Weldability of Metals
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Lecture-09
Weldability of Transformation Hardening Metals

Hello, I welcome you all in this presentation related with the subject weldability of metals and we have talked about the weldability of precipitation strengthen metals, work hardenable metals and metals which are strengthened by the solid solution strengthening. Today we will be talking about the weldability aspects related with the metals which are the strengthened by the transformation hardening.

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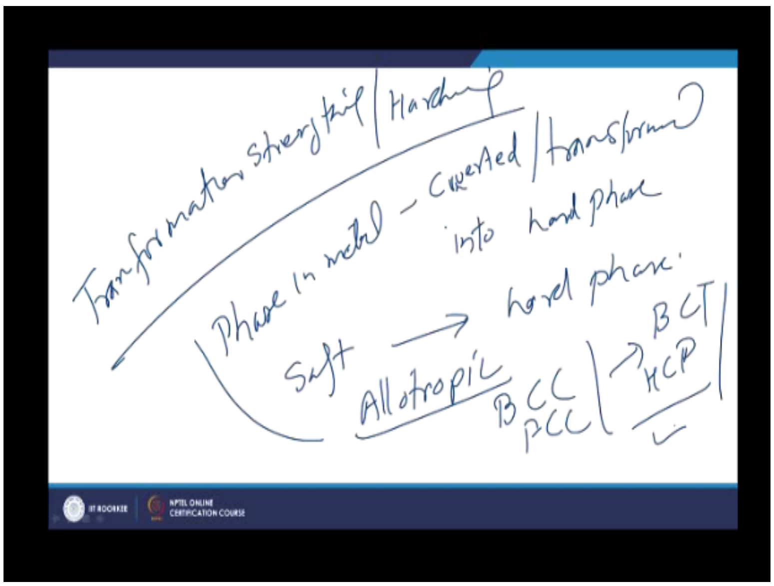

So what is this transformation hardening and how it is realized , in case of the transformation strengthening or hardening of metals actually the various phases present in the metal in very controlled way they are converted or transformed into the hard phases. So basically the soft phase transformation into the hard phases is realized and this is more commonly used in the metals which show the allotropic behaviour like say initially the metal maybe in BCC crystal structure or FCC crystal structure.

And when these are transformed in very control with they may have the BCT structure or HCP structure. So the control transformation of the soft phrases into the hard phases leads to the increase in strength of the metal and so when these are process during the welding some of such kind of the transformations take place both from hard to soft or soft to hard phases.

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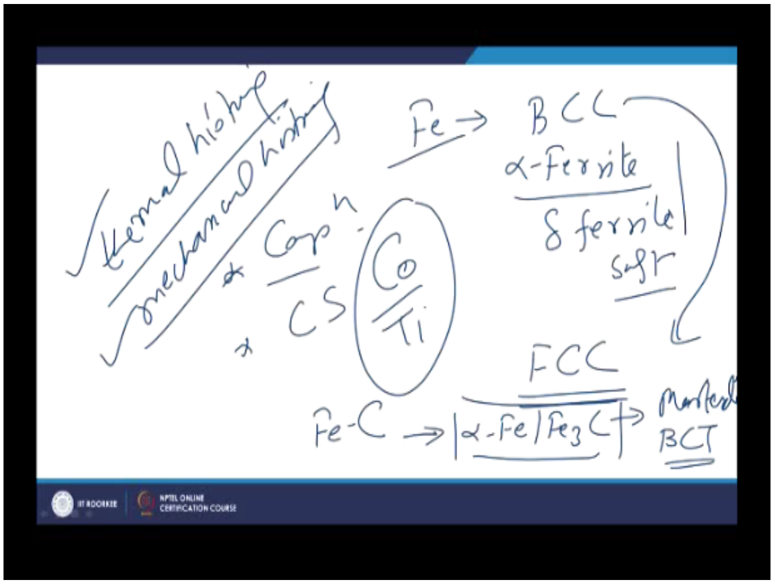

So as far as the phases are concerned like either there is a minor change in composition or just change in the crystal structure like iron may be present in form of the BCC structure like the ferrite or it may be in or delta ferrite, so this is alpha ferrite and the delta ferrite. Both are comparatively soft, but when it is heated to the high temperature or when control alloying is done iron can also be obtained in form of HCC crystal structure which offers all together different type of the mechanical properties.

