Weldability of Metals
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Lecture-04
Metal Properties and Weldability-II

Hello I welcome you all in this presentation related to the subject weldability of metals and you know we have talked about the 3 different types of the properties related to the metals which affect the weldability. These were the physical properties of the metal and then metallurgical properties of the metal and the chemical properties. In this presentation initially will be talking about the role of the mechanical properties on the weldability of the metals.

And then the strengthening mechanism role the by which a strengthening mechanism of the material affect the weldability. So as for as the mechanical properties of the metals which are important from the weldability point of view is the yield strength.

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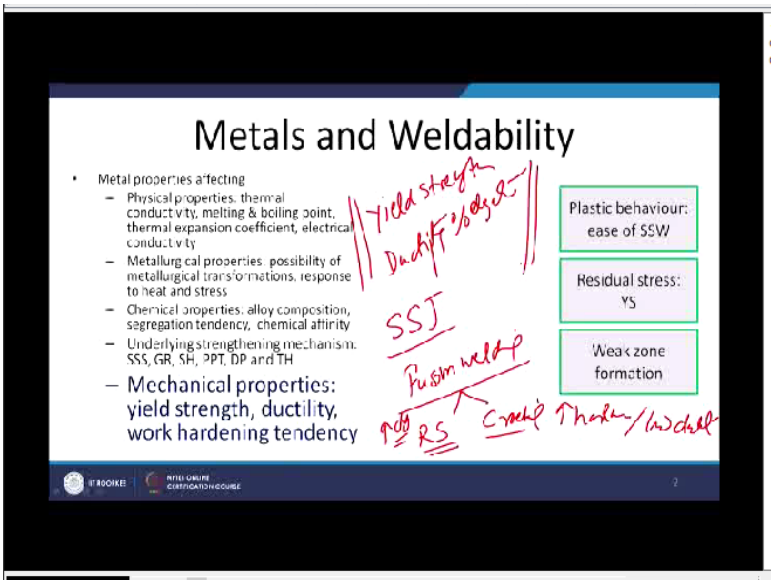

And the ductility which is usually characterized in terms of the percentage elongation and the mechanical properties affecting in the weldability is associated with the solid state joining. The role of the mechanical properties on the weldability with the regard to the fusion welding is very limited, in case of the fusion welding the mechanical properties of the metal primarily affect the development of the residual stresses as well as the cracking tendency of the materials.

Like the metals of the high hardness and the low ductility, they show greater tendency for cracking as compared to the low hardness and the high ductility metals. Likewise the metals of the high yield strength leads to the development of the higher residual stresses as compared to the lower yield strength metals. So primarily a will be focusing on the role of the mechanical properties on the solid state joining.

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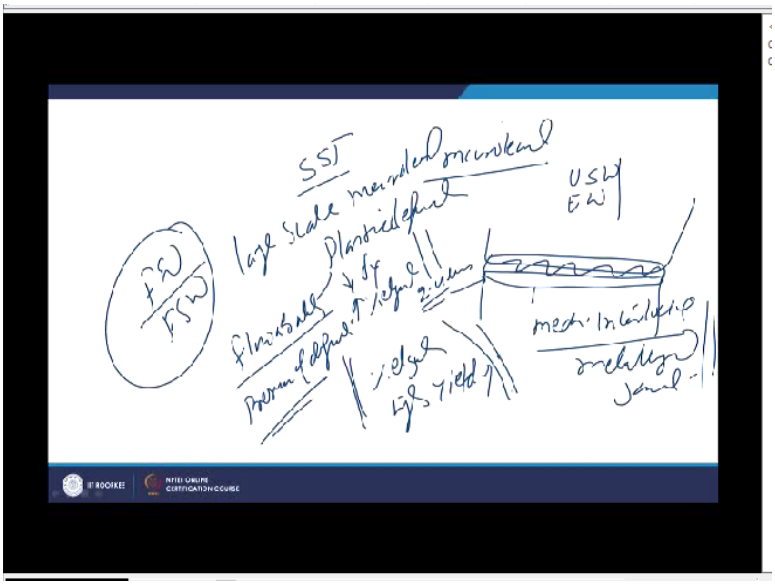

There are various types of the solid state joining processes where either the micro level plastic deformation takes place like in ultrasonic welding, explosion welding. So in these processes using the external mechanical energy the interfacial layers are deformed in very localized manner. So that up to the few micrometers like 2 to 4 micrometers from both the sides the plastic deformation takes place and which in turn facilitates first the mechanical interlocking.

