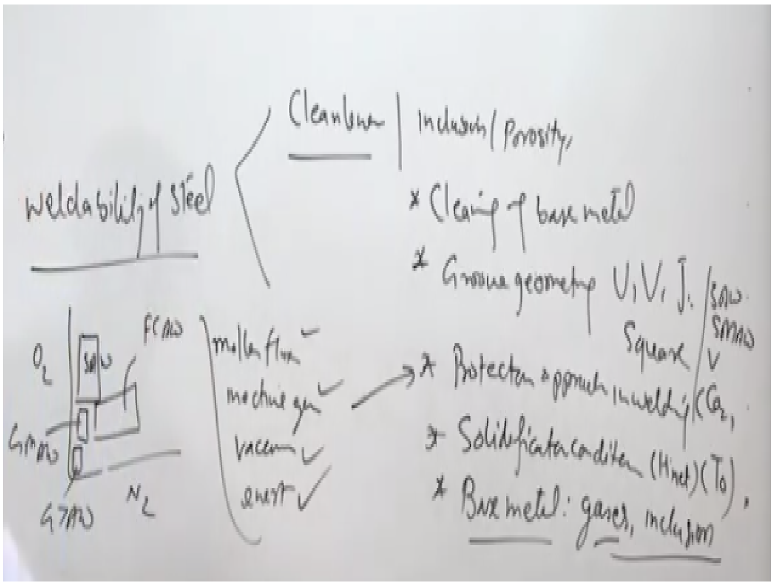
Joining Technologies of Commercial Importance
Dr. D. K. Dwivedi
Department of Mechanical and Industrial Engineering
Indian Institute of Technology – Roorkee

Lecture – 33
Weldability of Carbon and Alloy Steels: Fe-C, CCT

Hello, I welcome you all in this presentation. This presentation is based on the weldability of the steels and we will be talking about that what are the factors that matter for the weldability of the steels.

(Refer Slide Time: 00:32)



So weldability of steels, so as I have talked in the last lecture, cleanliness of the weld which is seen in terms of the may be say inclusions and porosity and this in turn is governed by the various factors like how effectively cleaning of the base metal is done faying surfaces of the base metal is done, what kind of the grove geometry is used, which will be U, V, J or single V, single U, double J or square like this.

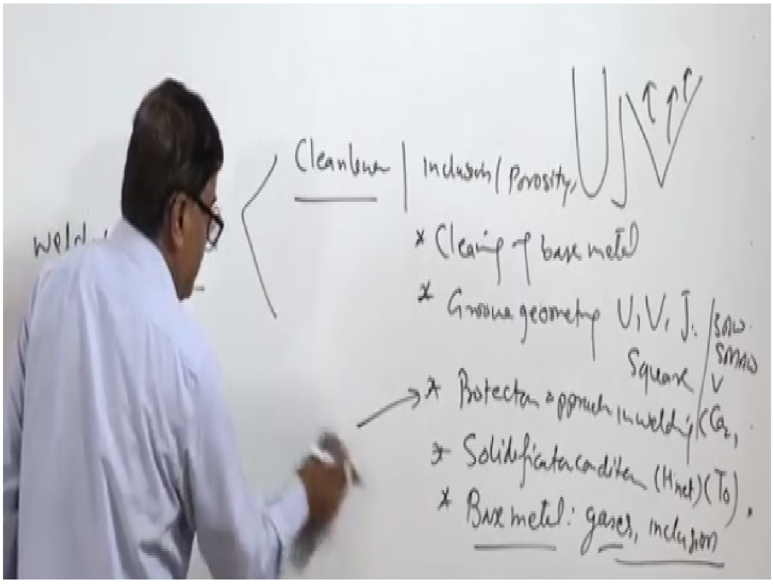
Then it is also affected by the kind of protection approach being used in welding, in a given welding process and in addition to this it is also affected by the solidification conditions and the base metal itself. Sometimes the base metal contains the dissolved gases or the impurities in form of the inclusions. So these are directly contribute towards the presence of the gases and inclusions in the weld metal.

Solidification conditions like the net heat input and the initial plate temperature, protection being used in a given welding process like the process is like its CO2, vacuum or simple SMAW kind of shielding is used, SAW kind of shielding is used. So depending upon the shielding approach we used for the shielding purpose like the molten flux like say SAW or inactive gases like in SMAW or the vacuum or inert gases.

