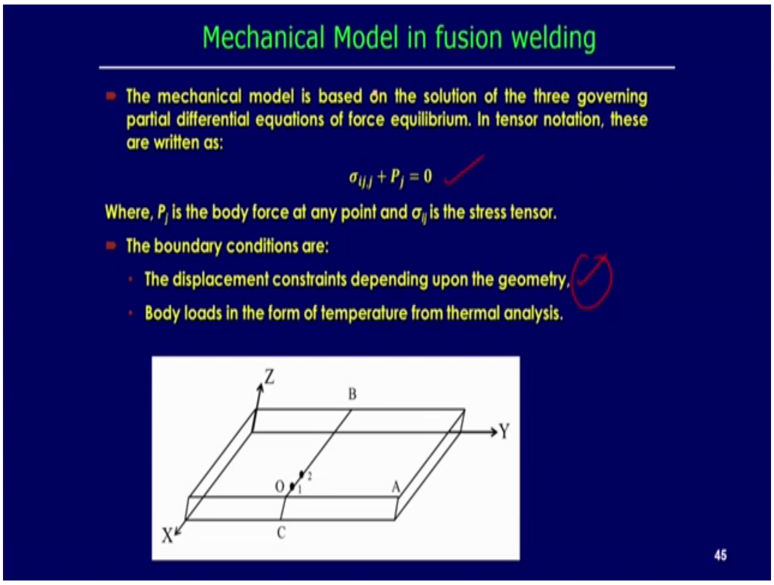

Now apart from the surface active elements and then how the presence of surface active is actually incorporated in some mathematical model, but just by simplifying or just by modifying the coefficient of surface tension value, we can incorporate the effect of the surface active elements. But of course, the platform is required to analyze both thermo fluid analysis that means, with heat transfer as well as the fluid flow analysis, then only we will be able to capture the effect of the surface active elements mathematically.

Now, we will try to shift that mechanical model that means, thermo mechanical analysis which is widely used in the welding process. So, here if we see the mechanical model in the fusion welding process, so we can say something thermo mechanical modeling. So, of course, in mechanical model is based on the solution of the three governing partial differential equations of the force equilibrium intention notation it is written that this is the governing equation that will stress here the body force per unit volume I think and the stress tensor they can make the equilibrium conditions. And if you try to solve these cases, we will be able to find out this thing.

But of course, the thermo mechanical analysis in general that there is a after doing the thermal analysis so that temperature distribution actually considered as an input to the mechanical model and then we try to relate the constitutive relation between the stress and strain or between the strain and displacement then we will generally predict the distortion field or finally, the residual stress field in the welding process. Because in fusion welding or maybe other solid state welding processes, it is important to predict and the final distortion level and the residual stress that is the mostly interested mostly we generally interest to predict that values.

So, of course, when you try to use this governing equation that mean force equilibrium equation along with that some boundary condition also that means, in terms of the displacement constant we generally put the boundary condition that depends on the geometry and the body force in the form of the temperature. So, displacement constant in terms of the boundary conditions. And at the same time and the body force can be that where we can say the load to the thermo mechanical model that can be estimated from the temperature distribution.

Here, we normally we create the geometry, and we can define this thing. And within the geometry depending upon the practical welding condition we can put the constraints displace the constraints that means, somehow we are putting the clamp, and therefore we need to put the displacement constraints maybe depending upon the direction we put the displacement zero in that specific directions or maybe on the symmetric surface therefore, the normal to the symmetric surface displacement we put the displacement constant I mean displacement becomes 0.

So, therefore, putting the boundary conditions in terms of the displacement and that and then solving the governing equation assuming the body force from the thermal load. And finally, we solved the a displacement field in the in a thermo mechanical analysis, and this that displacement from that displacement field the strain field can be calculated. And of course, from the strain field we can estimate the stress value also.

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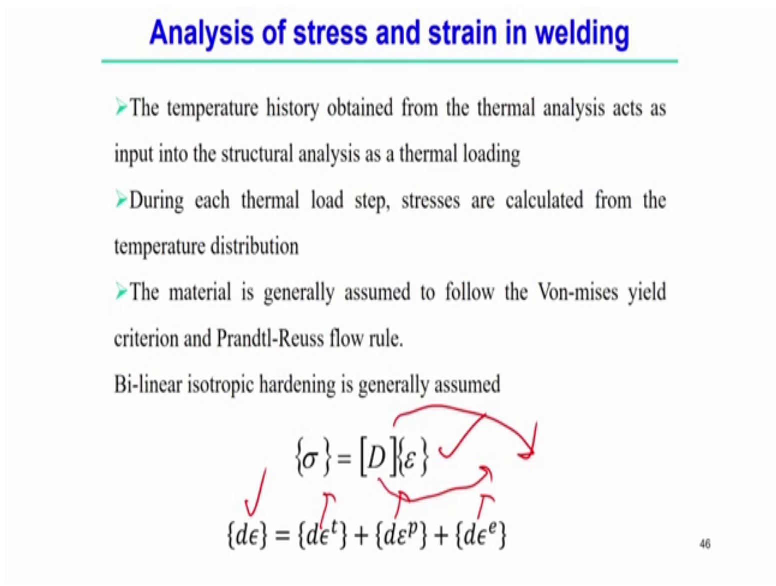

So, if we look into that how the analysis of the stress and strain is generally done in case of the welding process. Here you can see the temperature history first obtained from the thermal analysis and that actually acts as input to the structural analysis as a thermal loading. Therefore, each thermal load step and each of because when you apply the thermal load step, it is not the solution can be done exactly for the one single step. So, therefore, each thermal load step stresses are calculated from the temperature distribution; and normally material is material model in the sense that assume the follow the von-Mises yield criteria and the fondant (Refer Time: 23:50) flow rule.