Similarly for a given composition of the iron with the carbon we may have the alpha ferrite or iron carbide and when such kind of the mixture subjected in very controlled way for the phase transformation we may get the martensite which is comparatively hard, harder and brittle. So this will be having all together different kind of the crystal structure like BCT structure. So likewise like the iron the cobalt and the titanium alloys also show such kind of the transformation behaviour where either change in the thermal history of the material or the mechanical history of the material during the processing.

So either the controlled heating followed by cooling or the controlled plastic deformation of the metal leads to such kind of the phase transformations where change of the phase leads to the increase in mechanical properties or decrease in mechanical properties.

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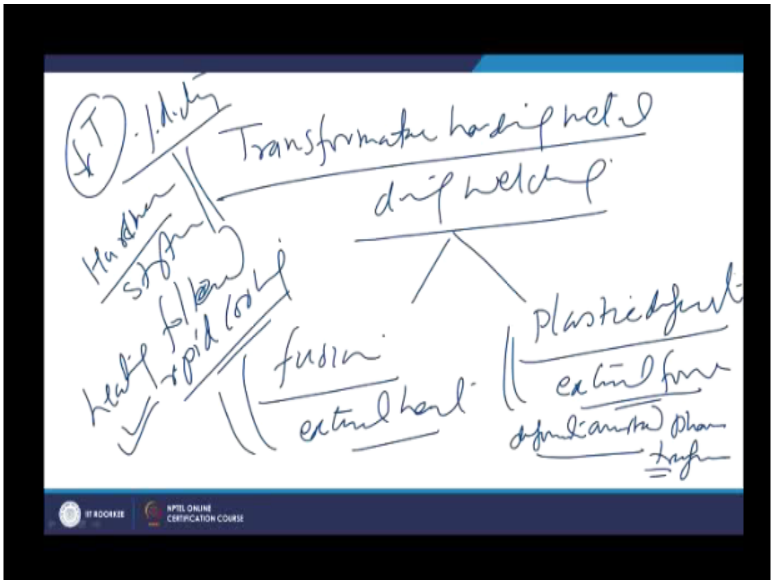

So in which way the material will be behaving means the transformation hardening metals will be behaving during the welding, we know that the welding broadly we can group under the two categories where the fusion is realized through the application of the external heat or very controlled plastic deformation is realized at the faying surfaces through the use of the external force.

So in both the cases responses will be different and in that case like the plastic deformation may lead to the deformation assisted phase transformation while in case of the fusion welding it is the heating followed by the rapid cooling that leads to the development of the variety of the phases. These phrases in general leads to the increase in the hardness and the strength.

Excessive increase in hardness sometimes lead to the reduction in toughness, reduction in ductility, so embrittlement of the weldments is also accompanied under the unfavourable conditions of the heating followed by rapid cooling or excessive plastic deformation leading to the excessive increase in the hardness of the weld metal and the heat affected zone. So here it is the weld thermal cycle which is leading to the various phase transformations.

And on the other hand it is the deformation assistant phase transformation which is causing the variation in mechanical properties of the joint. These transformation and show the related mechanical property variation maybe favourable, maybe unfavourable. So if it is favourable from the performance point of view will say that the weldability is good and otherwise it is poor.

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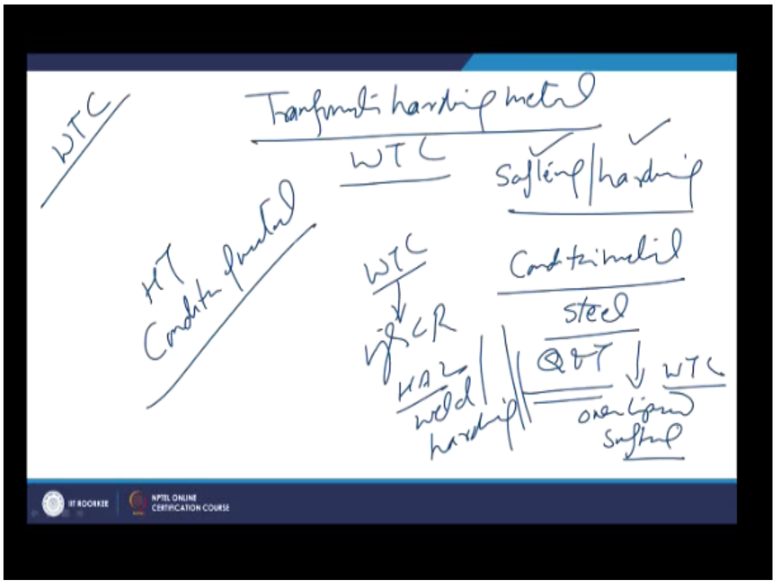

