Weldability of Metals
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Lecture-10
Weldability of Metals:
Combination of Strengthened Mechanisms

Hello, I welcome you all in this presentation related with the subject weldability of metals and you know we have talked about the weldability of the metals strengthen by the various mechanisms. Like solid solution strengthening, grain refinement, precipitation hardening, dispersion hardening and transformation hardening. And responses of the weld thermal cycles as well as the plastic deformation associated with the deformation based joining processes is different on each metal system.

But any metal system which is being welded will have the effect of the various strengthening mechanisms. It is not just the single strengthening mechanism which will be offering the required combination of the mechanical properties to the metal.

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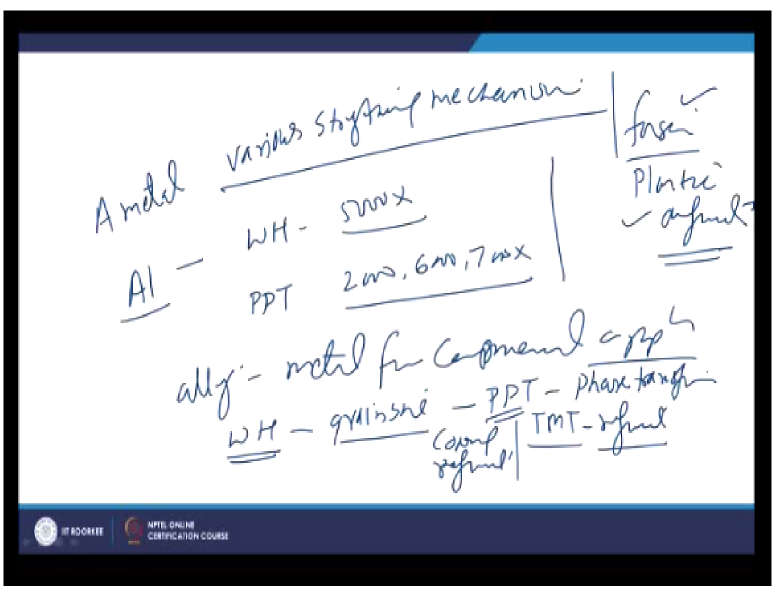

So, a metal basically comprises the effect of various strengthening mechanisms. So, if that is the case then what with the net set of the properties which will be achieved on fusion welding or on the plastic deformation based welding processes. So, let us take like simple aluminium in aluminium we have like work hardenable metals of 5000 series aluminium alloy.

And precipitation hardenable metals of 2000, 6000 and 7000 series aluminium alloys responses to the fusion welding as well as deformation of these metal systems will be different. And that is what we have talked under the different categories but whenever we make any alloy or metal for commercial applications it will have the combined effect of the various mechanisms which will include like the work hardening mechanism.

Due to the set of the manufacturing processes which are used to give the desired size and shape like cold rolling, forging etc. or wire drying are being performed in the metal to give the desired size and shape. So, they will have the work hardening effect whether it is designed for that or not whether the metal has been strengthened by that mechanism or not whenever there is work hardening or controlled thermal cycle application during the manufacturing there will be the grain size variation.

So, there may be the coarsening or there maybe the refinement of the grains, for example low cooling rate experience during the casting will be leading to the coarse structure. While the higher cooling rate experienced during the welding in the weld metal will be leading to the fine grain structure. Or in case of the thermo mechanical treatment, the refinement of the grain structure is achieved.

Apart from the grain refinement like in some of the steel is strengthening is realized through the formation of precipitates. So, it is also possible that the metal is having the effect of some of the precipitates or some of the phases which are being realized through the controlled phase transformation. So, I mean to say a metal may have the effect of the combination of the various strengthening mechanism at the same time.

