Manufacturing Process - I

Dr. D. K. Dwivedi
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

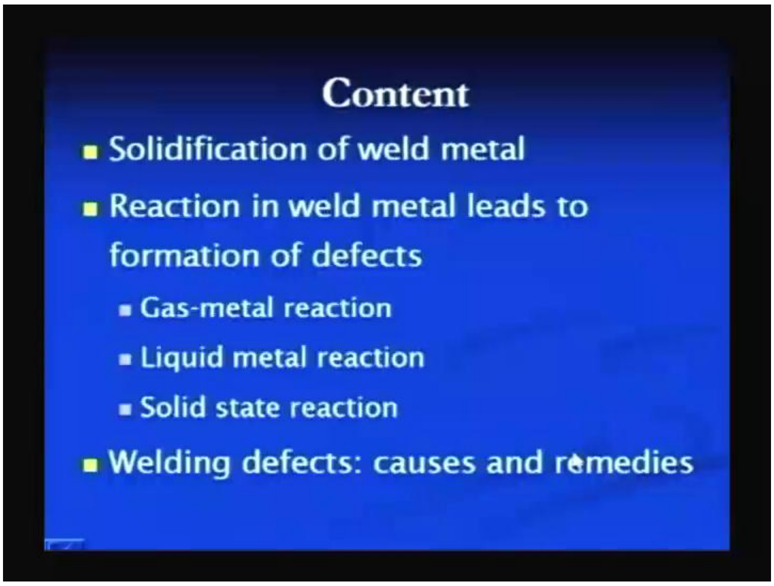
Module - 3
Lecture - 14
Reaction in Weld Region & Welding Defects

Welcome students. You, you have seen, that in fusion welding processes for joining the metals, localized heating from the different sources is used for melting the faying surfaces and to produce the weldment. And when molten metal is obtained by the application of heat, either from the arc or from the combustion of the gases.

Thereafter, the various reactions in the weld metal region takes place and these reactions may be in form of transformation of liquid metal to the solid state and the reaction of the gases with the molten metal, reaction of the slag with the molten metal and reactions, which can take place during the cooling of the weld metal and heat affected zone from, from the solidus temperature to the room temperature during the cooling portion. So, different reactions which take place in the weld region affect the soundness of weld joint and sometimes, these reactions lead to the various kinds of the defects in the weld metal.

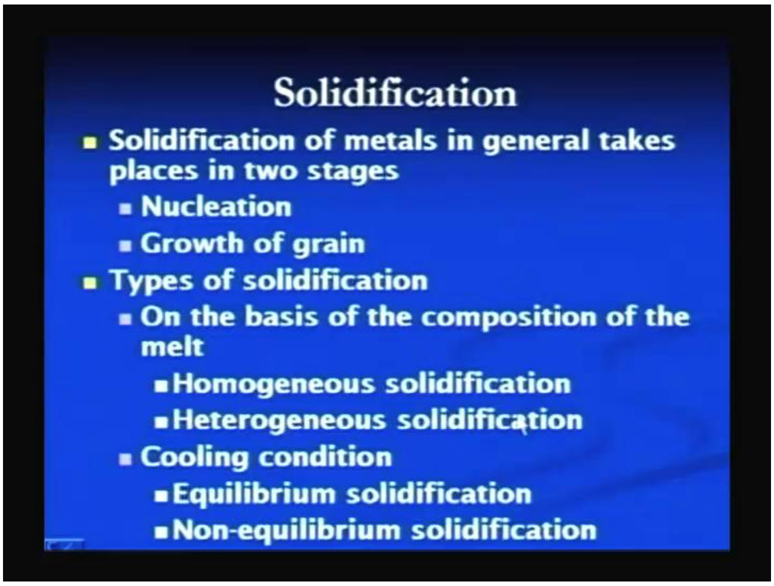
That is why, in this lecture, I will focus on the various reactions, which take place in the weld region. And as a result of that, what are the common defects observed in fusion welding processes and what are the main causes of the defects because of which these defects are formed in the weld metal, and how can we overcome these defects from the weld metal or the defects, which are formed in the weld metal.

(Refer Slide Time: 02:37)



So, in this lecture we shall cover the solidification of the weld metal aspects, the reaction in the weld metal, which may be in form of a gas-metal reaction, liquid-metal reaction and solid state reactions. And the various defects, which are normally observed in the weld metals along with their causes and the remedial actions, which will be taken to avoid the presence of weld defects, so that some weldment can be obtained.

(Refer Slide Time: 03:04)

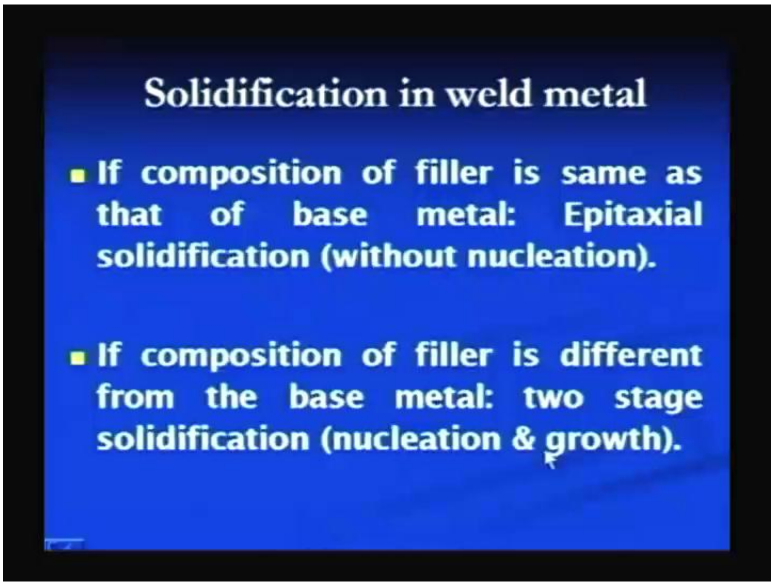


The solidification, in general, takes place in the two stages. If we get a metal in molten condition, then in general, it solidifies in two stages. The first one is the nucleation where cluster of the atoms are formed and they act as nucleant and thereafter, their growth takes place. So, in general, most of the metals solidify in, in two stages, one is nucleation and other is growth of the grain or growth of those nucleants, which are formed to complete the solidifications sequence.

If we classify the solidification types, then on the basis of the composition of the melt, it can be the homogenous solidification or the heterogeneous solidification. Extremely pure metal solidify by the homogenous pattern or homogenous. If the metals, if the molten metals is pure, then homogeneous solidification takes place and if impurities are there, then heterogeneous solidification takes place.

And on the basis of the cooling conditions if we classify the types of solidifications, then we can have the equilibrium solidification where cooling conditions are very, cooling rate is very low. While in under non-equilibrium cooling conditions means, the actual cooling conditions, which are normally encountered during the casting in foundries, the non-equilibrium solidification takes place. So, if the cooling rate is very low where all the phases, which are possible under very low cooling rate can be formed, then that is termed as equilibrium solidification, otherwise non-equilibrium solidifications where somewhat higher solidification is, higher cooling rate is experienced by the molten metal during the solidification.

(Refer Slide Time: 05:15)

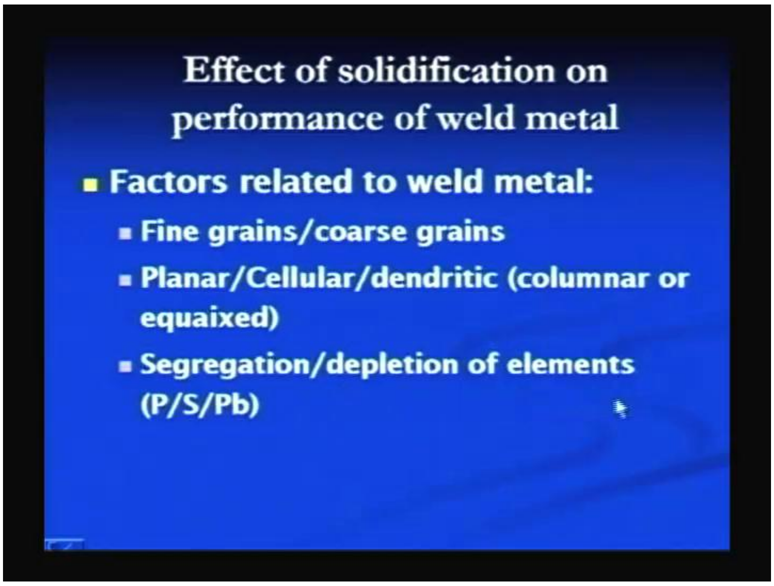


Solidification in the weld metal is somewhat different from which takes place in case of the conventional metal solidification in castings. In case of the weld metals, if the composition of the filler metal is same as that of the base metal, then solidification does not take place in the two stages, but only the growth stage of the solidification is observed and under these conditions, no nucleation is required for solidification to take place.

And solidification is completed in one stage only, that is, the growth of the partially melted grain. And this type of solidification is known as epitaxial solidification where, and this kind of solidification takes place in the weld metal when the filler metal composition being used to fill the groove between the plates is same as that of the base metal. Under such conditions, partially melted grains of the base metal act as a nucleant and they directly start to grow and during the solidification, to complete the solidification sequence.

And if the filler metal is totally different from the base metal composition, then the solidification takes place in two stages and that is the nucleation and the growth. This is what happens in the conventional casting conditions or under the foundry conditions. The most of the metals solidify in two stages, that is, nucleation and growth. And when the weld metal solidifies depending upon the cooling conditions and the composition of the base metal, the different kinds of structures are formed and those structures affect the performance of the weld metal, performance of the weld metal, particularly in terms of the mechanical properties, which will be intended from the weld joint.

(Refer Slide Time: 07:21)



So, depending upon the cooling conditions and the composition of the weld metal, the grain structure of the weld metal can be fine or coarse. Fine structure is always required for better mechanical properties. And fine structure is formed only when the cooling rates are high or few grain refiners are there in the weld metal composition.

And the grain structure can be of planar types, cellular type, dendritic type. Dendritic is, grains can be columnar or equaixed type. For the best mechanical properties the columnar or equaixed dendritic structure is preferred and it is formed when cooling rates are quite high. In next slides we will see, that under what conditions, columnar or equaixed dendritic structures are formed.

Segregation is another aspect, which significantly affects the performance of the joint produced by welding. If some of the alloying elements tend to segregate in, in very localized manner, either at weld center line or near the fusion boundary, then they adversely affect the mechanical performance or they increase the tendency for cracking or weaken them the weld joint.

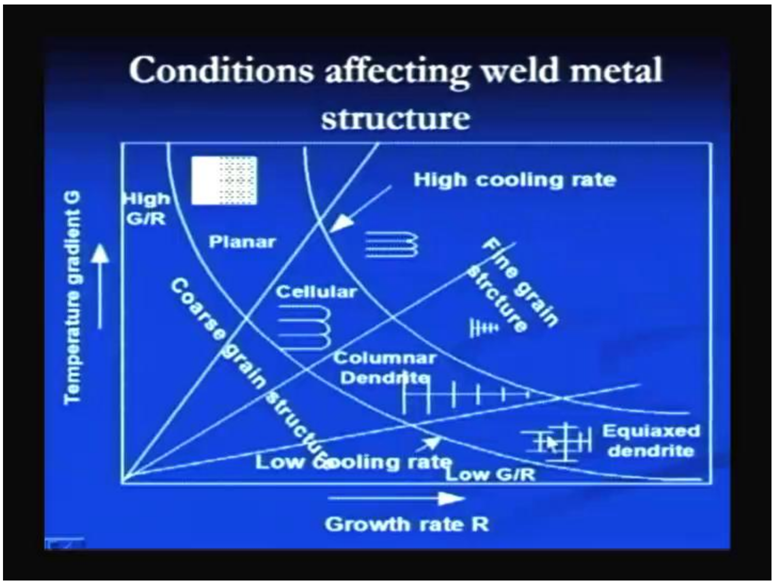
Like segregation of the low melting point elements or the compounds, which are formed by them, leads to deteriorate the mechanical performance of the weld metal and under these conditions, like segregation of the phosphorus, sulphur or lead in steels increase the tendency of hot cracking and which will deteriorate the mechanical properties of the weld joint, particularly notch toughness and the ductility and tensile strength.

