Joining Technologies of Commercial Importance

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Lecture - 39
Cracking of Welded Joints I: Solidification and Liquation Cracks

Hello, I welcome you all in this presentation, this presentation is based on the topic the Cracking of the Welded Joints since number of types of the cracks are observed in the welded joints either during the welding or after the welding, so this topic has been divided into the two parts in one part we will be talking about cracks observed in the weld metal and then also I will talk about the cracks observed in the heat affected zone.

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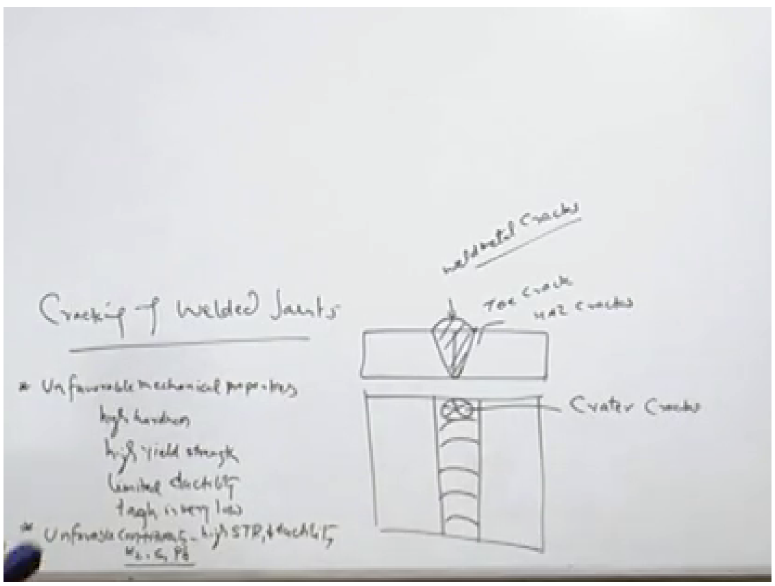

So we will start with the - the cracking of welded joints and the different types of the metal systems are found sensitive for the different types of the cracks which may be in the either heat affected zone or in the weld metal. So let us say the component like this joint using the fusion welding process, so in this case we may have cracks in the different locations which may be here like the toe of the weld in form of toe cracks - toe crack.

Or it may be very near to the fusion boundary like this, so this is HAZ cracks or crack maybe in the - in the weld metal itself, so the weld metal cracks we can say these are the 3 areas where the cracks can occur in addition to them, if we see the same thing in the top view and in this one this is the location here weld joint is ending. So we may find the cracks also in the crater where the weld pool in the last stage of the welding where the weld pool are solidifies this is called crater.

It is some kind of depression of the circular family and it is sensitive for cracks due to the high concentration of the impurities, so we can say the weld metal, the toe of the cracks or the cracks in the weld metal or cracks in the heat affected zone these are the - the that area wise the cracks which are observed. So depending upon the stage when they occur depending upon the location where they occur the different names have been given.

And these cracks developed due to some of the regions which are very predominant and among these like unfavorable - unfavorable mechanical properties of the either weld or heat affected zone. So unfavorable mechanical properties of the weld metal or of the heat affected zone includes like extremely high hardness which makes it brittle, high yield strength which does not allow yielding.

But facilitates the crack initiation and its growth, so high yield strength and very very limited ductility not permitting any yielding so limited ductility and low toughness in general, toughness is very low. So these are some of the mechanical properties which are if unfavorable either in the weld metal or in the heat affected zone then it will lead to the cracks in the weld in the toe region or in the heat affected zone.

In addition to this we may have other points also responsible for the development of such cracks like unfavorable constituents - unfavorable constituents. Sometimes presence of very unfavorable constituents lead to the very high solidification temperature range or very low ductility so this promote the cracking and these constituents like hydrogen in case of steels, sulphur in steels.

Lead in steels are the common elements which promote the cracking tendency due to the different regions like solidification temperature range is enhanced by the presence of the sulphur and the lead. While hydrogen reduces the ductility and increases the cracking tendency due to the cold cracking possibility. So in addition to these two types of the factors we may see that the cracking is also caused by other properties related with the weld joints.

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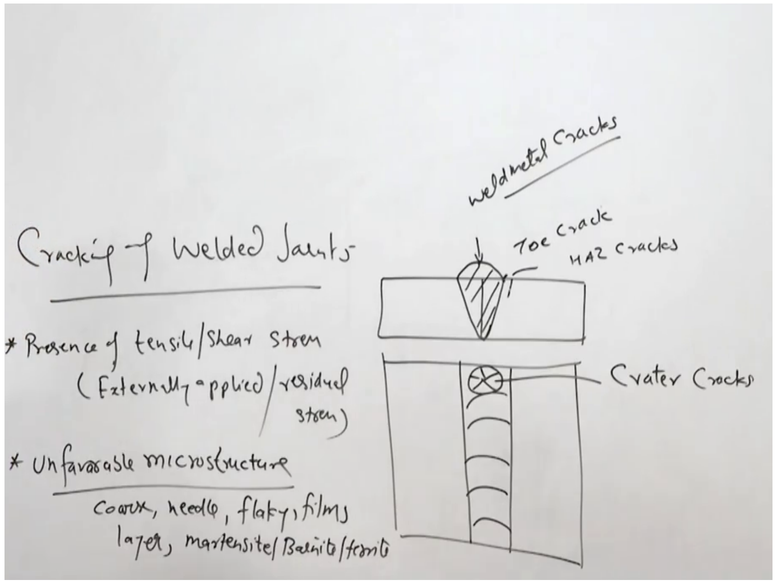

And it includes say the presence of the - presence of the tensile or shear stresses, these stresses may be externally applied - externally applied or this may develop due to the differential expansion and contraction during the welding so leading to the development of the residual stresses, so this also promote the cracking under the favorable conditions of the weld joints and third is favorable - favorable micro constituents micro structure.

