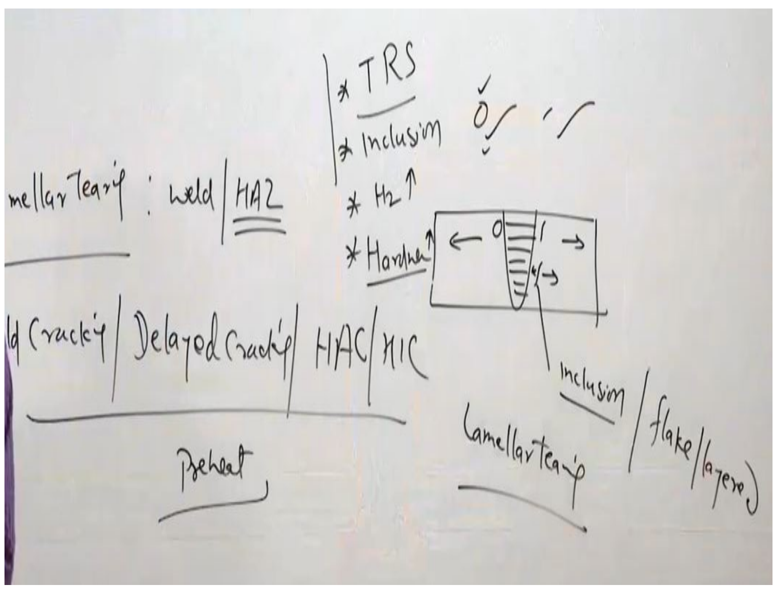
Joining Technologies of Commercial Importance
Dr. D. K. Dwivedi
Department of Mechanical and Industrial Engineering
Indian Institute of Technology – Roorkee

Lecture - 40
Cracking of Welded Joints II: Cold Cracks

Hello, I welcome you all in this presentation. This presentation is the second part of the last earlier presentation about the cracks in the welded joints. In the last presentation, I have talked about the two types of the cracks and their remedial methods. These were the solidification cracks and the liquefaction crack. Solidification crack is observed in the weld metal and liquefaction crack is observed next to the fusion boundary.

Today, I will be talking about the two types of these in this presentation.

(Refer Slide Time: 00:45)



First, the Lamellar tearing is one kind of the crack observed both in the weld and the heat affected zone. But the formation of this kind of the crack or tearing is more commonly observed in the heat affected zone and another one is called as the cold cracking also known as the delayed cracking, also termed as the Hydrogen Assisted Cracking or Hydrogen Induced Cracking. These are the four different names which are given to another type of the crack which is observed in the heat affected zone.

So, if we see for the lamellar tearing this is mainly caused by the presence of the inclusions. This is one thing, whenever the tensile residual stresses set in during the welding, presence of the inclusions, obviously these are either flake or layered form under the tensile residual stresses decohesion of such kind of inclusions from the metal matrix leads to the formation of the lamellar tearing.

So, what is mandatory for the lamellar tearing is the tensile residual stresses and which are basically developed due to the shrinkage of the weld metal and apart this, the presence of the inclusions is the another and important thing and inclusions of the spherical shape are not that harmful as compared to the lamellar or the layered or the flaky shaped inclusions.

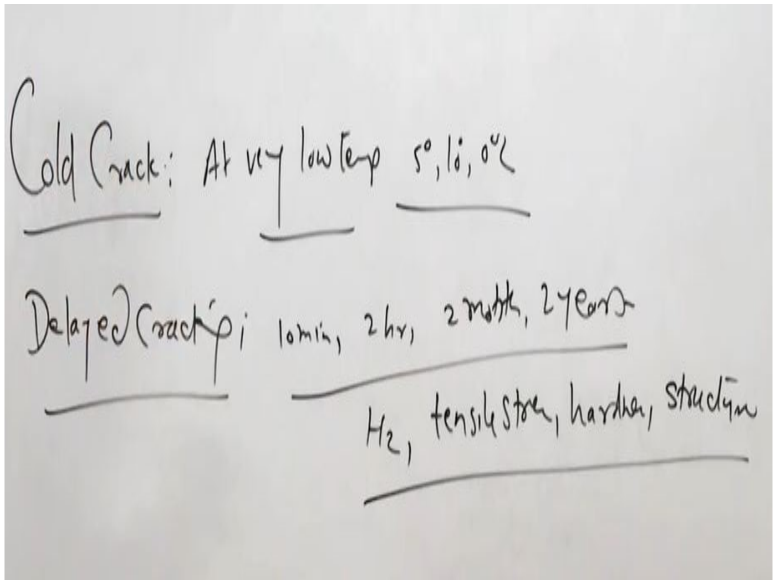
So the morphology of the inclusions also matter in increasing the lamellar tearing or in determining the lamellar tearing tendency like the fine inclusions will not be that harmful as the large size inclusions. Similarly, the nodular or the globular inclusions will not be that harmful as the flaky or the noodle or the layered shape inclusions. So these are the two primary regions, apart from these what we see that the presence of the hydrogen also increases such kind of the cracking tendency.

And the hardness increase in the hardness of the weld metal or the heat affected zone also promotes the lamellar tearing tendency. So higher hardness, higher tensile residual stresses, higher inclusion or the hydrogen content in the heat affected zone or in the weld metal, they promote the lamellar tearing tendency. So the best way is to preheat the plates before the welding.

