Weldability of Metals

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Lecture-03
Metal Properties and Weldability-I

Hello I welcome you all in this presentation related to the subject weldability of metals and you know last, in the previous lectures we have talked about the ways by which we can understand the weldability of metal and especially the weldability of metal is affected by the 3 important parameters like the welding process, the purpose for which the weld joint is being develop and the fabrication conditions under which a joint is to be developed.

And the 3 main ways which are can be use to assess the weldability one is like the efforts that we have to put in to produce the sound detectible joint and second is the quality of the weld which is produced and third is the cost related to aspects. Apart from this in previous lecture we have also a started that how the metal properties affect the ease of welding or the weldability. And under that we have talked about the effect of the physical properties like thermal expansion, coefficient, melting point, boiling point of the material, thermal conductivity or the materials.

So, those were the some of the properties about which we have talked with regard to their effect on the weldability of metals. In this presentation will be talking about the 3 or 4 other aspects related to the metal properties and their affects on the ease of welding or the weldability of metals. So, among those the characteristics about which will be talking includes like the metallurgical properties associated with the materials.

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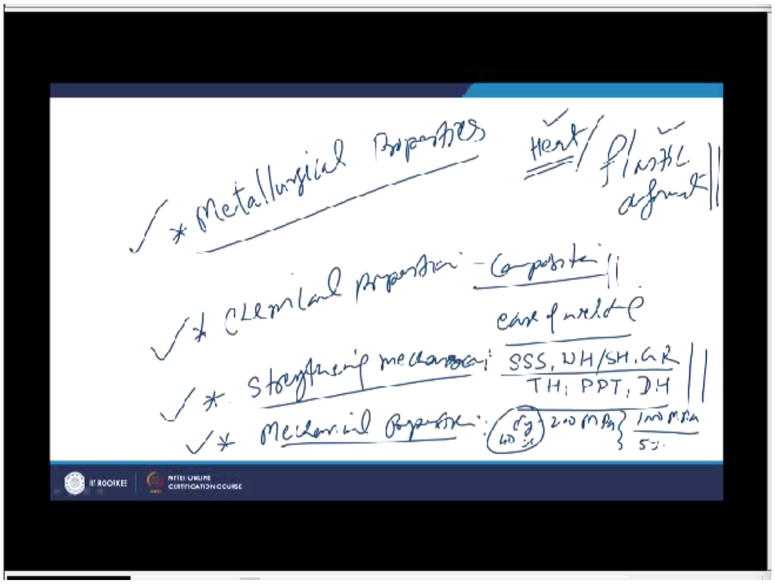

Like materials what happens when a metal is subjected to either heat during the fusion welding or plastic deformation during the solid state joining process. The second is the chemical properties which is primarily about the composition of a given metal system, so since the composition affects the microstructure and oxidation tendency the way by which we were reacting with the surrounding gases at high temperature.

It also affects the corrosion behavior and especially when the metal is subjected to the localized heating or the control plastic deformation during the welding. So we need to relate the composition of a given metal with the ease of welding. So, using those characteristics relate to the chemical composition will be trying to talk about the effect of the composition on the weldability of the metal.

And then there is another important aspect that is affecting the weldability of metal is the strengthening mechanism. Each metal system is designed using a particular kind of the mechanism, so what are the various mechanisms which are used for developing and the required strength in the metal system. And when the metal system developed or strengthened by a particular mechanism how does it behave when it is subjected to the welding.

Either show the fusion based approach or through the deformation or the plastic deformation based approach. So mechanisms like solid solution strengthening, work hardening or the strain hardening, then the grain refinement transformation hardening, precipitation hardening and that dispersion hardening. These are most commonly used mechanisms are the underlying mechanisms which are used for strengthening the metal systems.

And response of the welding with regard to the heat or the deformation to these mechanisms is found different and which in turn affects the ease of the welding of the metal. Then the mechanical properties of the material which is being welded, so this is another aspect like metallurgical properties, the mechanical properties of the metal which is to be welded. These properties also play a big role especially in case of the solid state joining where the plastic deformation plays a key role.

Like if the metal can have the yield strength of the 200 MPA or percentage elongation say 40% elongation. This material will behave completely in different way as compared to the other metal system which is offering the yield strength of the 1000 MPA and the ductility it is just the 5% in terms of the percentage elongation. Because these 2 characteristics or these 2 mechanical properties of the material will significantly be governing the stresses or the flow behavior of the material.