Depletion of the certain alloying elements also deteriorates the performance of the weld joint, like during the welding of the stainless steel, depletion of the chromium from the grain boundary degrades its corrosion resistance. So, the localized presence of certain elements or depletion of elements adversely affects the performance of the weld joint in number of ways.

So, for the better performance of the joint the grain structure should be fine and it should be of the equaixed dendritic type. And the alloying elements present in the weld metal must be homogenous. There should not be any segregation or the depletion of the elements.

Under the different conditions are encountered during the welding depending upon the kind of base metal, which is being welded; the groove geometry, which is being used; shielding gases, which are being used; and the welding parameters, which have been selected. And finally, we have to say, that what are the cooling conditions being experienced by or the cooling rate being experienced by the molten metal during this solidification.

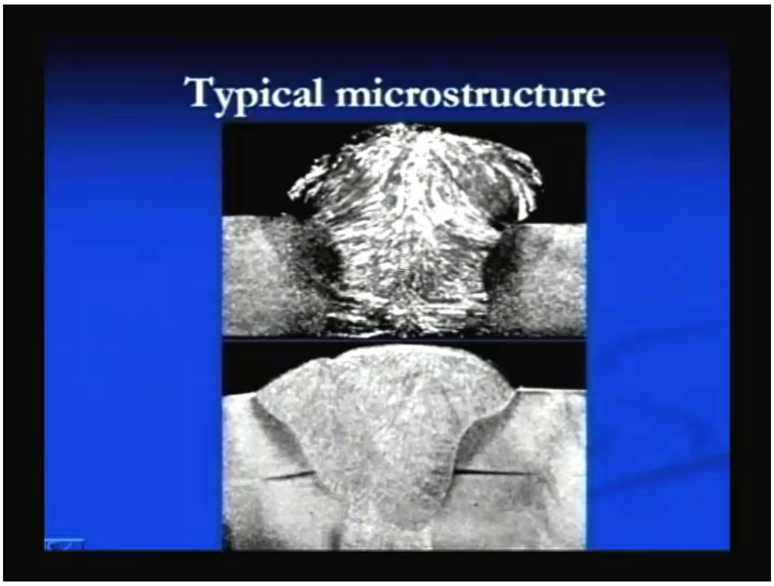
(Refer Slide Time: 10:38)



If the cooling conditions are high, cooling rate is high, then normally, we get the fine, fine structures. Like here, we can see, this line is corresponding to the high cooling rate and this line is corresponding to the low cooling rate and if the cooling rate is low, we get a coarse cellular structure and fine cellular structure, coarse planar structure, fine planar structure. Here, coarse columnar dendritic structure, fine columnar dendritic structure and here, coarse equaixed dendritic structure and fine dendritic structure.

So, depending upon the cooling rates being experienced by the molten metal during the solidification, their structure can be fine or coarse. And accordingly, also its morphologies or its, the shape of the grain is affected.

(Refer Slide Time: 11:24)

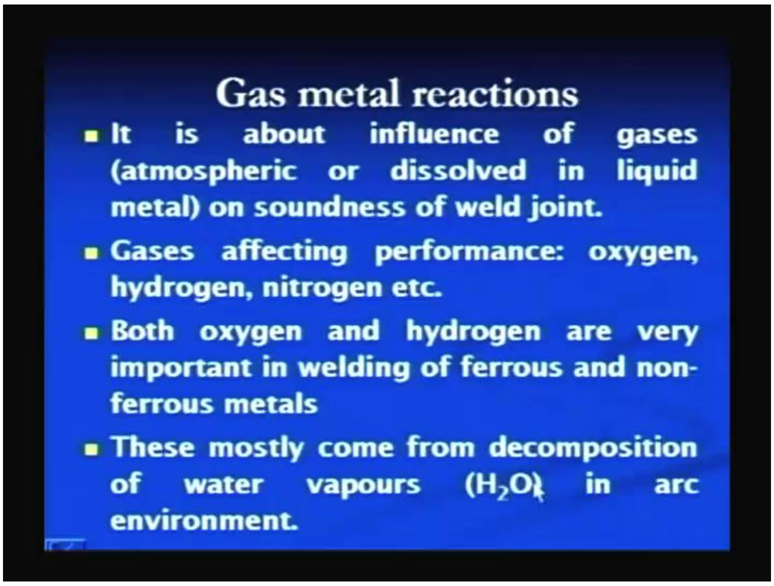


If we see here this typical weld metal, the micro structure of the grain in weld metal, we can see columnar grains, very coarse columnar grains in the weld metal. And the grains are very coarse near the top of the weld ((Refer Time: 11:38)), where cooling rates may be very low and here, at the center, equaixed fine grain structure can be seen.

And if we compare this structure with the another weld metal, which have been, which was produced using the parameters, which can supply only low heat input, that has produced very fine grain structure, and these columnar grain structures could not be observed.

Here, mainly fine grains we can see here and this change, this variation in grain structure significantly affects the performance of the weld metal. In general, fine grain structure like this improves the mechanical performance of the weld joint compared to the coarse columnar grainy structures.

(Refer Slide Time: 12:28)



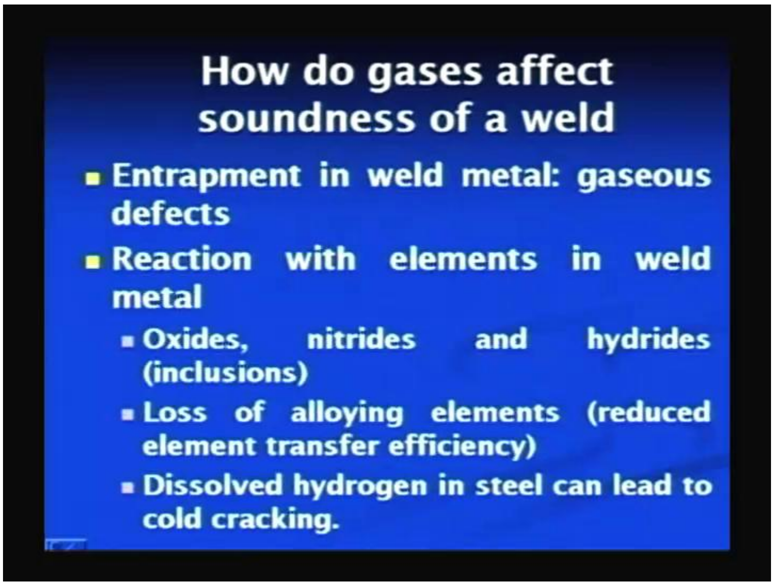
As I have said, that in the arc environment, the weld metal during this solidification is subjected to the various reactions. These reactions can take place between the gases, which are present in the arc environment or with the molten metal and with the molten metals. So, reactions between the gases and the metal lead to different kinds of the defects. And these gas metal reactions is about the influence of the gases, which may come either from the atmosphere or these gases may be dissolved in the metal itself and these reactions affect the soundness of weldment.

And there are number of gases, which affect the sound of weldment and out of these, many gases, the oxygen, hydrogen and nitrogen are known to deteriorate the performance of the weld joints significantly because the oxygen forms the oxides, hydrogen forms the hydride, hydrides, and nitrides are formed by the nitrogen. And presence of these oxides, hydrides and nitrides in the weld metal deteriorates in the mechanical performance. Because these particles, which are formed of oxides, hydrides, nitrides acts as an inclusion and thereby, weaken the weld metal and deteriorate the mechanical performance of the weld joint, particularly oxygen and hydrogen are considered very harmful for both ferrous and nonferrous metal because of high affinity of these metals to the oxygen and hydrogen.

And the hydrogen plays very significant role in, in affecting the performance of the weld metal of, of the ferrous and nonferrous metals because, particularly in iron, aluminum and magnesium, the solubility of the hydrogen is significantly high in the molten state compared to that in solid state. And because of this high difference in the solubility of the hydrogen in the liquid and solid states, it increases the tendency of the hydrogen induced porosity and in the steels, particularly the presence of hydrogen, increases the chances of the cold cracking.

And from where these hydrogen and oxygen, nitrogen come in the arc environment and with the weld metal? There are various sources, but for the hydrogen and oxygen, particularly the moisture, which is coming from the electrode coatings or moisture from in the atmospheric air, if that enters in the arc region, that moisture it decomposes into the hydrogen and oxygen and because of the good reactivity and solubility in the molten metal of these gases, these gases react with the metal to form their oxides, hydrides or get dissolved in the molten metal itself.

(Refer Slide Time: 15:50)



And what happens when these gases dissolve in the molten metal? These, these gases may come from either atmosphere or from the decomposition of the impurities present at the surface of the base metal or these may be are already there in the dissolved condition in the solid state in the base metal itself.

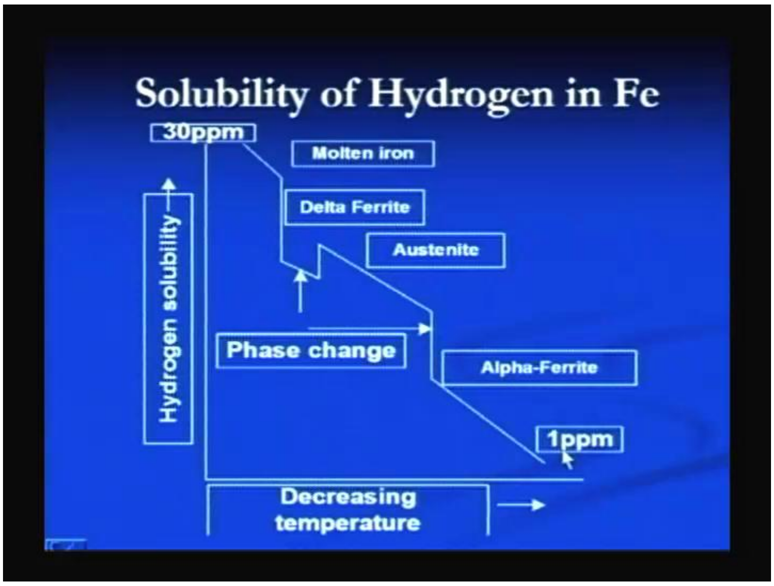
And when these gases, if these gases are present in, in the weld metal and normally, because of the high cooling rates encountered by the weld metal, these gases are unable to come out of the weld pool during the solidification. And that is why, these are get entrapped in the weld metal and which in turn, leads to the gaseous defects.

These gaseous defects may be in form of porosity, blow holes and sometimes these gases react with the weld metal itself to form their oxides, nitrides and hydrides. And when these oxides, nitrides and hydrides are formed, these may be present in the weld metal itself as inclusions. And when these gases react with the elements present in the weld metal, sometimes loss of the elements also takes place. And the localized loss of the alloying elements from the weld metal also degrades the mechanical performance of the joint.

On the other hand, the same also can be termed as, that it reduces the element transfer efficiency because presence of these gases sometimes react with the elements in very localized manner and lead to their loss from the weld zone. And therefore, the element transfer efficiency from the electrode to the weld metal sometimes decreases in presence of these gases.