So that the tensile residual stress magnitude can be reduced and if at all hydrogen is present, it can be diffused out by preheat or increase in temperature and the preheat will also help to lower down the hardness or will promote the softening of the base metal and thereby, it will reduce the tendency for cracking. So this was in brief about the lamellar tearing and where does it occur? What are the causes of the lamellar tearing?

And what should be done to reduce the lamellar tearing tendency? So all the things that we can do for reducing the tensile residual stresses is reducing the hydrogen content and reducing the inclusions in the base or in a heat affected zone should be tried for reducing the lamellar tearing tendency.

(Refer Slide Time: 05:20)



Another one is the cold crack or the delayed crack, the various names, which have been given very commonly known as cold crack. This type of cracking is called cold crack because it occurs normally at a very low temperature conditions like maybe 5 degree or 10 degree or 0 degree centigrade. So under the low temperature conditions this kind of cracking tendency is observed, delayed cracking is called so.

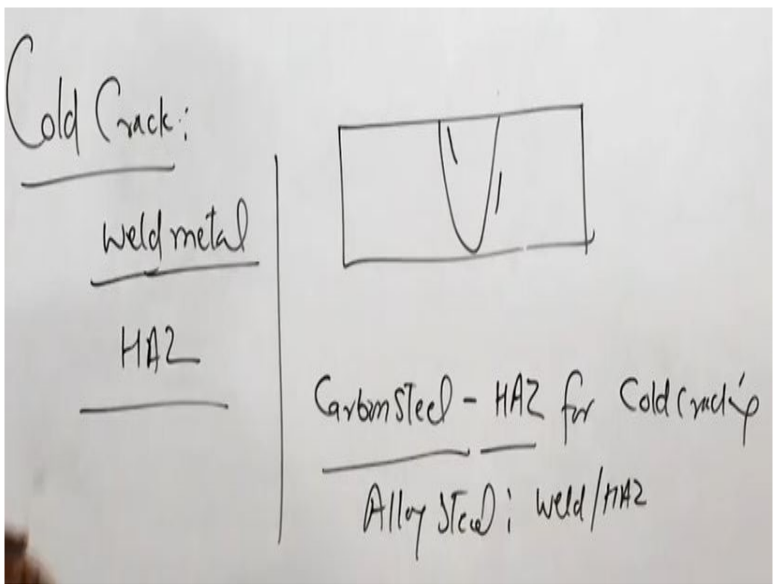
This is also called blade delayed cracking because sometimes, it is observed after, like say, 10 minutes of the welding sometimes 2 hours of the building or the 2 months and sometimes even after the 2 years of the welding depending upon the hydrogen content in the heat affected zone of the weld metal, depending upon the magnitude of the tensile stresses acting in the weld joint and depending on the hardness of the weld metal and the heat affected zone.

And a structural constituent of the weld metal and the heat affected zone. These are the four factors that significantly determine how fast the cold cracks will be developing. Since this kind of this type of cracks are observed after few, after some time of the development of the cracks, development of the weld joints and that is why they are called delayed cracking. This is also called hydrogen induced crack or hydrogen assisted cracks.

Because the hydrogen is, hydrogen plays a major role in development of such kind of cracks, which occur at low temperature under the presence of the tensile residual stresses especially in case when the hardness of the metal is high and the structure is sensitive for cracking. So, these are the reasons why they are called so by the different names and now we will see the causes of such kind of the cracks.

So as I have said the cracking, for the cracking it is necessary that either the tensile residual stresses are present or the shear stresses are present in the weld joints.

(Refer Slide Time: 07:45)

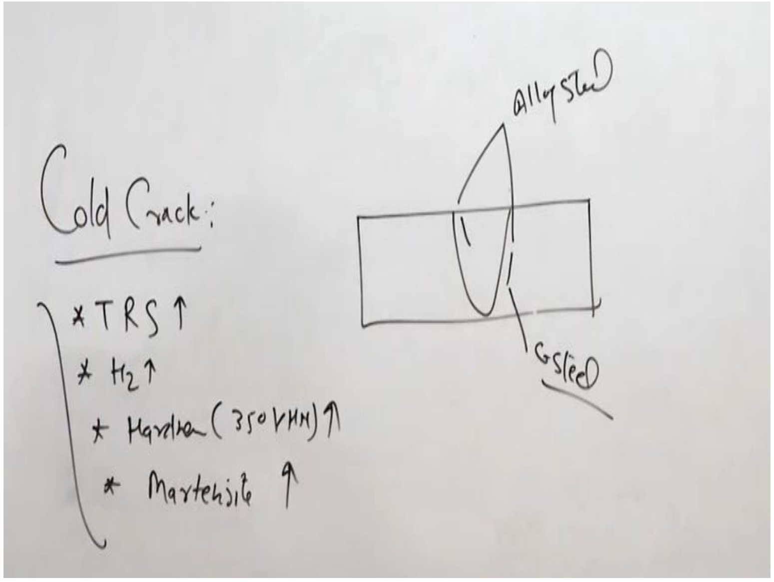


So this kind of crack can occur either in the weld metal if it has a favorable conditions like the martensitic structure, high tensile residual stresses and higher concentration of the hydrogen as well as the higher hardness. So the weld metal or it can also occur in the heat affected zone. It is commonly observed in the heat affected zone. Now coming to the kind of metal systems, which are sensitive for such kind of cracking.

