Welding Engineering
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Module - 8
Weldability of Metal
Lecture - 3
Weldability of Al Alloys

Dear students, this is the 3rd lecture on the weldability of the metals. And in this presentation, mainly we will be focusing about the weldability of the different kind of the aluminium alloys.

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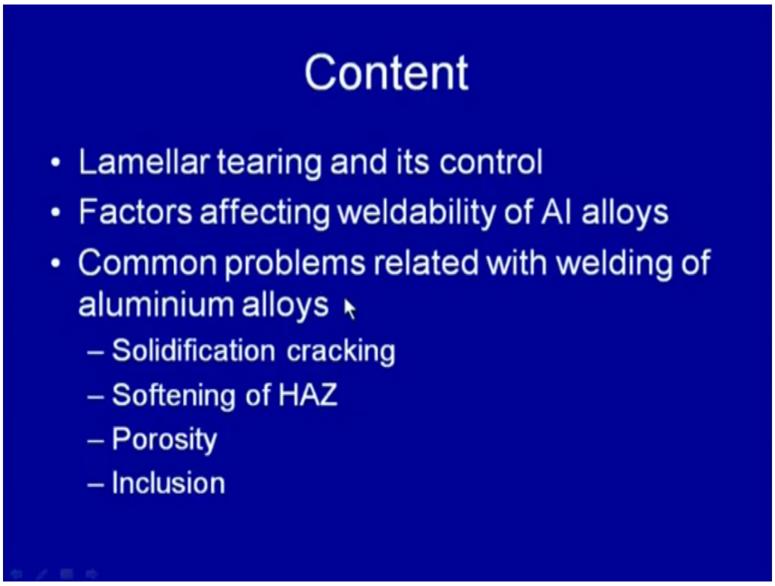

So, first of all in this presentation, I will be taking up the lamellar tearing, its mechanism and that how can we control it. Thereafter, we will see the weldability of the aluminium alloys and important factors that affect the weldability of aluminium alloys. These will be related with the properties of the material and the welding procedure and the conditions, under which welding is to be performed like the factors affecting the weldability of any metal system.

And then the common problems which are encountered during the welding of the aluminium and that dictates significantly it is ease of welding. Like the solidification cracking, softening of the heat affected zone, porosity inclusions, partial melting zone related problems. So, we will be starting with this one with the lamellar tearing; lamellar tearing is commonly encountered during the welding of the hardenable steels, which are having very limited Z direction ductility means through the thickness.

In the through thickness directions, ductility of the metal is limited and this mainly happens when there is a large amount of the inclusions present in form of the lamellar. So, in form of layers or laminates and these laminates are formed basically in form of the slag inclusions or silicate inclusions or the iron and sulphide inclusions, which are rolled during the manufacturing process.

So, these laminates, when these are present and when welding is done, so the setting up of the tensile residual stresses during the welding especially, in the direction perpendicular to the direction of thickness. The decohesion of these lamellas are of the inclusions, leads to the development of the cracks especially, in the regions close to the fusion boundary or below the weld zone.

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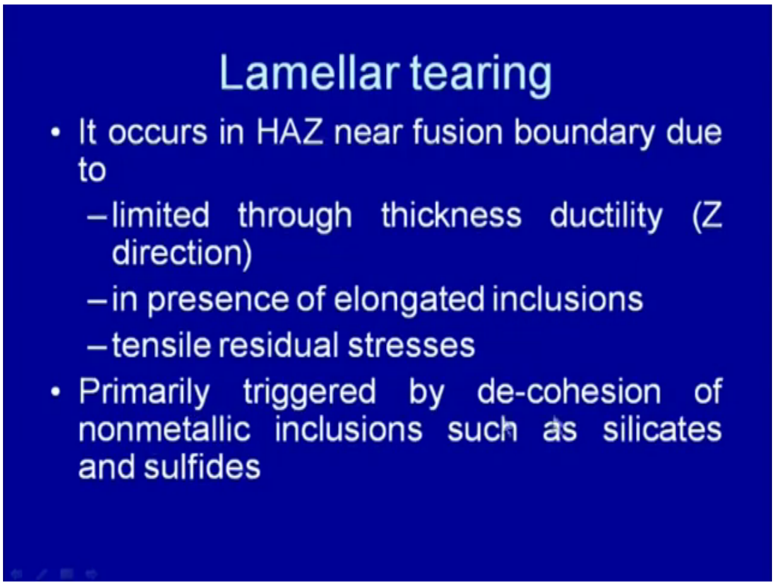

So here, since it is mainly encountered in the heat affected zone so it is a form of HAZ cracking and it mainly occurs due to the limited through thickness ductility. It is also called as a Z direction ductility and this limited Z direction ductility is caused by the presence of the elongated inclusions, which are formed due to the rolling during the forming process. And setting up of the residual tensile stresses due to the differential expansion and contraction, during the welding and this kind of the cracking mainly occurs during the development of the fillet welds or T joints. And primarily it is triggered by the decohesion of the non metallic inclusions such as silicates and sulphides, to see this areas, in which it is mainly developed.

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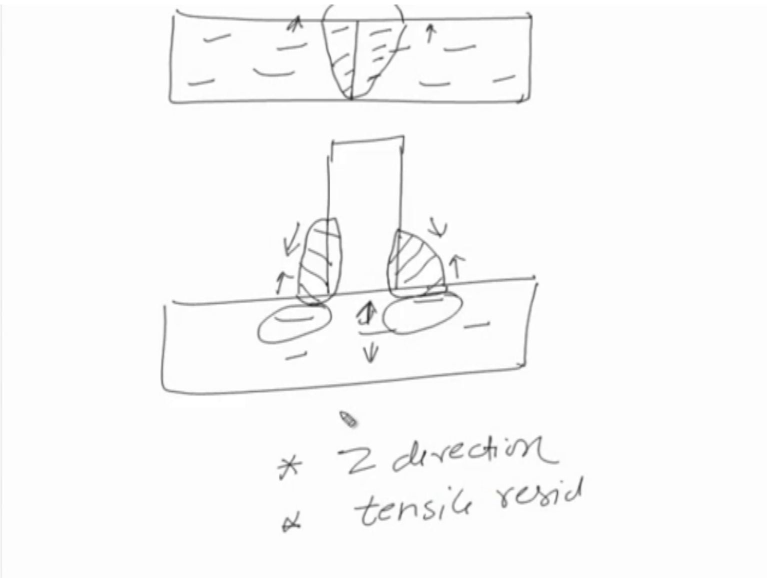

So for that, we need to see that, if this is the base plate and having the inclusions in form of here, laminates of the inclusions. And for the welding purpose, when the melting of the faying surface is done, the weld joint is developed like this and the tensile residual stresses will be set up and when the these stresses act in direction perpendicular to these lamellas, the decohesion takes place. Another possible situation is, when these lamellas are present like this near the surface layers and when the T joint is developed by developing a fillet weld.

So, the fillet weld, when it is size is longer especially in case when, leg length of the fillet weld is greater than 20 mm, lot of tensile residual stresses are set up due to the shrinkage of this fillet portion. And when shrinkage takes place in this fillet portion, this sets up the tensile residual stresses especially, in the area region close to the fusion boundary that is this zone. So, when this zone is subjected to the tensile stresses in direction perpendicular to the direction of thickness, the decohesion of these lamellas takes place and frequently leads to the cracking.

So, these cracks basically develop due to the decohesion of these laminates and this is mainly attributed to the limited Z direction ductility. So, main reason for this is the presence of the high tensile residual stresses and the limited Z direction ductility. So, if we try to reduce, if we try to improve this Z direction ductility by reducing the percentage of these lamellas, which are especially present near the surface or near the fusion boundary or reducing the development of the tensile residual stresses.

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Apart from the limited Z direction ductility and the tensile residual stresses, it is also facilitated by the hardened structure, which is formed in form of the martensite and the presence of the hydrogen in the heat affected zone. Hydrogen in the HAZ, further assists in the development of the lamellar tearing, so in order to avoid both these situations, if the preheating of the weld is done. Then it will help in diffusing out the hydrogen present in the HAZ and also, it will reduce the formation of the hardened structures like the martensite. So, those are approaches, which can be used in order to reduce the hydrogen content, in order to reduce the hardness and in order to reduce the residual stresses.

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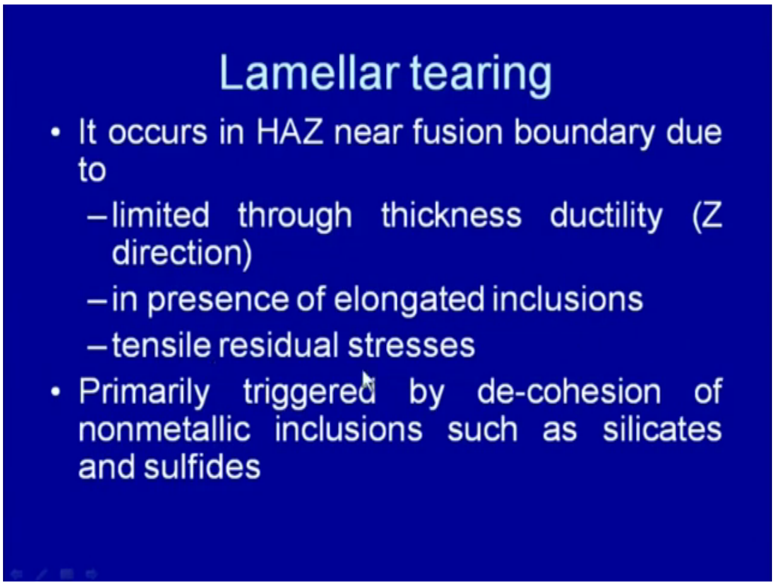

So, as far as the development is concerned, it is the limited through thickness ductility and the presence of inclusions. And the development of tensile stresses that lead to the lamellar tearing and it is primarily triggered by the decohesion of these non metallic inclusions.