And of course, some hardening behavior, you need to predict, we need to define if we do the thermo mechanical analysis. So, normally bilinear isotropic hardening is used. And then in the final form this is the equation between the stress and strain. So, all the components of the stress, and here sigma and all other components is represented by strain. And this the D is actually the properties material properties. And within the elastic limit if the inlet between the stress and strain, therefore this would be related in the elastic properties of the material that means, in the matrix form, but that elastic properties the young's modulus and similarly the poisons ratio .

And then normally we do the analysis assuming the metal is the material as a not only elastic. And most of the cases we assume the elastoplasticmaterial. So, in the material is the elastoplasticis in nature, then relation between the stress strain can be modified within the elastic limit the domestics the D is you can say the elastic elasticity matrix or if it is in the plastic zone then D is can be the D elastoplasticmatrix. So, then we need to incorporate the plastic form what are the material properties you need to incorporate, we will see that how D can be represented the in the different way; that means, either elastic analysis on the plastic analysis.

But overall stress analysis is done not in the in a single step, even we consider the bilinear isotropic hardening that is a linear curve. And it is possible to do the analysis the mostly because elastic component is in the linear elastic components. Therefore, the elastic component is represented by the slope that means, it is a linear path. Therefore, in single step it is possible to consider the elastic analysis, but when you enter the plastic stress then a strain component is divided into smalls then in the incremental mode.

Basically each an incremental mode that means, we divide the total strain strain values in the very small component; that means incremental D epsilon and that D epsilon consists of the all the three components ah. So, thermal may be if in welding process mainly the thermal load is here, we the thermal strain is generated. So, therefore, this is the thermal strain incremental mode, plastic strain and the elastic component elastic strain component so that each and every increment we assume this and then we update the stress value and the distortion value as well as the stress value in each table. But overall analysis for a long overall duration of the load we divide into small small components; that means, small small division small small steps of the strain and then we do the analysis in the incremental mode which is the basic mode of the analysis.

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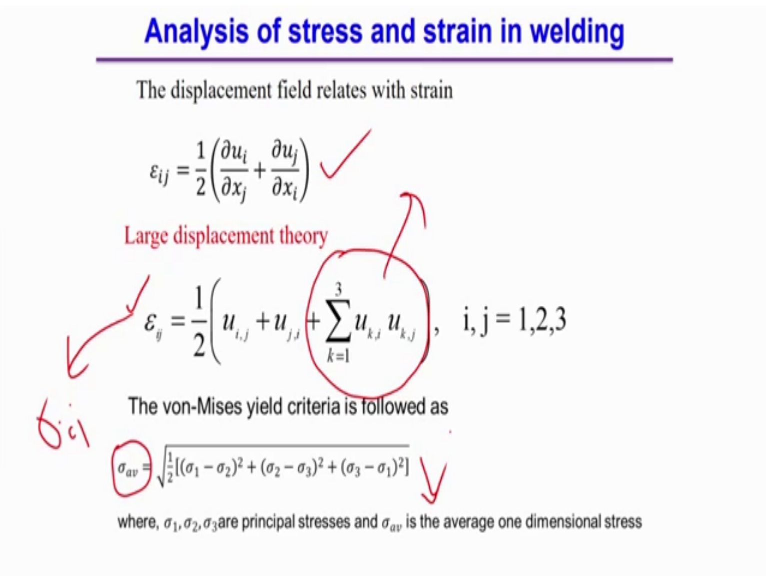

Then it is also important to know that how the displacement or strain is related. So, the displacement and step it is related by this equation this I think linear relation between the strain and the displacement component, but that is that is called a small displacement theory that means, in this case normally we neglect the and non-linear term of the distortion. And then we simply relate within the stress and strain by this way.

But of course, in some cases when you try to capture the we specifically in a very thin sheet, when you try to capture the local behavior in the zone, in that case large displacement theory is necessary to consider; that means, large displacement theory only components is the this component, there is non-linear component of the displacement also need to add such that we will be able to capture the exactly the deformation behavior in specifically is very small thin sheet and its most and which happens in a very locally localized zone. And that is the either small displacement theory or large displacement theory, we assume that and then based on that we simply relate between the strain and the displacement.

So, once strain has been estimated and from the strength we can estimate the stress value also , but overall von-Mises criteria when we try to follow the von-Mises yield criteria then that one effective stress or we can say the average value in one-dimensional form can be represents in the all the three principal components the sigma 1, sigma 2 and sigma sigma 3 all these three components principal components can be represent in one directional average stress value and that is that actually follow the von-Mises yield criteria yield functional form. This way also used in case of stress analysis.

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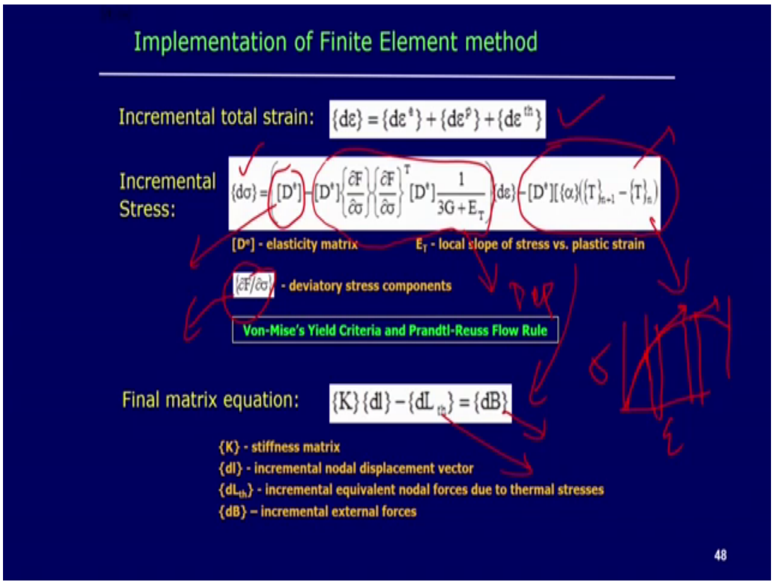

So, implementation the finite element method that means, how the stress analysis can be considered in when you try to do some develop using some finite element method. So, definitely first this point is the incremental mode, we do the analysis in the incremental mode that means, very small increment of the strain, we do the analysis. And incremental stress can be represented like that D sigma equal to D and we can find out we say expression for that. And these actually represent the thermal related to the thermal the thermal strain. And this we knew thermal strain and the elasticity matrix, then we represent that this is the thermal stress value.