So if you see, like say, this is the weld joint of the steel, so the cracks may occur in the weld or in the heat affected zone. So, the carbon steels, whose hardenability is limited is not that high. Their

HAZ is found sensitive for cold cracking while in case of the alloy steels having the high hardenability this, the weld as well as the HAZ both show cracking tendency for the cold cracking. So, this is about the metal systems and the kind of cold cracking and where does it occur commonly or it is observed commonly in the weld or in the heat affected zones.

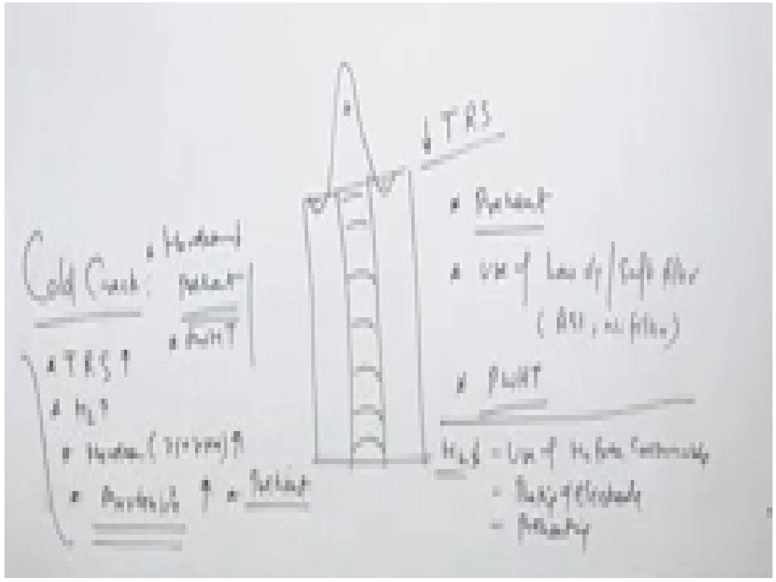
(Refer Slide Time: 09:20)



So this is common for the carbon steels and in case of the alloy steels both as well as the heat affected zone for the alloy steels. The things that are needed for such kind of cracking is like the presence of the tensile residual stresses, one, hydrogen concentration, two, so all these will be promoting the cracking tendency and the 3 higher hardness, a hardness greater than 350 VHN actually promotes the cracking and the sensitive structure like martensite.

So these are the four factors that significantly promote the cold cracking tendency and whenever these are present the steels found sensitive for cold cracking tendency. So what can be done to avoid this? So we need to work on all these four components in order to lower down the cracking tendency or the cold cracking tendency.

(Refer Slide Time: 10:45)



So for understanding this we know that any weld metal whenever welded using the fusion welding process, the weld joint is subjected to the higher tensile residual stresses, so the weld metal invariably has the tensile residual stresses. So in order to reduce the tensile residual stresses we have limited approaches like we can do the preheating so that differential thermal expansion and contraction in the weld and the heat affected zone.

And the base metal can be reduced. So preheating is the one thing, which can be done in order to reduce the tensile residual stresses, another is use of the low yield strength or the soft filler metal, this is another thing because the magnitude of the maximum residual stresses can be equal to the yield strength of the metal. So if the yield strength of filler metal is lower, then it will help to reduce the maximum magnitude of the residual stresses being developed.

Say in case of the steels, mainly the Austenitic stainless steel filler or the nickel fillers are commonly used because they are somewhat more ductile and are of the lower yield strength. So that helps in reducing the residual stresses and if possible go for PWHT or the Post Weld Heat Treatment, so that whatever residual stresses have been setting they can be eliminated or they can be reduced as far as.

So these are the approaches, which can be used for reducing the tensile residual stresses in the weld metal and the hydrogen content for reducing the hydrogen content. What is the important for reducing the hydrogen content because it is a very big factor, which leads to the development of the cold cracks? So for reducing the hydrogen content, use of hydrogen free consumables like shielding gas electrode or the fillers or the coatings.

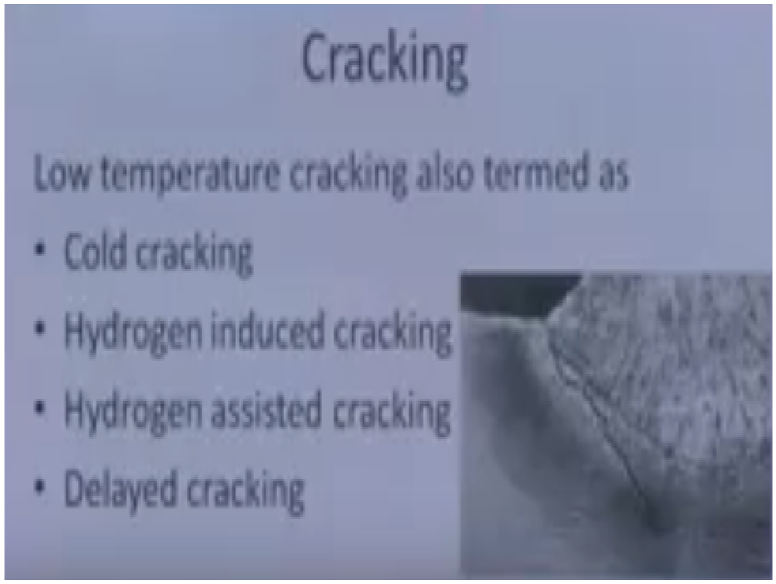
Whatever can contribute for the presence of the hydrogen in the weld metal that should be avoided or if the electrodes need to be used and if they have been exposed to the atmosphere then proper baking of the electrodes is to be done, so that whatever moisture has been there, it can be driven off. Another approach is that use of preheat, preheating will allow the rejection of the hydrogen more effectively.