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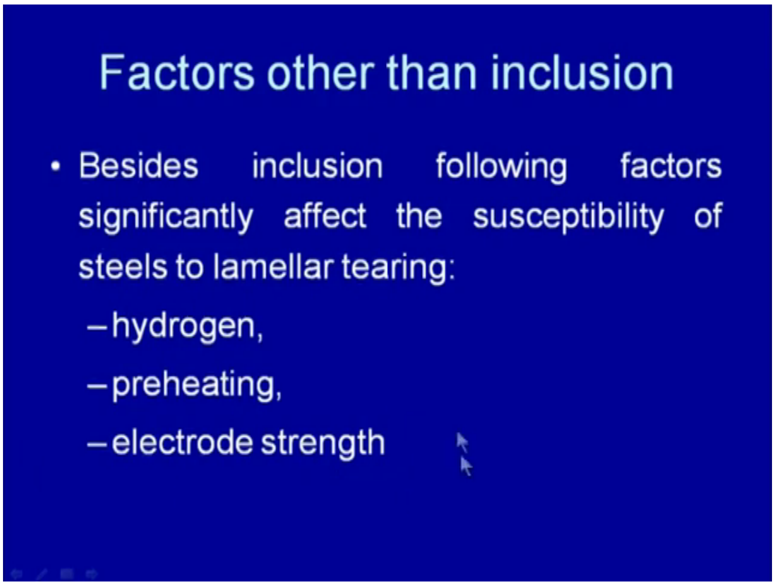

Apart from those three factors the presence of hydrogen, preheating and electrode strength affect the susceptibility to the lamellar tearing. Because, hydrogen assists in development of the cracks, preheating reduces the cracking tendency because it helps in escaping the hydrogen, it helps in reducing the tensile stress development due to the reduced differential expansion and contraction. And further it helps in forming the soft structures in the heat affected zone and the tensile electrode strength.

If the electrode is of the lower strength is used then it will be setting up the lower tensile strength, which in turn will be decreasing the lamellar tearing tendency. So, as far as the control of the lamellar tearing is concerned, it is better to control the lamellar tearing. It will better if the Z direction ductility of the metal system is good, which is measured in terms of the percentage reduction in area should be greater than 15.

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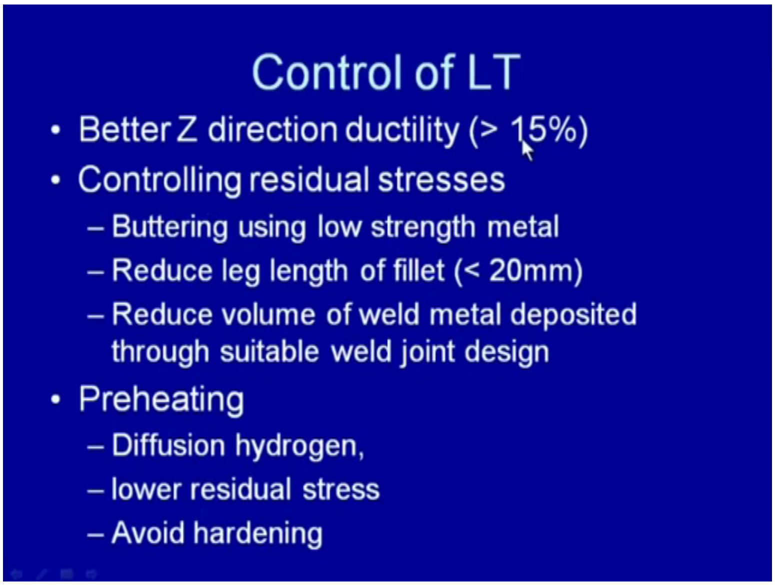

And then efforts should be made to control the residual stresses, for that purpose buttering of the base metal can be done before developing the weld joint, using the lowest strength metal. So that, the stresses are localized mainly in the buttered layer and the heat affected zone is not subjected to the higher tensile stresses. Reducing the leg length of the fillet, this will further help in reducing the extent of contraction and so that tensile stresses that are being developed due to the differential expansion and contraction.

So, reducing the leg length of the fillet also helps in reducing the tensile stresses then reduce the volume of the weld metal being deposited through the suitable joint design. So, any design which is helping in reducing the volume of weld metal design, eventually will be helping into reduce the magnitude of the tensile residual stresses or stresses that are being developed in the heat affected zone and in the weld area. These are the some of the approaches, which can be used to reduce the residual stresses in the weld zone and in the heat affected zone.

And the preheating is another commonly used approach, which helps in reducing the diffused hydrogen present in the heat affected zone and reducing the tensile residual stresses, because of the reduced temperature gradient from the fusion boundary to the heat affected zone. And further, it avoids the hardening of the heat affected zone because of, the formation of the soft phases like bainite and the pearlite. So, these are the some of the approaches, which can be used to reduce the cracking tendency means, the lamellar tearing tendency of the steel weld joints.

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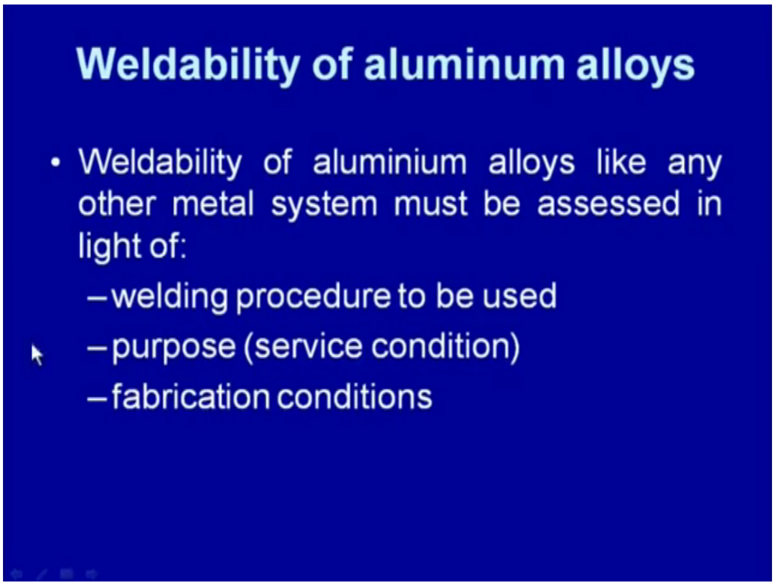

Now, we will be taking up the weldability of the aluminium alloys in general, aluminium alloys are considered to be difficult to weld as compared to that of the steels. And the reason for this difficulty in welding of the aluminium is that, it has high affinity to the oxygen, it offers the higher thermal expansion coefficient and the thermal and electrical conductivity of the aluminium is high. These are the very 3 key properties that, significantly affect the weldability of the aluminium.

So, if you want to assess the weldability of aluminium in this line of the weldability of any metal system, we need to see that, what kind of the weld joint can be performed, when it is welded using a given process, using given set of the procedures for a given purpose and the fabrication and in a given set of the fabrication conditions. So, we know that, if the steel is welded using the SMAW process, we can get the reasonably good quality weld. But, when SMAW welding is used for aluminium welding, we find very poor quality weld joint.

So, we need to put in more efforts and more skill for developing the weld joint of the aluminium alloys and that those efforts will be in form of use of like inert gases for protecting the weld pool from the atmospheric contamination or use of the tungsten electrode or the gas metal arc welding processes, which are for higher energy density for melting the faying surfaces of the aluminium alloys. Because, it is of the higher thermal conductivity, so again to assess the weldability of aluminium alloys, we we need to see that what quality of the weld joint will be produced using the given process and how that, particular weld joint can be used for a given purpose.

And with the change in condition, there will be great change in the weldability of the aluminium alloys. And the fabrication conditions, under what the weld joint is to be developed.

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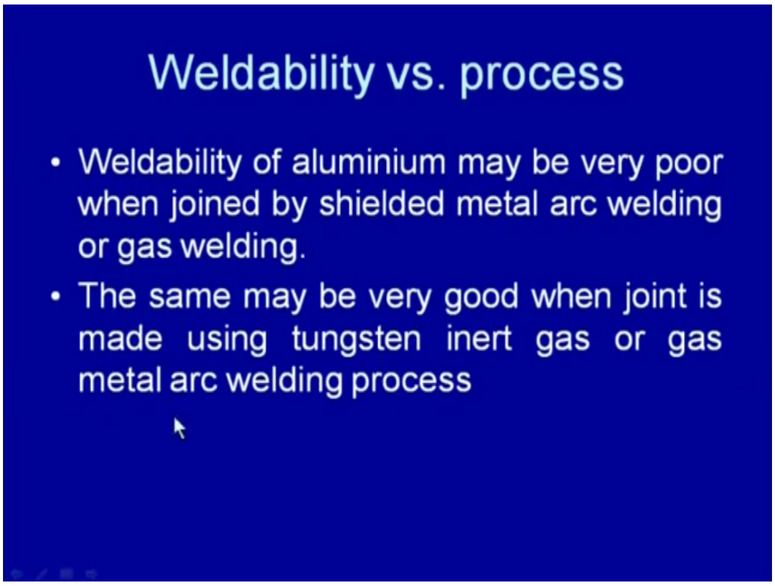

Weldability of aluminium may be poor and when welded using the SMAW process of the gas welding and because of this then this is because of the high affinity of the aluminium, with the atmospheric gases like oxygen. So, when the aluminium reacts with the oxygen, it forms the refractory aluminium oxide and it is found very difficult to melt this and the presence of the aluminium oxide decreases the melting means, in imposes difficulty in melting of the aluminium.

At the same time, if it is present in the weld, it will be acting as a inclusion or the weldability of the aluminium is, this is one of the reasons because of which, it is found difficult to weld aluminium by the SMAW process or the gas welding. The same may be but this the weldability of the aluminium may be very good of when some a tungsten inert gas welding process or the gas metal arc welding process is used. Because, the presence of these inert gases for protecting the weld pool from the gases present in the atmosphere help in developing the sound weld joint.

And which can serve the purpose of getting the weld joint, which can take up the service load as per the purpose or as per the intended application. Similarly, so that was the effect of the process, process significantly affect the weldability of the aluminium. It may be very poor with the SMAW and GMAW, it may be very poor with the gas welding but the weldability of the aluminium may be very good with the GTAW and GMAW processes.