So according we will getting the different kind of a the dissolved gases in the weld metal. We know the vacuum will be resulting in the best results thereof an inert gases, thereof an active gases and the molten flux will be producing the different amount of the gases in the weld metal and this what also we can see from this typical diagram when nitrogen content in x axis and oxygen contain in y axis.

So here the GTAW results in the minimum oxygen and minimum nitrogen and then we will see the GMAW process results in somewhat greater oxygen and greater amount of the nitrogen SAW causes further larger amount of the oxygen and nitrogen and then we will see the SMAW process. So SAW, GMAW, GTAW and likes self filled like FCAW processes.

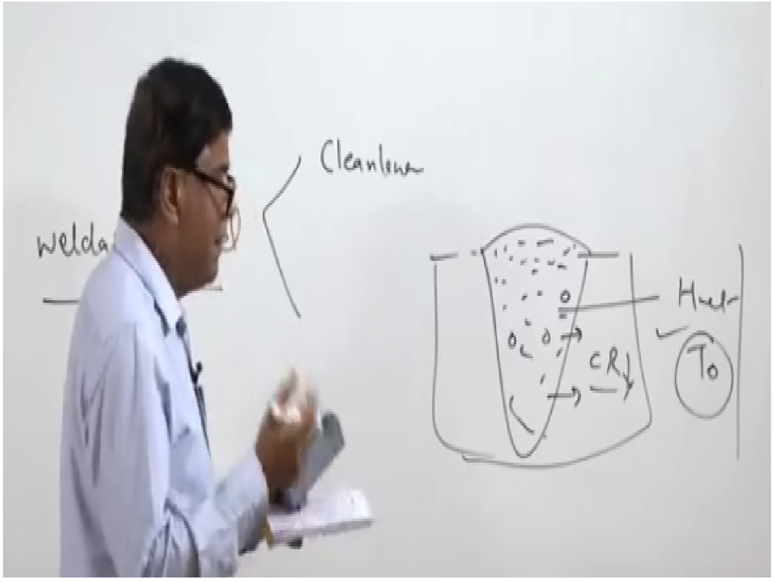
(Refer Slide Time: 04:23)



So these have since the production approach being used is different in different processes of the result in the different content of the oxygen and nitrogen in the weld metal. The group geometry the U, V, J, so the V grove geometry allows sufficient opening for the gases to come out as compared to the V and the J kind of the geometries then, we have the cleanliness of the weld.

If the base metal is not cleaned properly, cleanliness of the base metal is important like if the oil, grease, paint is left on the base metal surface or under the influence of the heat, these will be getting evaporated and get mixed up with the base metal with the base metal or weld metal and produce the inclusions and the porosity in the weld metals. So cleanliness of the weld metal is affected by number of such factors, which are related with the welding procedure and these need to be taken care of.

(Refer Slide Time: 05:13)

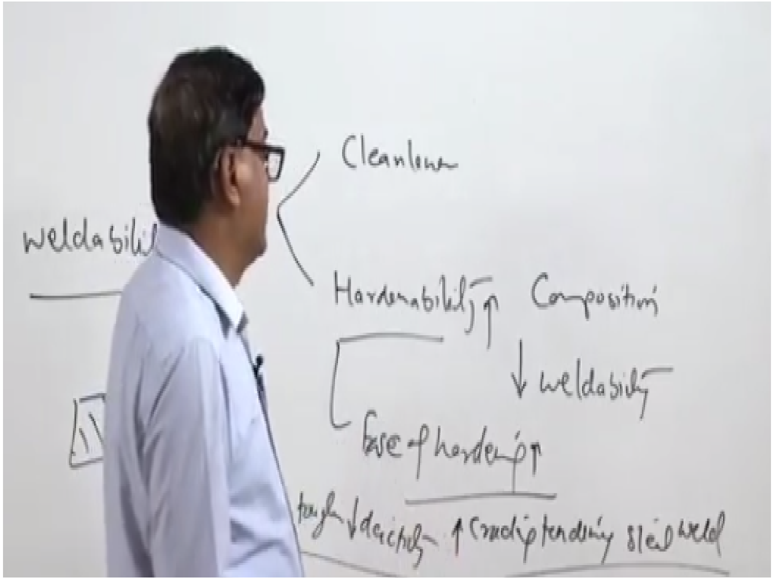


As far as the solidification aspect is concerned like if the weld metal is solidifying slowly then all the gases will be expelled tendency for an entrapment of the inclusions and the gases in the weld metal will be limited, but if the solidification is fast, then all these gases and inclusions will have greater tendency to get entrapped in the weld metal and thereby the cleanliness of the weld metal will be reduced.