And then metallurgical joint is produced, so if the metal is having very limited ductility and very high yield strength, then joining by the solid state joining processes becomes difficult likewise in case of the friction welding and the friction stir welding where large scale macro level plastic deformation takes place. For large scale plastic deformation is involved in this processes, so material should offer the good flow ability.

And that will be available with the metals of the low yield strength and the high ductility, so low yield strength and high ductile metals showing the good flow ability and the plastic behavior. They can be easily welded using these solid state joining processes otherwise limited flow ability will be leading to the presence of defects in the weld joints. So, in case of the solid state joining processes yield strength and the ductility of the metal place a bigger role as compared to that of the other properties.

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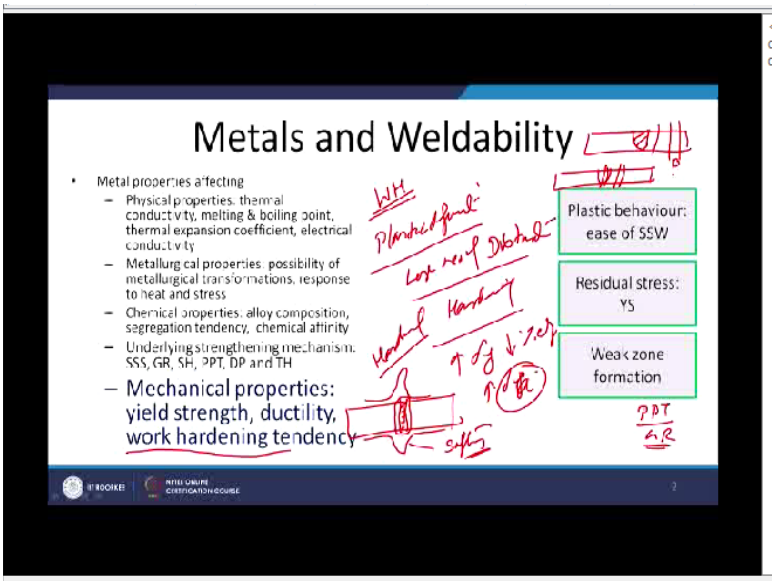

In addition to these yield strength and the ductility there is another important property that is the work hardening behavior of the material. What is this basically whenever a metal subjected to the plastic deformation due to the development of the large number of dislocations material is hardened and hardening of the metals increases the yield strength reduces in general reduces the ductility and increases the tensile strength as well ultimate strength sigma u.

So, because of these changes in all those joining process of welding process wherever the metal is work hardened the interfaces will be harder and stronger than the other portions like say this is the joint interface produced after the plastic deformation based approach of the joining. So, hardness distribution will be showing a significant increase in hardness as compared to the other areas at interface.

This kind of behavior is observed by the those metals which show good work hardening tendency. Then the reverse is also possible like those are precipitation hardenable or those strengthened using the grain refinement and work hardening behavior is very limited. In that case even the softening of the such kind of the zones can also take place which are subjected to the severe plastic deformation.

And in that case will find the low hardness zones especially at the weld interface or in the heat affected zone due to the development of the heat. So, this will be leading to the softening and in the case when the material is showing the good work hardened in tendency it will be leading to the hardening. So, mechanical properties like yield strength ductility and the work hardening tendency can affect the ability of the material to take up the service load service conditions as well as it can also affect the location where from fracture will be taking place.

So in case when the hardening is taking place due to the work hardening behavior obviously the failure will be occurring from the base metal or from the heat affected zone. But if the softening is taking place wherever the soft zone is being formed either it is the weld metal or in the heat affected zone the failure will be occurring from the minimum hardness zone. So, that is how we can see the role of the mechanical properties of the weld metal with regard to the weldability.