These microstructural features or the constituents like very coarse grains very large size grains promote the cracking and the nucleation of the cracks is compared to the fine grained structure and needle shaped constituents or the constituent having the larger aspect ratio or the constituent which are flaky in form of the films or the layers, these features are about the morphology or the shape of the constituent so means about the grain structure.

In terms of the phases structure like in case of the steels the martensite, bainite and ferrite these are in the descending order of the tendency of the cracks maximum cracking tendency is shown by the martensite, thereafter somewhat - somewhat less cracking tendency is executed by the by the bainite and the ferrite in case of the steels, so this we can say in general the 4 kind of the - the factors if which promote the cracking tendency in the welded joints.

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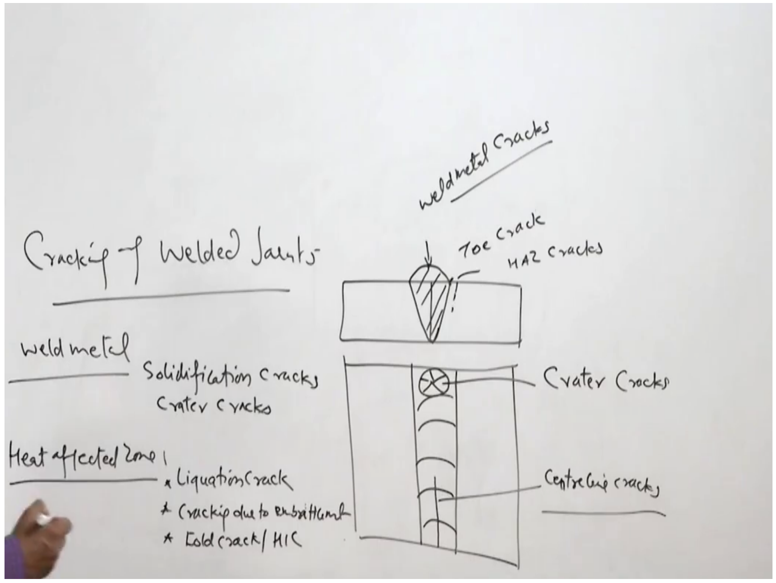

So but we will see that the specific types of the cracks and what are the reasons for their developments, so as I have said the broadly there are two locations the cracking in weld metal and cracking in the heat affected zone, so cracking in the weld metal in this category mainly we have the solidification crack which significantly - significantly - which significantly important because it leads to the rejection of the joints.

So solidification crack and as we have seen here the solidification cracks actually run all along the length of the weld at the center line, so solidification cracks are basically the center line crack in the weld metal running along the - the weld line and the crack crater crack is also observed in the weld metal where the weld joint ends and the last stage of the - the fusion welding. So here it actually the welding terminates.

Also another type of crack observed in the weld metal is the crater crack and this is this happens primarily due to the excessive concentration of the alloying elements among the heat affected zone the cracks which are observed in the heat affected zone very next to the fusion boundary what we can see here commonly is - is the liquation crack.

And thereafter we have the heat cracking due to embrittlement means that steels subjected to the tensile stress in heat affected zone - tensile residual stresses in the heat affected zone and martensitic transformation takes place then it leads to the embrittlement and such kind of embrittlement promotes the cracking in the heat affected zone. So - so this is cracking due to the embrittlement.

Then it is cold cracking or cold crack or the hydrogen induced crack commonly known as HAZ also termed as HAZ hydrogen assisted crack and the Lamellar tearing - lamellar tearing is also a crack commonly observed in the heat affected zone due to the decohesion of the - decohesion of the inclusion from the metallic matrix under the tensile residual stresses. So these are the common types of the cracks and the locations where they are observed.

And based on the orientation of the cracks this can be further classified as longitudinal crack or the transverse crack, so the cracks which are running parallel to the direction or along the direction of the weld are termed as a longitudinal crack or the transverse crack.

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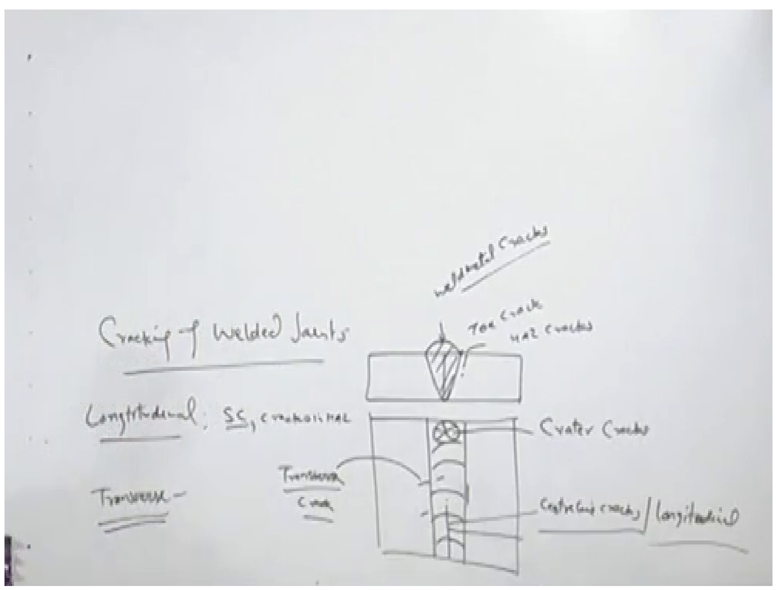

Longitudinal crack like the solidification crack is a typical example of the - the longitudinal crack, the cracks which are run parallel to the welding direction or the cracks which are next to the fusion boundary running along the welding direction parallel to the welding direction also can be termed as the longitudinal cracks, so normally crack - cracks in the HAZ running parallel to the welding directions can be termed as the transverse cracks.

