Welding Metallurgy
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Lecture No 47
Types of Weld Cracks

Welcome to the lecture on types of weld cracks. So, we have talked about the cracks and what are the different types and we will talk about in detail, the cracks and especially about the hot and cold cracks in this lecture. So, coming to the hot cracks, if you recall, we talked about these hot cracks in that you have, hot crack that may occur in the weld with zone so that weld metal zone where it is the solidification cracking or you may have the lamellar cracking.

Now, if you talk about the factors which will be promoting these hot cracks. So, there are different factors which promote these hot cracks. So, the first point is the solidification structure.

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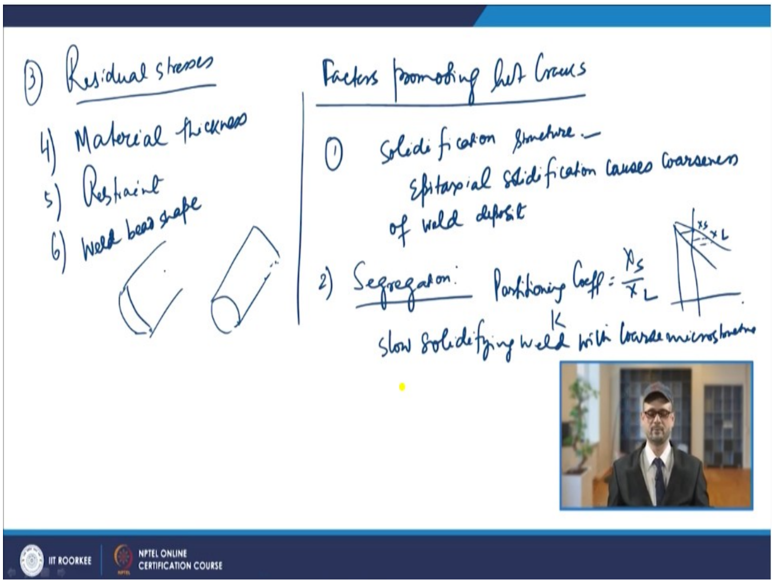

So, solidification structure means, as we know that in the case of weld solidification, you have the type of certification which is observed is the epitaxial type of solidification. Now, in that case, there is also as the temperature is higher, so, you will have the coarseness of the structure. So, you will have the epitaxial solidification that causes the coarseness of the weld deposit. So, what is happening that is inherited from the grain growth zone of the HAZ.

So, that basically now what is happening that you will have long sided columnar grains, so, in high speed welds basically that will be tending to be weaker under the stress than that another kind of grain that is your equiaxed type of grains. So, which is normally observed in the case of low speed welds. So, in those cases, so, the type of solidification structure which you obtain, that also affects the cracking tendency because that will promote in the case of high speed welding, so you will have these columnar grains which occur.

So, in the case our columnar grains, you have the higher segregation tendency and that leads to the formation of the cracks. Now, as we know, that you have the dendriting type of a structure, so, you will have dendritic growth is there in the case of weld metals, and we have already studied about the phenomena such as constitutional super cooling, which is observed when we talk about the alloys. So, in the case of solidification of alloys, you have the chances of the formation of the dendritic structures.

Because of the constitutional super cooling and in that case, you have the chances of higher segregation. So, as we know, if you recall the phenomena of segregation, so, the second point which is important is the segregation. So, segregation is another point which is very important factor for the hot cracking to occur. Now, we have already studied about the parameter, that is your partitioning coefficient, which is there, when we talked about the binary alloys phase diagrams.

So, in that we had studied about the partitioning coefficient. So, normally, segregation is unavoidable in case of alloys, because, you have the partitioning of elements during the initial stages of solidifications and we also define these partitioning coefficient, so partition partitioning coefficient is defined as the X_S/X_L. So, as we see that when we talk about, if you recall that when you had these phase diagram, so, if you come to any temperature, so, now, here you will have, this is your X_S.

And if you come here, so, at any particular temperature, you have these as X_L. So, you will have X_S/X_L, and it will be either less than 1 or it will be more than 1 depending upon how this binary phase diagram looks like. It may go like the slope may be less than 1 or more than 1 something like, so, positive or negative in fact, not more or less than 1. So, basically this leads to, so, because of this partitioning, coefficient values, so, you will have the alloying constituent, which is there in the weld deposit.

So, you may have the lower value of the K or you may have the higher value of K. And most likely, these elements which normally are segregating, they are like sulfur, oxygen, boron, phosphorus, carbon, titanium, all these elements, nitrogen and hydrogen. So, they are, normally trying to segregate and you have the segregating coefficient that is partitioning coefficient values are there, so, that can be found out from the tables in the standard books.