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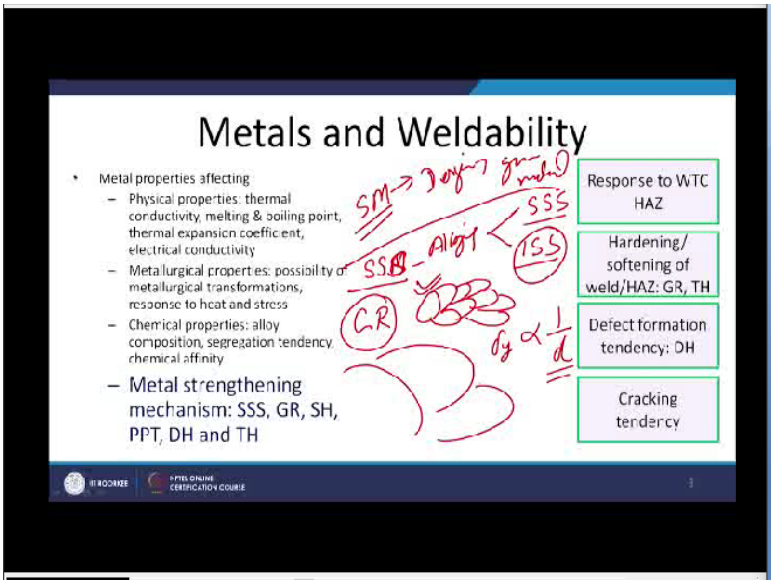

Now will see the way by which the strengthening mechanism which has been used to design a given metal for designing a given metal system, how the strengthening mechanisms will be affecting the ease of welding. We know that the different metals are designed using the different strengthening mechanisms and the most commonly used strengthening mechanisms are solid solution strengthening where alloying elements are added in a given metal.

So, that in a given elements, so that the joint strength is increased by forming either substitutional solid solution or interstitial solid solution. So, increase in the alloying element forming the interstitial solid solution will be leading to the much higher increasing strength as compared to that of the substitutional solid solution. In case of the those which are refined using the grain refinement approach or grain refinement principle.

In this principle is very simple where reduction in the grain size of the metals leads to the increase in the yield strength as compared to the metals having the larger grain size is like this. So, greater is the grain size lower will the yield strength as per the hall patch relationship. So, those metal systems which are designed to be strengthened through the grain refinement where yield strength is found inversely proportional to the grain diameter larger the grain size smaller will be the lower yield strength of the material. So, this is the another approach of strengthening of the metal system.

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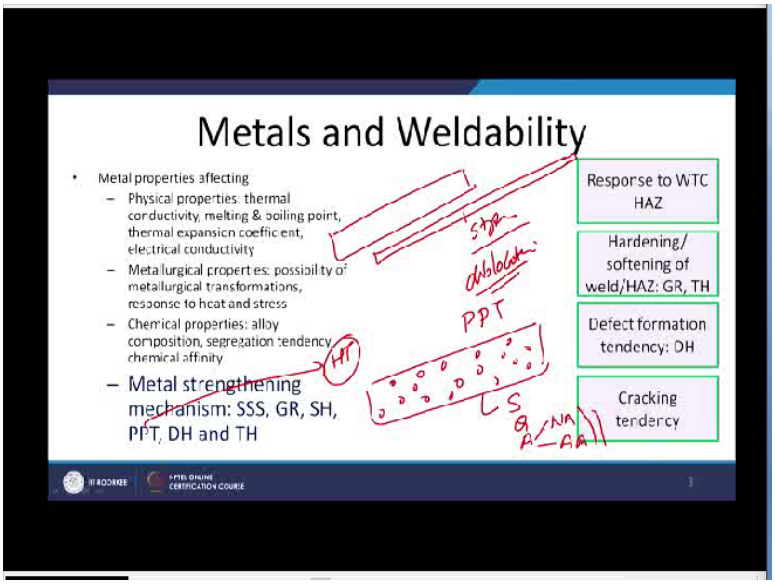

And then there is a strain hardening where there many metal systems which realize their strength to the plastic deformation like a metal system like this is subjected to the severe deformation through the controlled deformation at the many during the manufacturing and that is how they get their strength and this is due to the formation of large number of dislocations during the deformation.

So this is the strain hardening or work hardening mechanism for strengthening the metal. Then there is the heat treatment based approach of strengthening which is called precipitation hardening. In this case very fine precipitates well distributed precipitate of the suitable type are developed in the metal through the controlled heat treatment cycle of the solutionizing, quenching and aging which may be natural aging or the artificial aging.