So the solidification is governed by the H net and the T knot apart from thermal properties of the material. So greater the heat input, longer will be the heat, longer will be the time for the transfer of the heat. So solidification time will be long, solidification rate will be low because it experiences with the high heat input to the cooling rate experience is less. So it takes longer time for a solidification.

And this will allow, the sufficient time for these inclusions and gases to come out of the weld metal and thereby cleanliness will improve. The similar kind of effect is also offered by the initial plate temperature, if the initial plate temperature is high than cooling rate will be low and longer solidification time due to the low cooling rate will be resulting in the cleaner weld as compared to those cases where the solidification rate is high.

(Refer Slide Time: 06:32)



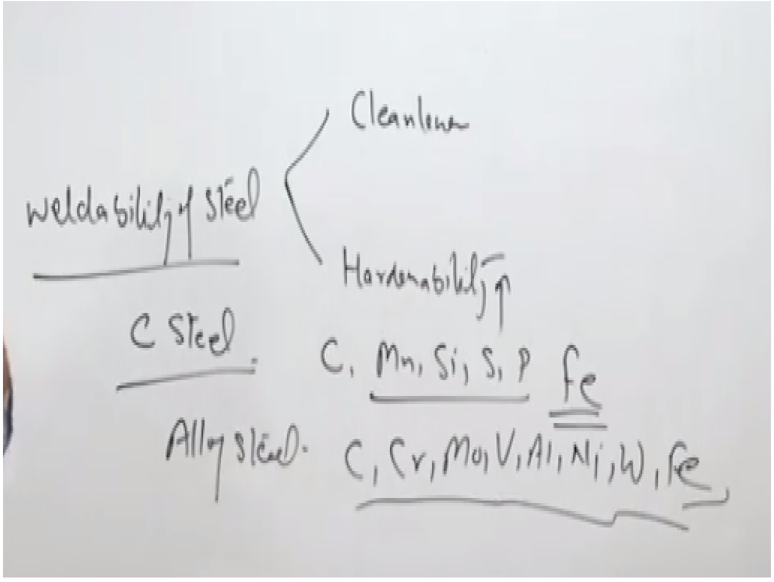
So solidification in general, reflects the kind of entrapment tendency and the inclusion entrapment tendency. Then another is the hardenability of the steel. This significantly affects the ease of welding of the steel. So hardenability of the steel is affected primarily by the composition. So in general higher the hardenability lower the weldability of the steel. So why this is so, hardenability is about the ease of hardening.

So like say is steel is hardenable if high hardenability then after austenitising when it is cooled, it forms easily the Martensitic structure and hardening of the steel. So ease of hardening is high, then it will result the hardening of a steel easily through the transformation of the austenite into the Martensitic easily and this will result in the high hardness reduced toughness, reduced ductility and all these tendency increased.

All these properties actually increase the cracking tendency of the steel welds and if the weld is made with the cracks then it is of no use, so it requires more preheat. So more efforts are required for preheating purpose, it will be more difficult to weld the preheated base plate as compared to the plate in the normal ambient conditions and that is why we will see that as the hardenability increases, the cracking tendency of the weld also increases.

And therefore we require more care to avoid the cracking of the weld and which in turn reduces the ease of welding or the weldability.

(Refer Slide Time: 09:15)