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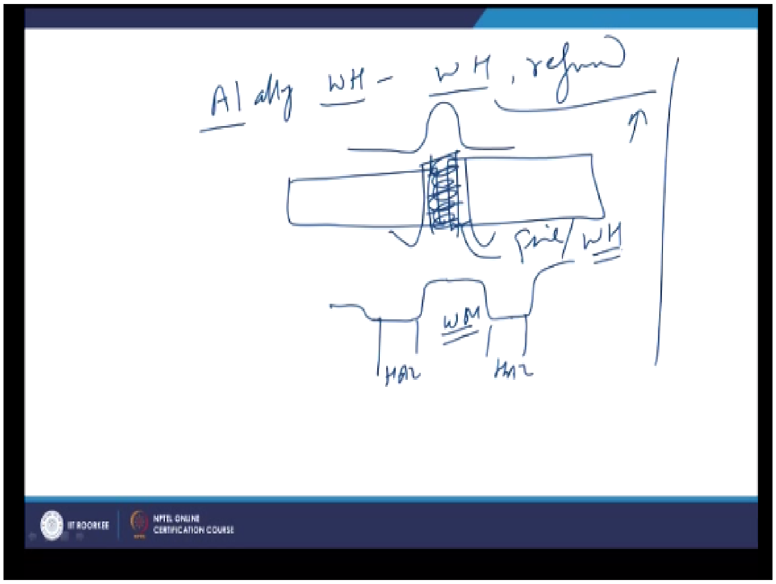

So, which effect will dominate in determining the final properties of the metal that is important to talk about like if we take a simple metal which is aluminium alloy of work hardening type, so sometimes what we see whenever material is deformed in very controlled way plastically. So, it is work hardened as well as it is refined and which has in increasing the mechanical properties and hardness of the weld zone systematically. So, if we see this one like the weld metal subjected to the control plastic deformation for developing the joints.

So, the zone which is experienced the plastic deformation will be offering the higher hardness and the strength. While there may be softening in the nearby zone due to the loss of the work hardening effect due to the heat generated during the welding process. So, there may be hardening of the weld metal and at the same time there may be softening of the heat affected zone, so weld metal and softening of the heat affected zone.

So, this is Hz region and this is Hz region and weld zone on the other hand what has been observed, so this is the case of the work hardening effect where both fine grain structure as well as the work hardening effect will be imparted.

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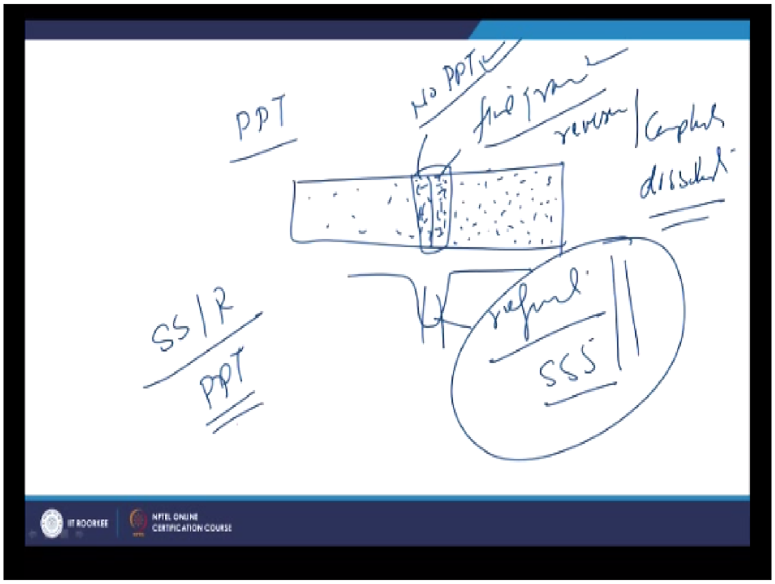

On the other hand if it is the precipitation hardenable aluminium alloy which gets it is strength from the formation of fine precipitates. So, controlled plastic deformation of the weld metal near the faying surfaces will be leading to the very fine grain structure. But the fracturing and the control plastic deformation followed by the high heat generation leads to the reversion and complete dissolution of the precipitates.

So, here this region has no precipitates but very fine grain structure in this situation if we try to just see the properties of the weld nugget area. Then we will notice the despite of the refinement there has been sharp drop in the weld metal hardness and weld metal strength. So, here there is a contradiction like despite of the refinement we are getting the reduction in strength.