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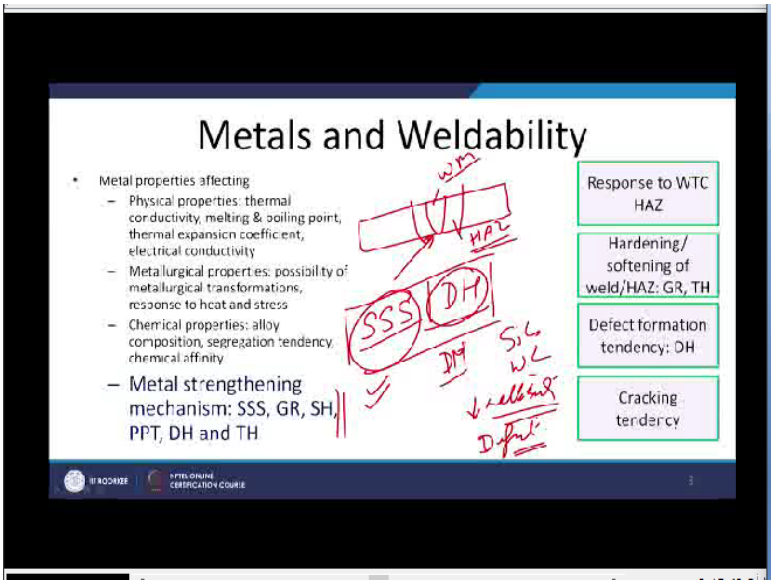

And it is leads to the formation of the required precipitates for realizing the desired strength. In case of the dispersion hardening the metal soft and the tough metal matrix is reinforced with the required a type of the particles in the matrix. So that the required combination of the properties can be realized by the development of suitable composite materials that uses the principle of the dispersion hardening DH. And then transformation hardening where in general material is having the soft phases.

But when it is subjected to the controller heat treatment cycle or controlled deformation cycle certain metallurgical transformations take place which leads to the increase or the change in properties of the material for strengthening purpose. So in transformation hardening basically the soft phases to the controlled heating are followed by cooling leading to the formation of the suitable type of the metallurgical transformations for a strengthening of the metal.

So, these are the strengthening mechanisms and the way by which they work as far as the response to the weld thermal cycle is concerned say when we are either developing the weld joint through the fusion base approach and narrow heat affected zone is perform, is developed due to the weld thermal cycle being achieved are being applied . But the influence of the weld thermal cycle to the properties of the heat affected zone as well as to the properties of the weld metal that will depend significantly on the underlying strengthening mechanism of the material .

Just to elaborate little bit here the metals designed for required strength to the solid solution strengthening and the dispersion hardening. These 2 types of the metal systems are not much influenced by the weld thermal cycle in the heat affected zone. But certainly the properties of the weld metal are affected because weld metal is the as cost structure and it will certainly be having the lower properties.

As compared to the respective the base metal properties however the effect of the weld thermal cycle on the heat affected zone properties will be very limited. In case of the dispersion hard and materials where some hard particles like silicon carbide, tungsten carbide or some other particles have been reinforced in the soft metal matrix. There in case of the fusion welding process due to the limited weldability feature of these reinforcing agent.

There will be tendency for the formation of the defects in the weld metal especially, so the defect formation tendency due to the reinforcing agent in the dispersion hardened materials will be more in case of the fusion welding. and that tendency will be less in case of the solid state joining process, since these are strengthened by the solid solution strengthening is due to the alloying elements which by enlarge remain intact.

Unless there is huge loss of the remaining elements from the weld metal properties are not significantly affected in the weld metal as well as heat affected zone. But in case of the dispersion hard and materials there will be defect formation tendency, then we will have the another aspect.