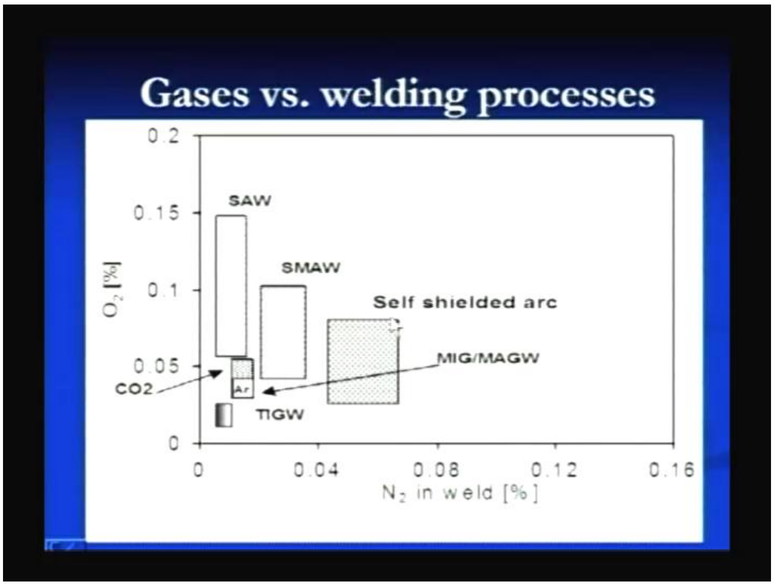
Presence of the hydrogen in the steel also creates the major problem and that is known as the cold cracking. Cold cracking takes place of the steel weld joints if it is present in the large amount, if the hydrogen is present in the large amount, and this cold cracking is also known as delayed cracking or hydrogen induced cracking. This cracking can takes place even when there is no external load or no external tensile force acting on the weld joint, that is why, it is very harmful. The solubility of the hydrogen in the iron is different as I have said, that the hydrogen is more harmful for the iron and the aluminum kind of metals because the solubility of the hydrogen in the liquid state and solid state is significantly different.

(Refer Slide Time: 18:56)



From here we can see, that with the decrease in temperature, right from the molten metal, say 1540 degree centigrade, how the solubility of the hydrogen in iron decreases. We can see, at above the melting temperature, say 1540 degree centigrade, the solubility of the hydrogen is 30 ppm. And when temperature comes down to the room temperature, means at the room temperature this solubility is about 1 ppm. So, the solubility decreases rapidly. But if the hydrogen dissolved in the weld metal of the iron or the steel, then, and if it is not able to come out of the molten metal, then it can lead to the hydrogen induced cracking or the hydrogen induced porosity. So, this diagram simply explains, that how the reduction in solubility of the hydrogen in iron takes place with the reduction in temperature.

(Refer Slide Time: 19:58)



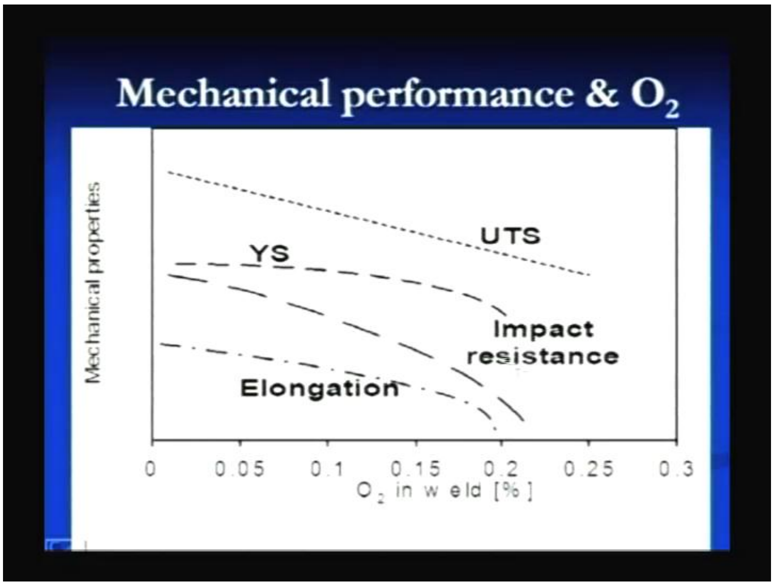
The different gases formed or, or presence of the different gases in the weldment to a great extent depends on the process, which has been used for producing the weld joint because, because their shielding effectiveness to shield the atmospheric gases or protection effectiveness for the atmospheric protection is different for the different processes. And that is why, the amount of the gases, like oxygen and nitrogen, which can be there in the weld metal, produced by the different gases can be different.

And if we see here, the tungsten inert gas welding process produces the weld joints, which has the minimum level of the hydrogen and that of nitrogen also. And then, if we see, that the metal inert gas welding process or gas metal arc welding process. If we use argon, then it is, it has somewhat higher level oxygen and somewhat higher level of the nitrogen. If we use C O 2, it will have further higher level of oxygen and nitrogen level will remain largely same.

And if we use the submerged arc welding and that there will not be major increase in the nitrogen percentage in the weld metal, but oxygen percentage in the weld metal increases significantly. If we go for shielded metal arc welding process, so we get somewhat greater percentage of oxygen in the weld metal and somewhat more percentage of the nitrogen in the weld metal. And self shielded arc produced further large quantity of the, means in the weld metals produced by self shielded arc welding processes we get the larger quantity of the oxygen and, and that of the nitrogen. However, oxygen percentage is maximum, here we can see, in, in, in the weld joints produced by the submerged arc welding processes. And, and the nitrogen percentage is maximum in this shielded, self shielded arc welding processes.

So, depending upon the welding process, which has been used, we may get the different percentage of the oxygen and nitrogen in the weldments. And according to the presence of these gases in the weld metal, these are going to affect the performance of the weld joint. We will see in the next few slides, how the presence of the oxygen and nitrogen affect the mechanical performance of the weld joint and the porosity formation.

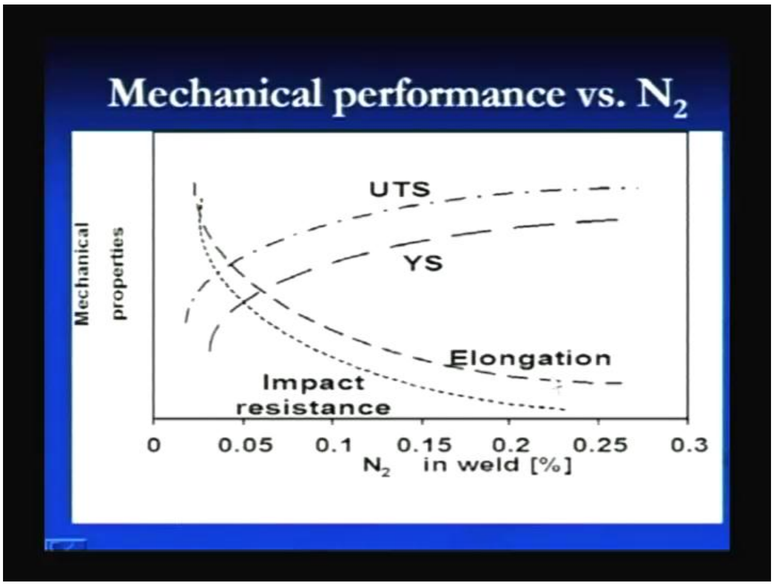
(Refer Slide Time: 22:52)



Here, this relation shows, that with the increase in percentage of the oxygen in the weld metal, most of the mechanical properties, like ultimate tensile strength, yield strength, impact resistance and elongation, all mechanical properties decreases with the increase in hydrogen percentage.

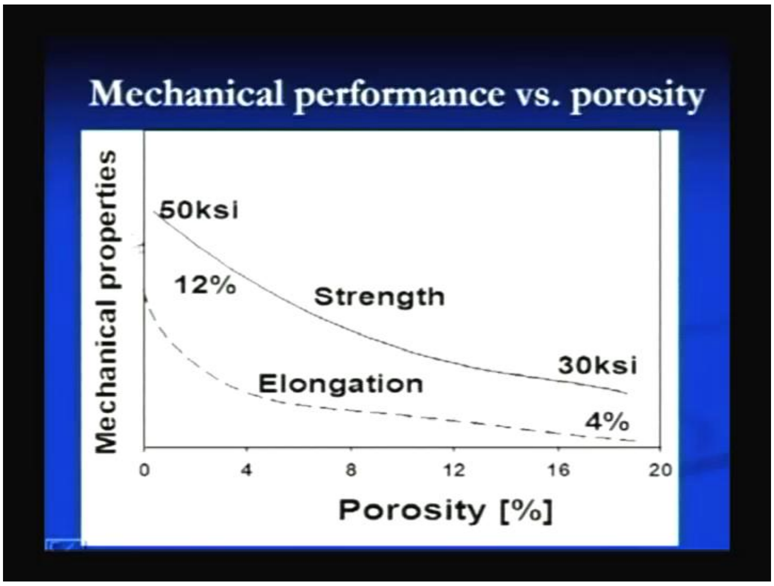
And this decrease is attributed to the formation of the oxides and which may be present there as inclusions, which these inclusions act as the site of the, as the site of the crack nucleation or site of the weak areas, and because of that the mechanical performance of the joint decreases.

(Refer Slide Time: 23:37)



And if we say, here the effect of the nitrogen percentage on the weld metal, mechanical performance of the weld metal, then we, we can see here, the ultimate tensile strength and yield strength increases while the elongation and impact resistance decreases. And this is attributed to the formation of the nitrites of the iron, which can increase the strength of the weld joint, but at the cost of the elongation and the impact resistance.

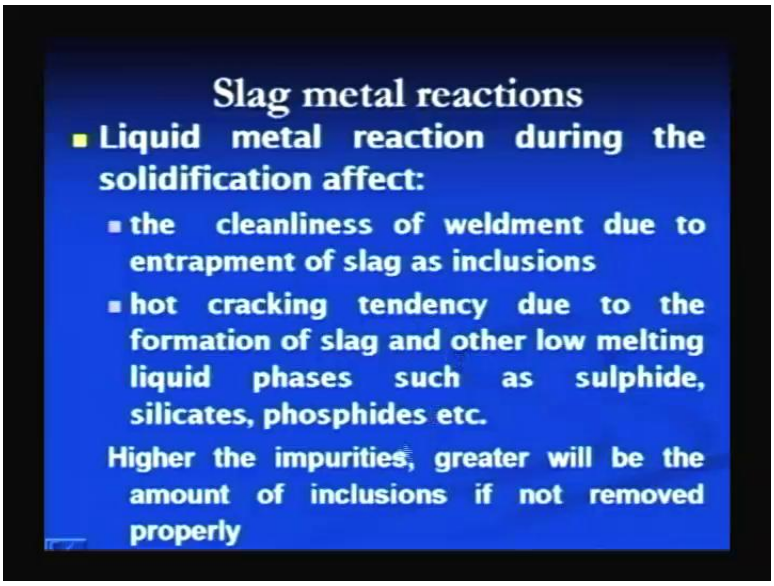
(Refer Slide Time: 24:12)



And if the large quantity of the gases like oxygen, nitrogen and hydrogen is present in the weld metal, then it lead to increase, it leads to increase the porosity in the weld metal.

And increase in porosity weakens the weld joint and therefore, it adversely affects the mechanical performance of the weld joint. If we see the relationship between the mechanical properties and the positive percentage and the strength and elongation, both decreases with the increase in percentage of the porosity.

(Refer Slide Time: 24:48)



Here, another important reaction, which take, takes place in the weld metal is the slag metal reaction or the liquid metal reaction. In, in this reaction, in the, in the reaction, basically the, because of this reaction two kinds of the effects are noticed in the weld metal. One is the, one is, that the presence of the impurities or the cleanliness of the weld metal and another effect of the slag, the liquid metal reaction is the formation of the hot tears or hot cracks.