Because this metal was primarily design to have the strength from the precipitates and if these precipitates have got dissolved. So refinement and solid solution strengthening will not be contributing that much as it was designed for the precipitation hardening. So although dissolution will be leading to the solid solution strengthening and the fracturing and refinement of the particles will be leading to the grain refinement.

But despite of combination of these 2 strengthening mechanism major factor which was contributing to this kind of the metal system was the formation of the precipitates. And if these precipitates have lost that will be losing the hardness will be losing the strength of the joint. So, this is the case where like solid solution is strengthening and the refinement are not working at all. It was the formation of the precipitates that was primarily responsible for the strength of such kind of metal system.

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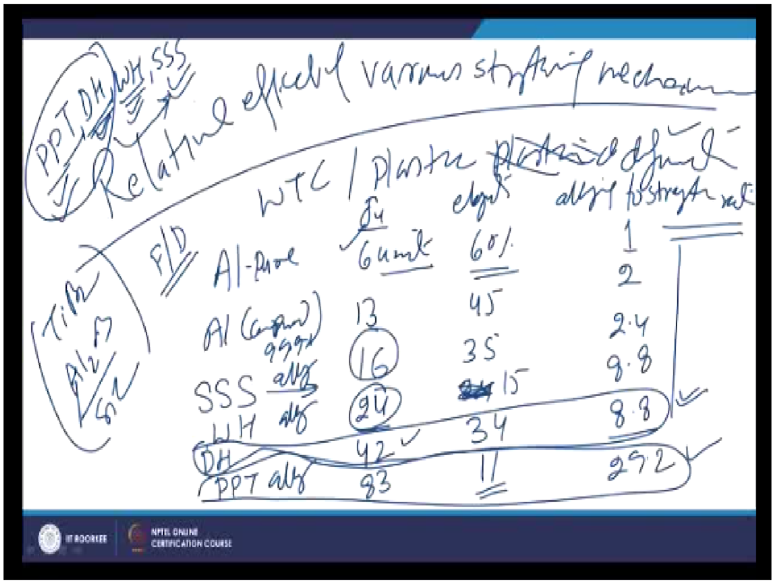

So, that is why it is necessary to see the relative effect of the various mechanisms how the relative effect of the various strengthening mechanisms. And how these respond to the weld thermal cycle or the controlled plastic deformation during the plastic deformation during the welding. So, just for an example I will take initially then example of the aluminium like when pure aluminium is used.

The UTS sigma U ultimate strength in maybe unit we can understand it is the relative value, so strength is say 6 units and the percentage elongation is 60%, the 60 units and the alloying to strength or yield strength ratio is 1, there is no alloying and a strength is minimum for this system and if we take aluminium of commercial purity which is 99.9% pure, the strength will be somewhat higher due to the presence of these impurities say 13 units.

And the ductility will be lower say 45 units and the alloying or impurities to the strength ratio will be somewhat high say 2. If we talk of the another when the aluminium alloy is strengthened through the solid solution strengthening approach by control alloying. There is further increase in the strength or higher strength is realized of the 16 units as compared to the pure aluminium of 6 units and the ductility is somewhat reduced whenever there is a increase in strength there will be loss of the ductility as well as the toughness .

And the alloying to the strength ration here is 2.4, if the aluminium alloy is strengthened through the work hardening approach, work hardening alloy. Then the strength is 24 unit and the % elongation is 15% and the alloying to the strength ratio is 8.8. Then dispersion hardening like the addition of the Al_2O_3 or silicon carbide or TiB_2 or some other alloying some other reinforcing agents are reinforced in the aluminium matrix.

Then the significant higher strength can be realized of the 42 units with the reasonably good percentage elongation of the 34% and with the high concentration of the alloying element to strength ratio 8.8. And dispersion sorry precipitation hardening the aluminium alloy when deign to get the strength from the formation of the precipitates. Then very significant increase in the strength is realized of 83 units with the elongation% of the 11 and alloying to the strength ratio is 29.2.