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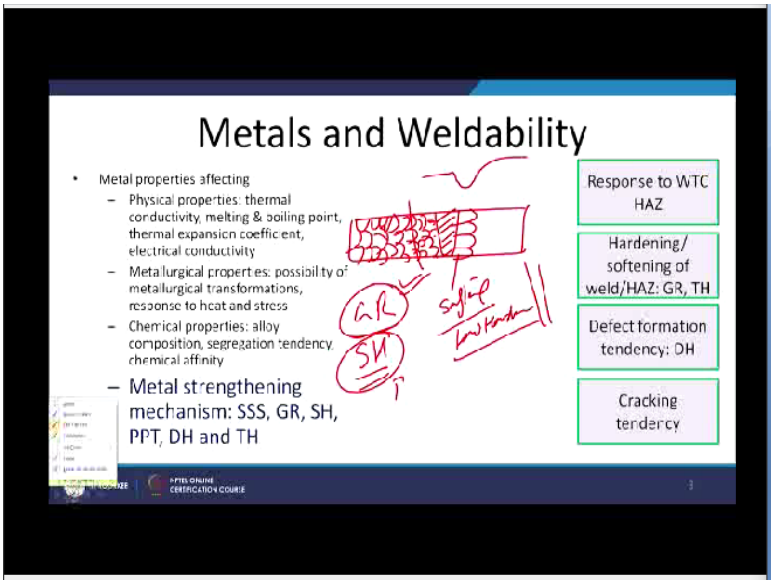

If the dispersion hard and material is subjected to the joining to the controller deformation based approach where like friction stir welding or the friction welding is being applied. In that case there maybe is refinement of those dispersion particles that may lead to the improvement or the iteration as per the way by which the particles are getting affected due to the controlled deformation during the welding.

Now will see the way by which the properties of the metal system strengthened by the grain refinement will be affected. And the work hardened material will be affected, so that is what we have to see now. So grain refinement materials means the metals strengthened by the grain refinement will of course we having the fine grain structure like this. But when the weld thermal cycle is applied due to the excessive rise in temperature in the zone next to the fusion boundary.

All these fine grains get coarsened like this, so coarsening of the grains in next to the fusion boundary zone leads to the softening. And the low hardness zone formation, so here what we may have like the HAZ maybe like hard weld is harder. But HAZ is weaker than this metal is a

stronger, so the HAZ softening can be observed significantly, in case of the grain refined metals subject to the fusion welding and the similar effect is also observed.

In case of the deformation based approach, where lot of heat is generated, if the heat generated during the deformation based approach of the welding process is very limited, then in case of the grain refinement materials the heat affected zone properties will not be much affected.

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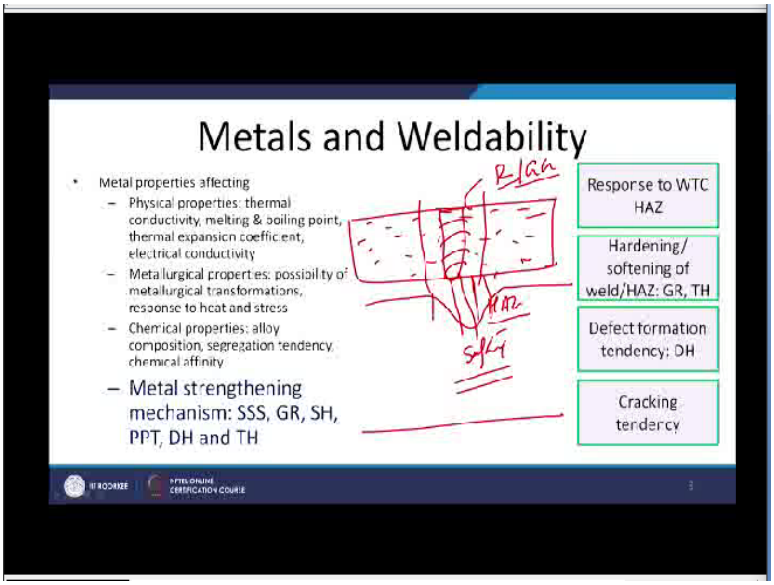

In case of the strain hardened metal systems, a stein hard and metal systems are designed to get there is strength from the formation of large number of the dislocations like this. So, when we use the fusion welding either by the laser or arc or the gas welding, the heat being dissipated next to the fusion boundary leading to the formation of the HAZ. This zone experiences the recrystallization as well as grain growth.

So because of recrystallization and grain growth all the dislocations which were formed for to provide the required strengthen to the metal. All these will be an illiterate, all this will be vanished due to the weld thermal cycle being experienced by the heat affected zone. And that is why you find that the heat affected zone has got soft and due to the loss of these dislocations which were developed in course of the strengthening of the metal.