So, that way, normally the rule is that if you have the slow solidifying weld and with the coarse microstructure, they will be promoting central line segregation normally. So the condition is that, if you have slow solidifying weld and also with coarse microstructure, so in those cases, the normally this is the case, in the case of welding process such as electroslag welding. So, in those cases, you will have more segregation likely to occur, so, that is there in the case of slag welding processes or so. Then another factor which is important is the residual stresses.

So, if you talk about the formation of the residual stresses, so as we have already studied that, the stress value should not reach to higher limit otherwise, once that crosses that limit, then that may lead to the cracking. So, that way, you should have the control of the residual stresses. Then you have material thickness. So, as far as the material thickness is concerned, thicker will be the material faster will be the cooling after the welding.

Because in most of the cases in welding, when you are surrounded with the metal which has normally the higher value of thermal conductivity. So, if your cooling rate is fast, in that case, you have the probability of formation of harder constituents and once you have more probability of the formation of higher constituents, in those cases, you will have more chance of formation of cracks also in that weld metal.

Then, the next factor is the restraint we have already studied about the restraint, which is there in the case of welding, so many a times we are using the gigging or use of gigs or clamping we do, so, we are providing these restraint. And so, if the hot strength of the weld metal is exceeded, the stress which is generated, if that exceeds the hot strength of that weld metal, in those cases, there is likelihood of the formation of cracks.

So, you have to minimize these restraint on the joints. So, that should be the practice that your joint restraint should be minimum and for that, you must have the provision for some space between 2 members, so that they can have the movement during the cooling. So, if you provide those spaces for their movement between the cooling, then these effect because of these restraint that can be minimized and many a times we try to do certain measures to minimize these joint restraint.

Then the next factor which is further important will be the weld bead shape. So, you may have the convex type of shape or you may have the concave type of weld bead shape. So, in that normally, when you have the concave weld bead shape. So, if you have a concave fillet, now that appear to be larger. So, you may have such kind of shape and that moves or you may have this kind of shape and that moves.

So, that way concave shaped fillet will be there and that will be larger than these convex weld and then you will have, but these concave type of fillet, they will have the lesser penetration into the welded plates and so, that they will have the smaller throat than the convex type of bead. So, the convex bead normally which you get, they appear to be stronger. Although they appear to be smaller, but they normally are smaller, because here the penetration is smaller, it is shallow.

So, that gives you more strong, but, however, in many cases these concave type of bead shape is preferred by the designers because, there will be smoother stress flow to resist the load on the joint, so, that is the trait of this concave type of weld bead shape. But, when you have these concave bead, when it cools and then shrinks, at that time, the outer surface will be under tension and then there may be cracks.

So on the contrary, when you talk about the convex bead, so, they have normally you have a very reduced shrinkage stresses in surface area and the possibility of crack during the cooling is normally smaller. So that way these are the traits about these concave or the convex type of bead shape and the shape plays one important role towards the development of cracks.

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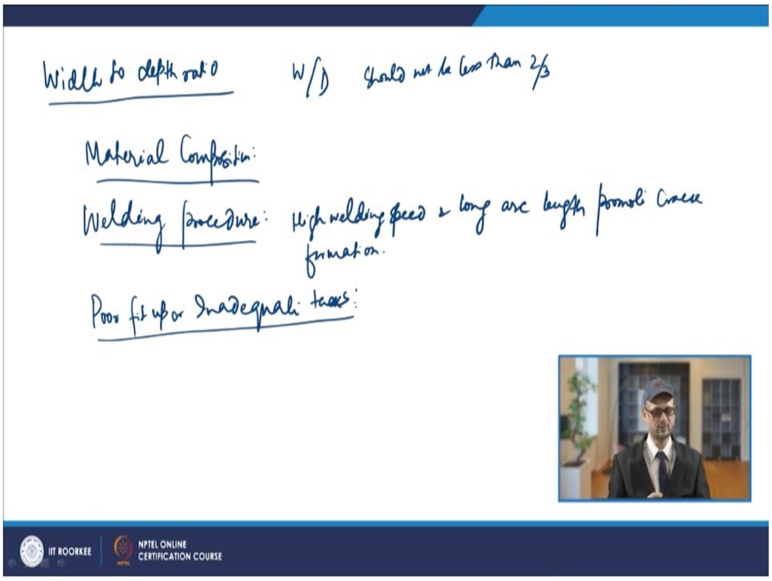

Then another factor, which is also important is the width to depth ratio. So normally, the width to depth ratio should not be very, very high and but it should not be less than 2/3 also. So, W/D that value should not be less than 2/3. So, these are the weld design principles which are followed and if your depth basically is a very, very large than the weld width, so what happens that may freeze, if the depth is very large than the width.