Because it will, whenever due to the differential solubility of the hydrogen in the liquid and solid state. As the temperature comes down, the hydrogen is rejected and this rejected hydrogen should get enough time for escaping and that would be possible only if the high temperature is maintained for the longer period, which is possible through the preheat. So preheating of the base metal during the welding helps to reduce, helps to diffuse out the (()) (14:24) of the hydrogen from the weld as well as the heat affected zone.

And that in turn will help to reduce the cracking tendency. Preheating reducing the hardness of the weld or of the heat affected zone. For this purpose, basically we can apply preheat, so preheating or the Post Weld Heat Treatment. Both can be tried for reducing the hardness of the base metal or of the weld metal or of the heat affected zone so that the cracking tendency can be reduced.

And the martensitic transformation, what does it mean the cracks sensitive structure like the formation of the martensite in the weld as well as the heat fluctuation also should be avoided. And for this purpose we can use the preheating, so that the softer structures are formed instead of the sensitive structure. So this is the base of the code cracking, as far as the factors, which cause to the cold cracking and the methods which can be tried for reducing the crack, cold cracking tendency.

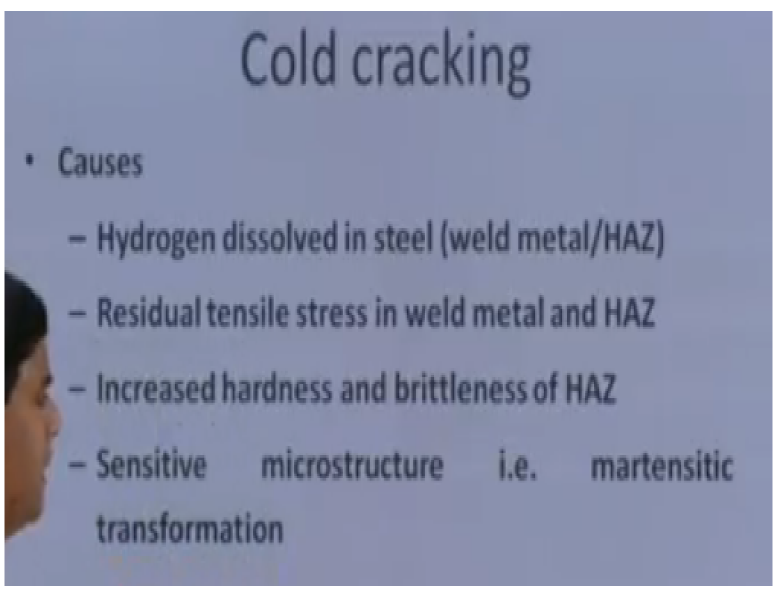
(Refer Slide Time: 15:44)



Now I will go systematically through the various aspects related to the cold cracking. So it is a low temperature cracking, now be termed as cold cracking as I have said a hydrogen induced cracking, hydrogen assisted cracking or the delayed cracking. And you can see this type of cracking is observed next to the weld. So this is the fusion boundary and next to the weld, it is being observed and it is starting at the toe of the weld.

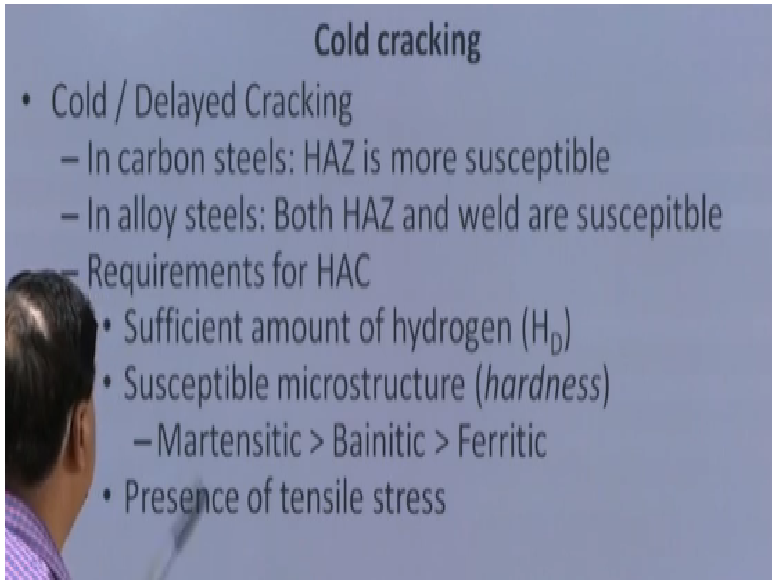
Because this is the area of the high stress concentration, which triggers the crack and then it grows near the fusion boundary in the heat affected zone, so which where it is having the favorable conditions.

(Refer Slide Time: 16:23)



These are the common causes, which are observed for the development of the cold cracks. Hydrogen dissolved in the weld metal, hydrogen dissolved in these steels like in the weld metal or in the heat affected zone, development in the tensile residual stresses in the weld or heat affected zone, higher hardness or the brittleness of the heat affected zone and the crack sensitive structure like the martensite formation in the heat affected zone.