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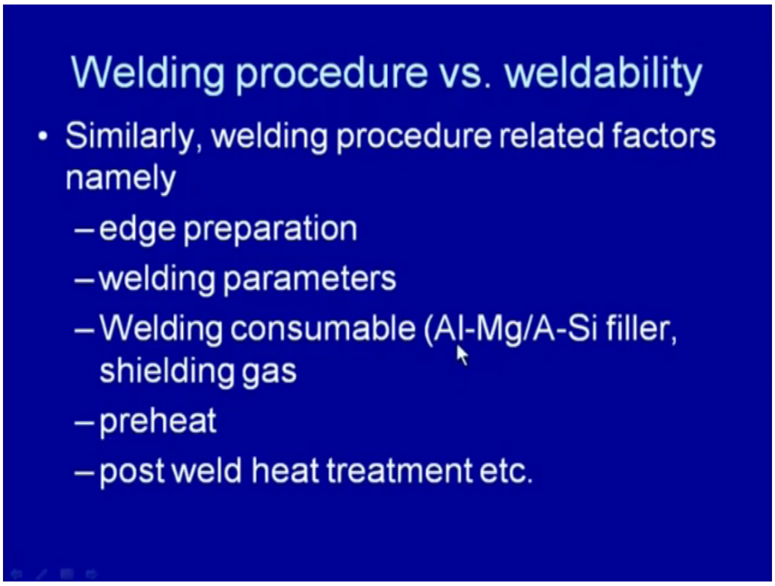

Similarly, the welding procedure significantly affect the weldability of aluminium alloys for example, edge preparation if the edge is being prepared properly means, proper cleaning is being done to remove the aluminium oxide. The welding procedure parameters are being used like the proper welding speed, and current are being used for ensuring the proper melting of the surfaces in order to develop the weld joint.

And if the welding current is low then due to the high thermal conductivity it may be difficult to weld, it may be difficult to melt the faying surfaces of the aluminium. Then the welding consumables like the use of the welding consumables in some of the cases like use of aluminium magnesium as a filler, causes the tendency of the solidification cracking tendency, while the use of the aluminium silicon filler sometimes decreases that the solidification cracking tendency.

Similarly, the use of the argon results in the weld joint, which is comparatively of the poor quality as compared to the case, when the helium is used or we can use the mixture of the argon with the oxygen or with the hydrogen and similarly we can use the carbon dioxide with the hydrogen. So, the presence of means, the change in the shielding gas will be affecting the protection being provided by these gases to the weld pool from the atmospheric contamination.

And accordingly, it will be affecting to the quality of the weld joint, which is being produced and then preheat. Preheating will be affecting the width of the heat affected zone so it may in case of the aluminium alloys especially, it will be leading to the increased softening of the heat affected zone. And the kind of post weld heat treatment is being used, whether we are using the stress relieving treatment or the treatment is of the solutionizing kind or it is the T 6 or the T 4 kind of heat treatment is being used accordingly, the properties of the weld joint will be affected significantly.

So, depending upon the procedural steps, which are being used for developing a weld joint aluminium, weld joint of the aluminium alloys, we may get a wide range of the weldability or the degree of weldability may vary significantly according to the combination of the procedural steps, which are being used for development of the weld joint.

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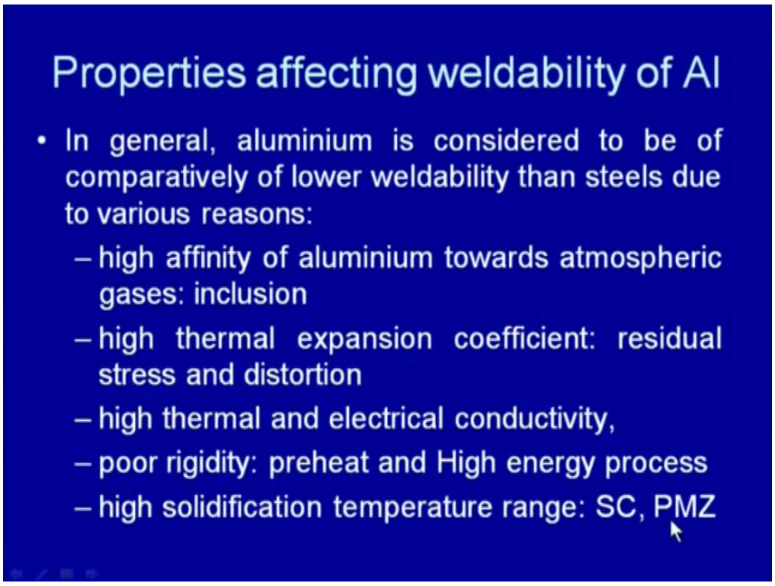

Then, the properties of the aluminium alloys, that affect it is weldability and because of which, it is found of the lower weldability than the steels. So, the main reason for the poor weldability of aluminium as compared to that of steel is the high affinity of the aluminium towards the atmospheric gases. When the aluminium reacts with the oxygen, it forms the refractory alumina and this is most of the time is present as an inclusion in the aluminium weld joint, which in turn decrease the mechanical performance.

Because, these provide easy side for a stress concentration and easily nucleate the crack and their growth is facilitated. High thermal expansion coefficient, the thermal expansion coefficient of aluminium is higher than the steel and because of this, it is subjected to the greater expansion and contraction during the welding, and increased expansion and contraction during the welding leads to the greater development of the residual stresses.

And because of which, increased tendency of the distortion and the cracking of the aluminium weld joint especially, from the heat affected zone and the partial melting zone means, from the weld zone. So, increased magnitude of that residual stresses in the weld region will be promoting the cracking tendency in some of the aluminium alloys from the weld region and then the heat affected zone, then the high thermal conductivity and electrical conductivity because of, high thermal and electrical conductivity of aluminium alloys.

These will be extracting the heat very rapidly from the weld region and because of this, melting of the aluminium alloys may be more difficult as compared to that of steel. And because of this, we require the welding processes of the higher energy density and a higher current levels are required to bring the aluminium alloys to the molten, to achieve the melting in the aluminium alloys in order to develop the weld joint.

Similarly, electrical connectivity plays a big role in spot welding of the aluminium alloys because of the electrical conductivity, it decreases the electrical resistance heating and the heat which is being developed at the interface. So, because of this, it requires the higher level of the current setting for developing the spot welds in the aluminium alloys as compared to that of the steel. Then the poor rigidity, aluminium is not considered to be that stiff and rigid, because of this poor rigidity.

When it is subjected to the residual stresses during the welding, this leads to the easy distortion and in order to take care of this, it is required that proper preheating is done and at the same time, high energy processes are used. So, that the sound weld joint can be developed without the problem of distortion and then high solidification temperature range, in most of the aluminium alloys, when addition of the alloying element is done, the solidification temperature range increases. And this increase in solidification range, increases the tendency of the solidification cracking and the cracking in the heat affected zone, due to the partial melting effect or in some of the areas especially, close to the fusion boundary.

These were the some of the characteristics related with the aluminium alloys that effect the ease of welding of the aluminium alloys significantly. So, we have seen that, there are various characteristics of the aluminium alloys, which impose difficulty in welding. So, in order to take care of the above characteristics so that, the sound weld joint can be developed.

Basically 2 types of approaches are used, one that effective protection of the weld pool from the atmospheric contaminations so that, for this purpose, helium and argon gases are used to shield the weld pool from so that, the affect of the atmospheric gases on to the weld pool can be reduced. And another is, this is most of the problems are related with the differential expansion and contraction, and the differential weld thermal cycle being experienced by the aluminium alloys during the welding.

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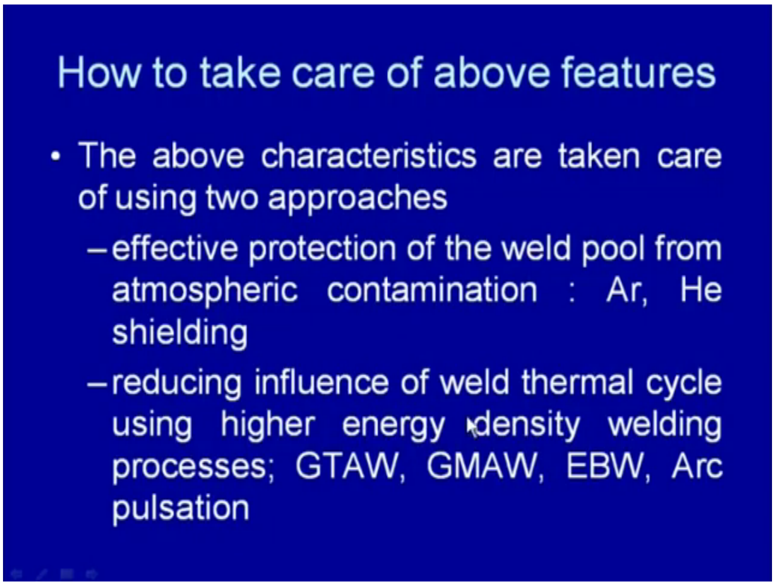

So, in order to reduce the effect of the weld thermal cycle on the properties of the weld zone and the heat affected zone, it is desired that the heat input is given as less as possible. And for that purpose, a high energy density processes like the GTAW, electron beam, laser beam are used and in the same line, arc pulsation can also be used. So, pulse tungsten inert gas welding, pulse GMAW processes, electron beam will be helping in this regard significantly in order to reduce, these will be helping significantly in reducing the amount of heat, that is being supplied during the welding.

And because of which, it will be reducing the adverse effect of the weld thermal cycle in the properties of the weld region and the heat affected zone. So, basically these are the 2 approaches, which are used to take care of the negative aspects, related with the welding of the aluminium alloys like effective protection of the weld pool and reducing the heat input, which is being given by using the higher energy density processes.