So now if we see the way by which we can understand the weld thermal cycle and it is effect on the weld joint characteristics of the transformation hardening materials. So transformation hardening metals so due to the weld thermal cycle experienced by the weld metal and the heat affected zone there can be softening or hardening as for the condition of the metal which is being welded which means if say for example if the steel is being welded unquenched and temper condition.

Then after the fusion welding due to the weld thermal cycle in the heat affected zone given to steel is over tempered and this leads to the softening, while in most of the cases due to the weld thermal cycle hire cooling rate associated with the Hz and the weld metal these cause the hardening of the metal. So as far as the transformation hardening metals are concerned due to the weld thermal cycle these can experience both hardening or suffering which will depend upon the condition.

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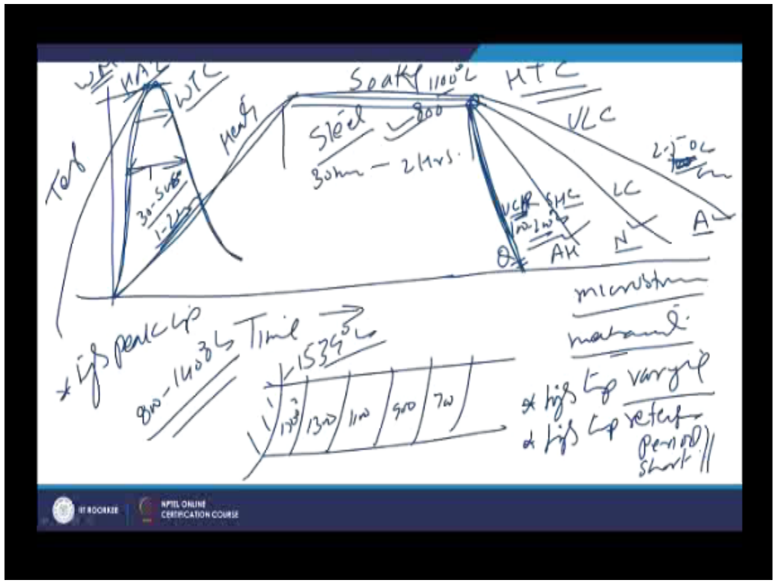

Basically heat treatment condition of the metal in which the welding is being performed, now we will try to see very closely the way by which the welding will be affecting the characteristics of the transformation hardening material say in X axis we have the time and in the y-axis we have the temperature. So if we try to understand the way by which weld thermal cycle shows the variation in temperature as a function of time.

This is WTC weld thermal cycle very rapid increase in the temperature followed by the fast cooling . So on the other hand if we compare it with the heat treatment rise in temperature is low than holding is for longer time followed by the cooling, because what heat treatment involved heating, then soaking and followed by the cooling at different rates as per the requirement of the properties and phase transformation like this.

So like a annealing normalizing air hardening or quenching, so the different cooling rates will be leading to the wearing are changing microstructures and which will be leading to the different mechanical properties. This what is typically used in case of the steel for changing or realizing the different set of the mechanical properties. So if we compare the weld thermal cycle with the that typical heat treatment cycle.

Then heat treatment cycle is very long wear it takes very long to heat to the required temperature which is normally say in the range of 800 to 1100 degree centigrade and then followed by the soaking for longer period which may vary as per the section size from say 30 minute to the 2 to 3 hours as per the case and then different cooling rates like cooling rate varying from 100 degree centigrade per second sorry like 2 to 5 degree centigrade per second to 100 to 200 degree centigrade per second.