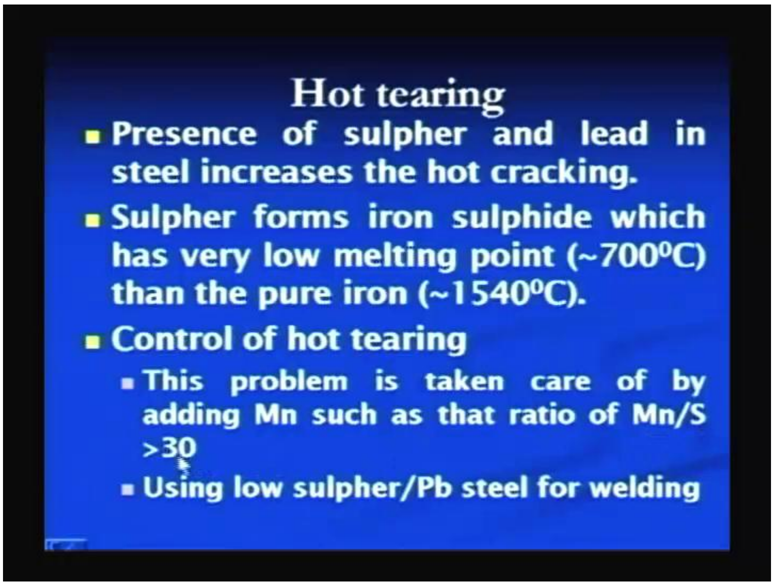
So, here if we see, that the liquid metal reaction, which take place during the solidification affects the cleanliness of the weldment due to the presence of the inclusions because if the impurities are present in, in in the weld, molten weld, molten weld metal and then, these impurities react with the flux to form slag.

Slag becomes light. So, that is why, it can float and come and it can float on the surface of the molten metal. And, but all the slag may not be able to come out of the molten metal and can float on the surface of the molten metal. And that is why, if even if a small amount of the slag is left with the weld metal that will be present as inclusion. And greater the amount of impurities present on the surface of, in the weld metal and greater will be the amount of slag, which will be formed and accordingly, greater will be the chances for having the inclusions in the weld metal. And therefore, cleanliness of the weld metal will be adversely affected accordingly.

So, another effect of the slag metal reaction is the hot cracking tendency. And due to the hot cracking tendency, this hot cracking tendency is noticed particularly due to the presence of the low melting point elements in the weld metal. If in, in the weld metal large quantity of the sulphur or the phosphorus or the lead is present, then the presence of this low melting point elements form the low melting point compounds, like iron sulphide, and which reduces the hot strength of the metal or the tensile strength of the metal at elevated temperature. And which in turn, encourages the hot cracking or hot tearing tendency of the weld joint.

So, hot cracking tendency is normally attributed to the formation of the low melting point phases such as sulphides, silicates and phosphides in the weld metal. And higher the impurities present in the weld metal, greater will be the amount of inclusions and greater will be the chances for the related defect formation

(Refer Slide Time: 28:11)

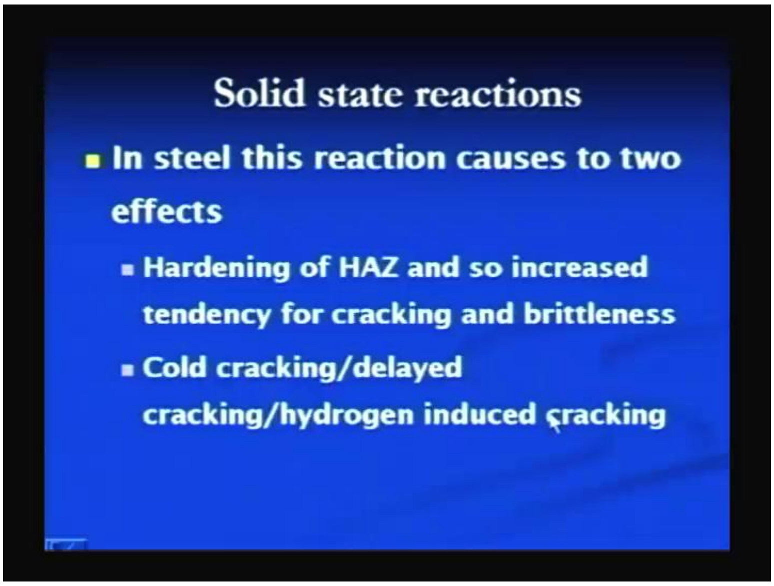


If we see, hot tearing in the presence of the sulphur and lead in the steel increases the hard cracking tendency because sulphur forms iron sulphide, which has very low melting point and the low melting point phases present in, in between the iron grain boundaries or in the inter dendritic areas. Under those conditions when tensile residual stresses develop during the solidification, the low melting point phase, presence of the low melting point phases lead to the formation of the cracks during the solidification itself.

And since these cracks are formed when the metal is red hot, that is why these are also called hot tears or hot cracks. And in order to control these hot tears, the two techniques can be used. One is, that the controlled alloying of the specific elements, like manganese in steel is added. Manganese is added in controlled manner, so that the manganese to sulphur ratio is greater than 30.

When manganese is added in, in, in the weld metal of the steel weld joints or the ferrous weld joints, then the manganese forms the manganese sulphide, which has higher melting point than the iron sulphide. And manganese sulphide is formed because it has greater affinity to the sulphur compared to that of iron. So, the formation of, helps to reduce the problem related to the hot cracking and another way is to avoid the presence of the sulphur or the lead or any other low melting point phase or element in, in the steel, which is to be welded.

(Refer Slide Time: 30:49)



Solid state reaction is related to the two effects and when these reactions takes place, these reactions normally takes place after the welding and during the cooling of the weld joint, after the solidification of the weld metal when it is being cooled from the solidus temperature to the room temperature. And because cooling rates are high, sometimes during the cooling at high cooling rates and hardening steels tend to harden the heat affected zone significantly and which in turn, increases the cracking tendency and makes the joint very brittle. So, the one effect of the solid state reactions in a steel is, that hardening of the heat affected zone and in, in the weld metal, which makes it more prone to the cracking and makes it brittle. And so, the ability to take up the soft load of the weld joint decreases.

Another effect of the solid state reactions in the steel is the cold cracking or the delayed cracking. This cold cracking takes place because it occurs at, cold cracking is termed as cold cracking because this type of cracking takes place at room temperature. And it takes some time after production of the weld joints that is why, it is also known as delayed cracking.

And the reason for this type of cracking is the hydrogen. Hydrogen is mainly attributed for this type of cracking to occur or to take place and that is why, it is also known as hydrogen induced cracking. So, cold cracking, delayed cracking and hydrogen induced cracking, all these three are the different names for the same type of the cracking, which is normally observed in the steel weld joints, and it occurs because of the presence of hydrogen in the steel in the weld metal or in the heat affected zone.

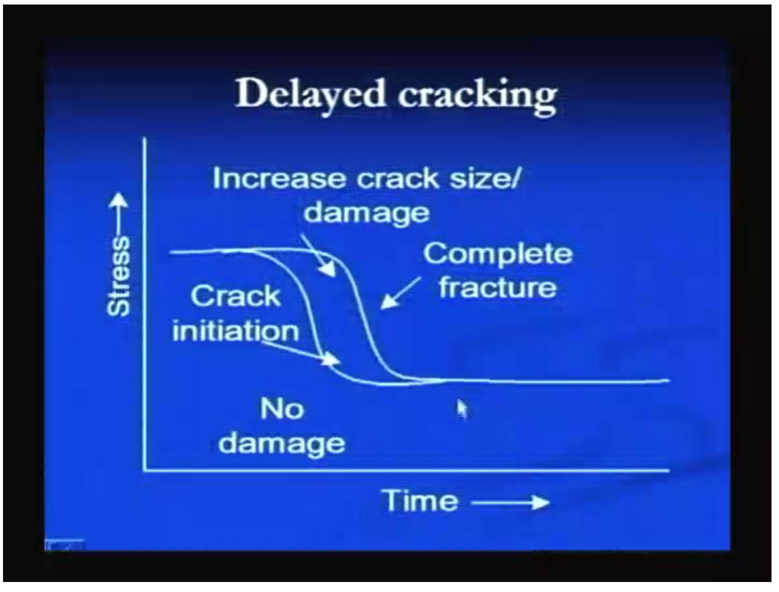
(Refer Slide Time: 32:12)

Cold cracking is caused by the, by the presence of the hydrogen and it occurs only when the tensile residual stresses developed during the welding or after the cooling of the weld joint to the room temperature or some external tensile stresses act on the weld joint. So, the presence of the tensile stresses and the presence of the hydrogen are the two most important things, which has to be there for cold cracking to take place.

And this cold cracking is further encouraged by the weld joint mechanical properties such as, if the weld joint is very hard and brittle, then the cold cracking tendency will be more compared to the case when it is of low yield strength and low hardness.

So, if we see the factors, which are causing to the cold cracking, then it is the presence of the hydrogen in a steel, which may be either from, may be there in weld metal or in heat affected zone. The presence of the tensile residual stresses is necessary for cracking to takes place. And if the weld metal or heat affected zone is of high hardness and the brittleness, then cracking will be encouraged. And this high hardness and brittleness normally developed due to martensitic transformation in heat affected zone. And, and this kind of transformation takes place because of the high cooling rate experienced by the steel in the heat affected zone during the welding.

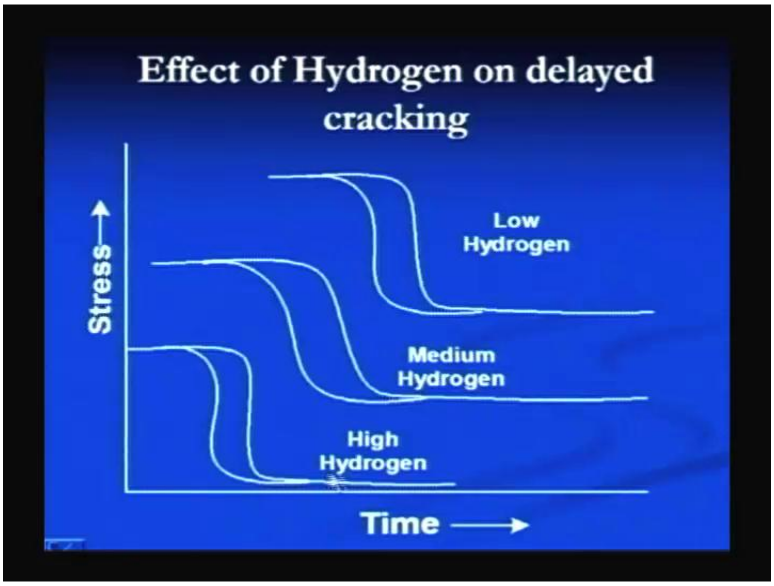
(Refer Slide Time: 34:44)



And if we see schematically, under the different level of the stresses it takes different times to nucleate and grow, growth of the crack to cause the complete fracture. X-axis shows the time and y-axis the stress level. The stress level is below this one, then there would not be any failure by the delayed cracking. But if the stress level is higher than this one, then after this much period is same. At this level of stress, after this much period, cracks will nucleate and then, they will propagate. And after this propagation will complete and complete fracture will occur. So, we can say, this will be the time after which failure of the weld joint due to the hydrogen induced cracking will take place.