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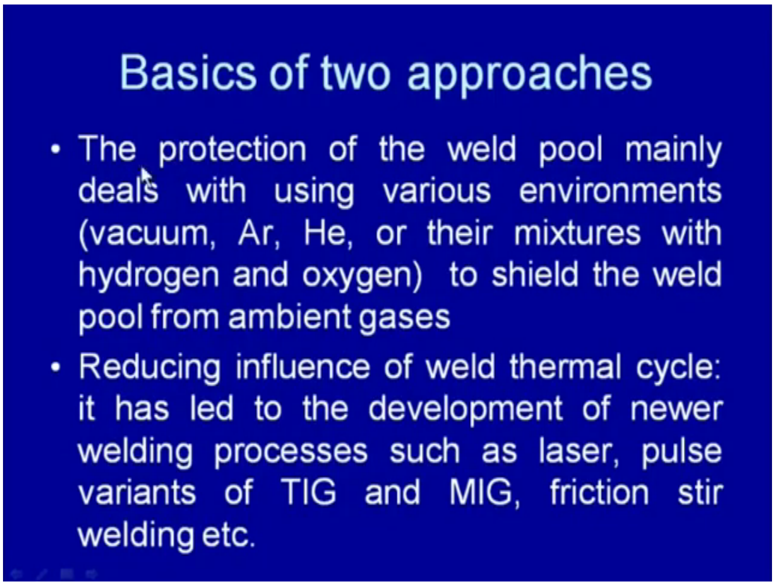

So, these two approaches basically work on the protection of the weld pool mainly, the protection of the weld pool approach mainly deals with the using various environment such as vacuum, helium, argon or the mixture of these gases with oxygen and hydrogen to shield the weld pools. So that, the adverse effect of the atmospheric gases on the weld pool can be reduced and the another is that, the reducing the influence of weld thermal cycle.

It has led to the development of the newer processes such as the laser, pulse variant of the GTA and GMAW, and the solid state processes like the friction, stir welding of the aluminium alloys. The friction, stir welding of the welding has been very extensively used for the welding of the aluminium alloys, because it is performed in the solid state. This process is being developed recently in by the TWI in 1991, in this process the melting of the aluminium is not required.

But, using the frictional heat and the deformational heat, the material is softened and then using the mechanical forces, consolidation is done between the components to be joined of the aluminium alloys. So, melting is not required and because of this reduced, because of this avoidance of the melting, the weld joint which are produced by the friction stir welding process of the aluminium alloys, the quality of the weld joint is found to be very good.

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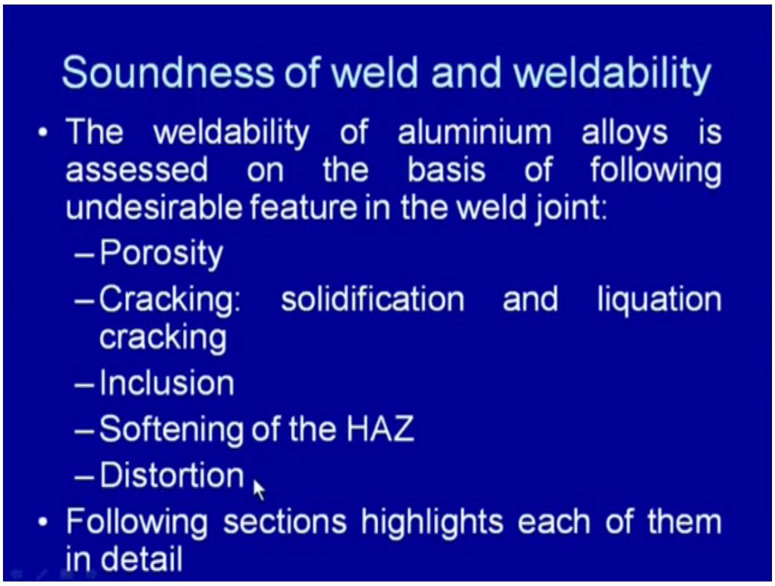

And the lot of research is still being done on the weldability or of the aluminium alloys using the friction stir welding process. Now, as far as the factors that decrease the quality of the weld joint of the aluminium alloys, and which in turn will be affecting the weldability, we need to see that what are the undesirable features that are commonly developed during the welding of the aluminium alloys. As these include the porosity cracking, which is in form of the solidification cracking and the liquation cracking.

Solidification cracking will be occurring in the weld region and the liquation cracking will be taking place in the heat affected zone. The inclusions primarily due to the formation of the aluminium oxide and the softening of the heat affected zone. This happens mainly due to the grain growth in the heat affected zone and the reversion of the hardening precipitates in the heat affected zone, and the coarsening of the hardening precipitates in the heat affected zone especially, in case of the precipitation hardenable aluminium alloys.

While the softening in case of the work hardenable aluminium alloys, like 5000 series aluminium alloys, 5052 or 5086, in these aluminium alloys basically, softening occurs due to the recovery and recrystallization effects of the weld thermal cycle. And the distortion is the another problem, which decreases the weldability of aluminium alloys and it is common in aluminium alloys.

Because, it offers the higher thermal expansion coefficient and high thermal expansion coefficient associated with the welding, increases the tendency of the differential expansion and contraction, and which in turn increases the tendency of the distortion. So now, each of these problems will be discussed one by one and what can be done in order to overcome them.

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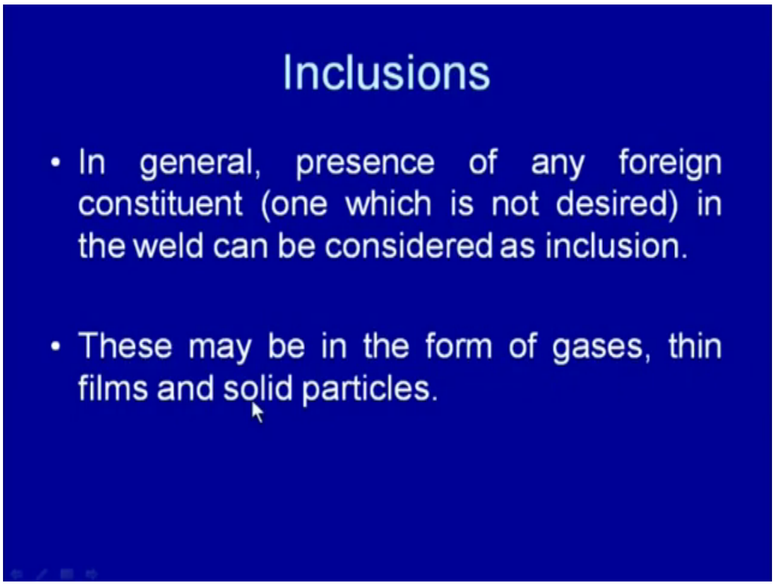

Inclusions are formed in the welds of the aluminium alloys mainly due to the presence of the foreign metals, foreign constituents like these may be impurities or these may be in form of gases or these may be in form of thin films and the solid particles. The inclusions in case of the aluminium welds are mainly found in form of the hydrogen gas and the aluminium oxide as a solid particles. So, if any foreign material, which is not expected to be there, if it is present can be considered as a inclusion and these inclusions may be in form of gases thin films and solid particles.

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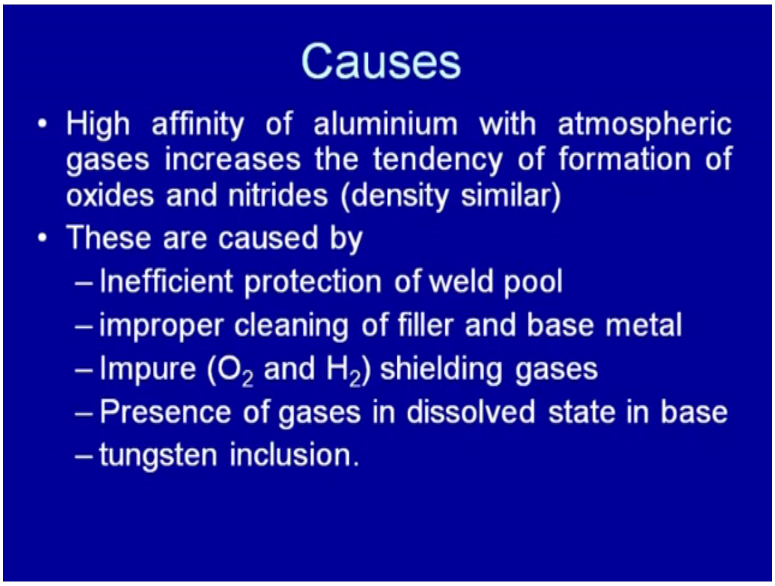

So, the main cause of the inclusions include the like high affinity of the aluminium with the atmospheric gases, increases the tendency of the formation of oxides and the nitrides. Because, these are of the densities similar to that of the aluminium and because of having the similar density as compared to that of the aluminium, these tend to remain in the molten weld pool. And because of that, they do not come at up to the surface in form of the slag or in form of impurities and because of this reason, these tend to be there in the weld region.

So, the main reason behind the presence of the aluminium oxides and the aluminium nitrides in the weld is that, if the reaction between the atmospheric gases and the aluminium is taking place, it will be forming oxides and nitrides, which will have the density similar to that of the molten aluminium. And they will have the tendency to be there and they will not be able to float on the surface of the molten metal. And because of this, the entrapment tendency of these oxides and nitrides in the weld region increases.

And these are caused and when these reactions take place, there the main things which promote the formation of the oxides and nitrides during the welding of the aluminium alloys, include the inefficient protection of the weld pool. Means, the whatever the method is being used to protect the weld pool, whether it is vacuum in case of electron beam welding or it is the shielding gas, which is being used not being in the same amount, which it should have been means, the gas flow rate is limited or excessive and the movement of the arc during the welding.

So, all the factors that are affecting the protection of the weld pool, they will be increasing the possibility of the inclusions and improper cleaning of the filler material. And the base material, if these have not been cleaned properly then the impurities may be in form of the hydrocarbons, which will be offering the hydrogen and carbon during the welding on decomposition, and then the shielding gas itself is impure. So, it will be providing the oxygen and hydrogen, which will be reacting with the aluminium to form the aluminium oxide as well as hydrogen will be increasing the hydrogen induced cracking in the aluminium hydrogen induced porosity in the aluminium weld. Then the presence of gases in the dissolved state in the base metal itself like gases like the hydrogen or oxygen, if these are already present in the base metal then these will be promoting the hydrogen induced porosity and the aluminium oxide inclusions.