So, for unit alloying the kind of the strength increase which is observed in precipitation hardening is maximum and then somewhat lower for others. So, if we see the effectiveness of the alloying through the precipitation hardening for increase of strength is maximum for the last approach which is precipitation hardening alloy system. And then the effectiveness is somewhat lower for the dispersion hardening system like this.

Strength of 42 units is realized and like say the strength increase in a strength for unit alloying is of 8.8 somewhat further lower effectiveness is observed in case of the work hardening and solid solution strengthening. So, if we see this one effectiveness is maximum of the precipitation hardening and then dispersion hardening then work hardening and then solid solution strengthening.

So, during the welding either by the fusion welding or by the deformation based approach if there is a loss of the precipitates then it will leading to the maximum softening. Similarly if there is loss of the dispersed constituents either they are due to the fracturing or their dissolution, then these will be causing the further severe loss of the hardness. Thereafter the loss of the work hardening effect due to the recovery and annihilation will be again leading to the reduction in strengthen hardness, minimum effectiveness is there of the solid solution strengthening.

So, whenever there is loss of precipitates or the dispersed wise present in the aluminium alloy and leading to the development of the either work hardening or the work hardening effect or the solid solution effect. Their effectiveness is limited and that is why we will notice either during the fusion welding or during due to the deformation, loss of precipitates or loss of the dispersed wise will be leading to the softening.

So, despite of the refinement, despite of the solid solution strengthening in case of the precipitation and dispersion hardening alloys, there is a loss of strength loss of hardness. So, this is the net effect for the aluminium alloys and the magnesium alloys which are precipitation, strengthened.

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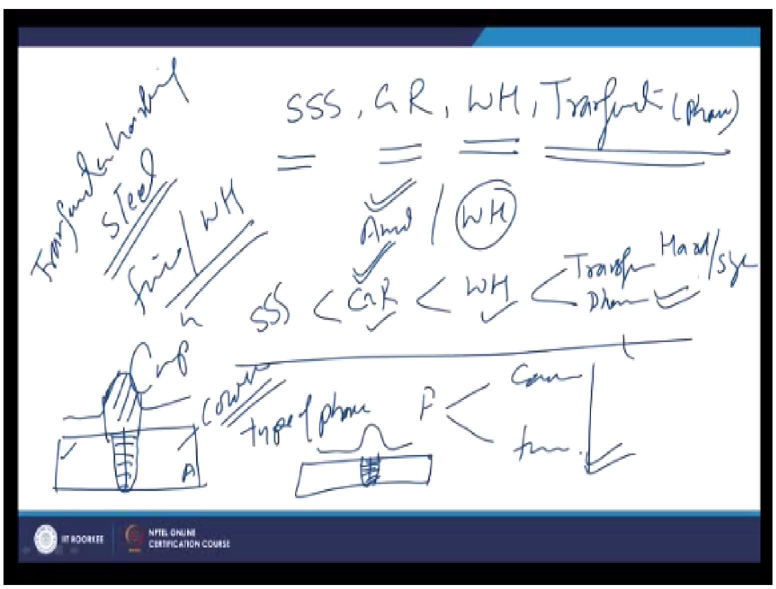

Now we will see the another case where like say the transformation hardening systems like steels or ferrous systems. So, in these cases the strength is offered of course through the solid solution strengthening, grain refinement, work hardening, transformation hardening like the kind of the kind of the phase is which are being formed. Again the effectiveness is maximum even for a given composition if we see the effectiveness of the work hardening is transformation hardening is maximum.

Then somewhat lower for the work hardening further lower for the grain refinement and further lower for the solid solution strengthening. So, as for as increase in the strength and hardness is concern the maximum effectiveness of the transformation hardening systems come from the phase transformation. Then work hardening, then grain refinement and then solid solution strengthening and that is why sometimes we will notice that if the type of phase is same type of phase is same which is like say the ferrite.