Sometimes the cracks also develop perpendicular to the welding direction in the weld as well as the heat affected zone so they are termed as that transverse cracks, so this is an example of the transverse crack and this is the center line crack or the longitudinal crack this is an example of the longitudinal crack, so this is I can say the based on the location or orientation of the cracks.

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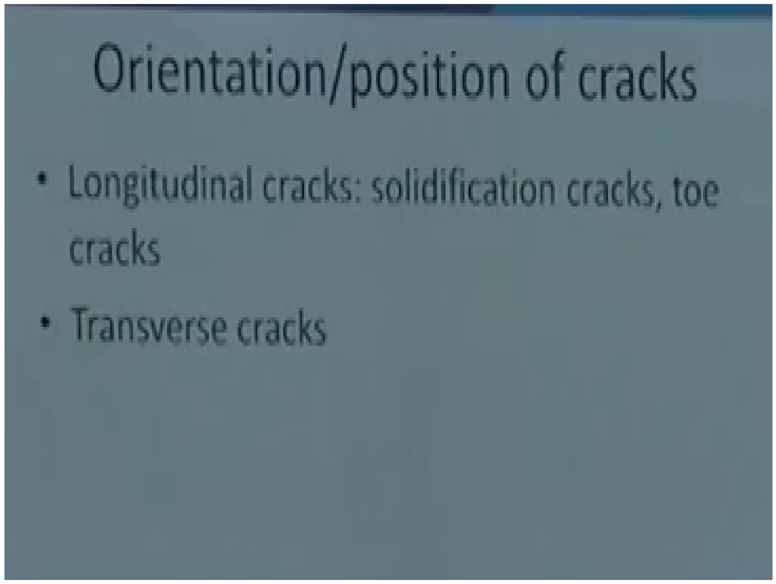

So orientation or position wise cracks, longitudinal crack say like solidification crack or the transverse cracks. So now I will take up the 3 types of the cracks one by one and what can be done to overcome the reduced tendency of development of such kind of cracks, so these 3 cracks are the solidification cracks, liquidation cracks and the lamellar tearing which is observed in the heat affected zone. So starting with the longitudinal sorry solidification cracks

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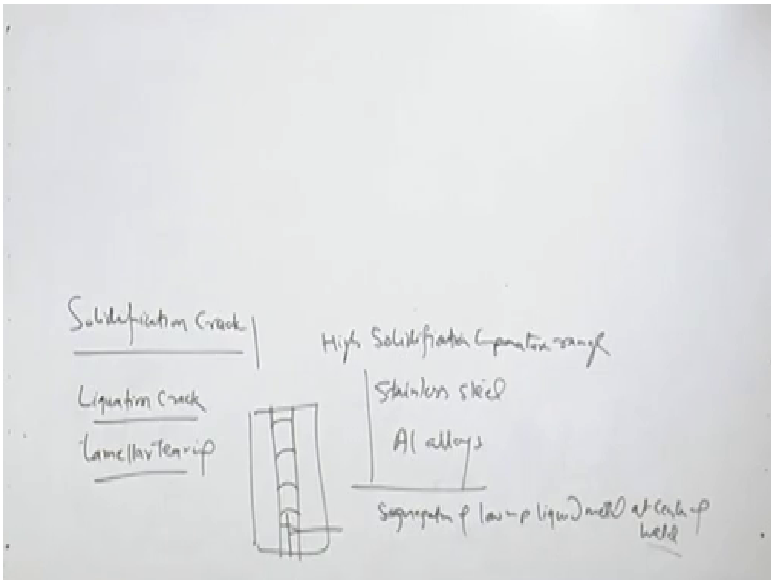

So I will be taking - talking about the solidification crack and then liquation crack and thereafter lamellar tearing, so the solidification crack basically this type of cracks I have talked in earlier lecture also, so I will be coming directly into the remedies which can be used to avoid such kind of cracks, we know that such kind of cracks are observed in the case of the metal systems having the high solidification temperature range.

So mostly the stainless steels and aluminium alloys are found sensitive for such kind of the cracking and this kind of the cracks - cracks are observed along weld center line, so the crack will be running along the welding in at the center line along the welding direction and it happens basically due to the segregation of low melting point liquid metal at the center of the weld - at the center of the weld.

So we have to reduce the segregation of the such kind of the low melting point liquid metal or we have to avoid the formation of such kind of the low melting point liquid metal so there is few approaches which are tried for reducing this solidification cracks, so as far as the recognition is concerned if we see the diagrams.

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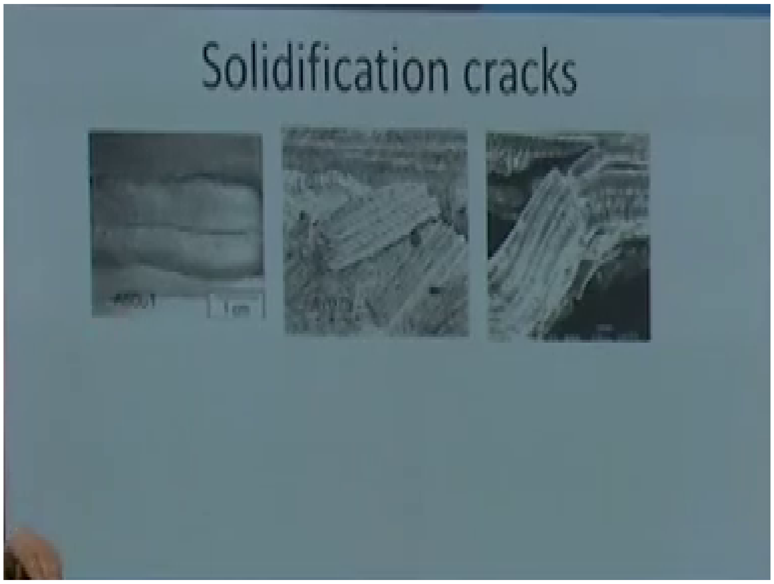

This diagram the typical weld metal of the 6061 aluminium alloy showing that crack is running along the center line of the weld and it happens and - and this kind of crack is formed like between the dendritic systems where the low melting point liquid metal exist.