So very low cooling rate then the low cooling rate somewhat high cooling rate and very high cooling rates are in cooling rate are used. So quenching will be experiencing extremely high cooling rate as and this is cooling rate will be higher than the cooling rights which are uhh imposed during the air hardening normalizing or annealing. So on the other hand weld thermal cycle if we see weld thermal cycle of the heat affected zone or of the weld metal region it experiences the higher peak temperature which is of importance likes 800 to almost up to the melting point.

Say in case of likes say steel 1400 degree centigrade, so this temperature will be changing next to the fusion boundary it will be like corresponding the fusion point fusion are the melting point 1539 for typical pure iron and the lower values for the steels. Then in the regions away from the fusion bonded the temperature will be decreasing like says 700 degree centigrade 900. 1100, 1300, 1500.

So on approaching towards the fusion boundary the peak temperature will be high at the same time the another point which we have to see is the time for high temperature, the time above which high temperature is maintained . So this a high temperature retention period is very very short this may be like 30 to 50 seconds or as per the welding process it may be longer like 1 to 2 minutes.

But it is not like this is not as high as which is observed in case of the typical heat treatment cycle. So that 2 aspects, 1 is the high temperature which is changing high temperature is varying from the base metal to the fusion boundary and the high temperature retention period, this is very short as compared to that of the typical heat treatment cycle and therefore this has a huge implication as far as the phase transformation is concerned .

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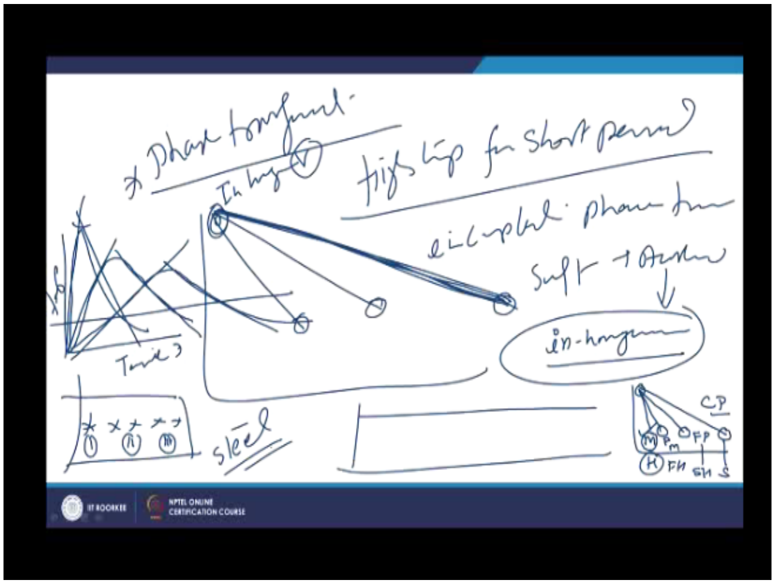

High temperature for short period, this leads to the for incomplete phase transformation from soft phases to the austenite and then, so whatever austenite is formed it is in homogenous like some where still the ferrite is present or somewhere the high carbon austenite is present. So whatever austenite is formed it is inhomogeneous and this inhomogeneous austenite when subjected to the transformation at varying cooling rate.

So if you see here we have the inhomogeneous austenite available for transformation and it will be subjected to the different cooling rates as per the distance away from the fusion boundary. The distance if the point is close to the fusion boundary it will be experiencing higher cooling rate and on increasing the distance away from the fusion boundary the cooling rate will keep on decreasing because of the varying thermal cycles which are experienced by the weld metal.

If we just take the example of this 0.1, 0.2, and 0.3, so the weld thermal cycle for 0.1 will go like this where very high cooling rate is observed and higher peak temperature as per as the weld thermal cycle is concerned time and temperature on the other hand for 0.2 that takes longer to reach the peak temperature and then lower cooling rate and further longer and shorter peak temperature longer time to reach the peak temperature.

And then further lower cooling rates, so this slope indicates the cooling rate being experienced and the slope during the heating indicates the heating rate and above particular temperature line it will be indicating that how long high temperature is being returned that for how long period the temperature above that value of the temperature is being return and that will be governing the kind of homogeneity or heterogeneity will be existing in the austenite.