And which in turn will be affecting the **the** plastic deformation tendency of the material and the change in the flow behavior and the plastic deformation tendency of the material will be affecting the ease of welding using the deformation based approach where either the micro level plastic deformation is used or the macro level plastic deformation is used.

Certainly the role of the mechanical properties on the fusion based welding processes means the weldability of the metal by the fusion based welding process is not the influenced by the mechanical properties. So, based on the approach which is being used for the welding purpose that will be significantly determining the extent up to which these properties of the materials will be affecting the ease of welding.

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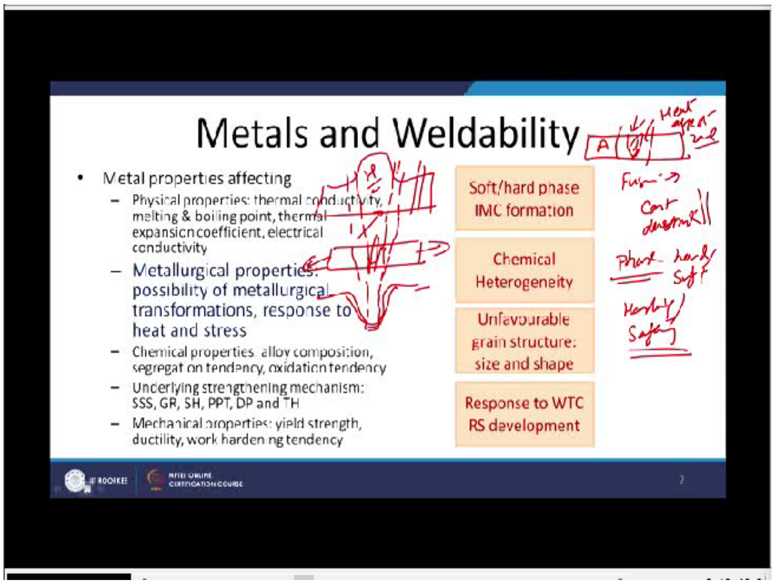

Now will be talking about these characteristics one by ne the first one is the metallurgical properties. So, with regard to the metallurgical properties if we say take one metal system A what happens to it when it is subjected to either the fusion through the application of the external heat from the external source or through the controlled plastic deformation, that all together depend upon the kind of the metal system and the strengthening mechanism which is being used for design of a given metal system.

So, if the fusion based approach is being used then it will be leading to the cast dendritic structure and it will not have any effect of any other strengthening mechanism which was used for developing the required strength in a given metal system. But apart from that there will also be formation of the heat affected zone due to the dissipation of heat from the well whirlpool, so heat affected zone formation.

So, these are the 2 integral part of any fusion welding process where one weld metal will you formed and one heat affected zone will be found. But what kind of the metallurgical transformations which will be taking place as per the kind of metal system it may be leading to the formation of the various types of the phases as per the approach of the building be used. These phrases may be soft or these may be hard.

So formation of the soft and hard phases either in the weld metal or in the heat affected zone will be leading to the hardening are the softening of the weld metal or of the heat affected zone. So, is hardening is taking place then of course there will be increase in strength and increase in ability of the material to take up the load. Of course with the cost of at the cost of the toughness and sometimes also at the cost of the ductility.

But on the other hand if the softening is taking place then it will be forming the weak zone and weak zone will be leading to the eventually structure under the external loading conditions say for example here in this case this the weld metal and if the hardening of the weld metal and heat affected zone is taking place. Then it will be showing us the increase in hardness both in the zone near in the heat affected zone as well as in the weld metal.

So, this is the case where weld metal is getting harden due to the formation of the heart phases on the other hand if another metal system under the influence of the heat which is being supplied for the welding purpose. And if the soft phases are being formed then it will be leading to the significant reduction in the hardness. This is the base metal hardness and as we approach towards the weld centre will see there is a drop in hardness.

This drop is attributed to the formation of the soft phases and the weld metal will be weak. So as per the kind of the metallurgical transformation or the kind of phases which are being formed these will be leading to the hardening or the softening. And accordingly under the external load if the softening is taking place it is the weld metal which will fail and if a hardening is taking place it is the base metal which will fail or the fracture will be occurring from the base metal. So, this is one of the aspects related with the kind of the phase transformation which is taking place.