So, if the ferrite is coarse and ferrite is fine then of course the fine ferrite will be leading to the better properties as compare to the coarse ferritic structure. But if the metal has been subjected to the annealing and on the same as also means subjected to the work hardening. Then the work harden metal will be offering the better properties as compare to the annealing even if there is no change in the phases.

Say for example if annealed steel is subjected to the welding through the plastic deformation approach, so it will have the work hardening effect in the weld zone while in other regions there will be annealing the base metal minimum effect of the minimum hardness and the lower strength. So, if we plot the variation in the hardness for the annealed base metal, annealed steel then in the weld zone it will be offering the greater hardness.

Due to the work hardening effect as compare to that of the annealed zone obviously annealed zone will have the annealed base metal have the coarse structure while the plastically deformed or work hardened metal will have the fine grain structure as well as the work hardening effect. For the same conditions, same phase fine grain structure will be offering the higher properties but if despite of the fine grain structure if the metal has been work hardened.

Then it will be offering the better properties like instead of annealing if we take the example of normalizing which of the finer grain structure. But if we go for work hardening then work hardening during the deformation during the welding then it will be offering us the better mechanical properties. So, we suggest that work hardening is more effective than the grain refinements. Sometimes despite of the coarser grain structures we get the higher properties that is the case of the phase transformations.

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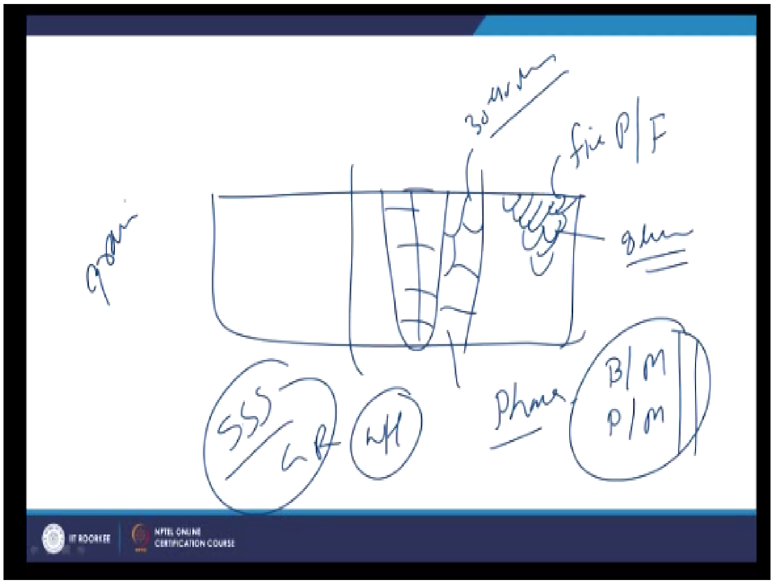

Like in a steel like say the steel the base metal is having very fine grain structure in form of fine pearlite and the ferrite. Average grain size is say 8 micro meter and due to the welding like say either fusion welding or the deformation based process heat generated leading to the coarse grain structure in the heat affected zone. So, this coarse grain structure maybe leading to the very coarse grains in the heat affected zone and say like 30 to 40 micrometer.

But since the phases being formed are like say the phases are different, now we may have the bernette, martensite of pearlite martensite mixture. Despite of having the coarser grain structure since these phases are harder than the simple ferrite and pearlite structures that is why we will be getting the greater hardness and greater strength in the heat affected zone

So, the grain size and work hardening is not that effective as the kind phase transformation because the phases being formed will be able to regulate the mechanical properties in bigger way. As compare to that of the simple solid solution strengthening or the grain refinement or the work hardening. So, work hardening will also be not effective if there is no phase transformation in such kind of the metal systems.