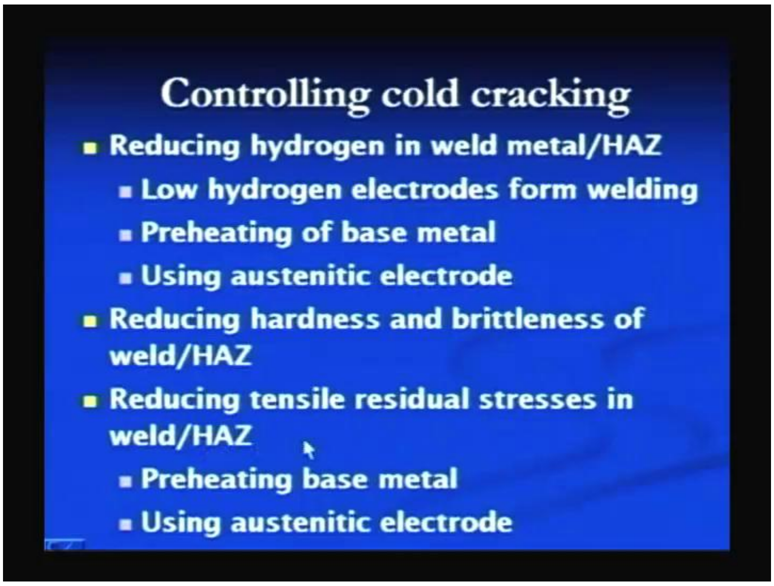
So, the location of these lines, like nucleation or the initiation of crack and the time required to come to have the complete fracture by the delayed cracking depends upon the kind of the stresses, which are being used, say higher the level of stress, lesser will be the time required to cause complete fracture. In the same way, higher will be the hydrogen level present in the weld metal, lesser the time it will take to cause the complete fracture.

(Refer Slide Time: 35:53)



So, effect of hydrogen on delayed cracking can be seen from here. This diagram, that for the low level of the hydrogen at a given level of the stress, time required to cause complete fracture, decreases the, increases the low level of hydrogen. This will be the time required to cause complete fracture, somewhat higher level of the hydrogen. This will be the time required to cause complete fracture and the time requirement to cause complete fracture decreases with the increase in the hydrogen percentage, and it also decreases the stress level, which is required to cause the fracture by the delayed cracking.

(Refer Slide Time: 36:30)



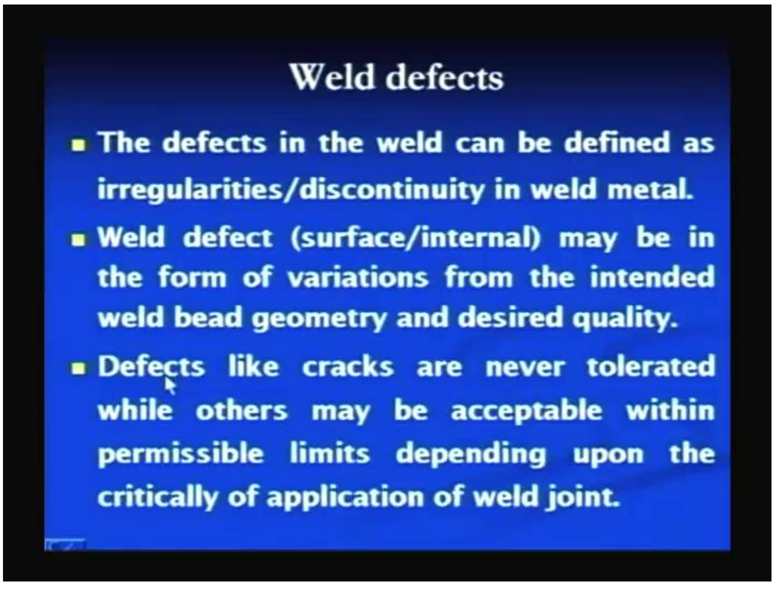
In order to control the delayed cracking we have to see, that the presence of hydrogen from the weldment is avoided or the development of the residual tensile stresses is reduced or the joint is made soft and of the low yield strength. And for this purpose, normally these three techniques are used.

The low hydrogen electrodes are used to produce the weld joints, so that the presence of hydrogen in the weld joint can be reduced. Preheating helps to soften the weld joint and also, reduces the percentage or the presence of the hydrogen in the weld metal. And the use of the austenitic electrode also produces the austenitic weld joint, which is tough and has the more ability to accommodate the larger percentage of the hydrogen without causing cold cracking.

And if we see, for reducing the hydrogen and reducing the hardness and the brittleness of the weld metal and for reducing the tensile residual stresses in the weld metal and heat affected zone, both these, metals will be, methods will be effective. Preheating of the base metal will reduce the hardness and the brittleness of the weld, weld joint and the heat affected zone. Use of austenitic tensile steel electrodes also help to reduce the tensile residual stresses and thereby, tend to reduce the hydrogen induced cracking chances.

The weld defects, as you have seen, that the three different reactions, which takes place in the weld region, like gas metal reactions, slag metal reactions and the solid state reactions, the number of the defects are caused by these three reactions. In addition to these, the defects or the problems in the weld joint, some other defects are also formed in weld joints and those defects we will see in, in, in detail one by one and how those can be removed during the welding.

(Refer Slide Time: 39:00)



If we see, that the defects in the weld metal can be defined as a regularity or discontinuity in the weld metal. Something, which is unwanted, which is not desirable, which is not intended, if that is present, is termed as discontinuity or irregularity in, in the weld metal and that is considered as a defect.

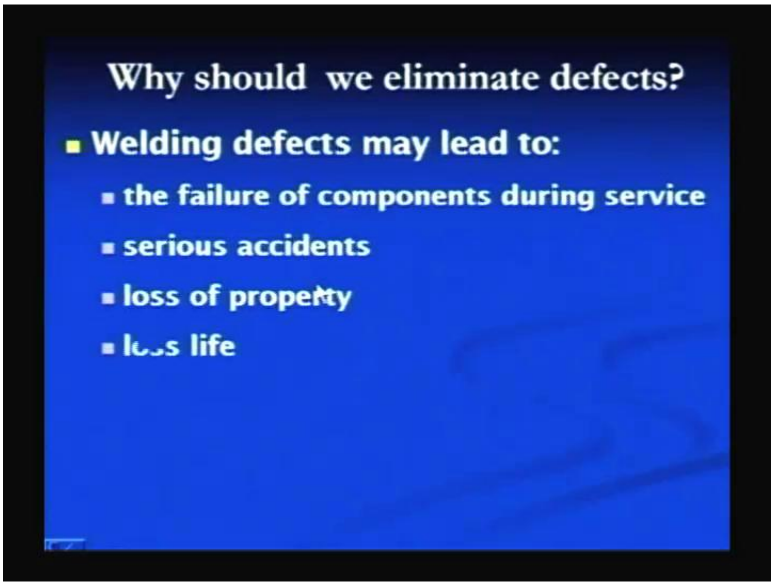
This weld defect may be in, of the different forms, like the shape of the weld bead is not desirable or the metal of the base metal has not melted properly. So, depending upon the location of these defects, these defects may be present at the surface or may be present in the inside portion of the weld metal.

So, accordingly is, that there may be surface defects or internal defects and these defects are the variations from the intended, the characteristics required in the weld bead, like the intended, the weld geometry or the desired quality in terms of mechanical or metallurgical characteristics or the presence of some undesirable features in the weld joint.

The defects, some of the defects can be tolerated because they may not affect the performance of the weld joint significantly for a given application, but some of the defects cannot be tolerated. And like the cracks of the large size particularly, are not tolerated, but if the applications are very critical, then the defects, the weld joints having the cracks like defects are simply rejected. And some other types of the defects within the permissible limits are also are accepted, provided the applications are not very critical.

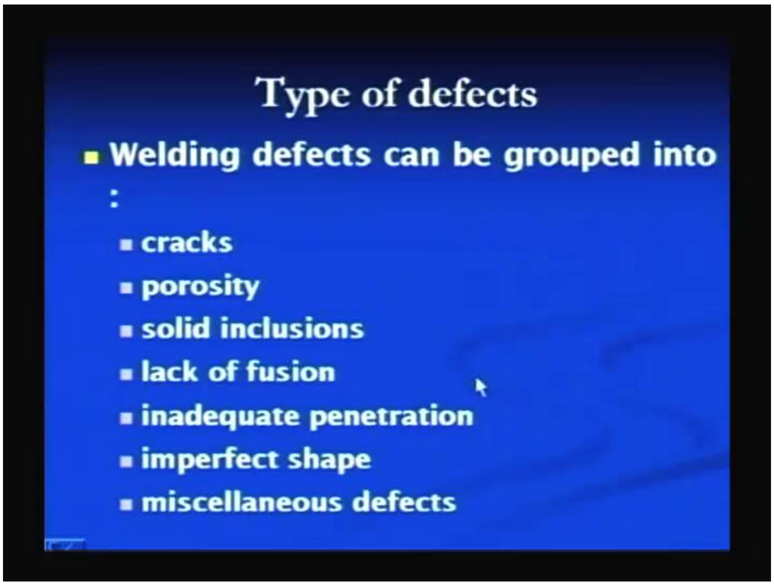
So, depending upon the criticality of the application of the weld joint, the defects may be, defects within the limits in size may be accepted or may not be accepted. So, the acceptance of the defects in the weld joint largely depends on the criticality of the application where weld joint is to be used.

(Refer Slide Time: 41:36)



Defects may lead to, if the defects are present in the weld joints, then these reduce the reliability of the joints significantly and sometimes it lead to the failure of the component during the surface. And when this failure takes place, it can cause the serious accidents, great loss of the property and loss of life. And that is why, the efforts are made to avoid these defects.

(Refer Slide Time: 41:43)

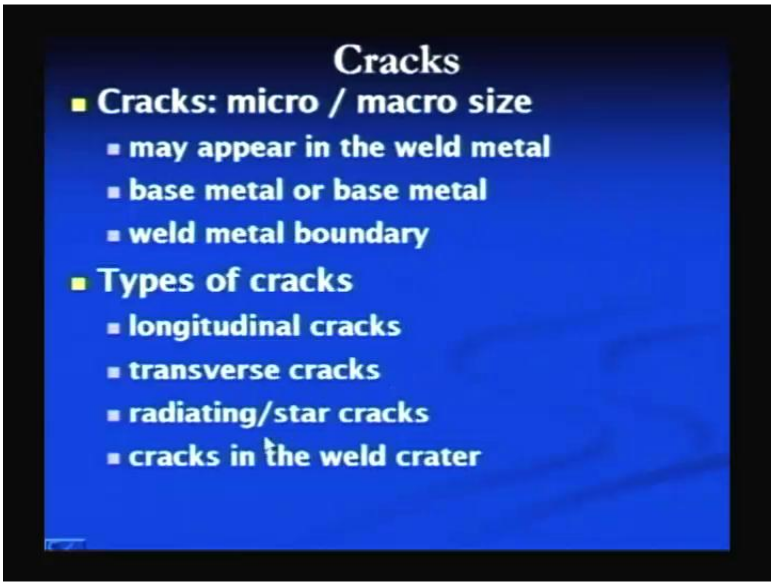


And if we classify, then the defects can be grouped into these major categories, like cracks, porosities, the solid inclusions, lack of fusion, inadequate penetration, imperfect shape, and some miscellaneous defects, like the marks formed due to the ((Refer Time: 43:08)) or the improper, the features generated in the weld bead. And the major causes in general, which are noticed for the formation of the defects in the weldments are, like incorrect. Weld parameter setting, like the welding speed, welding feed or the welding current, if has not been set, then it can lead to the number of defects.

The wrong welding procedure, like selection of the improper process, selection of the improper filler metal, selection of incorrect, the preheat or post heat treatment, all these can cause a number of problems in the weld joints or it can lead to the number of defects and the selection of the wrong filler metal for a given parent metal.