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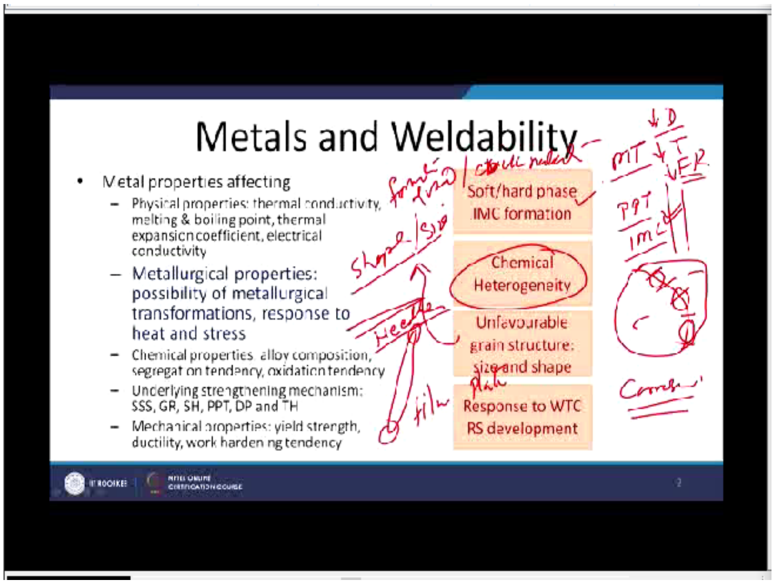

Sometimes what we see that during the metallurgical transformation some of the precipitates are formed or sometimes inter-metallic compounds are formed and formation of these precipitates and inter-metallic compounds either in the weld metal or in the heat affected zone will be leading to the localized enrichment or the deficiency of the alloying elements, like say this is one grain this is another.

So we may notice that some of the precipitates enriched with the particular element is being formed at the grain boundary while the grain is getting deficiency or depletion of that particular element. So this kind of the chemical heterogeneity promotes the corrosion tendency of the material and sometimes the stress corrosion cracking along the grain boundary is also increased. And this happens especially in the cases where in case is like a stainless steel and austenitic stainless steel where weld decay is observed.

But the underlying reason behind this kind of the undesirable effect is the chemical heterogeneity and which will be occurring primarily due to the formation of unfavorable precipitates and inter-metallic compounds , these precipitation inter-metallic compounds can also be of the undesirable geometry like shape and size may be highly unfavorable which is will be falling under the that metallurgical transformation leading to the formation of the undesirable grain structure.

So, if the precipitates are the inter-metallic compounds being formed due to the application of the heat during the welding or the deformation during the welding and if it is leading to the formation of the needle shaped or high aspect ratio inter-metallic compounds and the phases in form of films or the plates or needles. Then these inter-metallic compounds or the precipitate will be acting as a point of the stress concentration especially at the leading edge of the needles.

And the such kind of the in the plates and the films which are being formed and the increase concentration being offered by these the inter-metallic compounds and phases at the particle matrix interface that will be promoting the formation of the whites and easy crack nucleation. And so if such kind of the precipitate sand inter-metallic compounds are being formed having the higher aspect ratio having the needle structure or the plate shaped structures which will promoting the higher stress concentration at the particle matrix interface.

And that in turn will be reducing the ductility that internal also be reducing the toughness also we reducing the fatigue resistance of the weld joints. So, this is one aspect like the whether the soft and hard phases are being formed are the kind of heterogeneity chemical. Heterogeneity is being promoted to the formation of the precipitates and inter-metallic compounds and the kind of shape of these precipitates in totally compounds which is being found.

That will also be affecting the ability of the material to take up the external load with reasonable ductility or with the with reduced ductility. So, it as per the kind of phases which are being found and they are grainy structure, the ability of the weld joints will be changing significantly. And that in turn will be affecting the weldability, so if the ability of the material to take up the service conditions is improved due to the favorable metallurgical transformation.

Then this will be leading to the improved weldability and else the weldability will be adversely affected, further all the metal systems do not respond in equal way to the application of the heat being applied during the welding.