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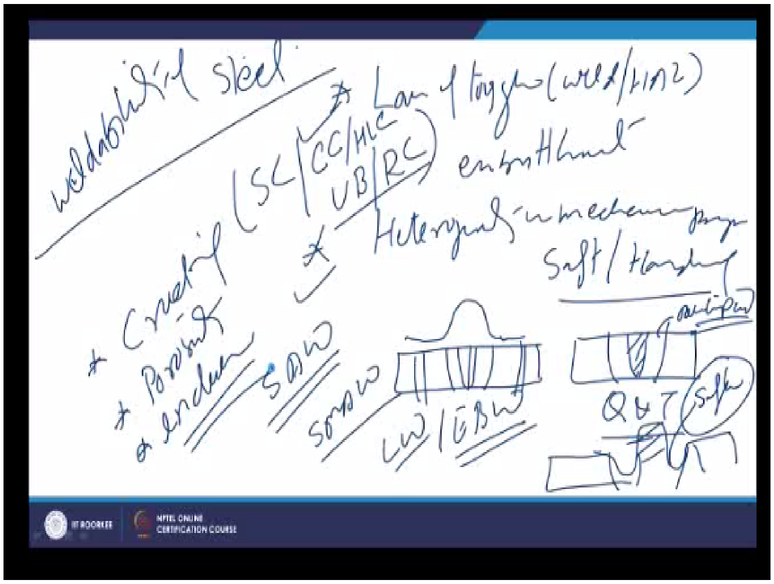

Now we will see what kind of the basically in the weldability of the metals we have to talk at length about the weldability of the ferrous systems. So, which primarily comprises the weldability of steels. So, the steels during the welding primarily suffer from the loss of toughness of the weld as well as heat affected zone, this is called embrittlement, so their ability to sustain the impact loads is reduced drastically.

Another one lot of heterogeneity in mechanical properties is observed which can be there in both form like softening as well as hardening. Mostly it is hardening which is observed but in some of the categories even softening is observed. I will give examples of both like in most of the steels will see the weld zone as well as heat affected zone experiences the martensitic transformation.

And therefore both the zones offer the higher hardness as compare to the base metal that is why failure mostly occurs from the base metal not from the Hz and the weld zone. But if the steel is in the Q and T conditions then we will notice that due to the higher cooling rate during the welding. The weld zone inferably experiences the martensitic transformation and so the higher hardness but the zone next to the weld metal is over tampered.

And that is why this zone experiences the loss of hardness, so the base metal is having higher hardness but as we approach to the heat affected zone hardness is reduced. Then in the weld metal again hardness is increased then hardness is reduced, so the reduction in hardness adjacent to the weld metal and away from the this adjacent to the weld metal which is the heat affected zone, this loss of hardness or which we can say the softening is basically attributed to the over tampering of the steel.

So, this kind of over tampering is more if the steel is welded by the SAW or SMAW processes. And even in the high this is also observed in case of the laser welding and electron beam welding process where in a energy density is very high and limited heat is used for the fusion of the metal. So, apart from these 2 factors governing the weldability like the cracking tendency in form of solidification cracking, cold cracking or hydrogen induced cracking and under bead cracking, reheat cracking.

These are common cracking's which are observed in the steel under the different conditions and so these also affect or determine the ease of welding of a steel significantly. And the low carbon steels, low alloy low carbon steels having the higher melting point they also show the tendency of the porosity development and inclusions in case of the rolled steels. So, now we will go through the different category of the steels which are commercially used and from the welding point of view how these are categorized.

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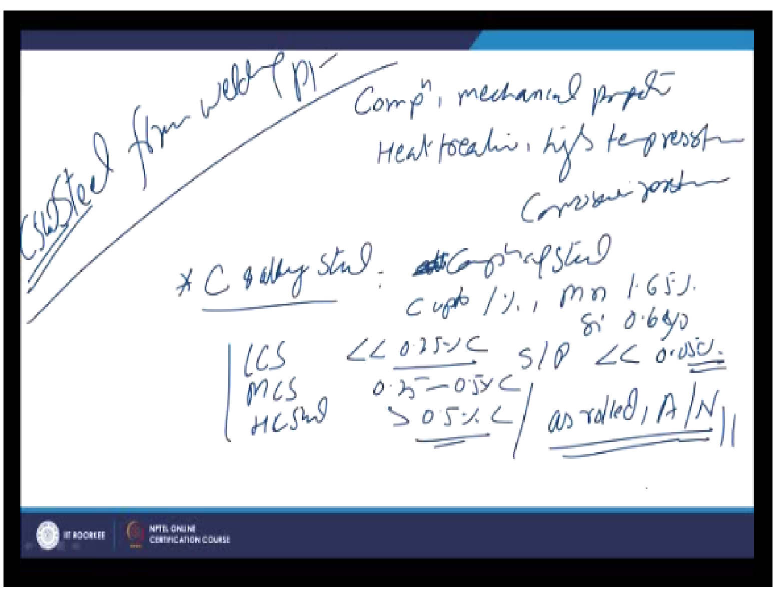