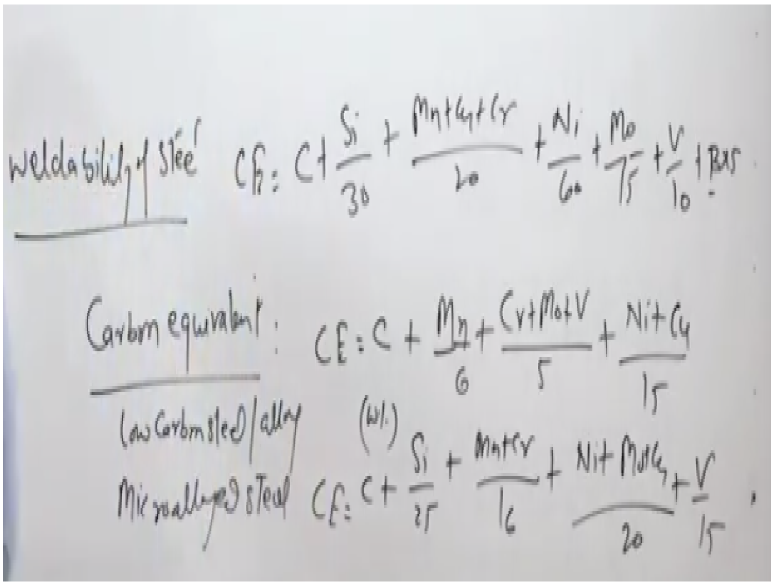
So the factors that affect the hardenability of the steel, one of the main factors that affects the hardenability of the steel is the composition. So for that purpose, steel composition, so what are the factors relate to the steel, compositions are the normal steel say, as I have said in typical carbon steel will primarily be having the carbon, manganese, silicon, sulphur and phosphorus where all these are the residual elements.

Apart from this the main element, the matrix is for the iron while in case of the alloy steels apart from the carbon, other alloying elements are also controlled like chromium, molybdenum, vanadium, aluminium, nickel, tungsten etc, all these are added intentionally for realising the specific set of the properties like the good toughness at low temperature or good resistance at high temperature.

So higher yield strength at elevated temperature or greater resistance to the softening at a higher temperature etc so there can be various kinds of the requirements for which specific set of the alloying elements are added and each alloying element offers a unique kind of the effect as far as the welding is concerned, so in which way these alloying elements will be affecting the hardenability.

So will see that to see actually the hardenability concept we need to see the DDD diagram and CCT diagram and for that purpose, those diagrams will be seeing slightly later. First of all, we will see that from the composition point of view, how the hardenability is affected.

(Refer Slide Time: 11:07)



So to since, there are various alloying elements in the steels, so effect of all alloying elements on the hardenability of a steel is checked using the one common term which is called carbon equivalent. Carbon equivalent is one parameter which is obtained by considering the relative effect of all alloying elements present in the steel which are having the effect similar to that of the carbon.

So the most common equation which is used for the low carbon steels and alloys steels is like this, so CE, CE basically one parameter which considers the effect of all alloying elements on the hardenability. And so these CE is basically is related to the hardenability and CE reflects that in which way different alloying elements will be behaving like carbon.

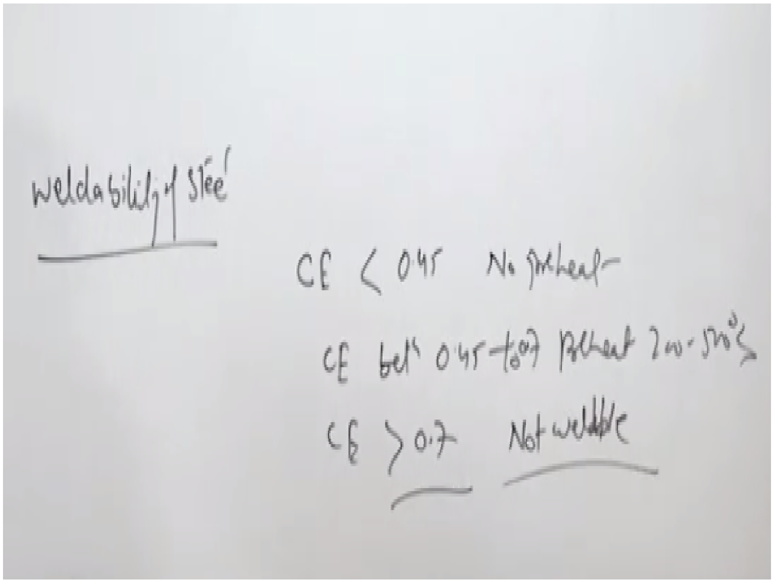
That is why it is called carbon equivalent. So here carbon is added as a it is manganese divided by 6 + chromium, molybdenum, vanadium divided by 5, nickel + copper divided by 15. So this is one typical equation which is commonly used. So all these alloying elements are kept like this so here like the weight percentage present in steel is used to determine weight percentage of each of these elements present in the steel is used to calculate the carbon equivalent.