And the tungsten inclusions are formed, when the tungsten inert gas welding process is used and commonly pure tungsten electrode is being used. So, when the pure tungsten is used as an as an electrode for the tungsten inert gas welding process, this tungsten due to the heat of the arc is degraded and decomposed and sometimes, it is transferred to the weld pool. And when it is transferred in form of the small pieces, it leads to the development of the tungsten inclusion in the aluminium weld. So, this is the and the tungsten inclusions are formed mainly in case, when the touch start method is used or very inappropriate the welding current and the polarity is being used for the tungsten inert gas welding process.

So, in order to control the inclusions to reduce the formation of inclusions, in the weld efforts should be made to protect the weld pool from the atmospheric gases properly. As for this purpose, shielding has to be done properly with the required flow rate and the correct kind of the gas and it is grade. Avoid the formation of the tungsten inclusion, for this we need to see that, the proper current setting is used for a given electrode size and the proper kind of polarity is used in order to avoid unnecessary degradation of the tungsten electrode.

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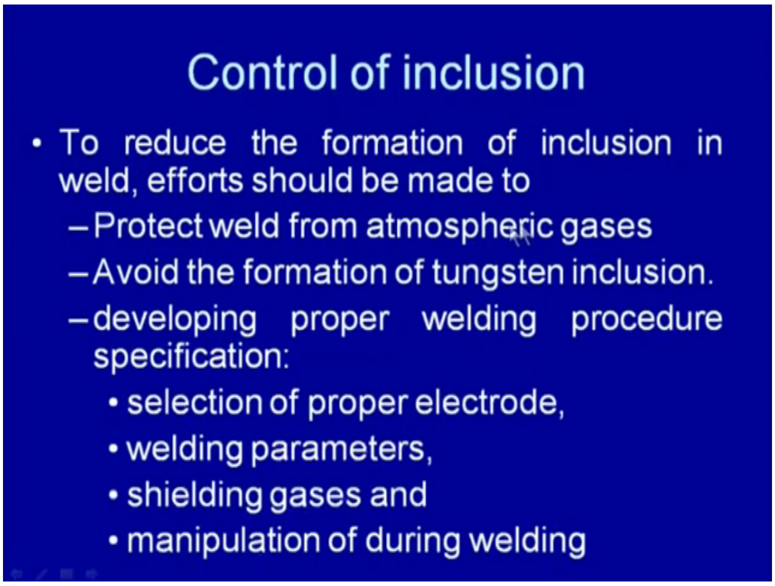

And further, the proper welding procedures should be established so that, we select the proper kind of electrode, suitable welding parameters are used and the correct kind of shielding gas is used and the arc is manipulated properly. So that, the unnecessary presence of the gases in the arc zone is avoided and the degradation of the tungsten and it is decomposition is reduced during the welding especially, in case of the tungsten inert gas welding process. And the desired purity of the shielding gas is also ensured so that, these gases means, oxygen, nitrogen or the hydrogen gases are not present with the shielding gas, which is being used for to protect the weld pool. So, these are the some of the steps, which can be used to control the inclusion formation in the weld joint of the aluminium alloys.

The solidification cracking is another common type of the problem, which is encountered during the welding of the aluminium alloys, mainly in case of the aluminium copper alloys, aluminium magnesium silicon alloys and aluminium zinc magnesium alloys. And these is mainly happens due to the 2 regions, that the tensile residual stresses develop at the weld centre and the properties of the weld metal are poor especially, at the high temperature.

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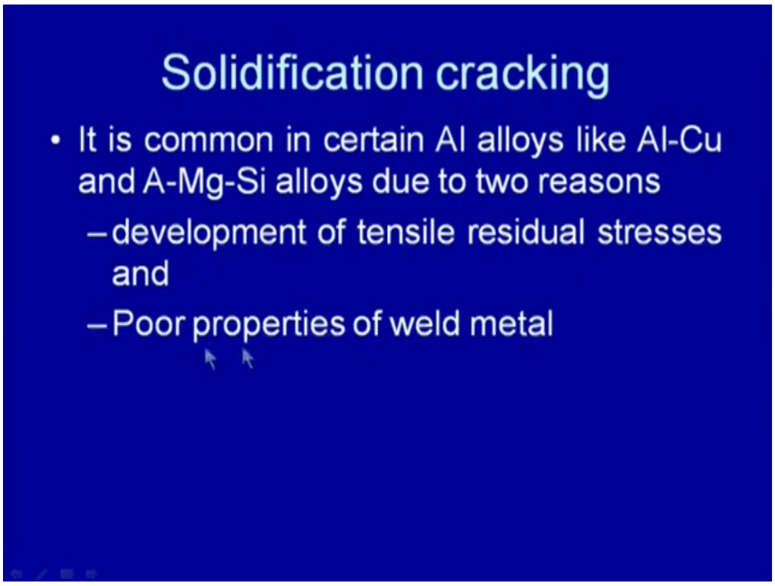

So, the poor properties of the weld metal at the high temperature are basically, because of the filler material in the weld metal characteristics, which are being used. And the differential expansion and contraction of the weld metal is attributed to the development of the tensile residual stresses in the weld zone. And this kind of the cracking is observed mainly along the weld centre line, due to the setting of the tensile residual stresses especially in the aluminium alloys, which offer the higher solidification temperature range.

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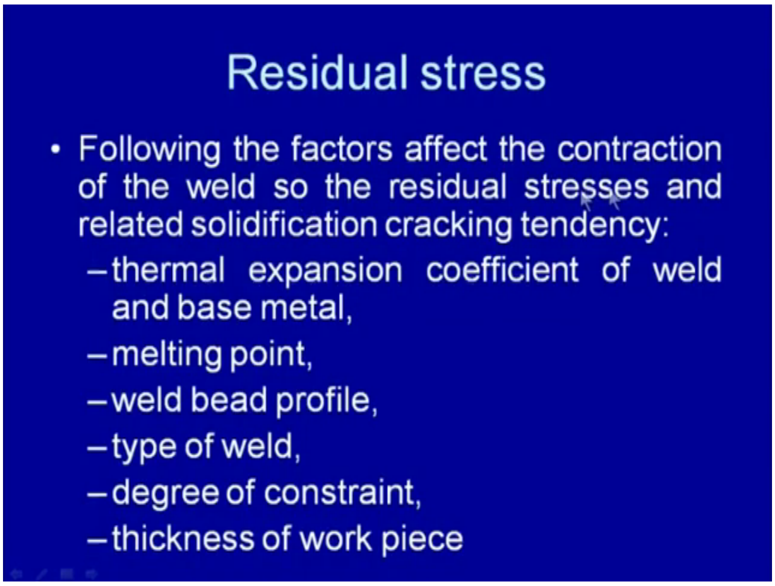

We have seen that, there are 2 main factors one is the setting up of the residual stresses, that is the tensile residual stresses and the second is poor mechanical properties of the weld at the high temperature. If the poor properties of the weld metal at high temperature in form of limited ductility low strength then under the tensile residual stresses, weld metal tends to crack. So, it is desirable to have the reduced magnitude of the tensile residual stresses, being set up in the weld zone.

At the same time, the desired the weld metal is having the reasonably good ductility and the strength even at the high temperature. So, the following factors affect the contraction of the weld and so the residual stresses, and which in turn affect the solidification cracking tendency, one is the thermal expansion coefficient of the weld metal and base metal. In general, higher is the thermal expansion coefficient, greater will be the residual stresses and so there will be increased solidification cracking tendency.

Then the melting point, those aluminium alloys having the, if melting point of the filler metal and the base metal, the relative values of the each say, if the solidification of the weld metal is taking place the first then the whole of the weld metal will be solidifying first. So, in order to avoid, this the solidification cracking tendency, it is necessary that, the melting point of the aluminium alloys is not over a wide range.

But, the range of the temperature over which solidification of the weld metal takes place, it is very narrow and because of this, most of the weld metal will be solidifying under the very short range of the temperature. And largely at the same time and because of this, most of the residual stresses have been set up, will not be localized along the weld centre line. And that is why, how it will be helping to reduce the solidification cracking tendency then the weld bead profile also affects the setting of the residual stresses.

For example, convex bead promotes the solidification cracking tendency, while the concave bead promotes the solidification cracking tendency in case of, fillet weld, while convex bead reduces this kind of cracking tendency. The type of weld and the degree of constraint and the thickness of the work piece so increase degree of constrained increase thickness, will be promoting the residual stresses and so the cracking tendency of the weld.

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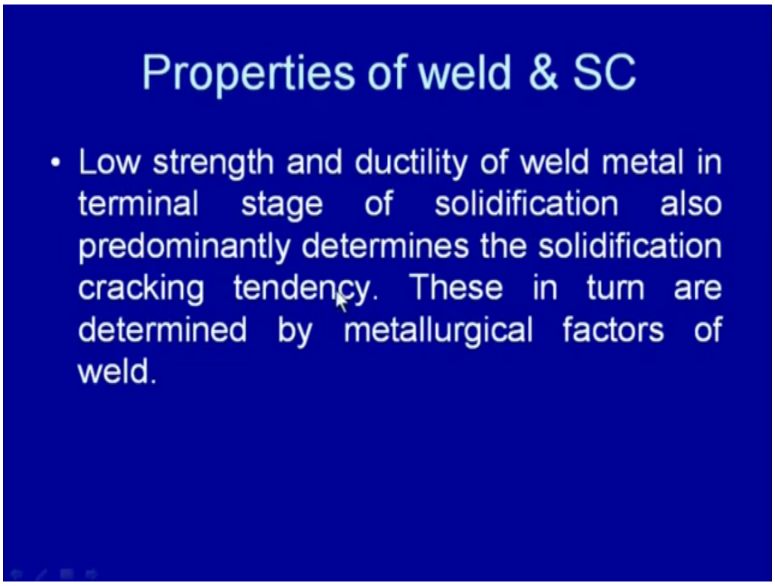

So, as far as the properties of the weld metal and the solidification cracking tendency is concerned, the lowest strength and the low ductility weld metal especially, in the last stage of the solidification or significantly increase the solidification cracking tendency. And therefore, efforts are always made to have the reasonably good strength and ductility, even at the high temperature near the end of the solidification stage. However, these properties are affected by the many metallurgical factors.