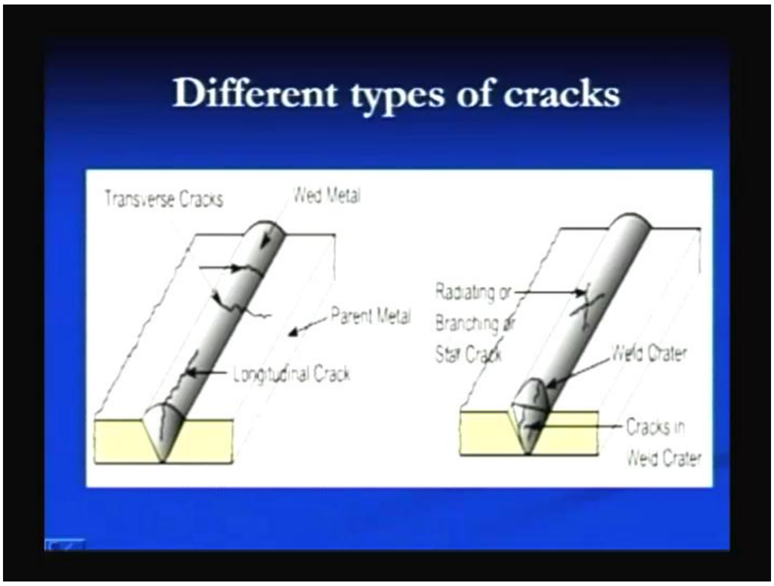
So, means, if the compatibility between the filler metal and the parent metal is not there, then it can lead to the different types of the cracking and the misfit between the two. The cracks can, cracks are commonly observed and these are more dangerous for the reliability of the weld joint and for the performance of the weld joint.

(Refer Slide Time: 42:27)



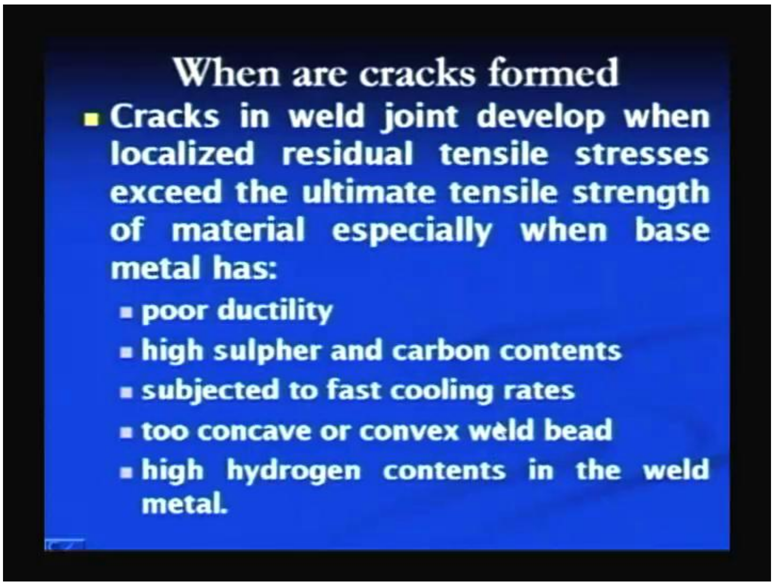
These cracks, depending upon the size can be of the macro or micro size. And these cracks may be present in the weld metal in the heat affected zone or in the weld fusion boundary along the fusion boundary. And these cracks, depending upon their orientation in the, in the weld bead or in the heat affected zone and their, their shape, these are classified as longitudinal cracks, transverse cracks, radiating or star like cracks and cracks in the weld crater.

(Refer Slide Time: 44:12)



In this diagram, we can see the different types of the cracks, which are normally observed. The cracks running along the weld center line is termed as the longitudinal crack and the crack, which is perpendicular to the weld centre line is termed as transverse crack. And here, these are the two cracks. Here, crack is also there in heat affected zone and here in the weld metal. And this another crack, transverse in the weld metal. And if we see here, star like cracks can be seen in the weld bead itself. And this is a crater, the crater area, the crack, which has taken place, the weld crater crack in the weld, crack, crater region.

(Refer Slide Time: 45:01)

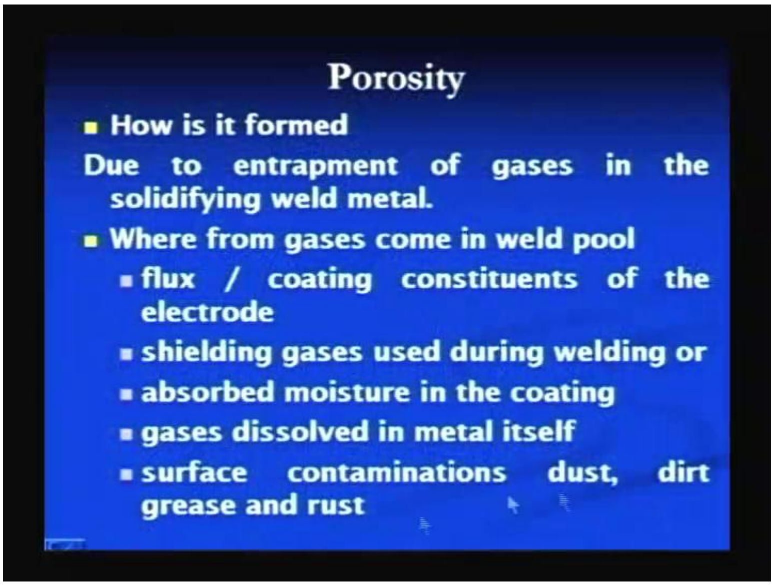


And these cracks are formed, particularly, when the tensile residual stresses developed in the weld metal and heat affected zone due to the shrinkage of the weld metal and non-uniform volumetric change during the welding in the weld metal and in the base metal and that leads to the cracks, particularly when these tensile residual stresses exceed the ultimate tensile strength of the material.

And these cracks are formed, particularly, when the ductility of the base metal is poor or the carbon content or the sulphur content in the ferrous metal is high, because these elements make the steel of the brittleness and more prone to the cracking or the weld joints subjected to the higher cooling rate and during the welding.

So, here, this also, high cooling rate increases the chances of martensitic transformation, which in turn increases the brittleness and decreases the ductility and makes the heat affected zone or weld metal more sensitive for cracking. The two concave or convex weld bead encourage the residual stresses, which promote cracking and high presence of the hydrogen in the weld metal also encourages cracking.

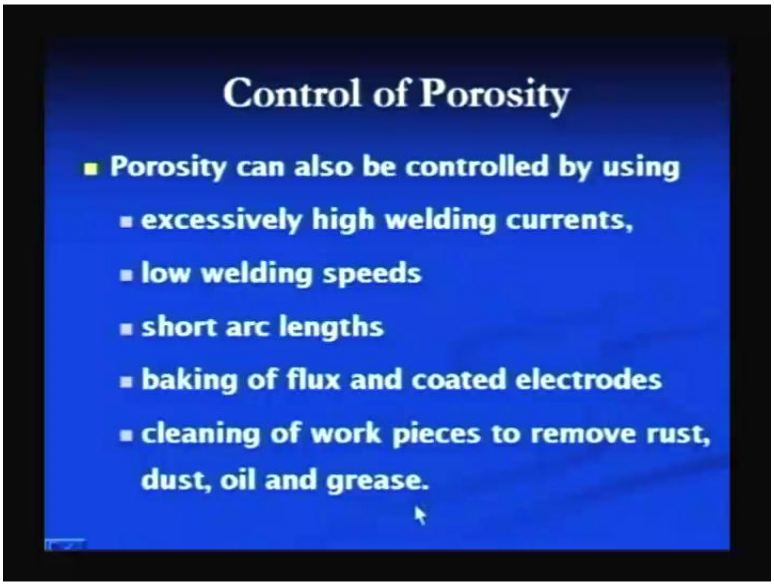
(Refer Slide Time: 46:31)



Porosity is the another defect, which is normally observed in the weld joints and it, it occurs mainly because of the entrapment of the gases in the weld region due to the high cooling rate experienced by molten metal during the solidification. And these gases may come from the decomposition of moisture, which is present in the coating or the flux of the electrode.

These gases may come from the impurities present in the shielding gases, which have been used during the welding or the decomposition of the moisture, which is present in the coating has been observed by the weld metal in the arc environment and the gases dissolved in the metal itself. If these gases are present and if they are not able to come out of the weld pool during the solidification, then these will get entrapped and will form different types of porosities. And the presence of surface contaminations, like dust, dirt, grease and rust also result in the gases in the arc environment at a high temperature and which also act as a source of the gases to the weld pool.

(Refer Slide Time: 48:06)

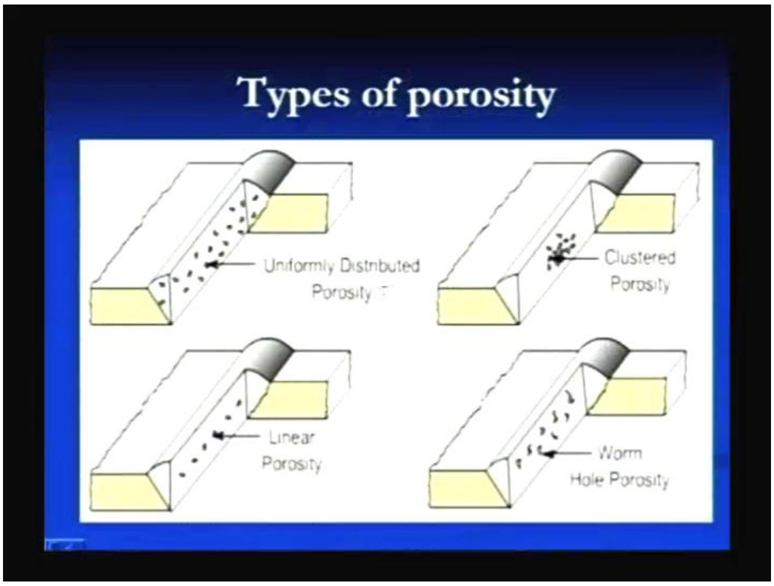


And when these porosities are formed, we need to control them in order to improve the performance of the weld joint and for that purpose we have to make sure, that cooling rate is slightly low, so that the solidification time is more and the gases get enough time to come out of weld pool during the solidification. And that can be done by using somewhat higher cooling, higher welding current, so that the heat input can be increased. And increased heat input lowers the solidification rate and increases the solidification time and therefore, gases get enough time for coming out of the weld pool.

The same effect also is obtained by reducing the welding speed, which increases the heat input and the lowers the cooling rate. The short arc length helps to reduce the sucking effect of the gases from the atmosphere and thereby, there help to control the porosity and to reduce the entry of the hydrogen and oxygen in form of moisture, which is coming from the fluxes and the coated electrodes.

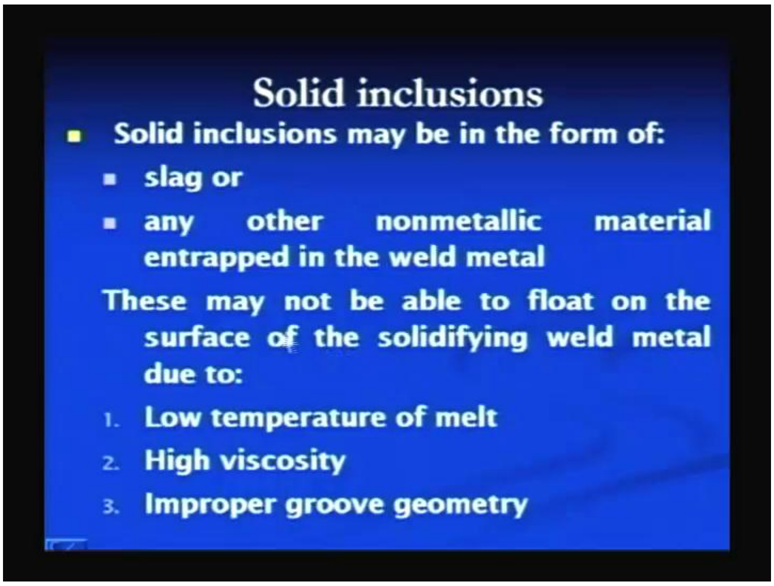
It is necessary that the fluxes and electrode, coat, coated electrodes are baked before using for the welding purpose. And this baking is normally done in the range of temperature 200 to 300 degree centigrade for 1 to 2 hours, depending upon the manufacture’s specifications. And the cleaning of the work piece is also important to remove rust, dust, oil and grease from the surface, which are also effective source of the gases to the weld pool.