So, here you can see that incremental stress value is a consists of the three component. This first component is related to the elasticity elastic part. This component the plastic part and this component is the thermal part. So, here you can see that d e actually present elasticity matrix and this we can see we can represent that d e p; that means, elasto plastic matrix. And here and this is the this component is the thermal stress value so that means say the incremental mode since incremental total stresses consists of three components, similarly incremental stress value can be the three components. So, of course, we generally follow the von-Mises yield criteria and Prandtl-Reuss flow rate.

But here delta f by delta sigma that actually considered the deviatory stress components. So, when you try to estimate the plastic component, we need to consider the deviatory stress component, we need to know the tangent modulus that means, local slope of stress versus strain that actually local. So, if you look into the elasto plastic matrix, plastic component that first component is the linear elastic and then it is in plastic nature. So, therefore, this part there is a continuous change of the slope. So, we need to consider that at any point at the incremental point, this is the strain value and this is the stress value.

So, this is the suppose this is the incremental point, and here we need to consider what is the slope. And this slope actually changes. So, the tangent modulus actually changes. So, at any point we need to consider the slope local stress versus the plastics in that slope we need to consider to find out the elasto plastic matrix and then final matrix in terms of the so therefore, doing this and final matrix can be in the in terms of the stiffness matrix k and d l is the incremental nodal displacement vector. And d is the incremental equivalent nodal force due to the thermal stresses and dB is the incremental external force if any presence.

So, if there is no external load presence then it simply becomes 0 that means we finally, we represent the equation in the form of the A x equal to B in the matrix form that means, in terms of the stiffness matrix. And we solve this stiffness matrix we will be able to find out the incremental value of the displacement nodal displacement. So, once we find out the increment of the nodal displacement that displacement field again converted to in terms of the strain component. And then once estimating the strain component that strain component can be can be converted to the stress value.

So, they are in that way we will be able to find out at any point of time at any stage what is the value of the displacement, what is the value of the strain, and what is the value of the stress or finally, once we know the stress distribution or if you know the principal stress component sigma, sigma 2, sigma 3, then will be able to find out the von-Mises yield function of that means average stress value following the von-Mises yield functional form. So, that all calculations are linked with respect to each other and we can find out in this way the strain field and strain field simply by predicting the displacement field in case of the simulation.

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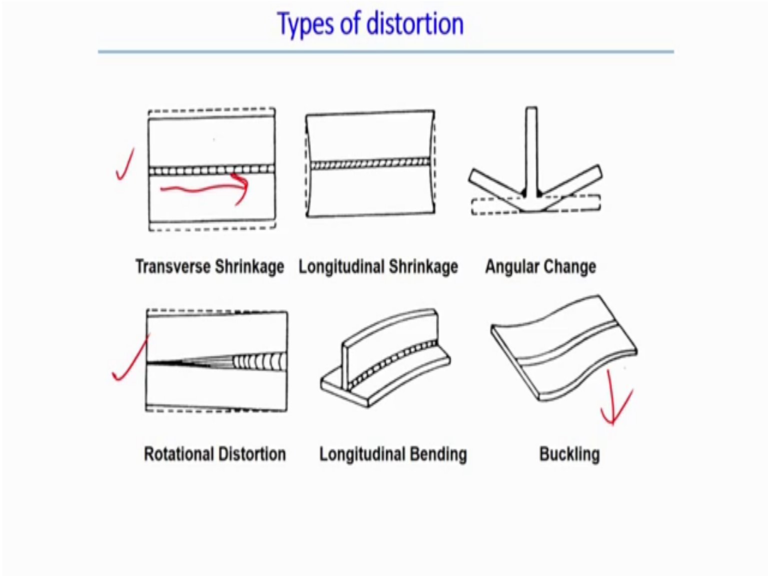

But after doing this to know some idea about the different types of the distortion, we can see that the transport shrinkage this is the one type of the distortion we generally follow in welding processes. And we can find out this is the transverse shrinkage. So, this actually represents the welding direction and the transport shrinkage that means, normal to that transverse direction there is a shrinkage of the metals that is called transverse shrinkage.

Then longitudinal shrinkage so with respect to normal to the longitudinal direction it is a longitudinal friction and then there may be angular changes in case of T joint after welding process. And rotational distortion cannels we find out in welding process. And then longitudinal bending; we can observe after welding process. And finally, if sheet it is very thin we can mostly we can find out the buckling of this thing. So, these are the different pattern of the distortion generally observed during the welding process.