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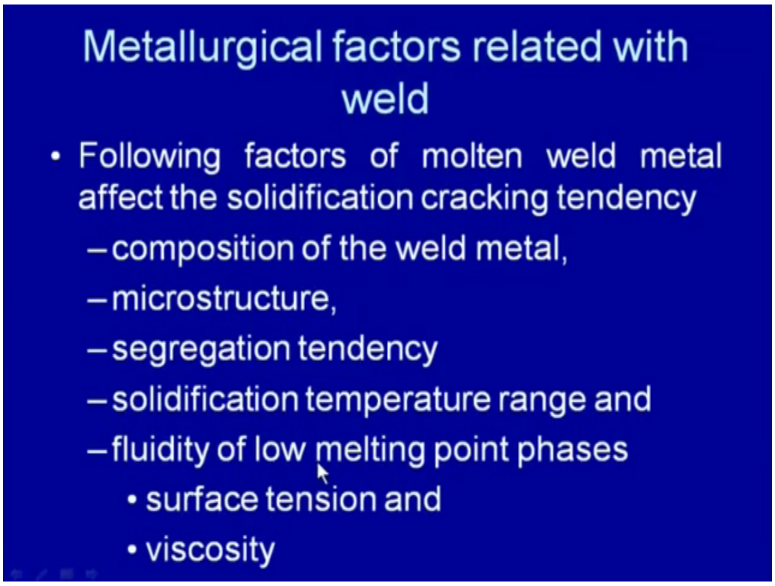

And the metallurgical factors, that are affecting to the solidification cracking tendency are many like the composition of the weld metal, the microstructure, segregation tendency, solidification temperature range, fluidity of the low melting point phases being formed in terms of the surface tension and the viscosity. So, these are the factors, that significantly affect the solidification cracking tendency and one by one these will be taken up.

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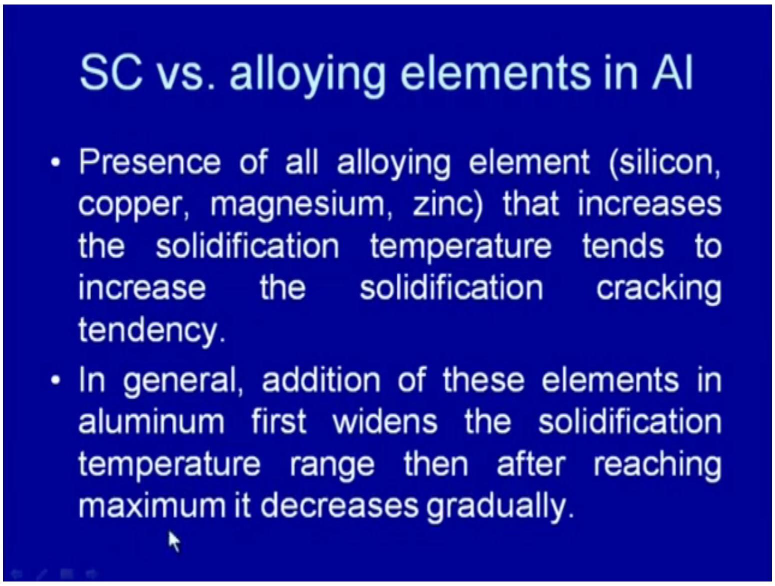

So, as far as composition is concerned, the presence of all alloying elements like silicon, copper, magnesium, zinc that increase the solidification temperature range tends to increase the solidification cracking tendency also. So, in general, addition of these elements in aluminium, first widens the solidification temperature range and then after reaching to the maximum, it decreases gradually.

And because of this also, when the alloying addition is done in aluminium, these increases solidification cracking tendency first. And now, after reaching to a maximum value, the solidification cracking tendency starts to decrease. And this happens mainly because of the first increase in solidification temperature range and thereafter, after reaching to the maximum value it decreases gradually.

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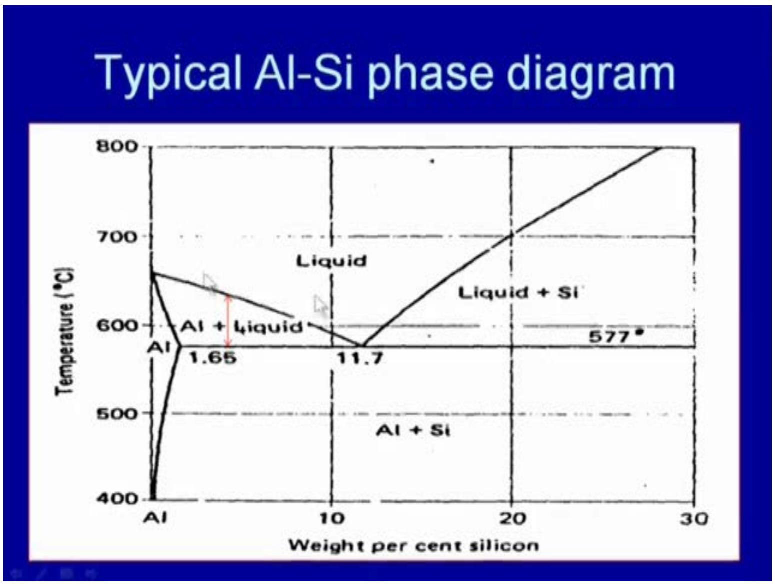

For example, if we see here, this is the liquidus line and this is solidus line in case of the aluminium silicon phase diagram. When aluminium is pure, it solidifies means, the melting and the solidification temperature is one and that is around 662.5 degree centigrade. And with the addition of the silicon, we can see there is the range of the solidification temperature keeps on increasing and for about say 1.65, the solidification temperature range is maximum.

And thereafter, it starts decreasing because the solidus and liquidus temperature keeps on coming closer. So, at this value means, for 11.7 and for the pure aluminium, whole of the solidification will be occurring at one temperature, while for 1.65 solidification will be occurring with maximum solidification temperature range. So, for this kind of composition, the cracking tendency of the aluminium silicon alloy will be maximum, while it will be nil for the pure aluminium and for the eutectic aluminium alloy system.

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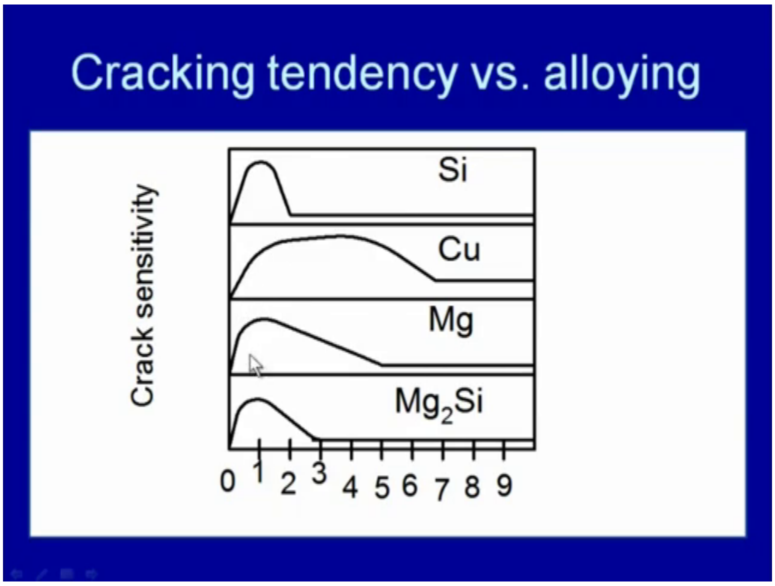

So, if we see that, how the variation in cracking tendency takes place with change of composition so for the silicon it is around 1.6 percent, for aluminium copper it is around 4 to 6 percent. And then for the magnesium, again it is around 1 to 2 percent and for the Mg 2 Si, it is a kind of inter metallic compound, for this the variation in the concentration of the Mg 2 Si around 1 percent it is maximum then it starts decreasing. So, when we have the large amount of the low melting point phase then it fills up the region, which is being cracked.

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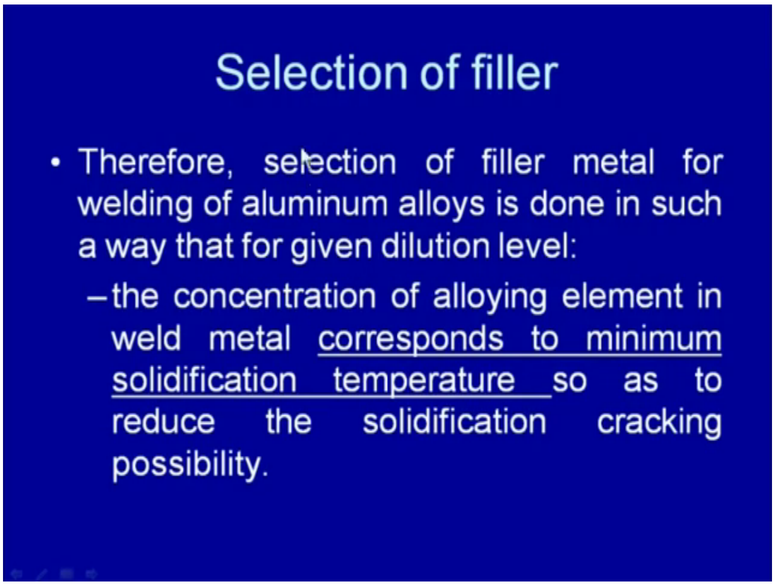

And because of this, the cracking tendency is found on the lower side, when the concentration of the alloying element is significant. So, but in all the cases, with the addition of the small amount of these alloying elements, the cracking tendency in all the cases can be seen that, it increases with the addition of all these alloying elements and after reaching to the maximum it starts decreasing. And keeping this, these concentrations of the silicon copper Mg, Mg 2 Si, the suitable filler material is selected during the welding of the aluminium. So that, we are not in the crack sensitive zone but we are in the safer zone.