(Refer Slide Time: 16:50)

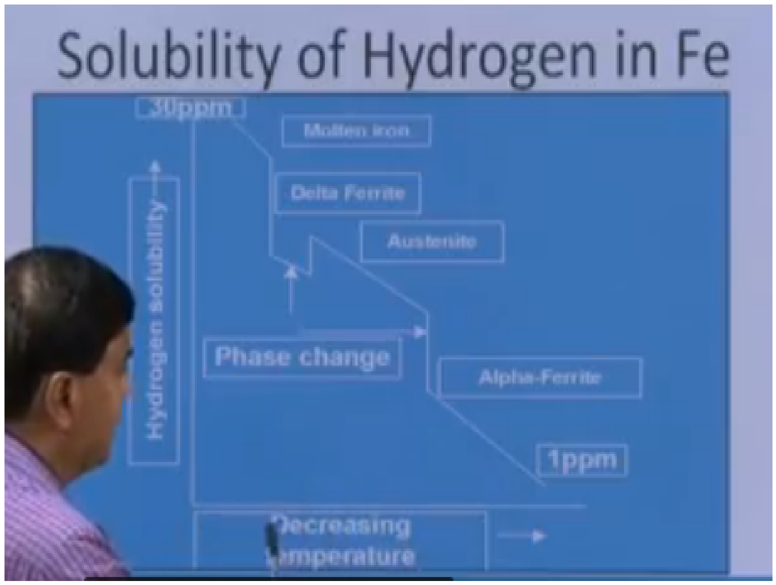


So if we see here, these what I have already said, in the carbon steels, HAZ is sensitive for the cold cracking, while the alloy steels has, in case of the alloy steels both HAZ and the weld are susceptible for the cold cracking. And so for development of the cold cracks or hydrogen assisted cracks, it is necessary that there is sufficient amount of hydrogen, susceptible microstructure, sufficient hardness.

And the presence of the tensile stresses, leads to the development of the hydrogen assisted cracks. As far as the comparative crack sensitivity of the 3 micro constituents, commonly absorbed micro constituents in these steel circumstances, Ferritic skills have the minimum cracking tendency. Thereafter somewhat more cracking tendency with the Bainitic and then Martensitic.

So the formation of the martensite frequently amuse commonly promotes the cold cracks in the steel. So if the pre heating or the post weld heating treatment, whatever help, can help us in doing away with the martensite, then that will help to avoid the cracking tendency.

(Refer Slide Time: 18:00)



Now, we will be going into the mechanism and the causes of the cracks. So here we will see that the solubility of the hydrogen in the well, in the liquid state and the solid state is different. Further the solubility also, solubility of the hydrogen in the iron changes with the temperature due to the change in the crystal structure or due to the change in the phases, which are observed.

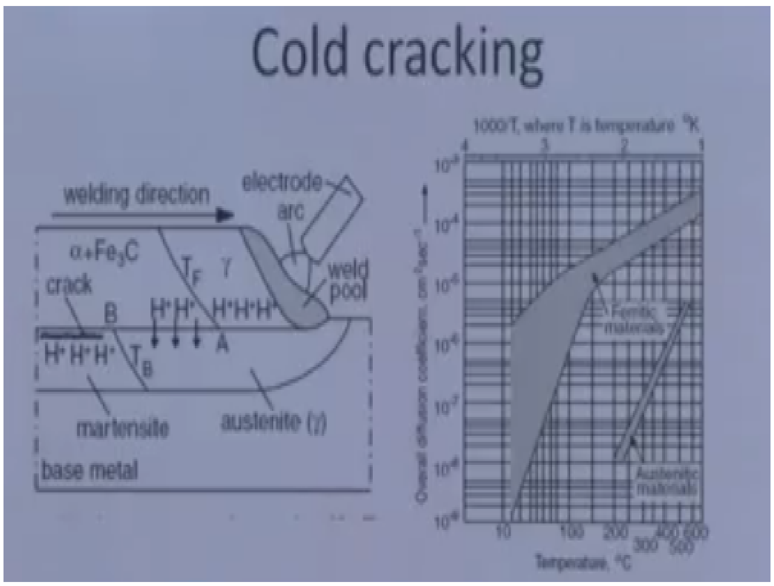
We know that the steel at the room temperature will be having very limited solubility, like say 1 ppm, where mainly we have iron carbide and the ferrite. So as we increase the temperature, the ferrite and the iron carbide, they change into the austenite. So whenever this change takes place, there is a sudden jump in the solubility of the hydrogen. We know that the increasing temperature, this is the direction for decreasing temperature.

And as we increase, we are increasing the temperature, there is an increase in solubility of the hydrogen in the iron. So there is sudden increase in the solubility of the hydrogen in the iron, even in the solid state, as soon as the transformation from the austenite or iron carbide to ferrite alpha, ferrite to the austenite takes place. This happens primarily at, for pure iron, it happens at 910 degree centigrade.

So this, here also in the austenite, the solubility of the hydrogen in the austenite keep on, keeps on increasing with the temperature. And then there is some drop, some of the drop in the solubility of the hydrogen is observed. That is primarily due to the, again change in phase crystal structure from HCC to BCC due to the formation of the delta ferrite. And then again, after this we reach to the melting point and as soon as the melt iron reaches to the molten state.