But if the but in case of the deformation based approach where large plastic deformation or the limited plastic deformation at the joint interface is being realized due to the deformation here will be experiencing the significant improvement in the strength and the hardness of the material. And so in case of the fusion welding of the work hardening materials we find a soft zone in the weld as well as the heat affected zone.

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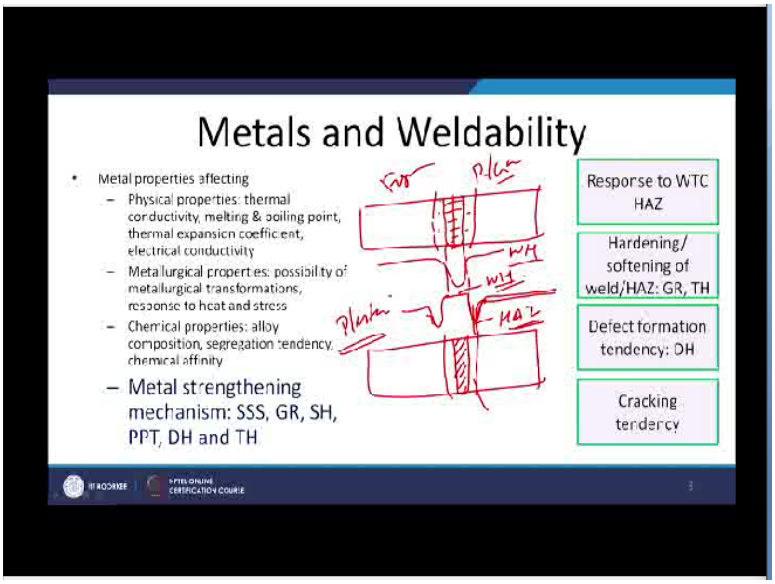

The reason behind this is very simple like a metal like this work hardened metal, when subjected to the fusion welding. All these effect is (()) (1954) and vanished. When the metal is brought to the marten site and next to that zone is also experiences the softening due to the loss of the work hardening effect caused by the recrystallization and grain growth, in case of fusion welding.

And because of this we may find that significant softening is taking place in the weld zone area in case of the work hardened metals. So heat affected zone as well as the weld zone both are soft and significantly like this. But if we are using the plastic deformation based approach then certainly will be having the opposite effect. Because the joint interface will be formed through the control plastic deformation.

And so the zone which is experiencing the control plastic deformations certainly will be offering the greater hardness. And then next to that zone which is experiencing the heat generated during the plastic deformation based processes that will be experiencing the softening primarily due to

the loss of work hardening effects. So here we will find a drop like this, so base metal is harder and stronger.

But the weak the heat affected zone will be softer and this is attributed to the loss of work hardening effect and inhalation. And the reduction in the number of dislocations due to the heat being experiencing due to the welding which is been generated in case of the deformation based approach. So, the similar trend we may find opposite side like this, so softening is primarily occurring here in this case.

In the heat affected zone and hardening is taking place in the weld zone where is control plastic deformation has been used for the deformation purpose.

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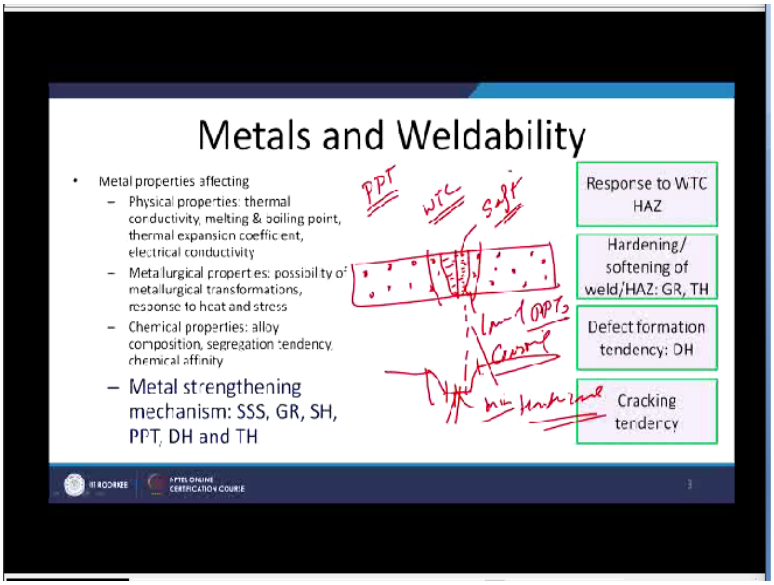