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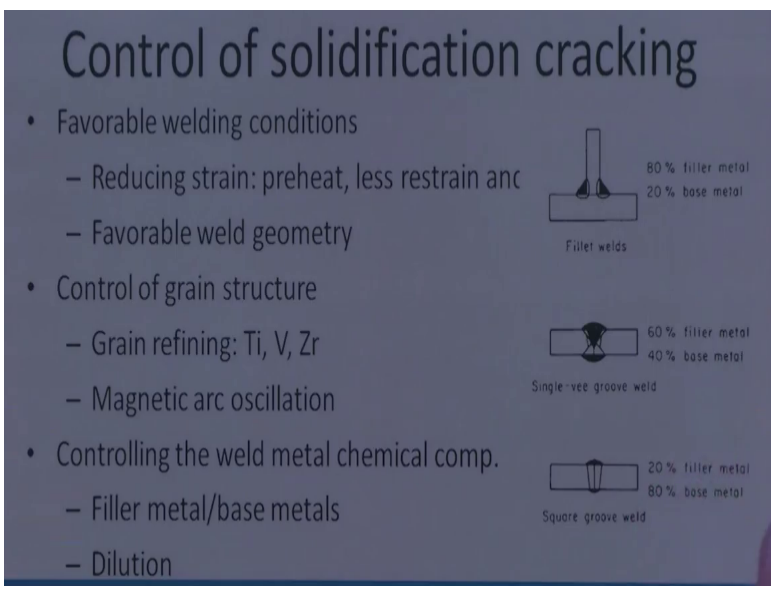

So in order to control such kind of the - such kind of the cracking the approaches which are used include the favorable developing the suitable favorable welding conditions developing the suitable grain structure and controlling the weld metal composition, so what can be done in this case for controlling the solidification cracking is that metal maybe very sensitive for the cracks but if the residual stresses developed are very less than the such kind of cracking will not be happening.

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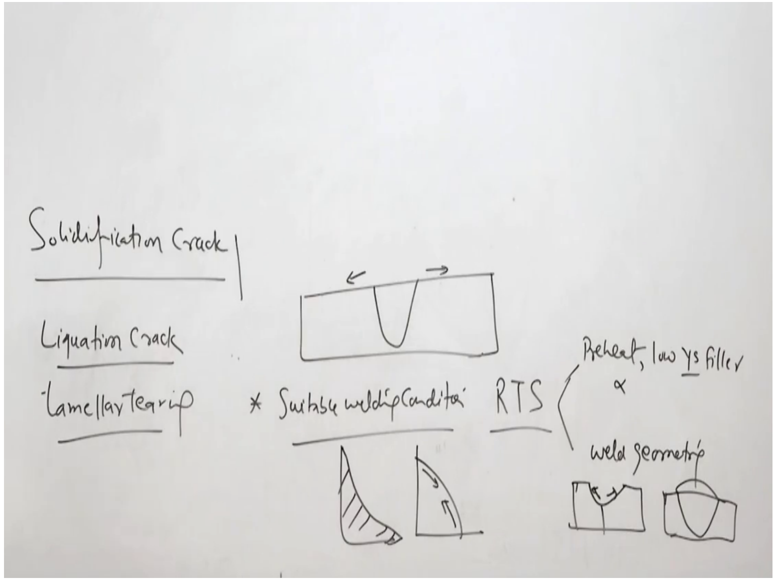

So these 3 approaches they work on the different concepts, the first one is like favorable or suitable welding condition, so that the residual tensile stresses can be reduced and for this purpose the approaches that are used, one is like using preheat so that the expansion and contraction is by enlarge differential expansion and contraction can be reduced in order to develop - in order to reduce the development of the residual tensile stresses.

Or use of the low yield strength filler, so that the maximum residual stresses magnitude being developed can be reduced or reducing the alpha or the thermal expansion coefficient of the filler metal which is being used or - or developing the suitable weld geometry. So this approach basically works on if the residual stress magnitude, tensile residual stress magnitude being developed in the weld metal is reduced through either preheating or using the lower yield strength filler or by developing the suitable weld geometry.

So instead of the tensile residual stress we have the compressive residual stresses then that will help to reduce the solidification crack. So as far as the weld bead geometry is concerned the whenever the weld geometry is concave in the shape like this then it leads to the increased cracking tendency due to the - due to the setting of the tensile residual stresses as compared to the another case when the weld bead geometry is of the convex type.

So concave weld geometry sets in that tensile residual stresses - stresses at the top surface of the weld bead. While the convex one will be setting in the compressive residual stresses this is what we can see, this kind of weld geometry will be reducing the solidification cracking tendency more as compared to the case when the weld bead geometry is like this having the concave as the this top surface.

So now this is how the reducing the tensile residual stresses through preheat or use of the lower fill yield strength filler or using suitable weld geometry can help to reduce that tensile stresses and thereby it can help to reduce the solidification cracking tendency. In addition to this developing suitable favorable conditions if we reduce the degree of restraint during the welding that also will help to reduce the tensile residual stresses or residual stresses is being developed.