So this is one typical equations. Another equation which is used for the micro alloyed steel to determine the carbon equivalent goes in like this where in CE = C + silicon divided by 25 + manganese chromium divide by 16 and nickel, molybdenum, copper divided by 20 and then vanadium divided by 15.

So this is another equation and they are likewise there are other equations also which are used like there is another equation for calculating the carbon equivalent that goes in like this where in CE = C + silicon divided by 30 + manganese copper chromium divided by 20, nickel divided by 60 molybdenum divided by 15 and vanadium divided by 10 + boron multiplied by 5.

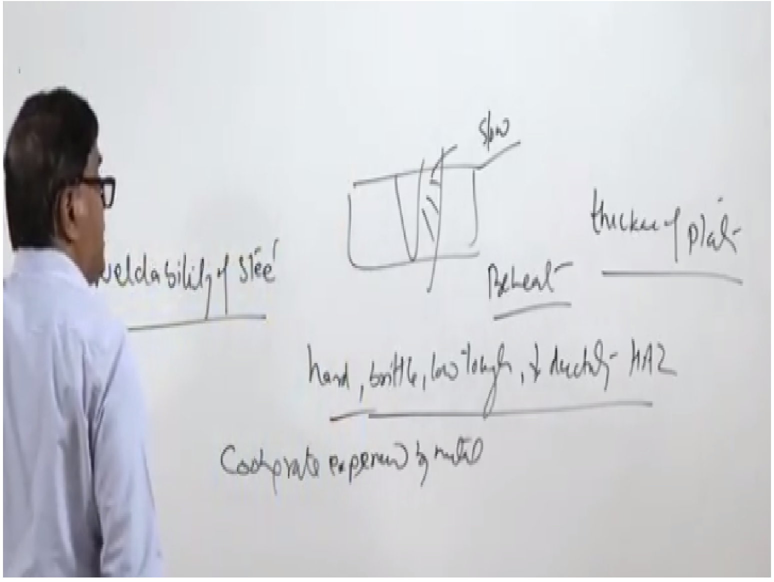
So here weight percentage of each of the alloying in the steel is put in these equations to calculate the carbon equivalent and the carbon equivalent the calculated based on the composition is related with the ease of welding. Since the carbon equivalent directly affects the hardenability and the hardenability of the steel determines the cracking tendency of the steels which in turn governs the kind of efforts required for waiting the cracking in terms of the preheating or trigger during the welding.

(Refer Slide Time: 15:33)



So the carbon equivalent is related with the ease of welding and which we can see from the thing like if the CE carbon equivalent is < 0.45 then no preheat is used and if the carbon equivalent is between 0.45 to 0.7 then preheat of 200-500 centigrade is used as per the carbon equivalent and if the carbon equivalent > 0.7 then the steel is found to be not weldable because it will impose lot of cracking issues and the joint will not be good.

(Refer Slide Time: 16:38)

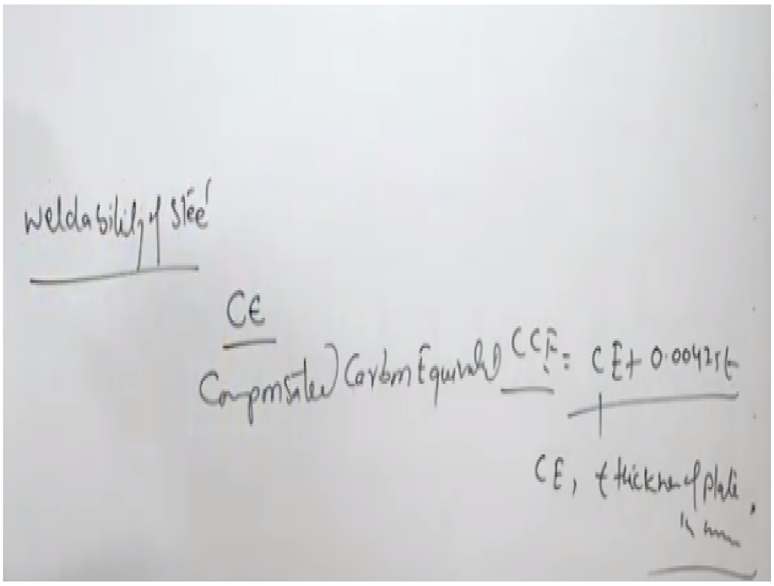


So the difficult to weld or not weldable above 0.6. In addition to this, the cracking tendency which is due to the development of the hard, brittle, low toughness, low ductility, HAZ. So since the hardenability leads to these things so and this happens primarily due to the kind of the cooling rate experienced by the metal especially in heat affected zone for example, like this the weld is made.