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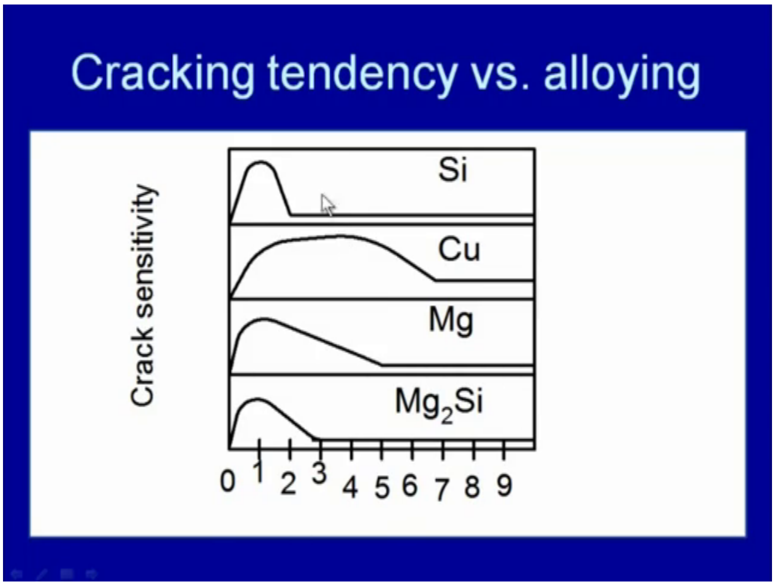

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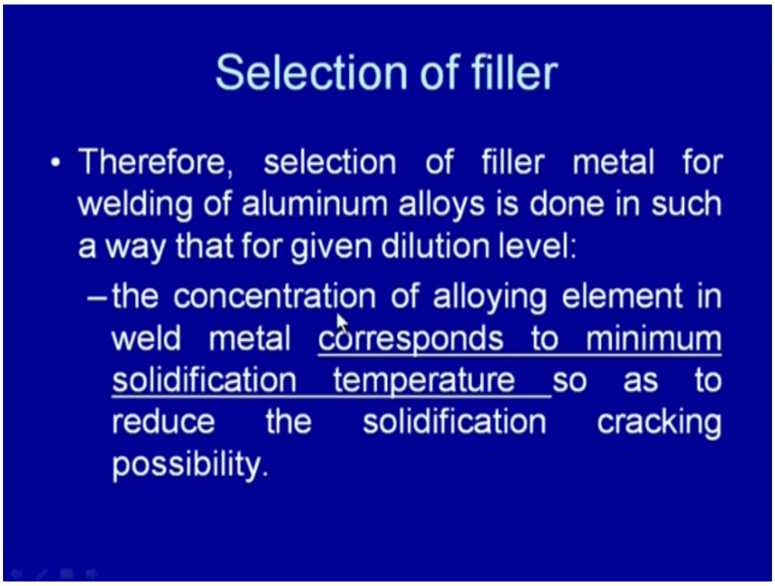

So, the safer zone again, this is the safer zone for the aluminium silicon system, this is the safer zone for the aluminium copper, for aluminium magnesium this is where, cracking tendency is minimum, this is for Mg 2 Si. So, filler material is selected in such a way, that we are in the safer zone where, cracking tendency is minimum.

So, the concentration of the alloying element in the weld metal so the filler metal is selected in such a way, that we have the weld metal composition corresponding to the minimum solidification temperature range or corresponding to the minimum cracking tendency zone. And for this purpose only, the 2 types of the filler material materials are commonly used.

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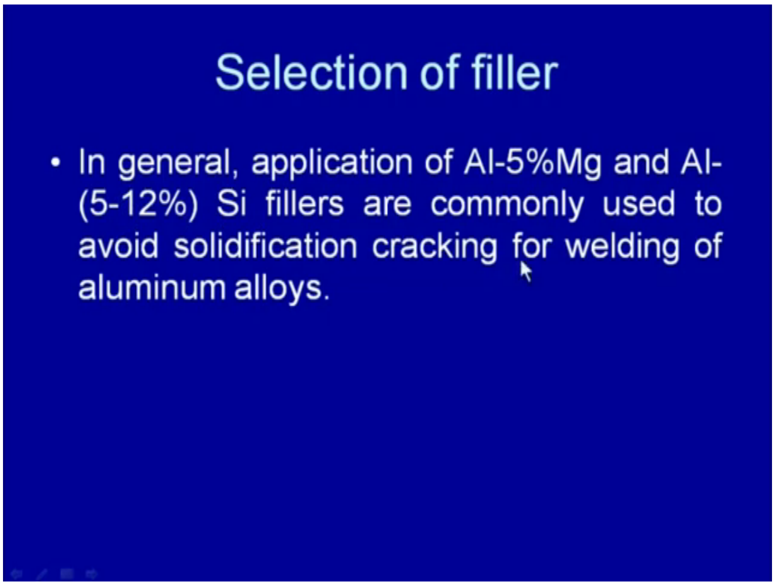

Where, aluminium 5 percent magnesium is used or aluminium 5 to 12 percent of the silicon is used. Use of the aluminium 5 to 12 percent of the silicon, significantly decreases the solidification cracking tendency in the welding of the aluminium alloys. And therefore, aluminium silicon filler metals are commonly used during the welding of aluminium alloys.

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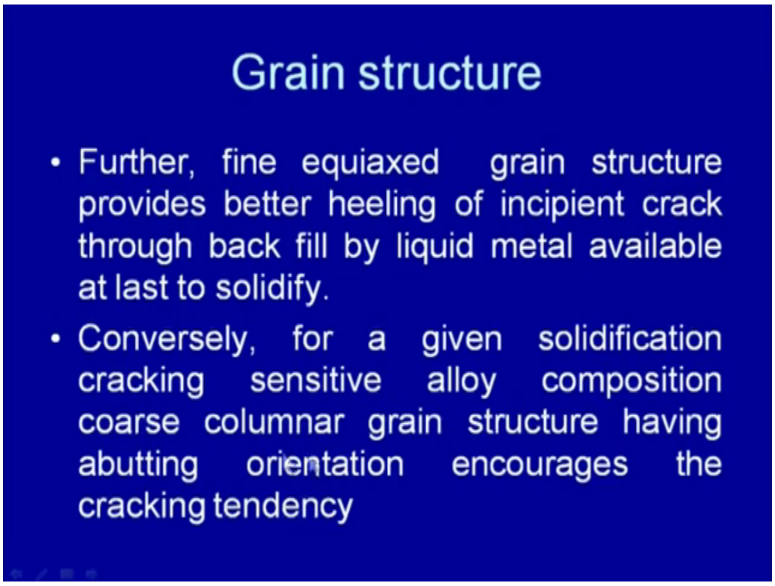

Now, we will see the effect of the grain structure on the solidification cracking tendency, we know that, if the grain structure is fine and equiaxed, it will provide the better flow of the liquid metal available for healing the cracks, which are being developed due to the localization of the tensile stresses. So, this the fine equiaxed grain structure will provide the better healing of the incipient cracks, through the back by the liquid metal available at the last stage to solidify.

And conversely, for a given solidification cracking sensitivity alloy, if we are having the columnar grain structure then the cracking tendency will be more as compared to the case, when we are having the fine equiaxed grain structure. And the reason for this is that, when we are having the coarse columnar grain structure, there will be more segregation of the alloying elements along the weld centre line, which will be increasing the cracking tendency especially, along the weld centre line because the grains will be aborting at the weld centre line.

And that will be pushing in the alloying elements along the at the weld centre line say, if we are using the low welding speed, we will be having the elliptical weld pool and the grains will be curved. And at the same time, we will be having a axial grains in this case, the concentration of the alloying elements will be distributed in better way as compared to the case, when we are using the higher welding speed.

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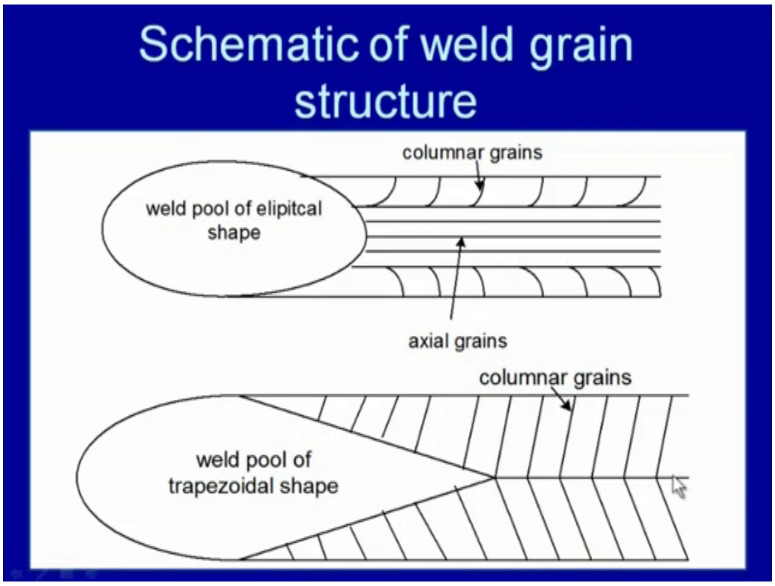

At a higher welding speed, most of the grains will be columnar and these will be pushing in the alloying elements along the weld centre line, and which in turn will be increasing the cracking tendency. So, if we are having the finer equiaxed grain structure, that will have the minimum cracking tendency as compared to the case, when we are having the coarse columnar grain structure.