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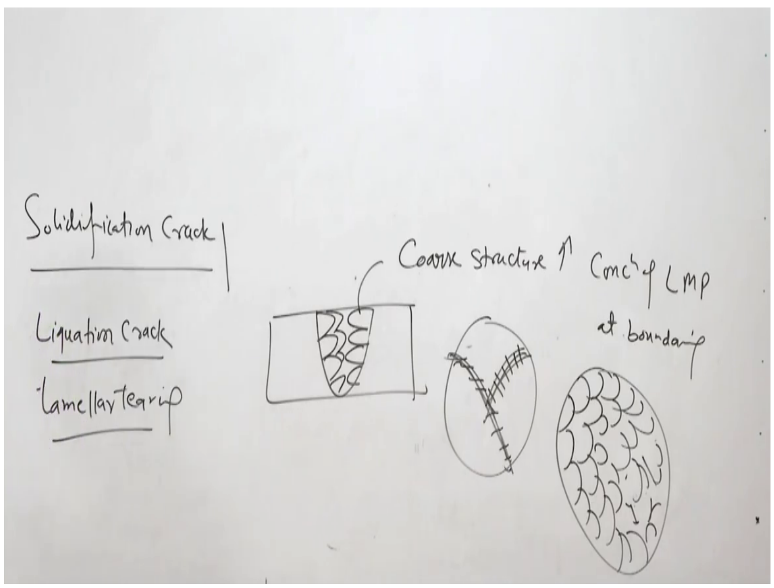

Another one is the refining the grain structure, if the grain structure of the weld metal is very coarse like this then - then it will be leading to the segregation of the alloying element at the center more segregation at the center as compared to the case when the grain structure is fine, so basically the coarse structure increases the concentration of the low melting point impurities at the boundaries or the grain boundaries.

Because the grain boundary area is limited in a given volume if they are just 3 or 4 number of the grains then the grain boundary area is limited and this will be resulting in the higher concentration of the impurities in the grain boundary area and leading to the easier solidification cracking as compared to the case when the same area is having the large number of the fine grains.

So fine grains will be resulting in the large grain boundary area which will be reducing the concentration of the low melting point things, so it is so refinement of the grain - grain structure helps in reducing the concentration of the low melting point constituents at the grain boundaries and that in turn helps to reduce the solidification cracking tendency and this what can be achieved through the inoculation approach or through the arc oscillation.

so grain boundary refined grain structural refinement is possible through the inoculation which wherein the alloying elements like titanium, vanadium or zirconium are added in the metal system, so they will refine like vanadium and zirconium or aluminium are added in the steels or the titanium is added in the aluminium alloys, so the weld metal structure is refined magnetic arc oscillation also helps to refine the grain structure or modify the grain structure

So controlling the weld metal composition in this case basically we tried to manipulate the weld metal composition in such a way that the solidification temperature range of the weld metal is reduced.

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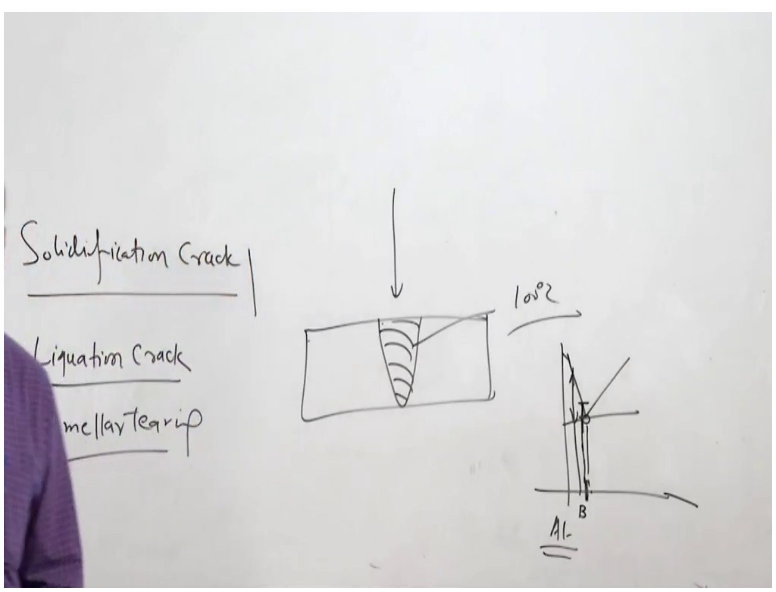

So if the base metal is actually sensitive for the cracking like say the base metal composition is sensitive for the cracking and leading to the solidification temperature range of 100 degree centigrade then will modify the weld -weld metal composition by adding suitable filler, so that the filler - filler and the base metal when both of the mix up together will be modifying the composition of the weld metal.

And which will be changing the microstructure of which will be changing the solidification temperature range, this what we can understand from this diagram where in like say this is the typical diagram for most of the aluminium - aluminium alloys where in like say this is the eutectic system and for - for this concentration of the alloying element of a particular alloying elements say B the solidification temperature range is high.

So when filler with the B is higher concentration of the B is added, so weld metal composition is shifted to this location that will have the somewhat lower solidification temperature range, I mean to say the selection of the filler metal in such a way is made in such a way that the weld metal composition modified composition of the weld metal will be leading to the reduction in solidification temperature range and that in turn will be reducing the cracking tendency.

So use of the suitable filler or the controlled dilution all helps to modify the composition of the weld metal in such a way that the solidification temperature range of the weld metal is reduced and so the cracking tendency of the weld metal - so the solidification cracking tendency of the weld metal is reduced.