So if the heat affected zone experiences the low cooling, slow cooling rate wherein slow cooling than the hard, brittle, low ductility and low toughness, HAZ is not formed. So to facilitate this especially preheating is done but the cooling rate being experienced by the heat affected zone is affected by the thickness of the plate also.

So thickness, if the plate is very thin, the cooling rate will be low and in that case hard, brittle and the low ductility HAZ may not form. So that may not have the cracking tendency otherwise that is why the carbon equivalent in addition to the carbon equivalent sometimes the thickness of the plate is also considered for determining the possible hardenability or the cracking tendency.

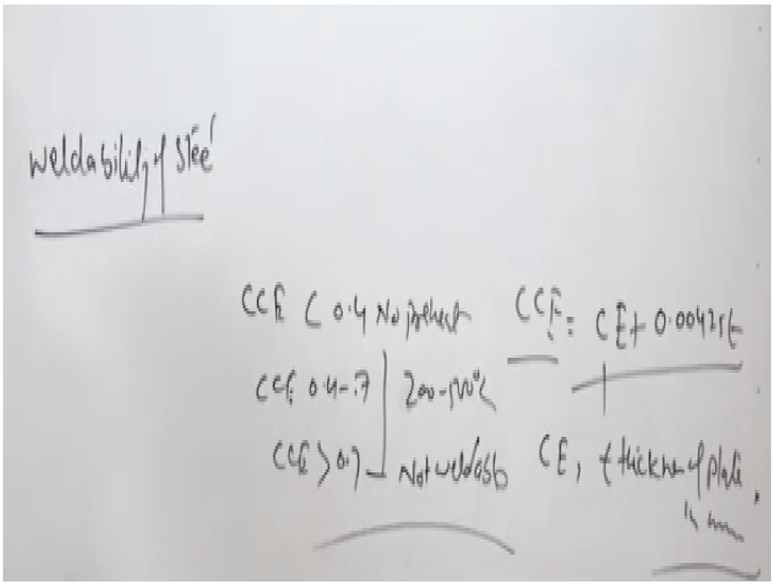
(Refer Slide Time: 18:23)



So for that purpose instead of using just carbon equivalent term one additional term like compensated carbon equivalent is calculated. So this is written as CCE, compensated carbon equivalent which considers the normal carbon equivalent as it is plus the thickness of parameter is also considered 0.00425t. So this is an empirical equations only which considers the thickness of the plate.

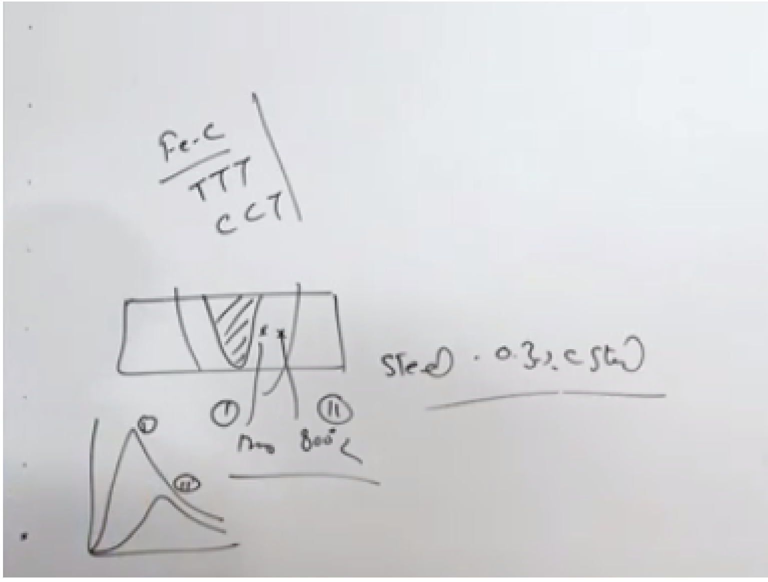
So CE stands for simple carbon equivalent and t is the thickness of the plate in mm. So obviously, even for the steel of the given composition if the thickness of the plate increases than it will be increasing the other compensated carbon equivalent and for the compensated carbon equivalent the different kind of the scheme or the broad guidelines are used as far as preheat is concerned.