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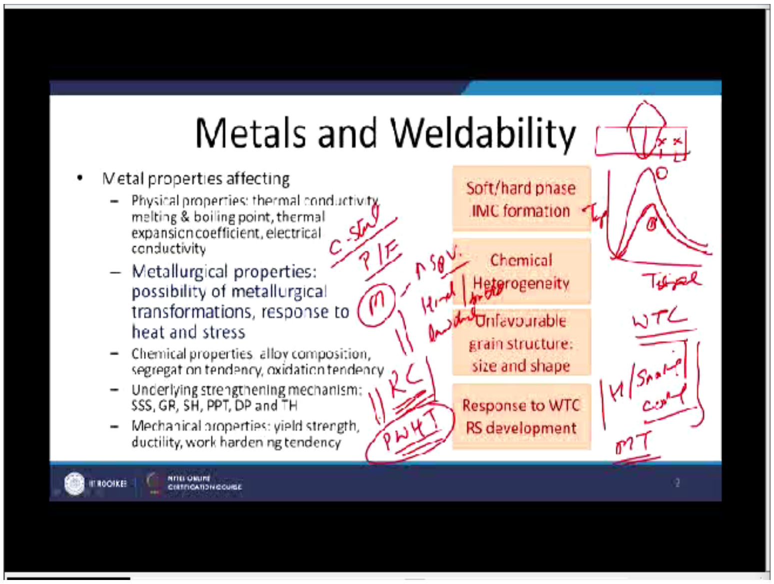

Like say whenever the heat is applied for melting the faying surfaces through the external heat like use of arc or laser. So, the fusion is realize, so if we will see the zones near the fusion boundary these will be experiencing the high temperature at very high rate and the temperature will be decreasing. So, this variation in temperature as a function of time is temperature.

This is known as weld thermal cycle, so this is the kind of variation in the temperature which is observed and this cycle will be different for the different points like say for 0.1 and 0.2. This is one weld thermal cycle weld thermal cycle for 0.2 will be like this which is away from the fusion boundary, so this for 0.2 m greater is the distance away from the fusion boundary lower will the temperature and lower will be the rate of rise in temperature.

And then the rate at which temperature will be decreasing will also be lower. So, this is what is called weld thermal cycle, now whenever there is heating and then soaking as per the kind of the weld thermal cycle followed by cooling. So these heating and the cooling will be affecting the metallurgical transformation, all the metal systems do not respond in the same way to the metallurgical transformation when the weld thermal cycle is imposed.

And that is why as per the nature of the material systems weld thermal metallurgical transformations will be different for a given weld thermal cycle. Apart from this some of the phases which are formed due to during metallurgical transformations like in case of simple carbon steel if the metallurgical in case of low carbon steel. If it is just the ferrite and the pearlite kind of the phases is being formed.

The residual stress development is very limited but if the martensite transformation takes place which occurs with the increase of a specific volume. And this material is very hard very brittle and of the low ductility, so at micro structural level it develops the residual compressive stress. because wherever the metallurgical transformation from the completely soft phase to the hard phases takes place with the increase of a specific volume.

It leads to the development of the residual compressive stress wherever it is being formed. But the region all around that will be under the tension, so metallurgical transformations also contribute towards the development of the residual stresses and to take care of these residual stresses. So, that their adverse effect on the performance of the weld joint can be reduced we carry out the post weld heat treatment.

So, if the metallurgical transformation is such that huge residual stresses are being developed than maybe require the additional steps to reduce the magnitude of the residual stresses. So, that the performance of the weld joint in service can be enhanced, so addition of the additional post weld heat treatment in order to enhance the joint performance will be lowering the weldability and if the weld joint is developed without much of the residual stresses.

So, they will not be any post weld heat treatment requirement to take care of the residual stress related aspects that will be offering certainly the better weldability. So, because we know that more the precautions, more the efforts, more the steps are required for producing given weld joint which can serve the internet function lower will be the weldability of the material.