So, before the center freezes, the surface may freeze. So, that may be the consequence of that factor and when this will be happening, in that case the shrinkage force will act on the, frozen center. So, that will cause a crack, so, that happens normally, so, that should be avoided, you must have the proper, width to depth ratio. Apart from that, you may have other factors like you have the material composition.

So, what is the composition of the material and the some of the materials amounts should be limited and normally, we try to avoid the higher percentages of some elements like carbon or nickel. Because the presence of these elements increase the hardenability of the steel and whenever the hardenability will be increased, then the susceptibility towards the crack formation will be higher.

So, we should try to have minimum value of these elements in the material, so, that the crack formation tendency is smaller. Then comes the effect of the welding procedure. So, if you talk about the welding procedures, so, what we see normally is that, if you use the high welding speed and if you are using the long arc length, so, they promote the development of these cracks.

So, that is the effect of these welding procedure and towards the end, you have also many a times we have studied that if there is poor fit up or inadequate tacks, so, that also leads into the formation of cracks. So, poor fit up means, you have the reduced throat thickness many a times. So, that leads to the poor penetration and there is poor fit up so, that leads to the formation of cracks similarly, if you are providing the inadequate tacks also, so, that also leads to the cracks.

So, these are the factors which are responsible for the formation of hot cracks, especially the solidification of cracks, which are occurring in the weld pool.

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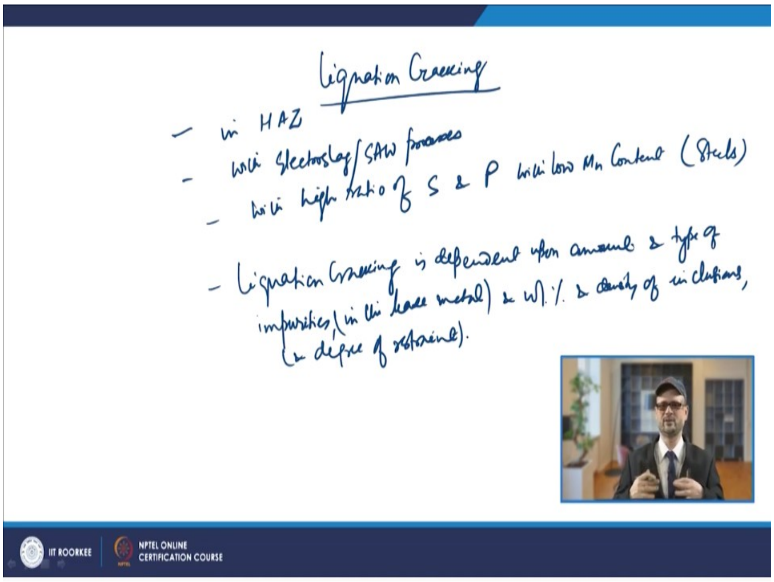

Now, coming to the other, type of crack that is your liquation cracking. So, liquation cracking as we know, this is also known as the burning. So, that is occurring normally in HAZ. Normally it will be occurring with the processes such as the electroslag or SAW process. So, they are high and also we had the studied that in these cases you have high ratio of sulfur and phosphorus with low manganese content. So, this is typically for steels, when this is the case in that case, your liquation cracking becomes predominant.

So, in the liquation cracking basically what is happening that when you have the hot rolling of the plate, when you are manufacturing so, in that case you have the sulfur and phosphorus that will be collecting around the grain boundaries and they are normally in the form of low temperature eutectics. So, you have the iron phosphide or you have other typical compounds which are basically the low temperature eutectics and the prolonged heat, which is passing, so that the heat basically what happens that when it passes through that.

And since it is a low temperature eutectics, so, when it passes through that region during the welding process, then that melts that region and then that eutectic phase will become basically the semi molten or in the molten state and then, once they cool then they will be forming the brittle films around the grains in the HAZ. So, normally, this is the main reason of the liquation cracking because the sulfur and phosphorus, so that is why we try to minimize these components.

Because they will be, even if in that HAZ zone, which is not going to that, temperature where there is melting, but then you get these low temperature eutectics which is there inside that region and along the grain boundaries there will be, so you will have the brittle film formation around that grains. Now, because of the stresses which are induced in these contracting material, now, that results into the micro-cracking of these zones and so, that will be reducing the strength and ductility of the material.

So, that cracks which are formed, these cracks are normally known as the liquation cracking. So, basically, as we know that the liquation cracking that is dependent upon the amount of impurities which is there in that base metal and depending upon the volume percent and as well as the density of also the inclusions. It will be also depending upon the degree of restraint. So, the liquation cracking is dependent upon the amount and type of impurities in the base metal and volume percent and density of inclusions and degree of restraint.