(Refer Slide Time: 49:54)



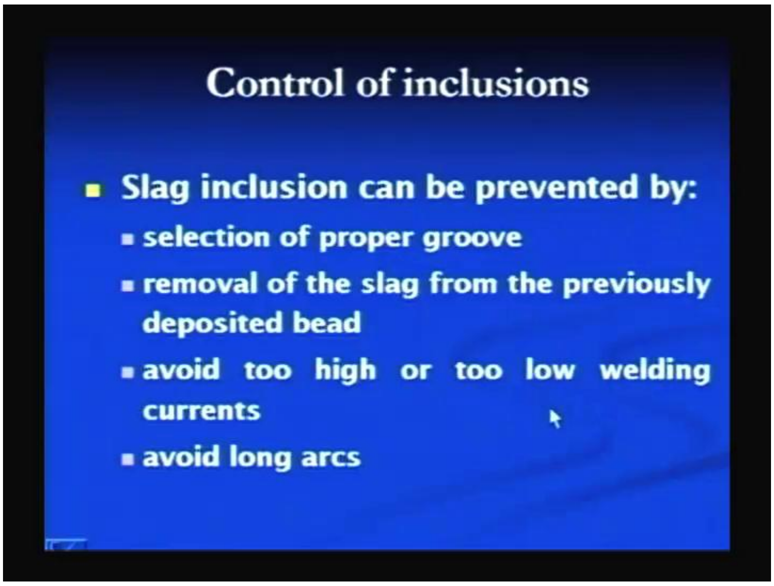
And if we see the different types of the porosity, which is normally observed depending upon the kind of the way by which porosity is distributed, these are categorized as uniformly distributed porosity when it is distributed largely uniformly or linear porosity along a particular line in the weld, weld bead, or worm shaped porosity, accordingly it is known as worm hole porosity or the segregated porosity where the number of pores had segregated in localized mirror in some portion of the weld bead. So, we can have uniform distributed porosity, clustered porosity, worm hole porosity or the linear porosity.

(Refer Slide Time: 50:31)



Inclusions are another type of the defects, which are formed, found in the well region and these inclusions may be there in form of slag or non-metallic materials entrapped in the weld region. And these entrapment, particularly, takes place because of their inability to come out of the weld pool and to get floating at the surface of the weld pool. And this happens, particularly, when the temperature of the molten metal is low, viscosity is high or the groove geometry is improper. Under these conditions the non-metallic materials are the slag, which may be there in the weld pool may not be able to come out and then, under these conditions it may get entrapped to form the solid inclusions in the weld metal.

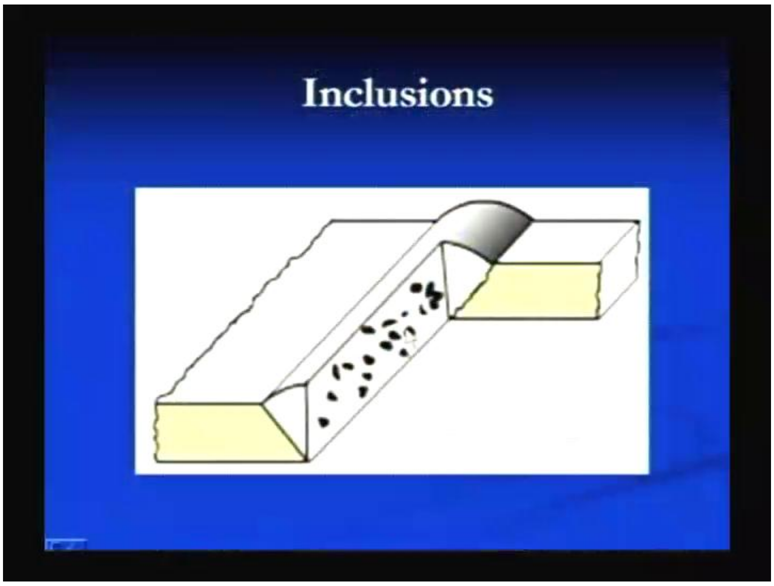
(Refer Slide Time: 51:35)



And to prevent these inclusions the groove geometry is selected properly, so that it is able to come out of the weld pool during the solidification and efforts should be made to remove the slag from the previously deposited weld bead. Otherwise, the slag already deposited in the weld bead can act as an inclusion.

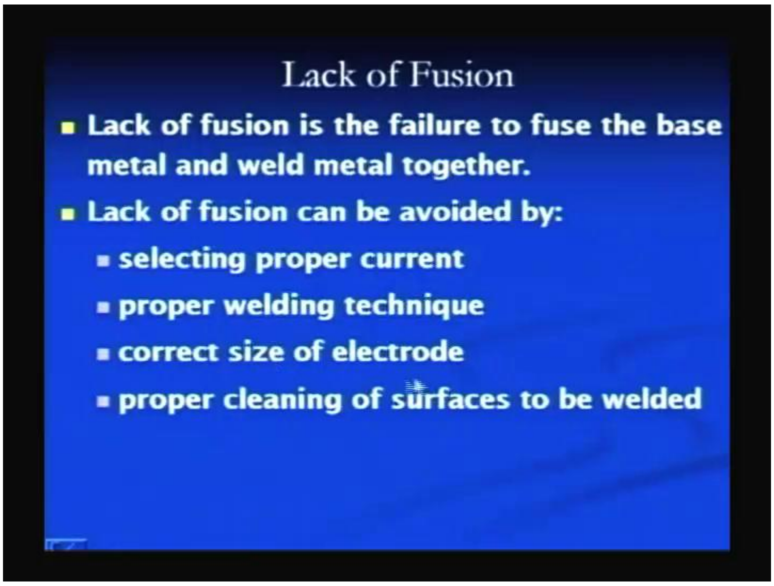
And we should avoid the use of too high or the too low welding current and the use of too long arcs also is to be avoided because in the, too long arcs help in the sucking of the gases in the arc environment and which leads to the formation of the non-metallic particles in the weld region, like oxides, nitrides and other hydrides. And therefore, to avoid the sucking of the gases the arc length should be reduced.

(Refer Slide Time: 52:31)



And we can see here, the inclusions distributed in the weld bead in the entire length of the weldment.

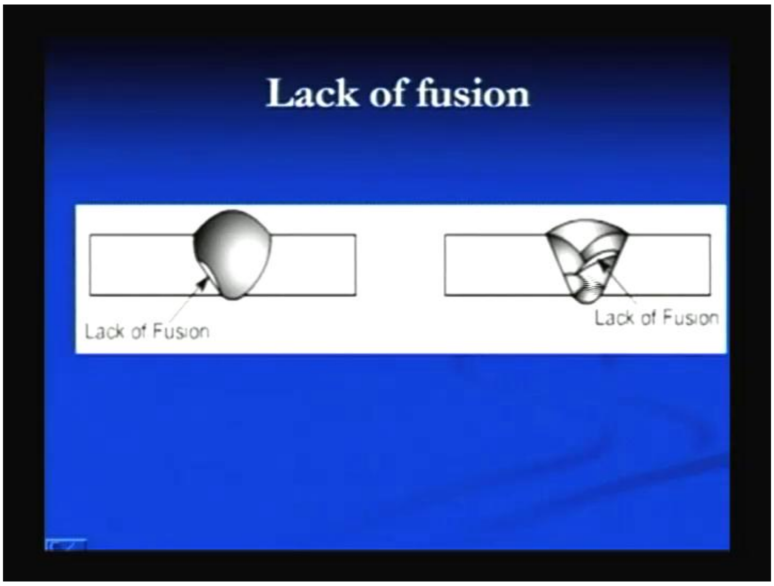
(Refer Slide Time: 52:37)



And the lack of fusion is another defect, which is noticed and it occurs when the base metal at the weld bead are not able to fuse together properly. And the origin for this kind of defect is the lack of the heat desired, heat input desired for producing the sound weld joint and the lack of fusion can be avoided by selecting proper current. So, the desired heat input can be given to the, given during the welding and proper technique is to be used, so that heat can be directed in the region where it is required.

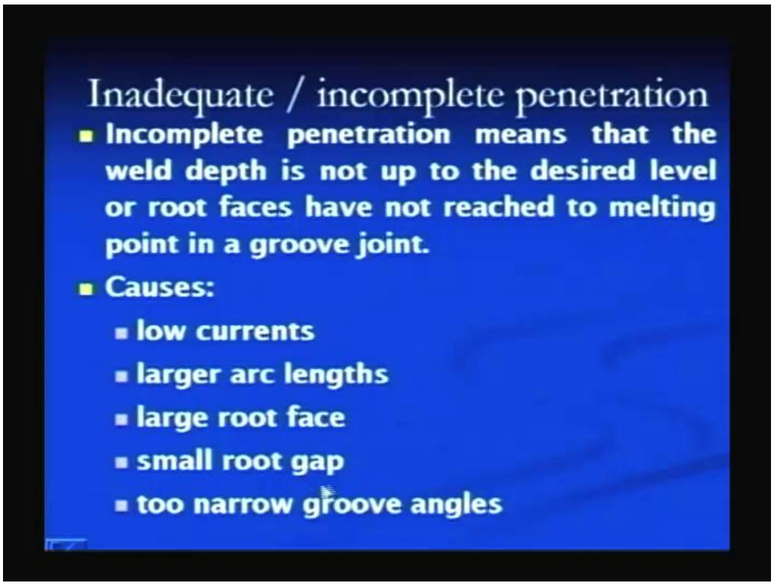
And the selection of the correct electrode size, if the thick plates are to be welded, then large heat input will be required for proper fusion and for that purpose we need to use higher current. And for higher currents we should go for the large size electrodes. So, selection of the optimum size electrodes is important for avoiding the lack of fusion and the surfaces are to be cleaned properly also, to have to avoid the lack of fusion.

(Refer Slide Time: 53:45)



We can see here, the fusion of the base metal has not taken place and that is why, the base metal and the weld metal have not fused together in this region. And the same can also take place in the multi pass welding where previously deposited weld bead has not melted in the next pass and that can lead to the lack of fusion defect.

(Refer Slide Time: 54:12)

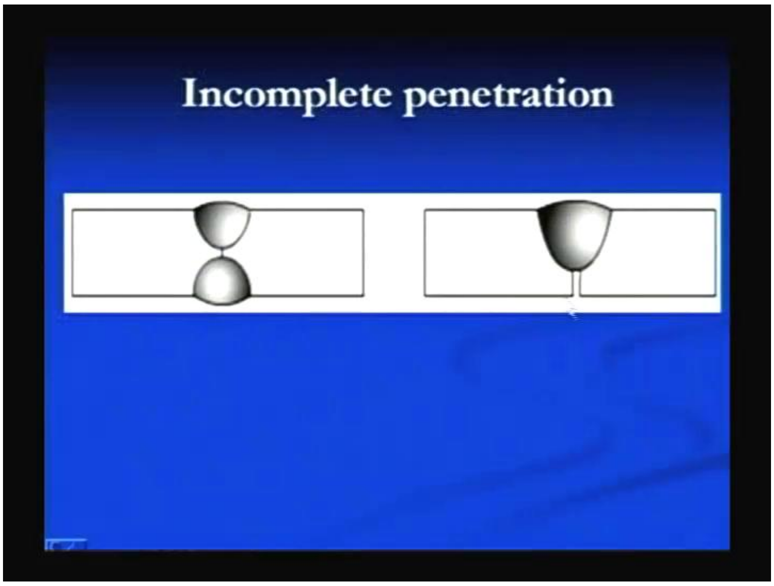


The incomplete penetration is the another defect, which is noticed particularly when the melting of the base metal is not up to the mark, which is required for producing the sound joint and then, it is termed as the incomplete penetration. It means, incomplete penetration means, that weld depth is not up to the desired level or the root phases have not been melted properly in the group joint.