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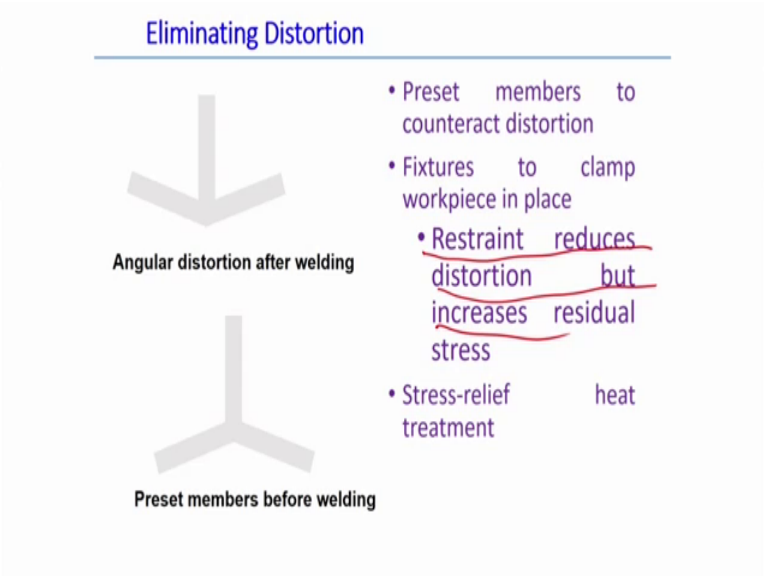

But how we can predict these things, but here you can see that how we can that is a serious problem in case welding process that to eliminate the distortion. Anyway the during the welding process and after finishing the welding process is considerably changing the phase transformation, micro structural changes also happen and that happens under the some mechanical constraints all actually responsible to produce the some amount of the distortion and the residuals in the final weld joint. But that phase is concerned how to control the distortion in case of the welding process or how to avoid that. Although it is not possible to completely avoid the distortion, but we can follow proper simple methodology such that distortion can be reduced.

So, one is the preset members to counteract distortion. So, before doing the welding process we can preset the members if we know which direction distortion will occurs. So, based on that, if you presetting the members simply to counteract the distortion that is possible. The second fixture to clamp work piece in proper position we can put the certain fixture in the proper position to avoid any kind of the distortion. Other is the restraint reduces the distortion, but at the same time when you put the some restraints definitely solutions, but at the same time it will try to increase the amount of the residual stress. So, therefore, you should be very careful to apply any kind of the mechanical resistance or to avoid to reduce the distortion or that actually increases the residual stress.

So, most of the cases after doing the welding process, we generally do the heat treatment such that the properties up to certain extent the it can be recovered then we can reduce the distortion, we can reduce the amount of the residual stress that is the normal procedure to do the heat treatment simply to recover the certain properties in case of the fusion welding process.

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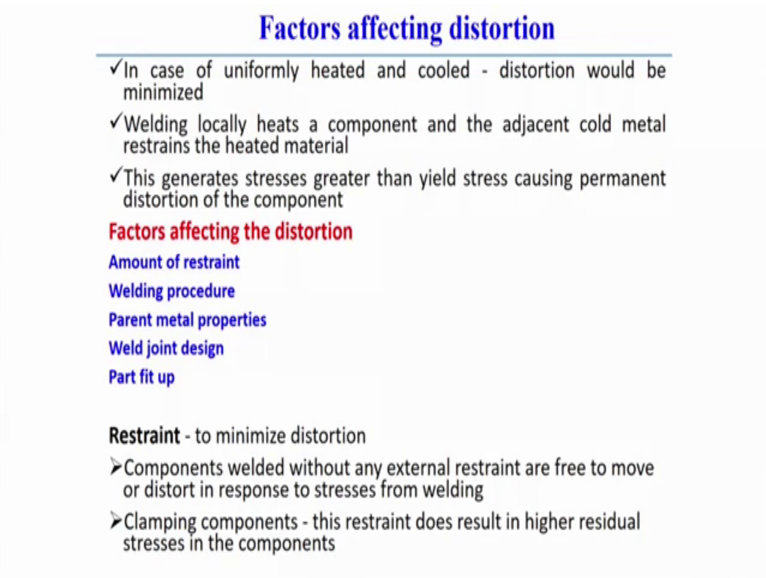

But normally what are the factors that actually affecting the distortion first if the one is the one factor is the uniformly loading heated and cooled, but in welding there is a it is a non uniform heating a non uniform cooling actually happens in the welding process that actually is the distortion code. If you try to create the mostly uniformly heating and the cooling process in case of welding that actually reduces the amount of the distortion. Second other factors at the welding locally heats a component.

So, one specific component we just local locally heat and therefore, adjacent part is the cold. So, therefore, heat difference in the or there is a huge temperature gradient exists between the two parts of the component that actually brings the some amount of the distortion. So, therefore, free heating sometimes helps to actually minimize the distortion. Other factors affecting the distortion is the amount of the withstand up to what extends the flexible restrain whether we were using or very rigid systems were using that actually that actually influence the amount of the distortion in case of the welding process.

Then welding procedure, welding procedure in the sense that what type of the heat source, what is the typical geometric shape and size and the material properties that actually used in the welding process that is also responsible, then the weld joint design with the butt joint, lab joint, t joint that actually this thing and the gap between the two components, all actually influence the influencing factor that actually generate the distortion in case of the welding process.

So, therefore, one is the restraint putting the restraint normally to minimize the distortion. So, therefore, components weld without any external restraints if you do not put any restraint are free from to move the distort the in respect of the in distort in response to the stress from welding process that is the one case. Therefore, clamping components, therefore, this restrain does result in the higher residual stress in the components. If you put the clamping components that actually try to produce the high amount of the residual, so there are in welding process not only the welding process.

So, how we are using the surrounding medium fixturing, fixturing or fixturing not only the fixturing and the material of the fixturing of the high conductive, low conductive material that actually also influences the amount of the stress that actually influence the rate of the cooling so that finally, cooling rate influence the amount of the residual stress generation .

But some idea about the measurement of the basic idea measurement of the residual stress normally we know that non-destructive techniques normally we use the x-ray diffraction or neutron diffraction. So, both use on the similar kind of the principle, but x-ray diffraction the limitation is the x using the x-ray diffraction method we can use we can generally measure the residual stress only on the surface that means, maximum depth of around point 0.05 millimeter, so that means, 50 micrometer this is a very less.