There is a sudden increase in the solubility, up to the 30 ppm. So the solubility of the hydrogen in the iron changes from 1 ppm to the 30 ppm from the solid state to the liquid state.

(Refer Slide Time: 20:09)



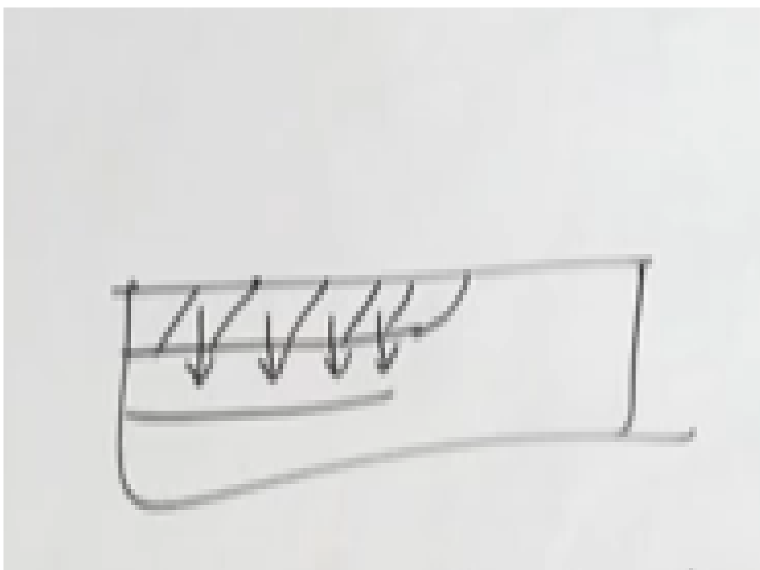
So what happens in case of the welding due to that, this difference in solubility? Let us say we, this is the direction of welding and this is the region next to the weld metal and this is the base metal. So base metal, of course will have the ferrite and the iron carbide. But whatever region falling in the weld metal zone or next to the fusion boundary that will be falling in the heat affected zone.

So we know that heat affected zone will have both austenite and after the cooling it will be resulting in the ferrite, pearlite and martensite or whatever as per the cooling rate. So let us say this is the weld bead having the hydrogen. At high temperature, hydrogen can dissolve, more amount of the hydrogen can be dissolved in larger quantity, as compared to that at low temperature.

So this is the liquid metal, if it is having the hydrogen after the solidification, this is the hydrogen can be dissolved in the larger quantity in the austenite. So it will be here, the weld metal will have the austenite. Weld metal will have the austenite and hydrogen will be, can be dissolved easily in the austenite. And in the course of the cooling, as soon as the austenite starts cooling, it forms the alpha ferrite and iron carbide.

So as soon as its formation starts, the hydrogen is rejected. Hydrogen is rejected to the base metal. So, where it will be rejected in the base metal?

(Refer Slide Time: 21:54)



Since the base metal or in the heat affected zone, which is still at the high temperature, since we know that, let us say this case, this is the region, which is the weld metal and this is the heat affected zone. So the weld will be solidifying and then cooling fast and thereafter the heat affected zone, so the weld metal may be at the lower temperature, but the heat affected zone, which is below the surface, will still be at higher temperature.

That is why, what we will see that the weld has solidified and its temperature has reduced, so it has converted into the alpha and iron carbide, but the heat affected zone is still at higher temperature, so it is of the austenite. So the weld metal, which has transformed into the ferrite and the iron carbide, will be rejecting the hydrogen because of the lower solubility to the austenite.

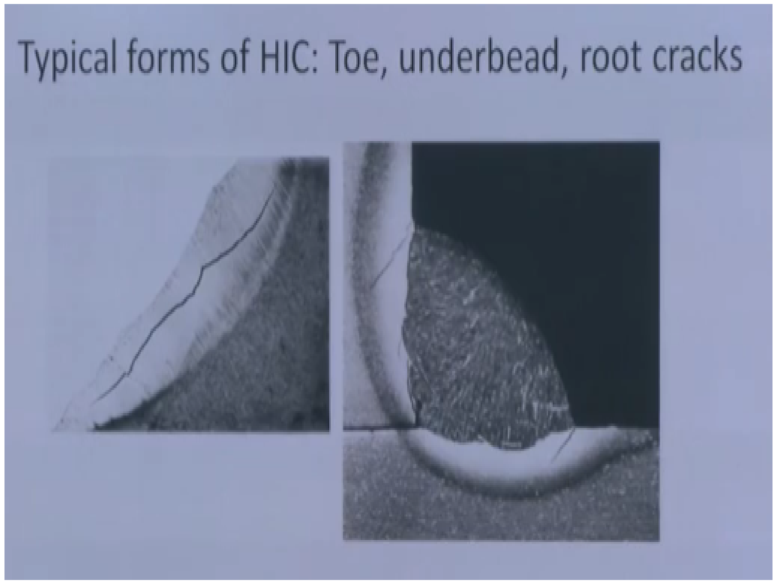
So this is the region where hydrogen will be transferred from the weld metal to the heat affected zone. And once it has got the hydrogen means, heat affected zone has received the hydrogen because of the higher solubility of the austenite. Subsequently this region will also be cooling down. So after cooling, the hydrogen will remain in the heat affected zone. And due to the higher cooling rate, if the cooling rate is high enough in the heat affected zone.