And this homogeneity of the austenite is very important for required phase transformation as per the composition of steel but if it is not so then it will be leading to the reduced hardening tendency or reduced phase transformation change tendency into the hard phases. So the point so there 2 aspects the formation of the inhomogeneous austenite as per the distance away from the fusion boundary the cooling rates will be changing.

So the point which is away from the fusion boundary that will be experiencing at the point which is at largest distance away from the fusion boundary that will be experiencing the low cooling rate as compared to those which are closer to the fusion boundary and accordingly the austenite will be transforming into the different phases, say one which is being cool very slowly that will be leading to the formation of the course pearlite.

Then one which is being cooled at higher rate this will be leading to the fine pearlite, even it may lead to the further higher cooling rate maybe leading to the formation of fine pearlite and martensite, further higher cooling rate may lead to the formation of complete martensite. Since each phase is having the different microstructure different crystal structure and so the different mechanical properties are offered by.

Like the course pearlite will be the softest then somewhat higher hardness, then further higher hardness and hardest are maximum hardness will be offered by the in the case when the point is very close to the fusion boundary it is experiencing the highest peak temperature, so leading to the complete homogenous austenite formation and subsequently higher cooling rate is leading to the complete martensite transformation.

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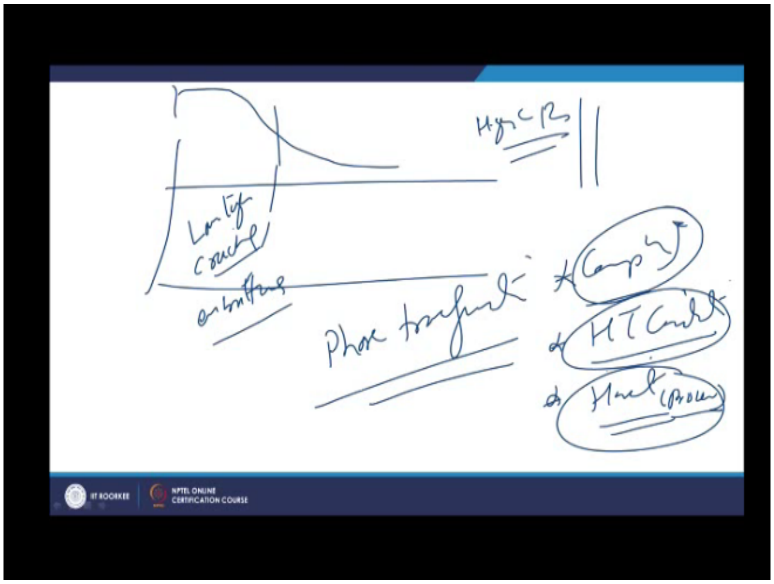

So the different zones of the same steel will be experiencing the different kind of the phase transformation and accordingly the property. So if we noticed the if we try to notice the variation in the hardness in such kind of cases then the zone next to the fusion boundary will be the hardest and then hardness will keep on decreasing. So the zone where hardness is very very high this will be experiencing the loss of toughness and this will show the tendency for cracking.

This will show the tendency for embrittlement, so this is the typical feature of the transformation hardening steels where high cooling rates will be leading to the increased embrittlement loss of toughness and the high hardness. But all the steels are not sensitive for this kind of the phase transformation that type of the phase transformation to a great extent is found a function of the composition.

The heat treatment condition of the base metal and the kind of the heat input which is being given in form of the (()) (20:45) the function of the welding process, heat treatment condition whether it is anneal condition, normalize condition or the quenched and tempered condition or the composition means the steels which are categorized based on the composition few are very high hardenable, few you offering higher hardenability as compared to the others.

So about the composition heat treatment related aspects and heat related aspects will be talking subsequently as well as the transformation hardening metals are concerned. We will so these aspects will be trying to see a closely the way by which the weld thermal cycle will be affecting the various phases next to the fusion boundary.