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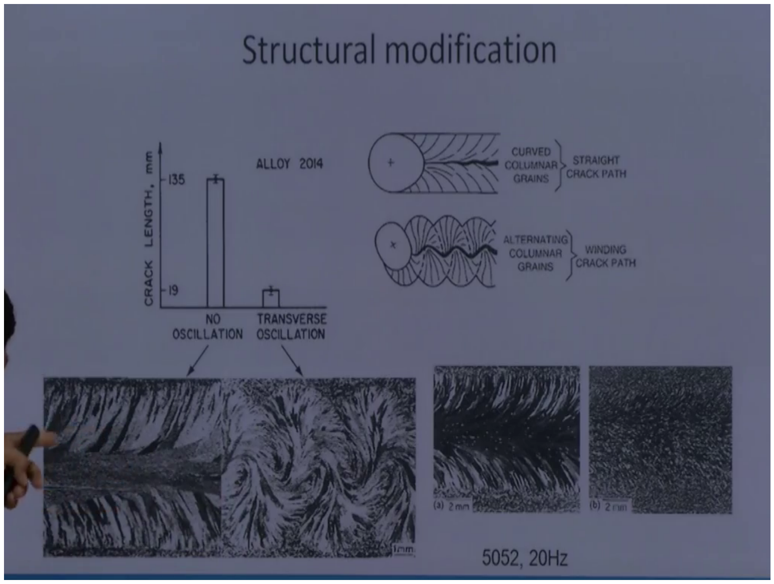

Now we will see that these are the typical methods which are used here like when there is no arc acceleration the grain size the crack length we will see the solidification cracking tendency the crack length is more and when the arc oscillation is implemented it refines the grain structure and modifies the grain structure and which in turn reduces the - the - the crack length which is observed of - after the welding.

Like say this kind of structure having the columnar structure from both the sides is found to more crack sensitive as compared to this case when the arc is manipulated in such a way that the grain - grains do not grow from both the sides and meet at center but the grain - grains are completely twisted in such a way that even if the crack is trying to - trying to grow it will not find the common path along the common week area for its growth at the center line, so it will be resisting the growth of the cracks.

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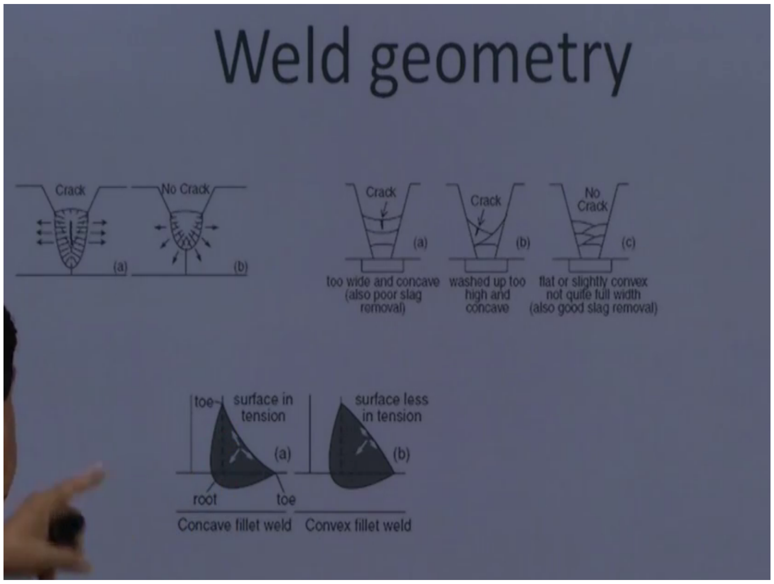

This is what I have explained the weld joint with the higher with the low depth to - low width to the depth ratio like this, will have the more cracking tendency as compared to the case when the width to the depth ratio is high, so the weld width to the depth ratio high weld width to the depth ratio reduces the cracking tendency, so this is what the same I have explained that the concave bead promotes the cracking tendency as compared to the concave bead – so convex bead.

So this is the convex bead example this is the concave, this is the same thing when the in fillet weld when we have concave weld bead geometry this will be leading to the development of the tensile residual stresses while when they set the tensile residual stresses basically it try to - tries to compress the metal at the center and thereby it reduces the cracking tendency.

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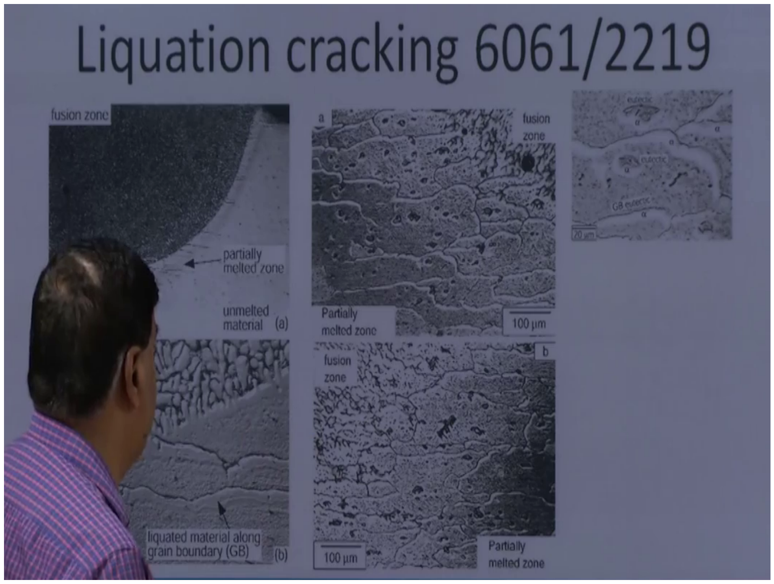

This is the another one the liquation cracking as I have said the liquidation cracking tendency is observed also in the high temperature solidification range metal systems and this primary occurs due to the - the formation of the two phase zone next to the fusion boundary and the such formation of liquid and the presence of the liquid and the solid mixture next in the very area very close to the fusion boundary in presence of the residual tensile stresses promotes the cracking tendency.

So - so the liquation cracking tendency is basically observed in aluminium alloys or the other alloys also which are showing the higher solidification temperature range and it is observed next to the fusion boundary and especially in the area where two phase zone exist like part of the liquid metal and part of the solid, so presence of the tensile residual stresses lead to the development of the liquidation crack.