Then it will be forming the martensite. We know that the weld as well as the heat affected zone region, generally experience the tensile residual stresses and if the presence of the hydrogen, formation of the martensite, presence of the tensile residual stresses and higher hardness, all these things, if they are present, then this simply promotes the cracking of the heat affected zone. Actually the cracking of the weld metal can be reduced to some extent by using the suitable filler, like austenitic filler.

But the cracking of the weld metal can be reduced by using the suitable filler like austenite, austenitic filler, which can absorb more amount of the hydrogen or which is of the softer, which is softer material offering the greater ductility. But not much can be done for the, for reducing the cracking tendency of the heat affected zone, except the preheating kind of thing. So, hydrogen diffusivity of the hydrogen is also different in case of the austenite and in case of the ferrite.

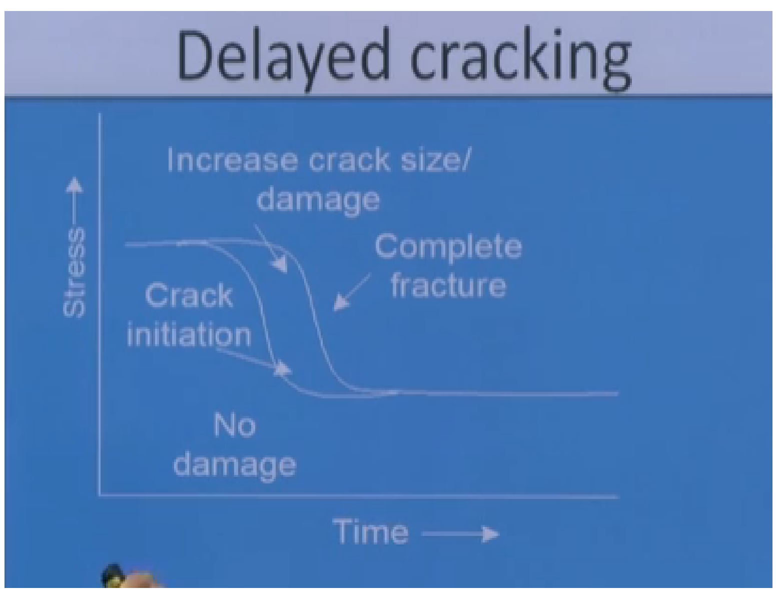
This is what we can see here, austenite diffusivity and y axis the diffusion coefficient of the hydrogen in austenite as well as in the ferrite, as a function of the temperature. So the diffusivity in the austenite is somewhat lower than that of the ferrite. Ferrite, in case of ferrite, it diffuses very fastest, compared to that in austenite.

(Refer Slide Time: 24:43)



So these are the typical diagrams or the photographs showing that hydrogen induced cracks in the weld as well as in the heat affected zone. So, if the weld is sensitive for the crack, then it will be having the crack. And this is that, in the crack in the toe region of the heat affected zone. So the toe of, since the toe is experienced, is the stress concentration and tensile residual stresses, so it promotes the cracking if the conditions are favorable like the hydrogen hardness and the martensitic transformation of the structure.

(Refer Slide Time: 25:18)

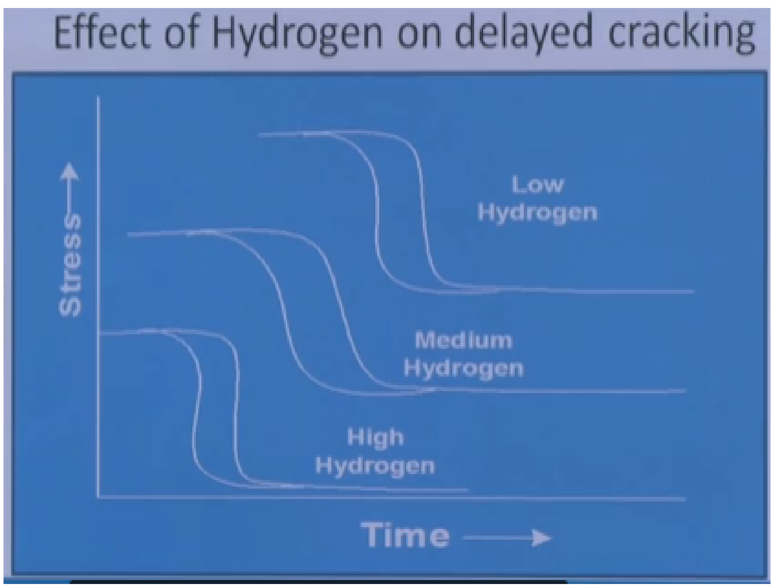


So the delayed cracking is the time based cracking, where it takes time under the different level of the stresses and the hydrogen concentration. This typical diagram shows that how the cracking starts and how it ends and leads to the fracture. So as a function of the stresses that may be tensile residual stresses or the external stresses, as a function of time, if we see, if the stresses are high.

So this is the band for a given value of this stress, for a one value of the stresses, cracking will initiate at this point of the time and then crack will grow and then catastrophic fracture or the complete fracture will be taking place at after this much time. So this band basically shows the time it takes for the growth of the crack, until fracture. So the increase in crack size or the damage is represented by this region. And of course in the presence of the hydrogen.