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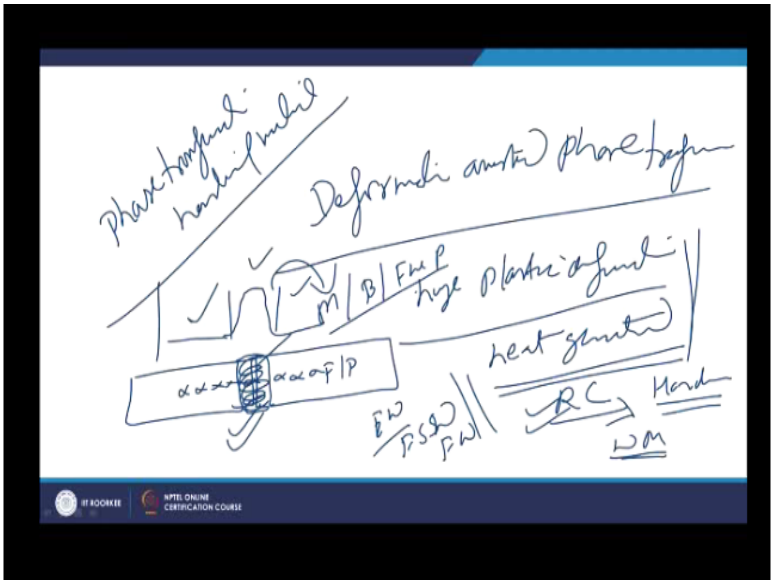

There is another aspect as far as the phase transformation hardening metals are concerned that is about the defamation assisted phase transformation. So those welding processes where huge plastic deformation is carried out for developing the required joints. So in this process lot of heat is generated and heat generated followed by the rapid cooling leads to the again formation of the hard phases in the weld zone as well as the in heat affected zone.

But mostly this kind of the phase transformations are experienced in the weld metal region, for example steel when subjected to the welding through the plastic deformation based process so huge plastic deformation of the faying surfaces leading to the formation of the most of the martensite followed by the bernette and the fine pearlite. So while the base metal maybe having simplify ferrite and the pearlite.

But the control plastic deformation and the associated weld thermal cycle leads to the development of the martensite and the bernette and fine pearlite and if we measure if you try to check the hardness distribution across the weld interface then will notice that the weld hardness is low but as soon as we come across the weld zone the hardness increases suddenly and then again it comes down.

So this sir increase in the hardness is attributed to the formation of the martensite bernette and fine pearlite due to the plastic deformation and the related heat generation followed by the rapid cooling. So the processes like the explosive welding, friction welding, friction stir welding and friction welding all these will be leading to the property variation in this way. These conditions may be favourable if the joint is not subjected to the impact loading.

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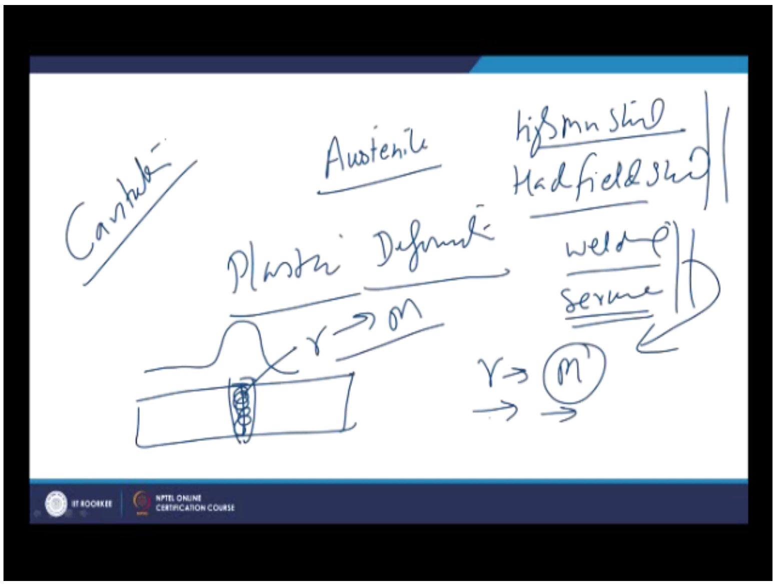

But if the joint is subjected to the impact loading during the service then it will be considered of the poor weldability otherwise the favourable weldability. There is another aspect in the deformation based or deformation assisted phase transformations like there few categories of the steels where the met steel is primarily having the austenite at room temperature, like in high manganese steels or had filled steel.