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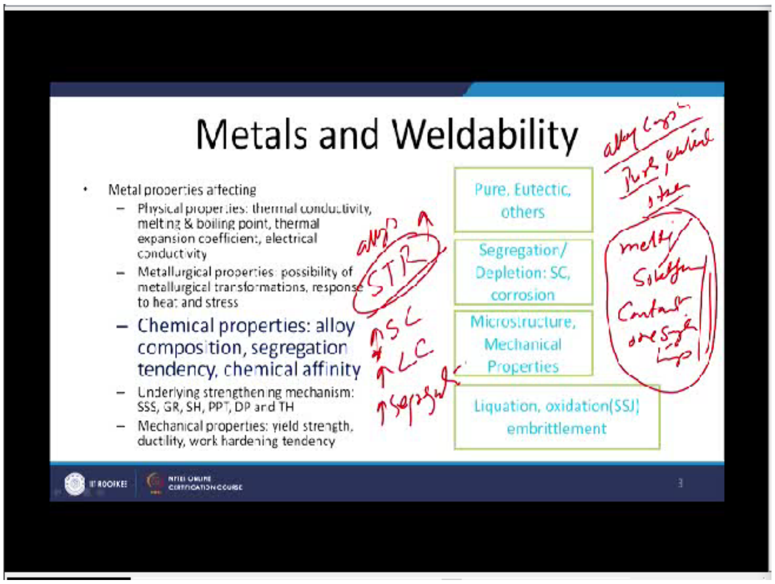

Now will see the next property of the material we know that if we say chemical composition which considers the alloy composition. So metal which is to be welded it is composition certainly plays a very big role in determining the weldability. It metal can be pure or it can be of the eutectic composition or other composition. So we that the pure metals and the eutectic alloys, alloys of the eutectic composition will be melting and solidifying at constant temperature at single temperature.

So this is very good site where the solidification is starts and end at one temperature. So, when our the pure metal or an alloy of the eutectic composition is welded due to the melting and the solidification at a one temperature this leads to the development of the minimum welding defect related tendency. And that is why they offer a good weldability as compared to the alloys where the solidification takes place over a range of temperature.

So the alloys offering a solidification temperature range or you can wider solidification temperature range there will be increased tendency for the solidification cracking there will be increased tendency for the liquation cracking. So and there will be increase tendency for segregation of the alloys or chemical heterogeneity. So our metallurgical heterogeneity will exist.

Mechanical properties will also be changing significantly from the weld zone to the heat affected zone, that is why there will be more problems related with the welding especially in the alloys which are having the wider solidification temperature range. And those problems will by a large be absent in case of the pure metals or the alloys of the eutectic composition. So as we have and is effect we can directly observed in case of the solidification cracking tendency during the welding.

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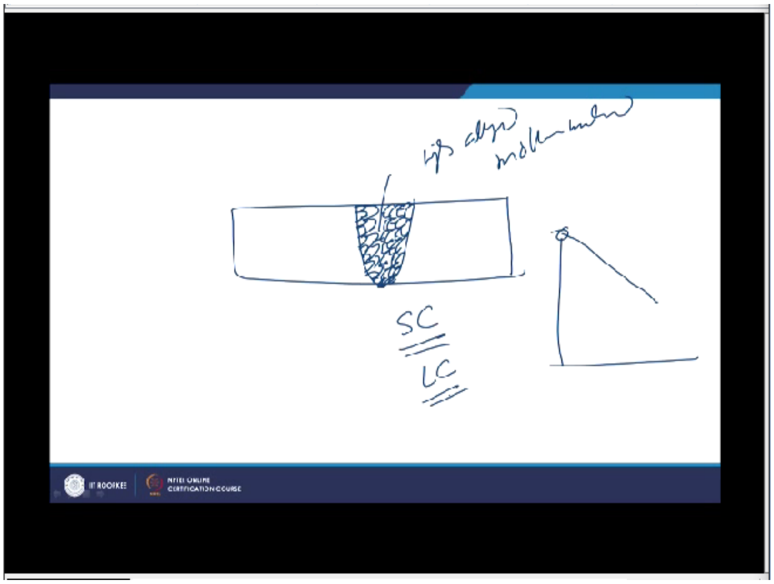

So in that case like say this is the weld metal, so the solidification begins at the fusion boundary and it progresses towards the centre line of the weld like this. So, obviously the things which certify first hour in pure form and the axis of the alloying elements in case of the alloys having the wider solidification range. The alloying elements are ejected in the liquid metal, so as a solidification progresses from the fusion boundary towards the weld centre what we will notice that alloying element concentration will keep on changing.

And alloying elements will be knowing alloying elements will be in enriching especially in the left out liquid metal and at the end we get the high alloyed molten metal. And we know that the pure metals have the highest solidification temperature as compared to the metal having the or molten metal having the higher concentration of the alloying elements. So, that is what we can see simply from any phase diagram pure metals will solidifying at high temperature than our liquid will be decreasing with the addition of the alloying elements.