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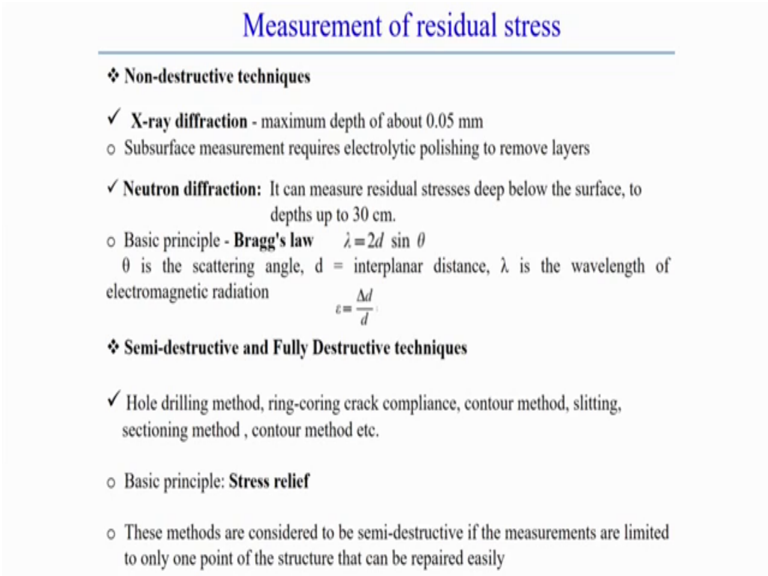

So, normal you can say on the surface we can using the x-ray diffraction we can you measure the residual stress on the surface, but neutron diffraction it can measure the up to certain depth. maybe up to 30 centimeter depth, it is possible to measure the residual stress. But if we want to measure the residual stress using the x ray diffraction at very high depth then it is possible to remove the top of the layer once you measure the residual stress from the top surface, then we need to remove that layer then after that we put the similar technology we put the again x-ray diffraction methods follow for the next layer of the surface to measure the residual stress.

But neutron diffraction it is not such limitation is not there it can go up to very high depth of penetration, we can measure the residual stress. So, it follows the Bragg's principle that lambda equal to 2 d sine theta. Here we see the theta is scattering angle indeed inter planar spacing, and lambda is the wavelength of the electromagnetic radiation. So, therefore, the strain is measured by changing in terms of the d. So, delta d by d actually that actually measure the change these thing. So, x-ray diffraction is the well method to measure the residual stress. Other semi destructive method and or and fully destructive techniques that can also be used there hole drilling method other these are ring, coring crack compliances, contour method, slitting method slitting, sectioning method. And of course, these are the other typical type of the semi destructive residual stress measuring unit, but all actually follow the principle of the strain stress relief.

And then of course, this hole drilling method all this kind of method is we just if we put the using the simple strain gauge using the very high sensitive strain gauge you can use it using this and then its captured the amount of the strain changes when there is a relief of the stress. And based on that, we can measure the amount of the residual stress. These methods are considered the semi destructive because if the measurements are limited to only one point of the structure and therefore, that can be repaired very quickly. So, these are the typical methodology for the or basic principle for the measurement of the residual stress.

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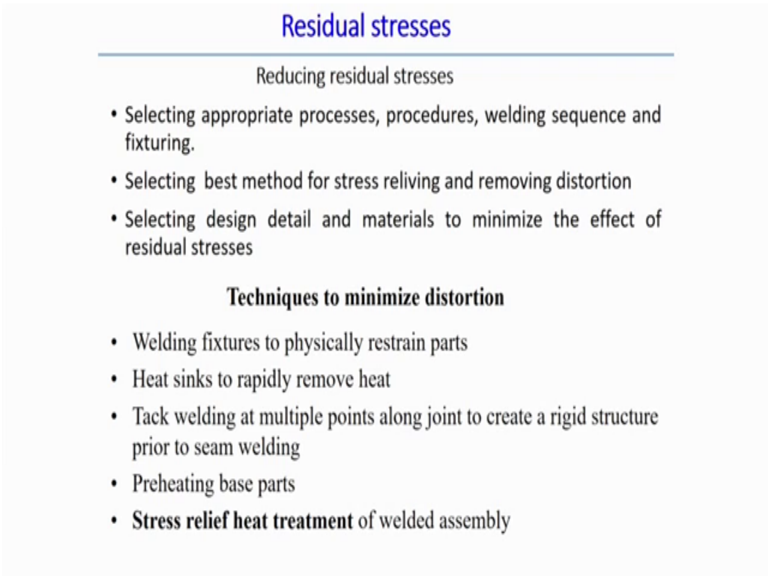

But one important thing is the in analysis or maybe direction the work in in case of the welding process that is the measurement of the residual stress, and how to reduce the residual stress because residual stress actually impact of the life life of the weld joint. Therefore, it is necessary to very important to assess the amount of the residual stress in basically generated during the welding process. So, reducing the residual stress some simple or methodology is that selecting the appropriate processes. Therefore, certain process so we need to select the welding processes some procedures followed and sequence of the welding and fixturing. If you use the proper way we can reduce the residual stress generation during the welding process selecting the best method for stress relieving and the removing distortion.

So, stress relieve and the review session we need to consider the best method. Therefore, selecting design detail and the material to minimize the effect of the residual stress. These are the basic principle up to reduce the residual stress, but what are the techniques for the minimize the distortion residual stress is the welding fixture to physically restrain parts. Heat sinks to rapidly remove the heat it is possible to rapidly remove the heat, therefore, you can use the heat sinks also that actually do the distortion or will be high conductive fixture which and also we can use it that actually reduce the actually quickly rapidly remove the heat.

Tack welding at multi we can put the tack at multiple points along the joint to create the rigid structure before the seam welding that actually minimize the distortion preheating the base part and finally, the stress relief of the heat treatment process that actually of the weld assembly. This is the most general method to reduce the amount of the distortion and residual stress simply doing the heat treatment of welding process.