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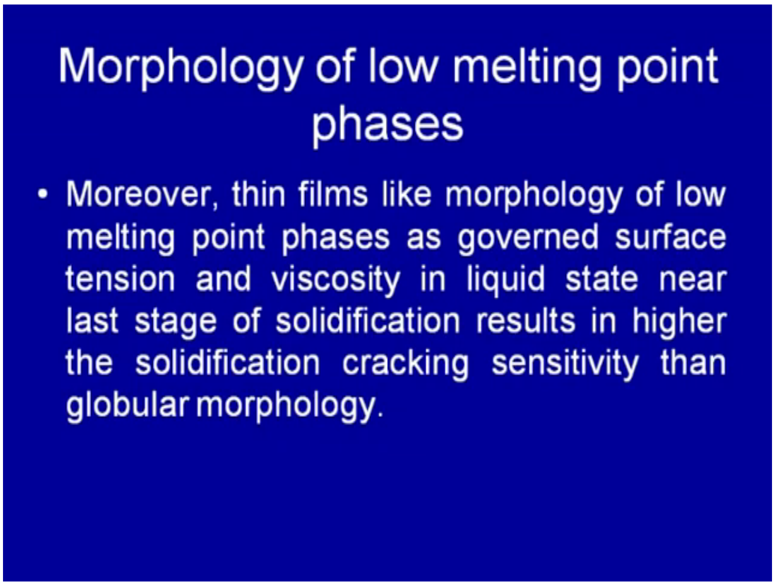

Then, the morphology of the low melting point phases, many low melting point phases are formed during the welding of the aluminium alloys and the steels also. So, in case when the low melting point phases are present in form of thin films, these kind of the morphology is more sensitive towards the solidification cracking as compared to the case, when the low melting point phases are present in form of the globules.

And because of this, thin films like, morphology of the low melting point phases is formed, when the surface tension and viscosity of the liquid metal last to solidify is very low. And these results in the higher solidification cracking tendency as compared to the case, when the low melting point phases are formed in form of the globular morphology.

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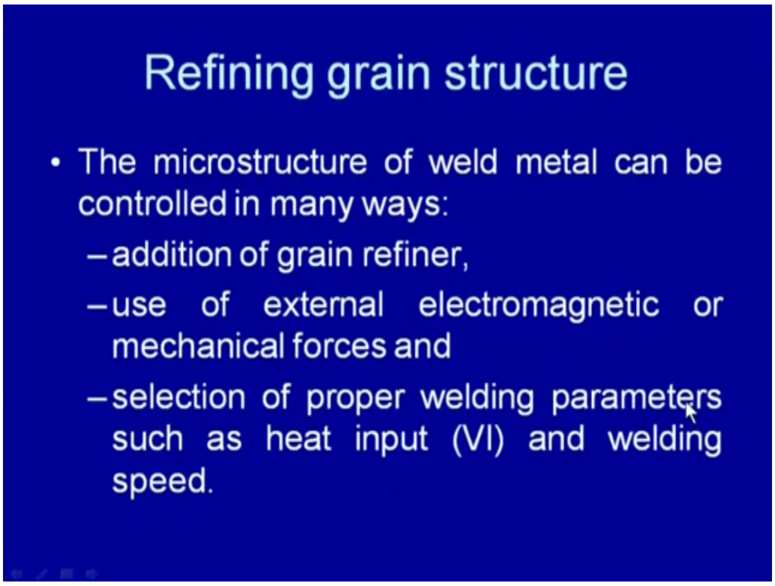

So, then refinement of the grain structure is the approach, which is used to control the solidification cracking tendency. We have seen that, the coarse columnar grains increase the solidification cracking tendency so refinement of the grain structure especially with the equiaxed grains, helps in developing the resistance to the solidification cracking tendencies significantly. So, the refinement of the microstructure of the weldment can be achieved using the various approaches like the inoculation where, the grain refiner is added from outside, which can act as a nucleant to refine the grain structure.

Use of the external force like the electromagnetic forces or a mechanical force in form of mechanical vibrations, these methods are basically used to create the disturbance in the weld pool. So, that the ((Refer Time: 44:30)) fragmentation and grain detachment can be used, can be obtained in order to produce large number of nucleants in the weld pool. So as to, refine the grain structure and further reducing the heat input so that, the high cooling rate can be achieved in order to obtain the finer grain structure, and this is done by adjusting the welding parameters in such a way, that the heat input can be reduced. And for this, V and I are reduced, the heat input is reduced, the welding speed is increased.

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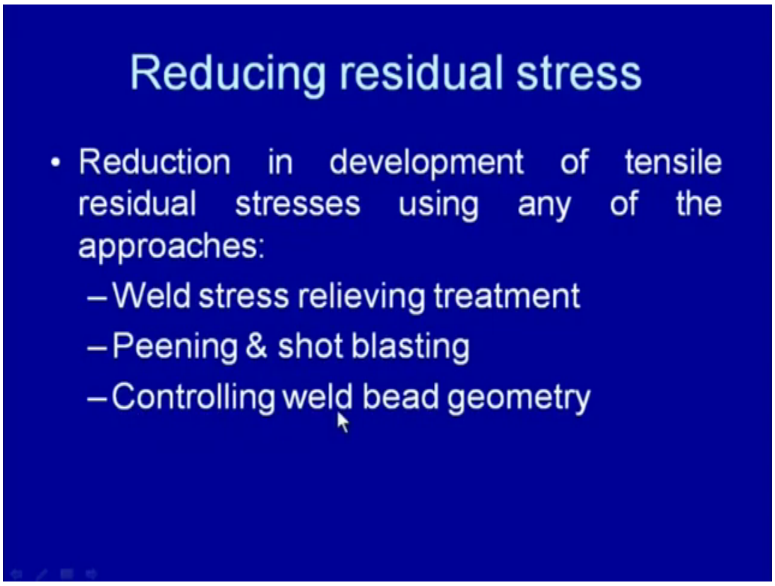

Then, another approaches of reducing the solidification cracking tendency is reducing the tensile residual stresses and for this purpose, the weld stress relieving treatment can be done just after the welding. And the mechanical methods like the shot peening and the shot blasting can be used in order to have the localized deformation at the surface. So that, the development of the tensile residual stress can be reduced and controlling the weld bead geometry like, having the convex weed can be developed in place of the concave weed, which will be reducing the solidification cracking tendency, because of the setting up of the compressive stresses especially at the surface.

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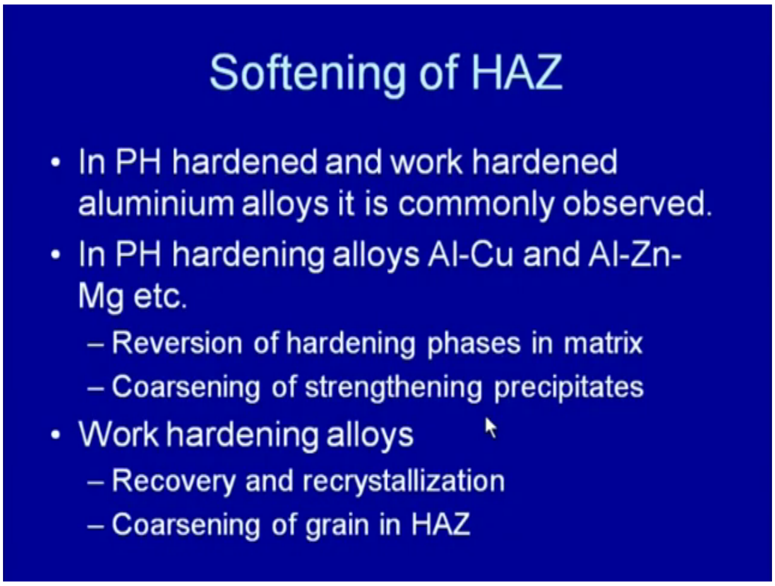

Now, softening is the another effect related with the welding of the aluminium alloys, which is observed and it adversely effects the weldability of the aluminium alloys. Softening of the heat effected zone is observed in both kind of aluminium alloys, either they are of the precipitation hardenable or work hardenable. A precipitation hardenable aluminium alloys like the aluminium copper system, aluminium zinc magnesium, aluminium magnesium silicon systems.

In these systems basically, when the exposure of the heat is given during the welding, whatever hardening precipitates are there, they tend to get dissolve in the aluminium matrix and the dissolution of the hardening precipitates decreases the hardness and this phenomena is called a reversion of the hardening precipitates. And apart from reversion the coarsening means, the hardening precipitates tend to coarsen due to the over exposure of the heat affected zone to the weld thermal cycle of the heat, which is being applied during the welding.

So, coarsening of the precipitates also decreases the hardness of the aluminium alloys especially, in the heat affected zone. And the work hardening aluminium alloys are also subjected to the softening, because of the recovery and the recrystallization effects. During the recovery basically, the dislocations will be decreased significantly and by the recovery fresh grained structure and by the recrystallization, fresh grains will be formed which will be decreasing.

So, recovery and recrystallization both will be decreasing the hardness, because of the elimination of the work hardening effect. And apart from the recovery and recrystallization, coarsening of the grain structure and heat affected zone also decreases the hardness. So, whether it is the work hardenable aluminium alloy or the precipitation hardenable aluminium alloys, in both the cases the softening of the heat affected zone will be taking place.

And that will be weakening the weld joint and frequently, it becomes the zone where, from fracture can take place under the tensile loading or under the fatigue loading conditions. And therefore, to avoid the adverse effect of the softening of the heat effected zone, the precipitation of hardening treatment is done after the completion of the weld joint.

Now, I will summarize this presentation, in this presentation first of all, we saw the basic mechanism contributing towards the development of the lamellar tearing and the approaches, which can be used to control the lamellar tearing. Thereafter, we have seen the factors that effect the weldability of aluminium alloys and important problems, which are encountered during the welding of aluminium alloys and what can be done in order to control them.

Now, in the next presentation, that will be the last presentation on the weldability of aluminium alloys mainly, we will be talking about the failure analysis approach, which is used to establish the cause of the failure of a particular component. We will be supporting those means, the failure analysis and prevention of the weld joint will also be taken up with some examples.

So, thank you for your attention.