So, the same concept visa concept is applicable here also where with the enrichment of the alloying elements in the liquid metal their certification temperature we keep on coming down. So, this in turn subsequently leads to the development of the certification crack and this is happening primarily due to the presence of access alloying elements at the weld centre line. And the same is also reason same is the reason for the liquation cracking where lot of chemical heterogeneity existing at the grain boundaries leading to the widest solidification temperature ranges even in the heat affected zone increasing the liquation cracking.

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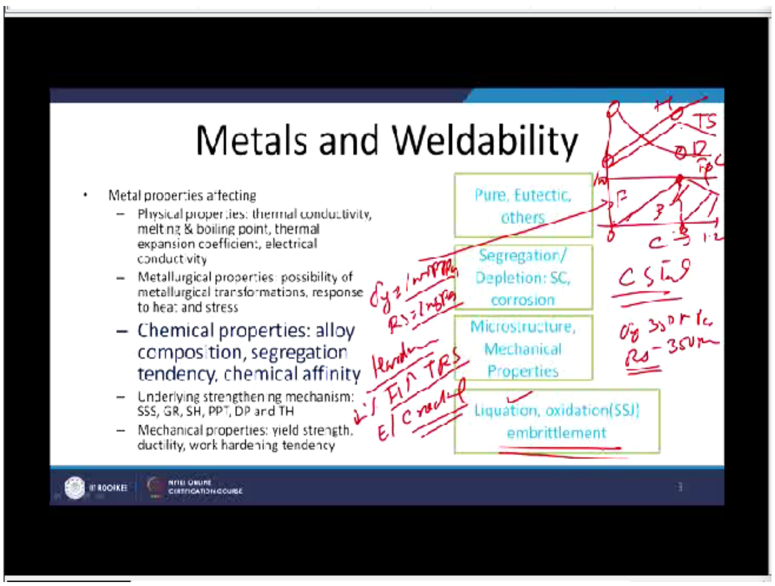

Chemical heterogeneity also from the corrosion tendency like I gave one example where either the enrichment of the alloying elements at the weld centre is taking place or in the heat affected zone some unfavorable metallurgical transformation is taking place where the phases which are being formed or enriched with the particular kind of the alloying element and the nearby we are having the deficiency of that particular element.

So such kind of the chemical heterogeneity will be promoting the galvanic corrosion, somewhere it is diffusion and somewhere it is enriched. So, wherever it is more as compared to the another location, so like in case of the austenitic stainless steel chromium carbide is formed, so this particles having the higher chromium as compared to the other areas where chromium is absent or it is in reduced quantities.

So, wherever chromium is less in case of the austenitic stainless steel this will be acting as anode and this particles will be acting as a cathode. So the chromium deficient areas will be experiencing the loss of metal in the favorable corrosive environment. And that will be a promoting the corrosion of the weld joint especially in the heat affected zone. And have the primary reason behind this is the chemical heterogeneity which is being promoted to the metallurgical transformation.

We know that the chemical composition of the base metal directly affects it is behavior and response to the heat treatment. And that is what we can say with regard to this plain carbon steel we know that if the carbon content in case of the steel is increased will be seen that the ferrite concentration will be decreasing. And pearlite concentration will be increasing like say this is 0% carbon this is 0.8% carbon and say this is 1.2 % carbon.

So, when the carbon is absent we have the 100% of the ferrite and pearlite is 0 and as the carbon content keeps on increasing our pearlite fraction will keep on increasing. And it will become for eutectoid composition will become 100%. And there after fe3c is iron carbide starts appearing and then this entire zone belongs to the pearlite. So, pearlite fractional will started decreasing and the iron carbide or the cement fractional will start increasing beyond the 0.8% carbon.

And if we see it is effect on the properties mechanical properties there will be continuous increase of the hotness with the increase of carbon content and their increase of the high strength up to the eutectoid point and thereafter strength will start decreasing. While the ductility and toughness both will be decreasing with increase of the carbon contents, so both mechanical properties and the microstructure are affected by the composition.

I have this is just an example for the carbon steel and likewise it will be happening in other cases as well. So, since the phases micro structures have direct effect on the mechanical properties, low carbon steels having the lower strength, higher ductility. While high carbon steels will be having the higher strength and the lower ductility and that is why so this ductility tensile strength and this is hardness.