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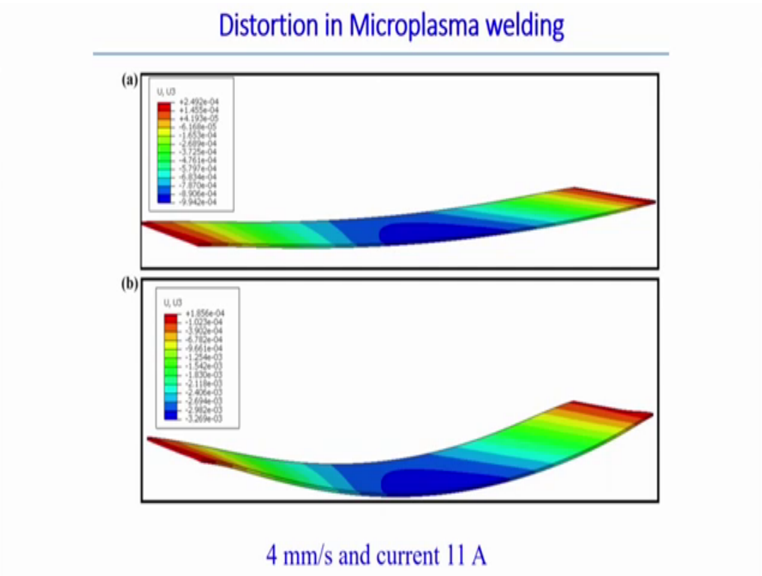

Now, well to try to see some distortion field simulation and we can in microplasma welding process. So, here you can see that distortion pattern of 500 micrometer thickness see it. And here I think in microplasma welding this has been welded and we try to predict the distortion field. So, here you can see that one cases the distortion is not much flat pattern; other cases it is a bending is more on the other cases. So, one cases that that means, my point is that the of course, irrespective of the magnitude of the at maximum distortion amount, the difference the maximum to minimum is one cases is less other cases it is very high.

So, in the first case, it was considered that the small displacement theory; that means, when you try to relate between the strain and the displacement in that case we do not consider the non-linear component of the displacement so in the first case. In the second case we consider the local behavior; that means, non-linear part of the distortion and that actually predict more precisely the distribution of the distortion in case of the very thin sheet and that is the in case of the second case. So, therefore, you very thin sheet, it is we should use the large displacement theory to predict the displacement field.

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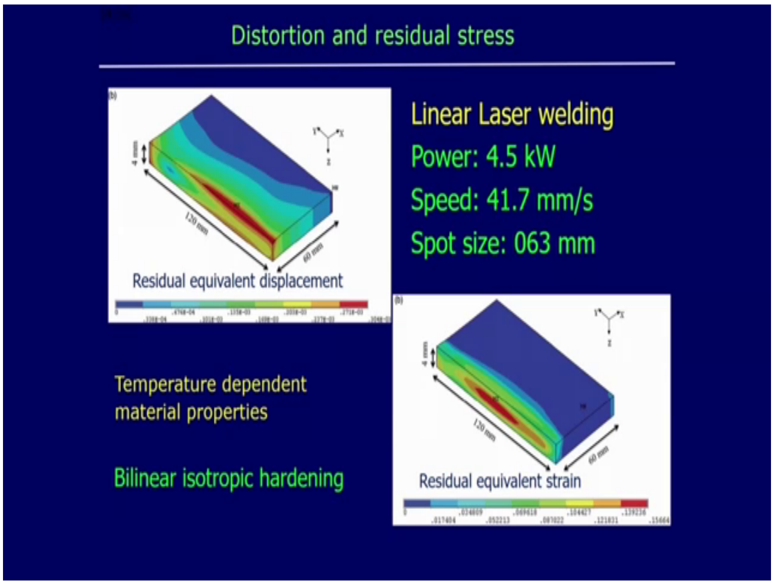

And of course, in the other laser welding process I think it is a laser welding process yes power 4.5 kilowatt and the speed 41.7 millimeter per second and spot size is point i think not spots 0.63 millimeter. And here you can see using the temperature dependent metal properties and bilinear isotropic hardening the first case the residual equivalent displacement here we can see that displacement is maximum at the which point the heat source we move at the edge along the edge.

And the second case or the residual equivalent strain amount also generated more or less than along the weld line. So, this way it is possible to predict through the finite element base numerical model the amount of the residual equivalent displacement and although residual equivalent stress that means, single value of the displacement and single value of the strain. Here you can see the maximum strain amount is as you around 0.156 and residual displacement we can find out that around I think 0.3 millimeter.

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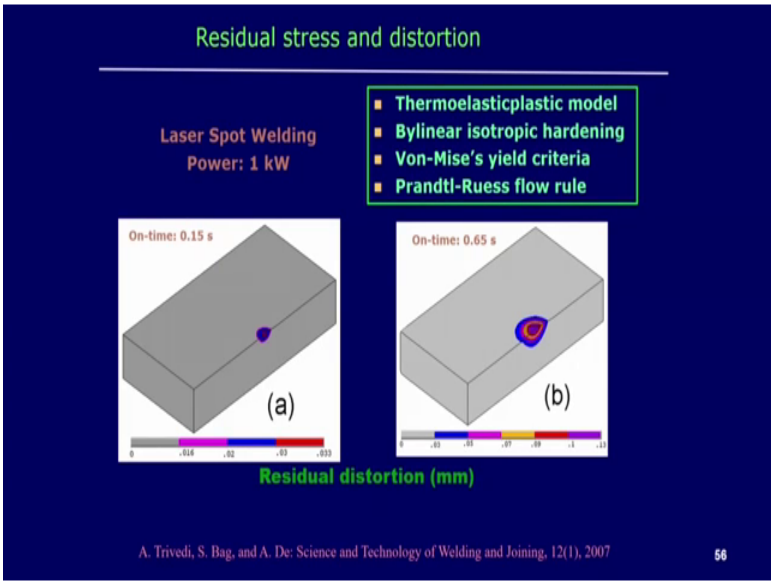

Similarly in the laser spot welding also we can find out the for 1 kilowatt laser spot welding, this is the simulation of the residual distortion. So, in the first case, the if you on time is 0.015 second laser is on then we can find out the distortion residual distortion is very small, and it is confined into the very small area. But once the is increases that my laser on time is increases up to 0.65 second then we can find out the that residual distortion the area actually increasing through which the residual distortion; we can observe.