And the main causes for the incomplete penetration, main cause for this is the lack of heat input, which is required for the welding. But the lack of heat input not means the improper heat input, may be due to the lower current setting than that is required. The longer arc lengths being used, the larger root phases there, a small root gap is there, so that electrode is not able to reach in the region where it is required or too narrow groove angle is being used.

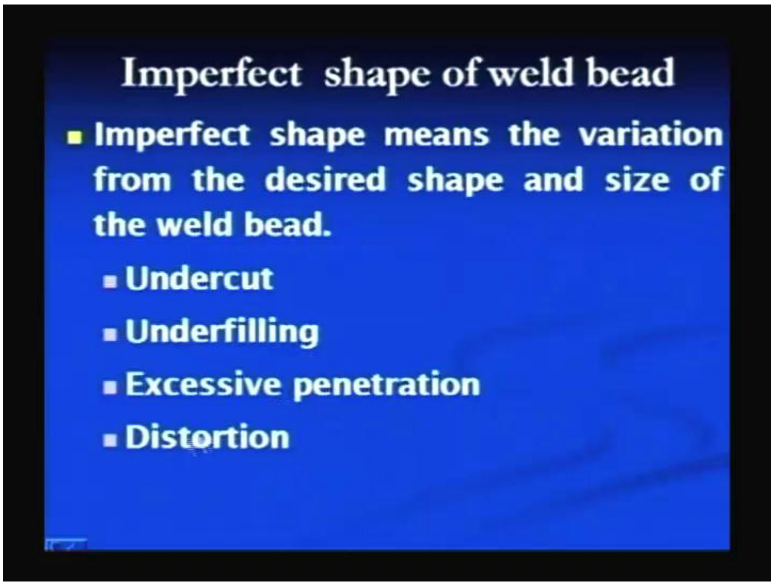
So, these are the some of the sub causes, but the main cause of the incomplete penetration is the lack of the heat input desired for the melting of the base metal.

(Refer Slide Time: 55:40)



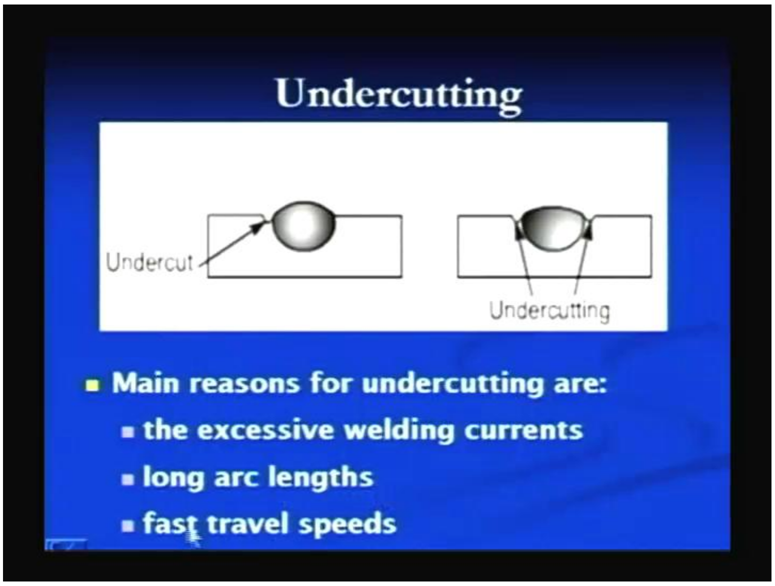
We can see here, the melting from both the sides have taken place, but in between the base metal has not melted. And here also the root of the joint has not melted properly. Both these are examples of the incomplete penetration.

(Refer Slide Time: 55:46)



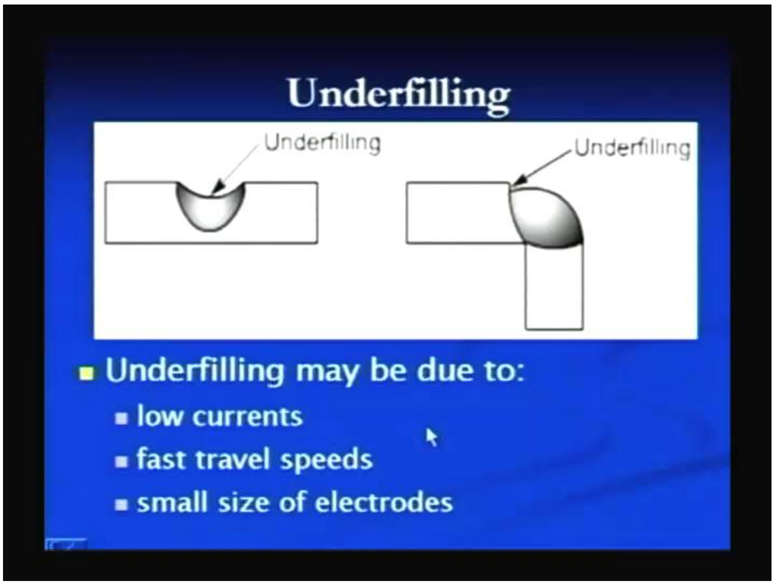
And another defect, which is normally observed in the weld joint is the imperfect shape of the weld bead. Imperfect shape of the weld bead means, it is having the shape, which is not desired or which is not acceptable because either it can require unnecessary extra work or it will develop the undesirable residual stresses in the weld metal or in the weld joint, which can adversely affect the performance of the joint. And these undesirable shapes or imperfect shapes can be in form of undercut, under filling, excessive penetration and the distortion one by one. All these imperfect shapes will be taken up.

(Refer Slide Time: 56:32)



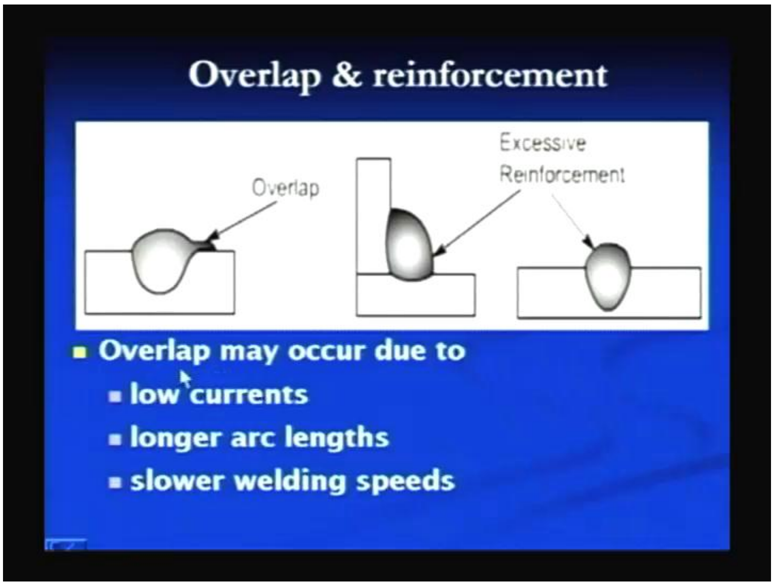
Under cutting is one where at the sides some sort of the notch is left during the welding. And it is noticed under the conditions when either excessive welding current is used or the too long arc lengths are used or welding speed is very high.

(Refer Slide Time: 56:48)



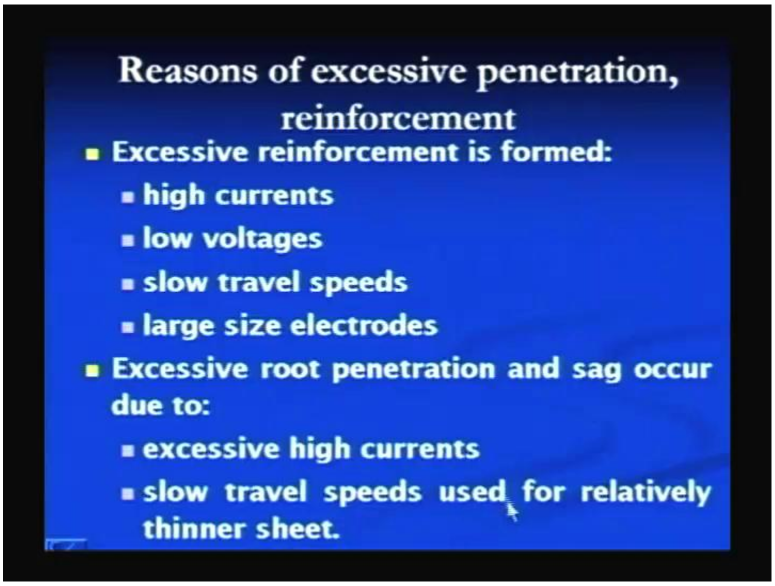
And under filling is observed. When under filling takes place, sagging can be seen in on the upper surface of the weld pool. And here, in this, the fillet joint in this region and it occurs when the lower currents are used, very high welding speed is used or smaller size electrodes are used.

(Refer Slide Time: 57:12)



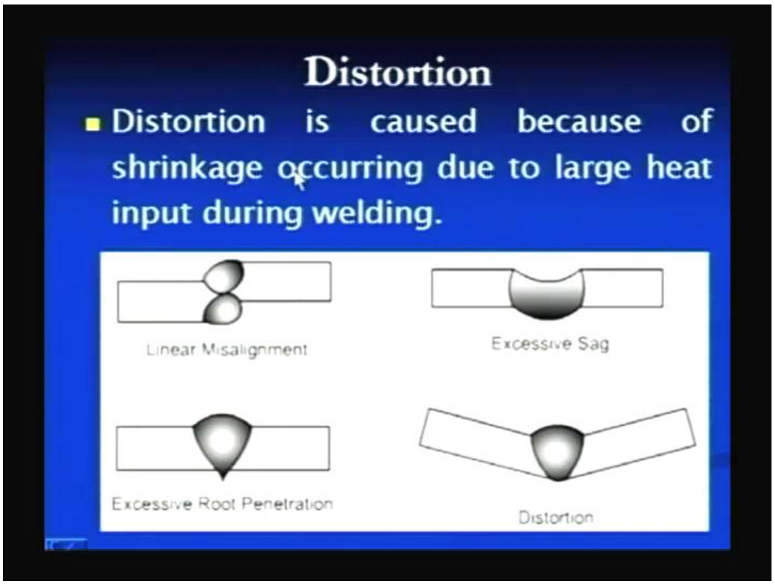
And overlaps, we can see here, this means, the metal is deposited in the region where it is not required. Or the reinforcement, the excessive reinforcement is one, means, the level of the weld bead above the surface of the base metal is too high, that is termed as excessive reinforcement. Here, this is the fillet weld and the butt weld. Unnecessary extra deposition of the material on the upper side can be termed as extra excessive reinforcement and the overlap occurs due to the lower current, longer arc lengths and slower welding speeds.

(Refer Slide Time: 57:48)



And the reasons for excessive penetration is the high current, lower voltage, slower welding speeds and the large electrode size. And the root penetration, excessive root penetration and the sagging are another or other improper shapes, which are observed and this occur when the excessive welding currents are used or slower welding speeds are used for welding of thin sheets.

(Refer Slide Time: 58:15)



To see, that the different excessive sagging or excessive root penetration, it is desired, that only the root phases melted further, melting below that does not takes place. And here, the sagging between the two plates have taken place. So, these are the two undesirable, undesirable shapes of the weld joint. Distortion is the another undesirable shape, which, which is observed particularly when the plates go, the plates joined by the welding go out of the positions and we get the joined components in the positions where it is not required.

Like in this case, we can see, that the two plates have gone out of position and this kind of distortion is known as angular distortion here because of the greater shrinkage on the upper side leads to the deflection of two plates and some sort of angle is formed, that is why this is known as angular distortion.

So, now we will summarize this lecture. We have seen, that the different reactions takes place in the arc environment or in the molten metal because of which various kinds of the defects are formed. At the same time, improper selection of the process parameters also lead to the number of defects and that is why, we need to take care of the process parameters properly to avoid the formation of the weld joints.

Thank you.