Sot these steel means subjected to the controlled plastic deformation either during the welding or during the service then these will be transformation is austenite will be transforming into the martensite. So in this cases also when they will be subjected to the wedding to the plastic deformation based joining process so the control plastic deformation of the faying surfaces will be leading to the transformation of austenite into the martensite.

And again will be getting the similar kind of the trend of variation in the hardness, so here the plastic deformation is important and such kind of the skills steels are found very suitable for the applications like cavitation, applications where cavitation is involved like in the fluid flow systems where cavitation is causing the loss of the materials, so the cavitation which is developing the impact of the high pressure waves on to the steel leading to the control surface layer deformation.

And the control surface deformation associated with the austenite to martensite transformation increases the hardness and thereby helps in reducing the erosion of the material.

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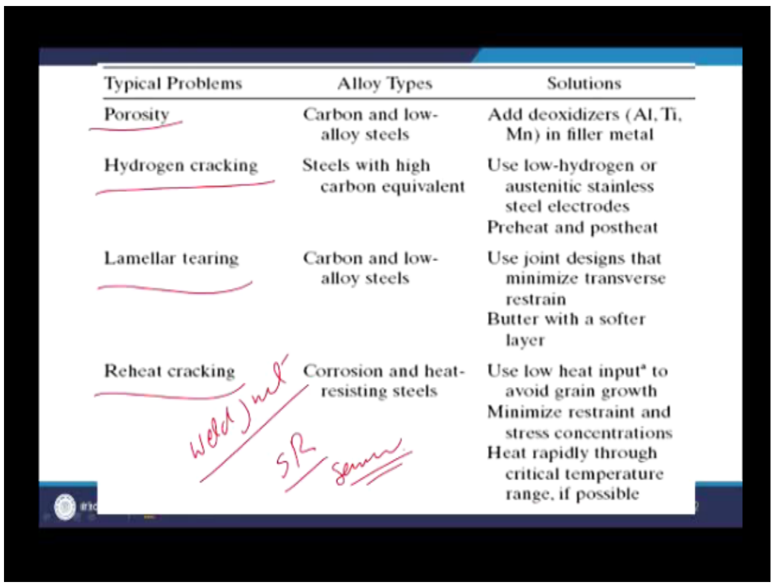

Typical Problems	Alloy Types	Solutions
Porosity	Carbon and low-alloy steels	Add deoxidizers (Al, Ti, Mn) in filler metal
Hydrogen cracking	Steels with high carbon equivalent	Use low-hydrogen or austenitic stainless steel electrodes Preheat and postheat
Lamellar tearing	Carbon and low-alloy steels	Use joint designs that minimize transverse restrain Butter with a softer layer
Reheat cracking	Corrosion and heat-resisting steels	Use low heat input* to avoid grain growth Minimize restraint and stress concentrations Heat rapidly through critical temperature range, if possible

Now we will be seeing the some of the aspects the way by which the weldability of the transformation hardening metals like typical one is the steel, so the factors that govern the weldability of the steel includes like whenever steels are welded they will be showing the tendency for the porosity formation, mostly low carbon steels I will be experiencing this kind of tenancy, then some of the medium carbon and high carbon steel is an alloy steel show the hydrogen embrittlement as well as the lamellar tearing tenancy.

And some of chromium molybdenum steels which are used for high temperature applications as well as some of the alloy steels this show the tendency for the reheat cracking. So in this case basically the weld joint is developed so it will be leading to the formation of some undesirable phases and when such kind of joint is again subjected to the higher temperature either during the stress relieving or during the service high temperature exposure leads to the development of crack.