(Refer Slide Time: 19:34)



So for the CCE, < 0.4 no preheat is used and the preheat for CCE in range of 0.4-0.7, the preheat from 200-500 degree centigrade is used and CCE > 0.7 steel is not weldable, this is how in general we can relate with the weldability of the steels or the kind of precautions that we need to relate the carbon equivalent or the compensated carbon equivalent with the ease of welding or the weldability of the steels.

(Refer Slide Time: 20:27)

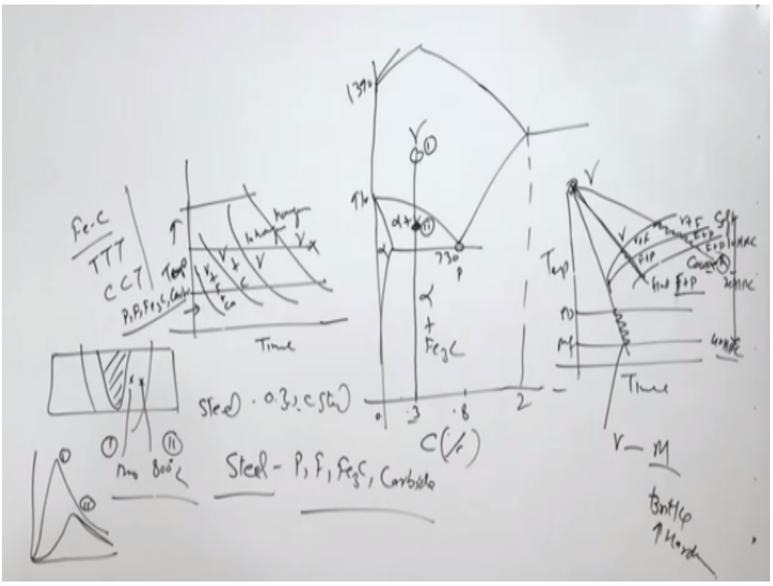


Now we will see that, now sequentially we can go through to understand in which way the steel composition can affect the ease of welding. So for this we need to see certain diagrams like iron carbon diagram and TTT diagram and CCT diagrams. I will try to summarise all these in one of a using this approach where like say this is a given steel for example, 0.3% carbon is steel or we may consider like 0.8% carbon is still anything.

So when the steel is welded, so this portion will be reaching to the molten state and the areas close to the weld reaching to the different temperatures like say 1200 degree centigrade, 800 degree centigrade etc. And we know that different points will be experienced in the different weld thermal cycle like this. So for 0.1 and for point 0.2 the weld thermal cycles are like this, 0.1 and 0.2.

So the 0.1 will be experiencing the greater temperature for longer duration as compared to the 0.2, 0.2 will be experienced lower temperature as compared to the 0.1. Now what kind of changes will be taking place at the 0.1 and what kind of changes will be taking place at 0.2 during the heating and during the cooling that is what we will try to understand from this iron and carbon diagram.

(Refer Slide Time: 21:55)



If you know like say this is 0.8% carbon like this and here like say 0 and this is the temperatures, so here like this, this is 910, this is 730 degree centigrade and say 0.3% carbon is still is somewhere here. So this is the gamma loop here we have 1390 degree centigrade, like this so here we have the gamma loop like this, this is corresponding to the 2% of the carbon is still like this.

So this is our, the gamma zone, this is alpha + gamma, this is alpha, this is alpha + FE3C zone. This is eutectoid point right. So here we will have just the per light and this is the uniform zone. So when the 0.3 is heated obviously the 0.3 is heated say up to the 1200 degree centigrade. So the 0.3 will be experiencing the changes like this. So here the 0.3 will be subjected to the austenitic state and since the cooling rates are quite highest compared to the 0.2.

So while the 0.2, there is the 0.2 will be heated. So for same 0.3, so this if for 0.1 and 0.2 will be heated to two phase zone like say this is the maximum temperature for 0.2. So 0.1 is being heated for much higher temperature for longer period while 0.2 is being heated just up to 800 degree centigrade for shorter period. So how does it matter, for this we need to see this diagram which shows in like how the time is affected as a function of temperature for homogenization.