So, all these factors basically will be controlling this liquation cracking. So, basically you will have the high energy welding processes, they increase the susceptibility to these problems. The dwell time in the high temperature zone that also is very important. So, that is why these high energy welding process basically aggravate these liquation cracking during the welding. Now, this is about that liquid cracking. Now, another type of cracking which is more importantly to be studied, is the cold cracking.

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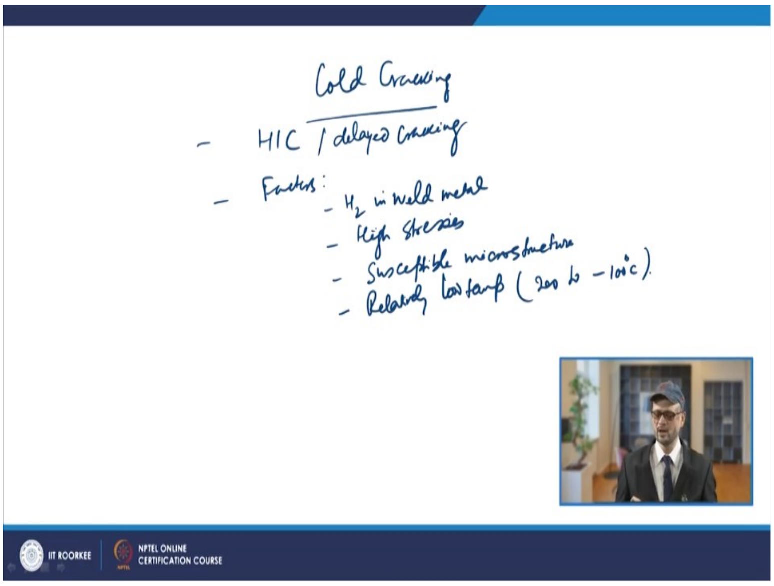

So, as we had the studied that the cold cracking is also known as the HIC or hydrogen induced cracking and it is also known as the delayed cracking. So, it occurs late, so it is known as the delayed cracking and normally you have the welding of high strength steels then these cracks are developed. And the factors which are present simultaneously which are responsible for these type of cold cracking are the hydrogen in weld metal, then you have the high stresses.

You have the susceptible micro-structure that is the formation of martensite and also you have relatively low temperature that is between 200 to -100 °C. So, normally, what happens that there are many constraint like heat input constraint or you have the other constraints that induces the high stresses. One is the presence of hydrogen, so, that has to be minimized then you have high stresses, especially when your martensite is formed, so that results into high stresses.

So, under that case, you will have more susceptibility towards the formation of these cold cracking and if the martensite finished temperature that is or start temperature martensite formation temperature that is MS if relatively it is low, then the HIC will be relatively operating at the lower temperatures. And that is why this name is the cold cracking. Now, the main source of these cold cracking is normally the presence of hydrogen in that weld metal and you will have the presence of water vapor, which is in the welding arc.

So, basically hydrogen which is there in the atomic form, now that can easily penetrate into the steel and that can cause cracking. So, the water vapor which is there, that will be broken and you will have the hydrogen in the atomic form and this can penetrate and that can provide the cracks, you have the blister formation and also that we be resulting into the loss of ductility. So, what is important is that one of the trait which is there of these type of cracks is that it can even go into a very high hard areas also.

So, like it can be appear in the area of heat affected zones, and also it can appear in the area of localized hard spots. So, that way it can be found in those areas too. Also, if you can understand by the presence of these type of cracks. So, normally the components which will be filling by the cold cracks, so, you will have, at some time, so, you will see that they have the fish eyed type of phenomena. So, you have the circular areas of quasi cleavage fracture centered on a large inclusion.

So, you will have clusters of smaller inclusions will be there, like you have silicates or Al_2O_3 particle. So, that is normally what you see in these cases of cold cracking. Apart from this hydrogen, or water vapor which is there, you can have the presence of hydrogen from other sources also like the hydrogen can come from the corrosion reactions, it can come from the chemical processing reactions, then you have many a times because of the purposeful additions also.

So, from all these sources, the hydrogen may go, we use many times the coatings also, in the shielded metal arc welding, you use the coating, so, there from also, there may be absorption of hydrogen, so, that may go into the weld. So, many a times we do something, so, there is some moisture if it is there, so, we try to avoid these moistures by preheating those electrodes also, that is also a common way to avoid cold cracking phenomena.

So, if you try to sum it up, you can promote these cold cracking weldments, by the presence of hydrogen in the weld metal zone. You may have the joint restraint and high thermal conductivity that may also result into the high stresses, you may have the presence of impurities, you have the susceptible microstructures, then you have lower current density because of that low temperature is there, or insufficient cross sectional area is there.

So, that way, these are the reasons because of this cold cracking occurs. We will talk about the specific type of cracks in our subsequent lectures. Thank you very much.