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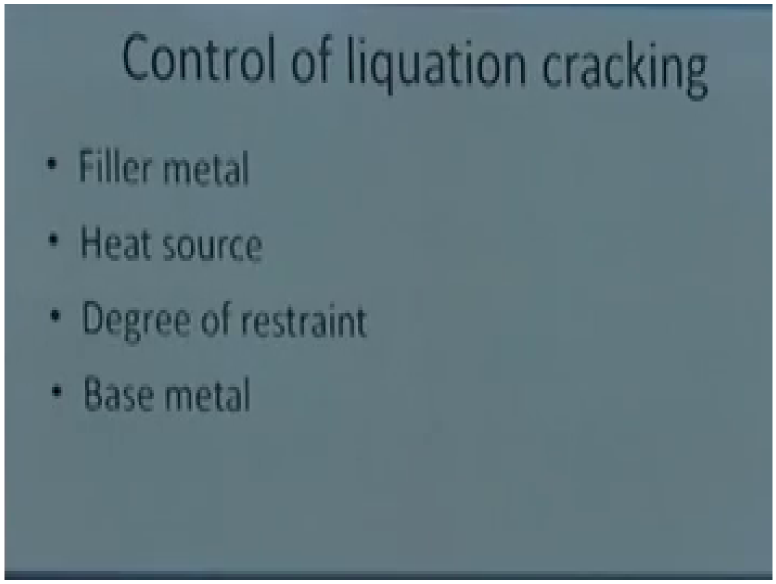

About this also I have talked earlier, so basically I will be talking about the methods used to control the liquation cracks. The first one is the filler metal, filler metal is selected in such a way that the weld metal solidifies after the solidification of the heat affected zone.

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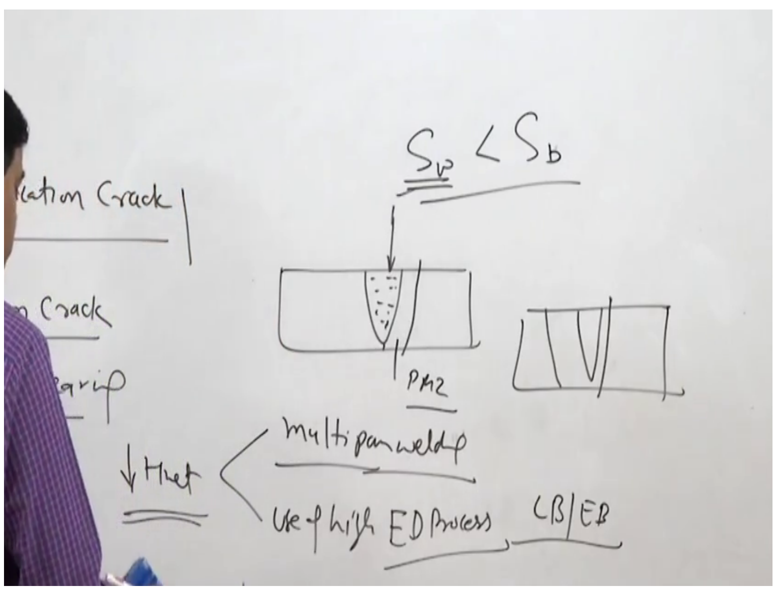

So what we do basically the filler is selected in such a way that the liquidus of the filler is - is lower than the base metal, so the liquidus of the weld is lower than the base metal, so this is what we can say liquidus of the base is sorry here the solidus of the solidus of the weld is lower than the solidus of the base, so in this case the when the filler is selected in such a way that if the weld is still in the liquidus state because solidus is slower.

So the weld maybe in the liquidus state, while the since the solidus of the base is high so whatever the partial melting is taking place next to the fusion boundary that will be in this zone PMZ zone basically it will be solidifying first before the solidification of the weld metal will be starting.

So if the solidification of the heat affected zone is taking first then it will reduce the crack it will reduce the cracking tendency because - and it will be able to resist the tensile residual stresses if they are being set in heat source - heat source is to be used in such a way heat source the purpose of the using heat source is to reduce the partial melting zone region of the partial melting zone so like this.

If the partial melting zone is very limited then the cracking tendency will also be less and if the partial melting zone is wide then cracking tendency will be more, so this difference in the zone of the partial melting zone can be achieved by - can also be achieved through the two approaches by reducing the heat input - reducing the net heat input and for this one approach is use of the multi-pass welding.

So limited heat input will help to reduce the heat affect will - will help to reduce the - the partial melting zone size or use of the high energy density process - use of high energy density process, so high energy density process also help to reduce the - reduce the net amount of the heat required for achieving the fusion.

So that the weld can be made so the processes like the laser beam or the electron beam helps in achieving the same thing with the limited heat input and that in turn helps to reduce the size of the heat affected zone or the partial melting zone and reduction in partial melting zone will help to reduce the cracking tendency.

Then degree of restraints we know that if there is no residual stresses in the weld metal then there will not be any crack even if the metal is sensitive for the cracking, so the that the target of - the target of means the target should also be to reduce the residual tensile strength stresses in the weld joints and the one of the approach is to reduce the degree of restraint or use the - reduce the volume of the weld metal or reduce or use the filler metal of the low yield strength, so all these approaches can be used in order to reduce the residual stress magnitude as for as.