So here in y axis we have temperature and in x axis we have time. So how does it happen like say first of all our pearlite transforms into the austenite. Here say what we have pearlite, ferrite, FE3C and then carbonates if they are there in the steels. So as per the composition is steel and alloy steel in the room temperature conditions will have pearlite, ferrite or cementite and then carbonates if they are.

So first of all, pearlite transforms into the austenite. So here we have pearlite and all these phases in this area and as the heating continues at a high temperature then what we get our pearlite transforms into the austenites. So we get austenite + ferrite + carbonates all these things. If heating continues for high temperature for long, then ferrite transforms into the austenites.

So we have austenite + carbonates. If further heating continues for long then what will have only the austenite, but this is inhomogeneous. Wherever carbon content is high that will have the higher concentration of the carbon as compared to the other areas. So this is inhomogeneous austenite and if the heating continues for further long then we will be having the homogeneous austenite.

So if you see this diagram to have the homogenous austenite it takes long and if it is just the plane carbon steel, then it is much time it will take because in this case we will not have the carbonates. So it takes long if the temperature is high it takes short, if shorter period to have the homogenous austenite and if the temperature is low then it takes long. This is what I am trying to tell the 0.1 experiences higher temperature, it requires shorter period to have the homogeneous austenite.

And once we have homogenous austenite then only it will offer the desired structural transformations as per the cooling rate being experienced. So the 0.1 will be experiencing the higher cooling rate as compared to the 0.2. So the what metals here is that the temperature up to which any particular point in the heat affected zone is heated that is important and then how long it is kept under those temperature conditions that also matters.

It is the homogeneous austenite formation which is important for its transformation into the various phases as per the continuous cooling diagram. So if you consider the continuous cooling diagram for this phase and what will have this one like this. So in case of the continuous cooling diagram this is say time, this is temperature and this is time, here this is the nose.

So our austenite which is homogenous at high temperature as per the cooling rate here it transforms in this zone. So what are these zone, this is homogenous austenite region, here will have MS and MF zone Martensites start and Martensites finish temperatures. So here as per the cooling rates say cooling of 1 or cooling rate A. Cooling rate A is slow, so here austenite first transforms into the proeutectoid ferrite. So here will have austenite + ferrite.

And then remaining austenite will be transforming into the ferrite + pearlite. So here basically will have ferrite + pearlite, which is very fine. This is very coarse because cooling rate is very slow. If you use higher cooling rate like this, so here also austenite + ferrite here ferrite + pearlite and then here transformation will complete, transformation austenite into the pearlite will complete and here will have fine ferrite + pearlite in this area.

If the cooling rate is really fast, then we will have whole transformation of all austenite into the Martensite and will get the complete Martensitic transformation. So as per the cooling rate, if the 0.1 is very close to the fusion boundary, it will be experiencing the higher cooling rate, so it may change, it will be the homogeneous austenite and the higher cooling rate conditions austenite may transform into the Martensite.

So the Martensite transformation will be brittle and it will be leading to the high hardness. On the other hand, the 0.2 is away from the fusion boundary, it experiences the lower cooling rate. So lower cooling rate as per the cooling rate it may have the fine ferrite or pearlite or it may have core ferrite and pearlite. So in this diagram if you see here this will be a trend of increasing hardness initially we get the soft like say 10HRC, 20HRC.

And after the hardening, we may have like say 40HRC. So as the cooling rate increases, our hardness keeps on increasing and this happens due to the structural transformation from the austenite to the ferrite and at the same time, the refinement or the grain size is also affected. So this is how we can relate the weld thermal cycle being experienced by the heat affected zone and the iron carbon diagram how the austenite transformation takes place.

And then when the two different points cool at different rates, what we get at the room temperature subsequently on cooling. So here the high cooling rate results in the Martensitic transformation which makes the heat affected zone very brittle and of the low toughness while the pointed 2 which is away from the fusion boundary experiencing the lower cooling rate, lower peak temperature that will be having either ferrite, fine ferrite and pearlite or it will have the coarse ferrite and pearlite.

And so accordingly it will have its effects on the properties of the heat affected zone. So now here I will summarize this presentation. In this presentation I have talked about how the different alloying elements affect the ease of the welding or the weldability of a steel and how the carbon equivalent can be related with the weldability and in which way the properties of the heat affected zone can be related or can be understood using the iron carbon diagram and continuous cooling diagram. Thank you for your attention.