So, **so** it will be easier to weld the low carbon steels by the deformation based processes **base** as they have the lower yield strength and the higher ductility as compute the high carbon steels. While in case of the fusion welding the role of the mechanical properties probably is limited to the development of the residual stresses. For example the metals of the high yield strength like 1000 MPA.

It can develop the maximum residual stress also of the 1000 MPA on the other hand another metal having the maximum having the yield strength of the 350MPA. Then the residual stress magnitude can also be maximum 350MPA, so means the residual stress magnitude can be maximum equal to that of the yield strength material and because higher level of the stresses will be leading to the deformation.

And the yielding of the material and the residual stress will be eased out and that is why the maximum magnitude of the residual stress which can be written in the weld joint will be equal to the yield strength of the metal. So higher the strength of the yield strength of the metal greater will be the residual stress and another aspect is that the hardness of the material because the chemical composition will be affecting the microstructure.

And that in turn will be leading to the change in mechanical properties and the mechanical properties will have the effect on the performance of the joints like if the ductility is very less if the material hardness is very high under the tensile residual stress conditions. The weld joints will be showing the embrittlement as well as the cracking tendency, so increased cracking tendency will be leading to the reduction in the weldability of the material.

So like I have explained like the greater chemical heterogeneity if existing then it will be leading to the liquation cracking and the solidification cracking tendency. And similarly in case of the steels the carbon content and the alloying elements directly affect the carbon equivalent which in turn affects the hardenability of the steel and increased hardenability of steel will be affecting the embrittlement or the low ductility low toughness tendency of the weld joint.

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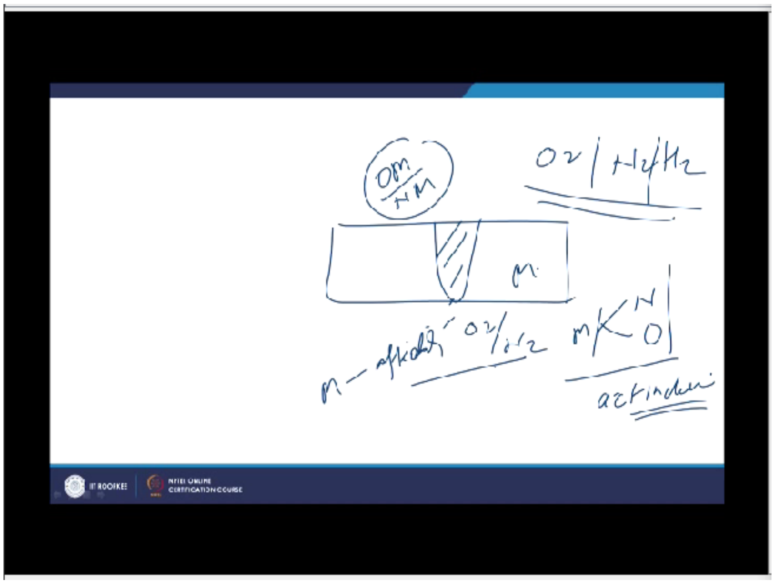

The chemical affinity is the another important aspect that I will explain little bit like if there is a metal system which is subjected to the external heat for the fusion. So, at high temperature there will be environmental gases like oxygen, nitrogen and hydrogen, so the way by which metal has the affinity to these gases which are present all around during the welding it can lead to the formation of the oxides of the metal or the nitrites of that given metal.

And these oxides and nitrites maybe refractory in nature then these may be hard and brittle, these may interfere with the fusion of the metal. So these will make the welding difficult, at the same time these oxides of the metal oxides and nitrites will be of the in general they are hard and brittle. So, this act as a if these are left in the weld joint and these inclusions promote the nucleation of the cracks in the weld metal under the external tensile loading and thereby theses reduce the performance of the weld joint.

So, if the metal is having the greater affinity, chemical affinity to the oxygen and nitrogen then we need much better production, more effective a process which can protect the weld metal from these gases. So that the sound weld joint and for that we need to put in extra efforts and that internally be reducing the weldability of the metals, so metals having the greater affinity to the environmental gases that will be leading to the reduction in the weldability.

Now I will summarize here this presentation, in this presentation basically I have talked about the ways by which the metallurgical properties and the chemical properties of the weld metal can affect the ease of the welding or weldability of metals, thank you for your attention.