So, the steel categorization, steels basically these are carbon steel categorization from the welding point of view. So, there this categorization is based on the composition mechanical properties, heat treatment, ability to withstand at a high temperature. So, high temperature resistance and corrosion resistance these are 6 categories, corrosion resistance or corrosion protection.

So, the grouping of the steels from the welding point of view is about the carbon or low alloy steels. This grouping is primarily based on the alloy sorry the composition of steel, carbon steels primarily comprise the carbon up to 1% with the manganese 1.65% and silicon 0.6%. While the sulfur and phosphorus concentration is maintain below 0.05 level higher concentration leads to the increased tendency for the solidification cracking.

So, the steels based on this like the low carbon steel or the medium carbon steel or high carbon steels. So, low carbon steels like those having less than 0.25% carbon, medium carbon steel like 0.25 to 0.5% carbon and those having the carbon greater than 0.5% will be falling under the high carbon steel category. And most of these steels are used in as role conditions annealed or normalized condition.

Since the heat treatment condition of the steel significantly governs the weldability that is why it is important to know about the condition of the steel or heat treatment condition of the steel.

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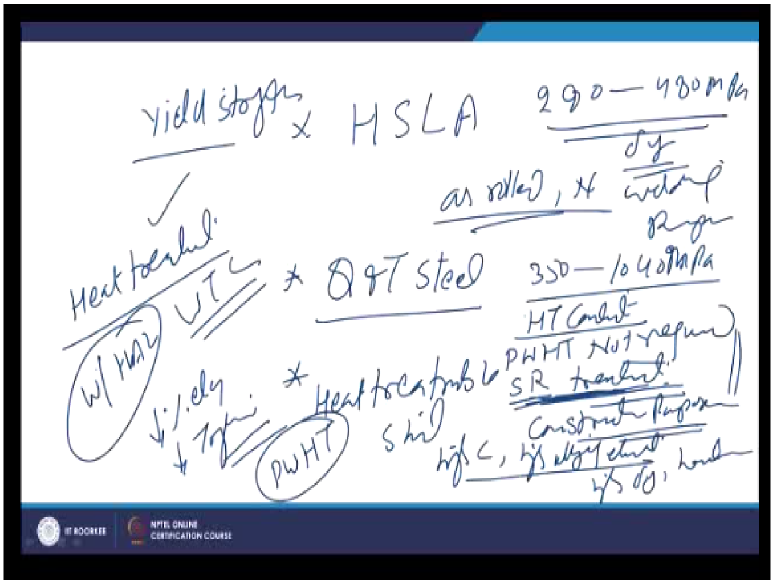

Another grouping is based on the minimum yield strength or the mechanical property which is called HSLA high strength low alloy steels. High strength low alloy steels these are designed to have the strength from about 280 to 480 mpa there is a minimum yield this is the yield strength range for which these are designed by the controlled addition of the alloying elements and these are mostly used in form of the in the as rolled condition**,** normalized condition for the welding purpose .

Then third grouping is based on the heat treatment aspects , so they are 2 categories of the steels in this group 1 is the quenched and tampered steel. These steels are obviously they these are quenched followed by tampering, so that higher strength range can be realized in this category and they are designed to have the yield strength from 350 to about 1040 mpa. And mostly these are welded in the heat treated condition Q and T conditions.