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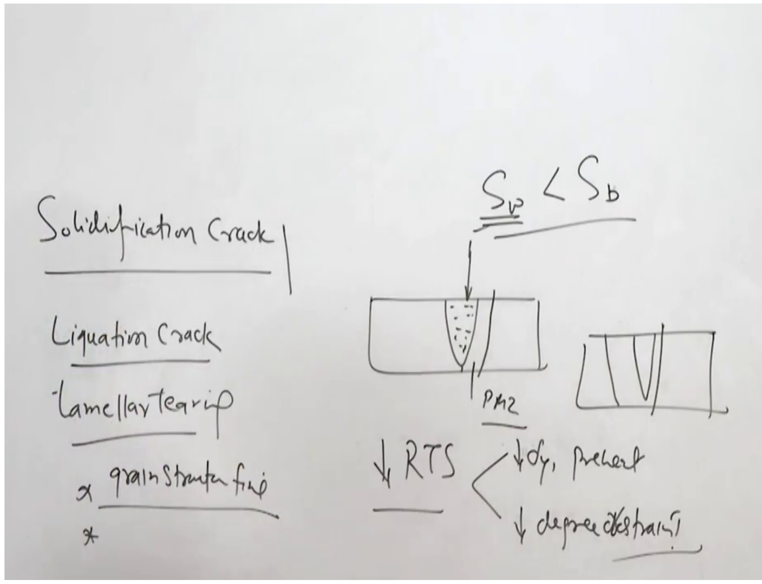

So the one of the points means one of the ways of reducing the cracking in the liquation - liquation cracking in the PMZ region or partial melting zone is to reduce the residual tensile stresses for which we can use the low yield strength filler or we can use preheat or we can reduce the degree of restraint - degree of restraint, so all these approaches will help to reduce the magnitude of the residual stresses being developed.

And the base metal, so base metal composition should be such that the grain structure - grain structure is fine this is one and the base metal is - is not sensitive to the composition of - not sensitive to the - the liquidation crack due to the wide solidification temperature range.

So this is what we will be seeing in terms of the base metal it is the composition that decides the solidification temperature range the composition need to be adjusted of the weld metal of the way need to be adjusted of the base metal in such a way that the solidification temperature range can be reduced and the grain structure the fine grain structure are reduces the liquation cracking as compared to the coarse grain structure.

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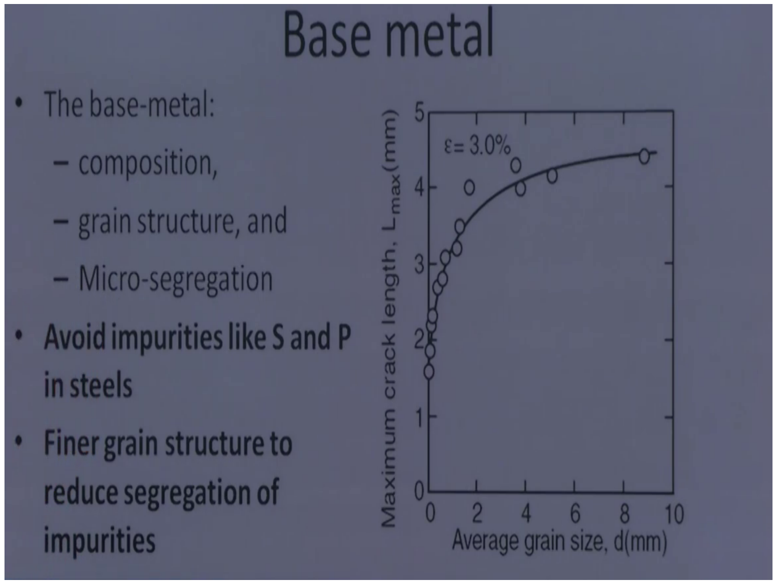

This is what we can see here when average grain structure, average grain size is less than the crack length is also less, while the when the grain size is increased it increases the cracking tendency at the same time the presence of the impurities in the base metal like sulphur and phosphorus also need to be avoided and we need to refine the grain structure so that the segregation tendency of these impurities in the - in the base metal can be reduced.

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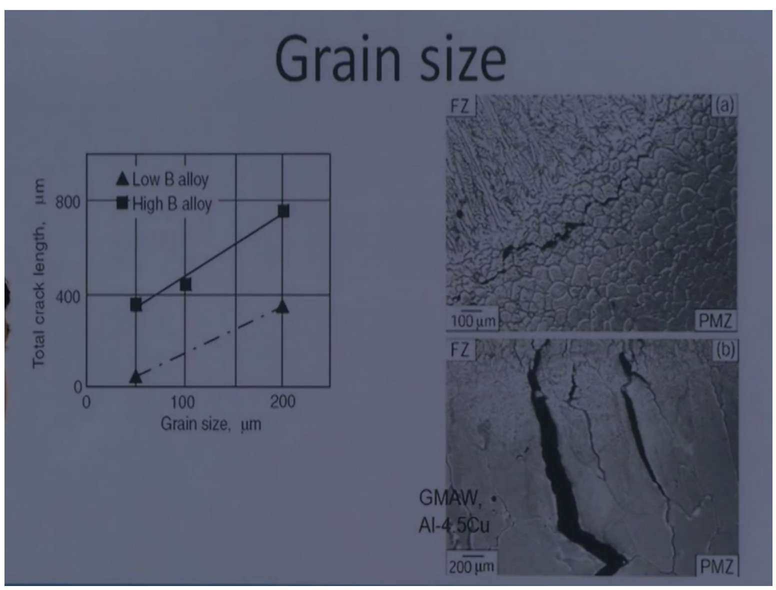

So here it shows the typical way by which the - the grain structure affects the cracking tendency, so when the grain size is fine the crack length is limited and the grain size is large the crack size is more this is what we can see here this is weld zone this is a base metals side, so this is the area where the two phase means the mushy zone will be forming means liquid and the solid both will be formed and under the tensile residual stresses will be leaded to the development of cracks.

So such wide cracks can be observed in the heat affected zone. So this is where I will summarize this lecture, in this lecture, in this presentation I have talked about the - the development of the cracks in the weld joints primarily in the weld metal and next to the fusion boundary. So the cracks observed in the weld metal is the solidification crack and the crack which is observed next to the fusion boundary is the liquation crack.

And in this presentation, I have talked about the remedial methods which can be used in order to reduce these two types of the cracks, thank you for your attention.