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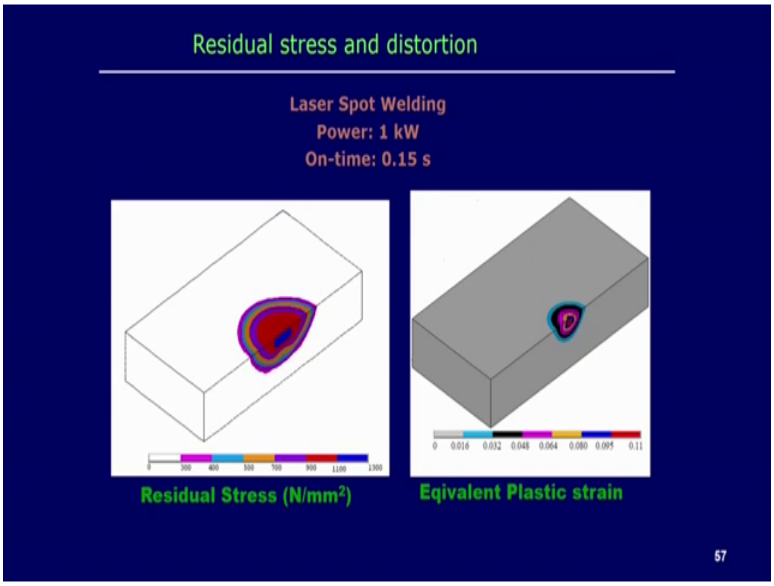

And of course, in this cases that one cases the residual stress and the equivalent plastic strain in the two cases one is the at 0.15 second, 1 kilowatt laser we can see the residual stress is basically conferred is a small area near about the weld spot. In other cases, we can equivalent plastic strain also confined, it is a very small area.

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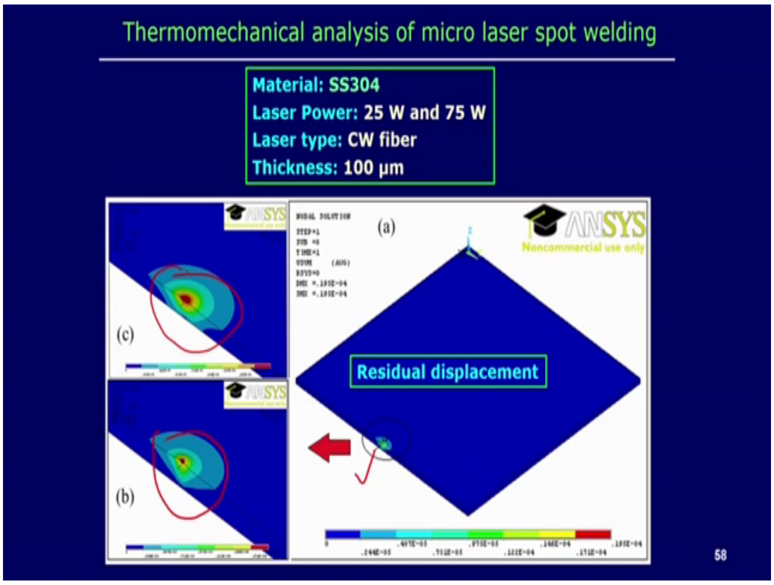

We can see other also that thermo mechanic analysis of the micro laser spot welding process. So, that material SS304 stainless steel here and two laser power 25 watt and 75 watt has been used and laser type container cell fiber and thickness is only 100 micrometer. So, in this case we can see and the residual displacement is actually confined, it is a in a very small, it is the spot welding, it is a very small zone, but if we zoom it we can see that this is the displacement of the residual stress here in the thing. And here you can see the two different; I think here is the two different cases.

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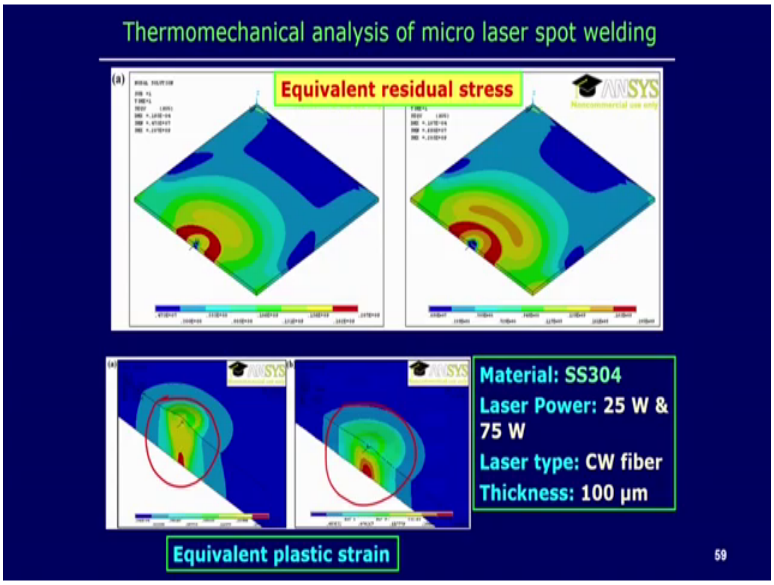

Similarly, equivalent residual stress we can find out that this is the distribution normally the residual stress distributed over us bigger zone as compared to the residual displacement. So, here you can see the first figure, the residual stress distribution, and the second with the equivalent plastic strain rough plastic strain is basically confined it is very small area. And of course, the maximum value is towards the bottom site of this thing, which seen heat actually depends the thick sheet thickness and that because normally thickness direction the temperature gradient is less.