And PWHT mostly is not required for these steels and if at all some kind of the PWHT is needed. Then that is primarily done for the stress relieving treatment. And therefore since the PWHT mostly is are not required for this purpose and therefore these are mostly use for the construction purposes where heavy structures are to be design to be made then Q and T steels are used.

Because subsequently these do not require extensive PWHT for enhancement of the mechanical properties but these sometimes the stress relieving is needed in order to avoid in order to reduce the residual stresses. Then there is heat treatable steels they have the higher carbon content then the HSLA and the Q and T steels and higher alloying concentration, alloying elements. So, these respond very good to the heat treatment, of course they offer high strength and high hardness.

But of course this will be happening at the cost of reduction in the % elongation and the reduction in the toughness. These steels are mostly subjected to the post weld treatment after the welding in order to restore the properties after the welding. Because these respond very rapidly to the weld thermal cycle after the welding. So, this will be leading to the embrittlement of the weld as well as the heat affected zones, so in order to restore the toughness as well as other mechanical properties the post weld heat treatment is given to these steels.

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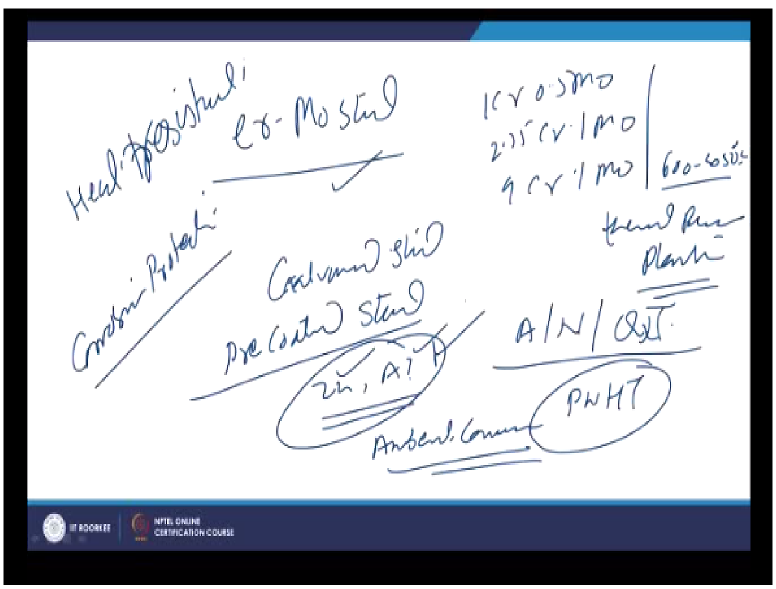

Next category of the steel is the heat resistant steels these are basically chromium molybdenum steels there are various chromium molybdenum like 1 chromium, 0.5 molybdenum 2.25 chromium, 1 molybdenum. Then 9 chromium, 1 molybdenum, so there are various combinations of the chromium molybdenum steels which are used for the high temperature applications like 600 to 650 degree centigrade in thermal power plants.

So, these need to be welded mostly in the annealed condition, normalized condition or in the q and T conditions and these after the welding mostly before putting such kind of the weld joints of the chromium molybdenum steels. The PWHT is given in order to have the expected performance during the service of these steels. Mostly these then there is one more category that is the steels offering the good corrosion protection.

Like these are the galvanized steels or these are like pre coated steels, coated with the zinc, aluminium primarily for the improved ambient corrosion resistance. And this can be performed means coating of these metals can be performed through the thermally spraying or hot dipping method. When such kind of the steels are welded of course the zinc and aluminium can interfere during the welding and that can in turn govern the weldability of the metal.

Now I will summarize this presentation, in this presentation basically I talked about that how the weldability of the metals which are having the effect of the various strengthening mechanisms is affected and what are the various categories of the steels which are grouped on the basis of the welding. So, there are 5, 6 categories of the steels. And this categorization of such kind of the steel is based on the composition, mechanical properties, heat treatment the corrosion resistance and the heat resistance applications, thank you for your attention.