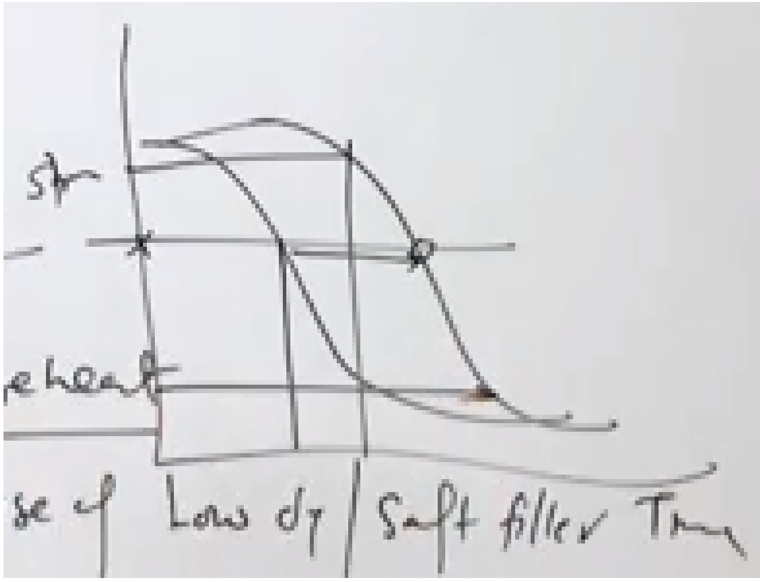
So as a function of the hydrogen, we will see another diagram, how the cracking tendency and the time requirement for that the failure or the fracture, due to the hydrogen induced cracks it takes place.

(Refer Slide Time: 26:32)



So under given set of the stress conditions, like if we increase the stress magnitude, the time required for the complete fracture or initiation of the crack reduces basically. If we have the lower hydrogen, then it can sustain higher stresses and as compared to the case, when the hydrogen content in the weld meal is lower. So this is the, this what can be explained using this diagram here.

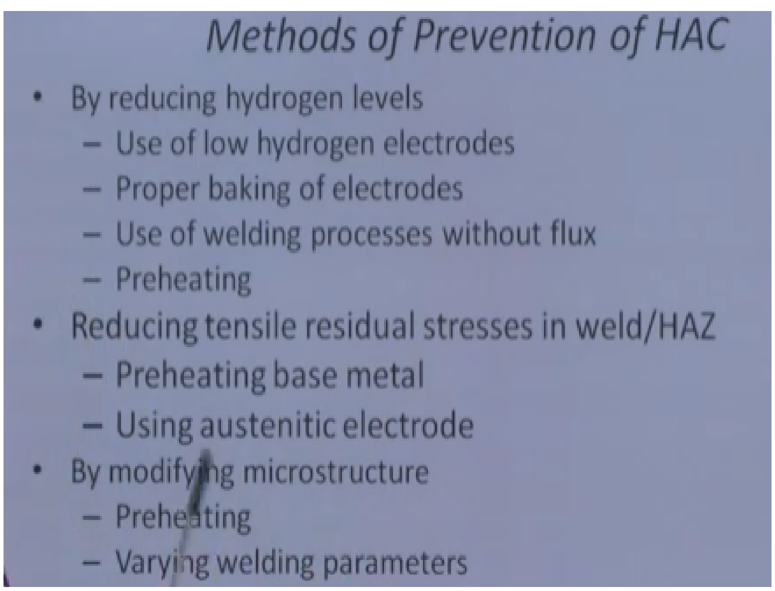
(Refer Slide Time: 27:00)



This diagram goes in like this. So this is the time and here we have stresses. So for any magnitude of this stress, this is the time when the crack will, the hydrogen crack will initiate and hydrogen induced crack will initiate. And this is the time when cracking will complete and the fracture will start. So higher the stresses, lesser the time it takes for complete fracture or initiation of the crack and lower is this stress, greater is the time it takes to.

Similarly, lower is the hydrogen concentration in the weld or in the heat affected zone, longer time it will for complete fracture.

(Refer Slide Time: 27:46)



These are the prevention methods. As I have explained earlier, reducing the hydrogen level, using the low hydrogen electrodes, proper baking of electrodes or use of the welding process, which are without flux or preheating. All these things I have already explained for reducing the hydrogen. And reducing the tensile residual stresses in the weld metal, as I have said, use of austenitic filler or the preheating of base metal also helps to reduce the magnitude of the stresses.

And the modifying base structures, so that we have the less crack sensitive structure in the weld metal, like preheating. This helps to have the formation of the softer phases like the bainite or the pearlite. And wherein the welding parameters in such a way that, the cooling rates are not high enough in the weld metal, for formation of weld metal as well as the heat affected zone, for the formation of the crack.

So now, I will summarize this presentation. In this presentation, I have talked about the two types of cracks which are observed in the heat affected zone. One was the lamellar tearing and another was the heat affected cold cracking. And I have also talked about the different methods, which can be used for reducing the lamellar tearing tendency as well as reducing the cold cracking tendency.

So participants of the course, this was my last presentation and in this subject I have talked about the range of the topics, starting from the fusion welding to the solid state joining and the solid and liquid state joining, besides the physical metallurgical aspects of welded joints. So I hope that you have, you would have learnt a lot about the welding and the different technological aspects related to the welding and what can be done in order to develop the sound weld joints.

I wish you a very best of luck for your future endowers, endeavors and for success in the area of the welding related with the subject. Thank you for your attention.