And of course, at the at the same time what is the amount of the heat loss from the bottom surface that means, whether we using any kind of high conductive material from the bottom site based on that the location of the equivalent strain or residual still maximum amount will be will vary depending upon that.

So, this just want to see that here you can see that what way that residual stress is distributed in case of the welding process. So, that of course, this is these is residual stress it has been calculated once the after putting the heat input and then when you heat increase not in this way; that means, after solidification happens and when it is come back to the room temperature then this is the permanent amount of the stress strain or distortion field is actually generated in the welding process these are the typical distribution.

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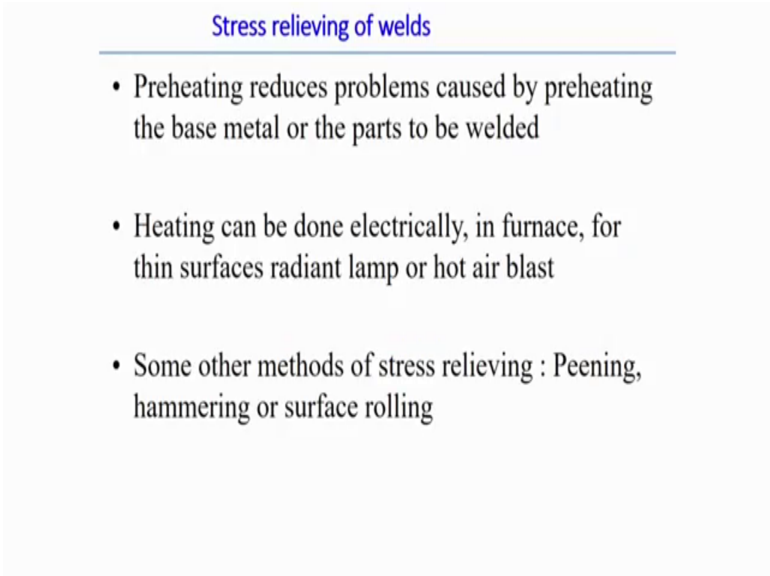

So, stress relieving up well some significant points that related to the residual stress and distortion in welding process that preheating actually reduces the problem. So, before welding process, if we preheat the sample that actually reduces the problem caused by the during the welding process. Second is the heating can be done, but this preheating can be done electrically in the furnace for the thin surface radiant lamp or may be hot air blast. So, therefore, there are several way to actually practically do the preheating, because preheating some time reduces the amount of the problem related to the welding process. Then some other methods of stress relieving; that means, peening, hammering, surface rolling, these are the other mechanical methods that actually remove the amount of the residual stress in the welding process.

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Summary

- Different heat source models – depending on type of welding
- Estimation of temperature distribution in the weld zone and heat affected zone by solving heat conduction equation
- Incorporation of fluid flow enhances the calculated results of temperature distribution
- Influence of surface active elements is explained by the fluid flow phenomena
- Coupled thermo-fluid analysis is computationally expensive
- Mechanical analysis predicts distortion and residual stress
- Coupled thermo-mechanical analysis is also computationally expensive
- Cooling rate is linked with the microstructure in a welded structure
- Experimental measurement of all phenomena in welding is difficult and costly

So, in summary for the whole the computational methods in case of the welding processes, we can see that first we have described the different heat source model depending on the type of the welding process because heat source model is significant. If you try to correctly predict the amount of the distortion residual stress, so in that sense correctly representation of the heat source is important in the welding simulation.

So, therefore, and that representation of the heat source actually depends on the two points, one is the geometric shape of the heat source and second point is the distribution; so, based on that, different type of the heat source models has been developed to represent the different welding processes. Next to us; estimation of the temperature distribution in the weld zone and the heat affected zone by solving the heat conduction. So, we have discussed using the simple the temperature distribution can be done by simply solving the heat conduction equation with the proper boundary conditions.

Of course incorporation of the fluid flow enhance the that means, more precision results of temperature distribution and the fluid flow material flow is better represented if we consider the material fluid flow in case of the welding process as compared to the only the heat conduction analysis. And of course, surface active elements presence of the odd effect of the suffix at elements is better represented or better explained by incorporating the fluid flow phenomena in the weld pool simulation.

And coupled, but point is that coupled thermal fluid analysis is definitely computationally very expensive, so most of the cases we neglect the fluid flow analysis and we we do only the heat conduction analysis. Then mechanical analysis predicts the distortion and the residual stress ah, but mechanical analysis needs to be considered the temperature distribution as an input to predict the distortion residual stress in case of the welding process. Then of course, coupled thermo mechanical analysis again is also computationally very expensive. And then cooling rate we can from this numerical model or data if you know the temperature distribution, so from that temperature distribution we can estimate the cooling rate and that cooling rate can be linked with the microstructure in a welded or welded structure.

So, therefore, just simply calculating the cooling rate, it is possible to predict; what are the microstructure presence in the coil adjourn. Then of course, simulation is important or significant when there is a difficulty of doing or to capture the phenomena simply by doing the experiments, because it is not possible to capture all the phenomena that happens during the welding process experimentally. So, here there is a need of the numerical simulation. For example, the experimental evidence of the material flow within the weld pool is very difficult to do experimentally. So, therefore, numerical simulation can be recurs to better understanding of this phenomenological behavior in case of the weld pool simulation.

So, with this; so thank you very much for your kind attention.