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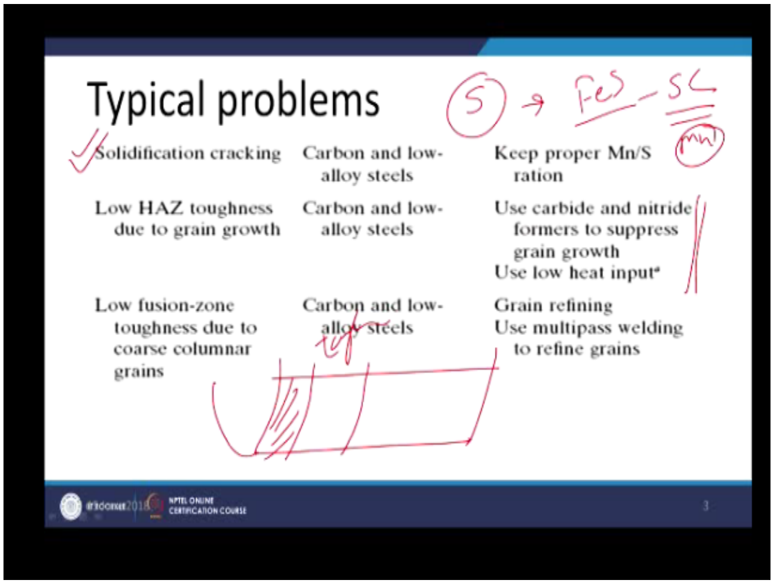

And that intern leads to the weldability of the metal , other aspects which govern the weldability of the steel is the solidification cracking like most of the steels have the sulphur which at during the welding forms the iron sulphide and increases the tendency for the solidification cracking. So the addition of the manganese is used for controlling the solidification cracking tenancy.

As I have explained that the heat affected zone and the weld metal also of the transformation hardening metals like it steels shows the leads to the formation of the course grained the martensite which leads to the reduction in toughness and increased embrittlement of the heat affected zone. So sometimes we require the post weld heat treatment to restore the toughness or controlled alloying also helps to reduce the the embrittlement or control the loss of toughness of the heat affected zone and of the weld joints .

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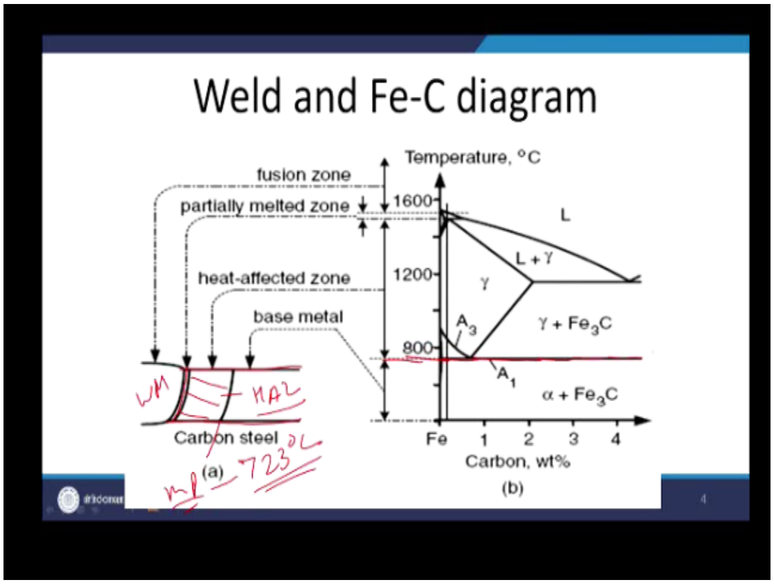

Now we will see the way by which the weld thermal cycle will be affecting are the microstructure of the steel next to the fusion boundary. So if say if we take up carbon steel is this so when the external heat is applied a part of the metal is brought to the molten state which forms the weld metal and next to that region will be experiencing the higher temperature due to the heat dissipation from the weld metal.

So that zone will be forming the heat affected zone, so this is the region which will be formed due to the rise in temperature in say carbon steels any time zone which is heated above 723 degree centigrade up to the melting point that zone will be galling in the heat affected zone and all the regions which are below this 723 degree centigrade in case of the carbon steels is which are not heated above this lower critical temperature line.

That will be in the base metals zone because it will not be affecting or experiencing the major changes in the properties. So in detail about the possible the phases phase transformation which are taking place in the steel due to the weld thermal cycle and followed by the rapid cooling which also will be reading to the various phase transformation.

So these aspect I will be talking in the next presentation, so I will summarize this presentation, in this presentation basically I have talked about the way by which the structural changes as well as the property changes in the weld joints of the transformation hardening metals can take place due to the wed thermal cycle and the mechanical history which will be experienced by them during the welding process, thank you for your attention.