Then lastly will be talking about the metals strengthened by the precipitation hardening. The metals strengthened by the precipitation hardening like say these are the 2 metals both are designed to be strengthened by formation of suitable precipitates like this. Now when these are subjected to the fusion welding all these precipitates will be brought to the molten state and they will get a dissolved.

And certainly the way they do not have the conditions favourable for formation of their formation again during the solidification so. In any case the weld zone will be softer in case of

the precipitation strengthened materials, next to that the heat affected zone which is being formed there also due to the weld thermal cycle will be having the loss of these precipitates which is called reversion as well as coarsening of the grains is also observed.

So both these also reduce the hardness, so the weld will be having the minimum hardness then hardness will be having, HAZ will be somewhat greater hardness and then base metal. And the similar trend will be observed both the sides, so this is the zone where hardness reduction is taking place due to the loss of precipitates from the heat affected zone. And this is the zone where both the sides.

And this is the zone where complete loss has been realized to the fusion of the base metal where re-precipitation of the precipitates was not possible. And that is why this will be leading to the formation of the minimum hardness zone, so if wee in this case the failure fracture will be occurring from the weld metal. And while in other cases where HAZ is weaker than the fracture will be occurring from the heat affected zone. So, it is the minimum hardness zone that will be leading to the development of the fracture under the external loading or an during the tensile test.

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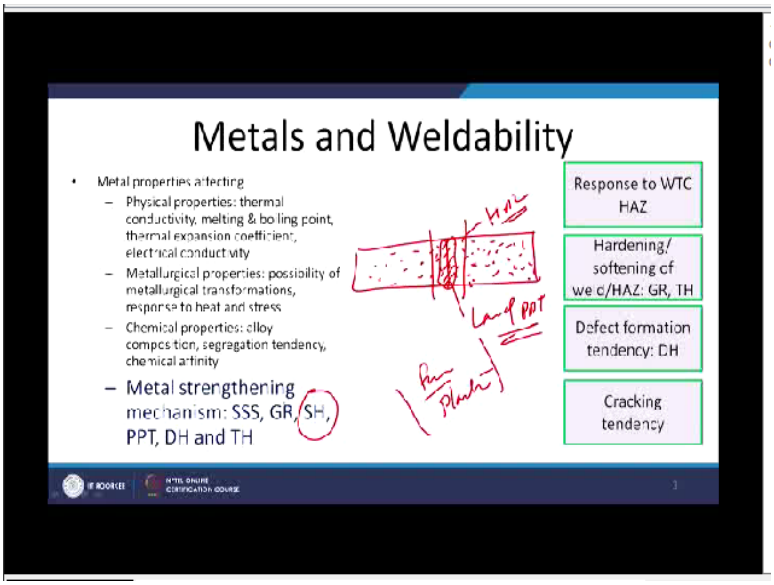

In case of the another solid state joining process in case of a solid state joining process of the precipitation hardened materials we are precipitates are there. So in case of the where severe plastic deformation is achieved, all these precipitates will get fractured and they will get

dissolved in the matrix. So again loss of precipitates will be occurring from the weld zone and the heat generated is also more than the sum of the reversion or the loss of precipitates will be occurring from the heat affected zone will also be taking place.

So in both the cases whether it is the fusion welding or the plastic deformation based approach the loss of the precipitate is going to take place from the weld zone. And the partial loss of the precipitates will be occurring as per the amount of heat which is being supply for the development of the joint. And **is** it is being transferred to the heat affected zone, so as per the extent of the loss of the precipitates from the heat affected zone that will be determining the extent of softening or the reduction in properties which will be taking place.

So in general greater is the loss of the precipitates lower will be the strength lower will be the weldability of the metal. Because this will be leading to the formation of the of the weak zone and eventually fracture will be taking place from that area. So now will be talking about the weldability of one particular type of the metals which is strengthened by the strain hardening or the work hardening mechanism.

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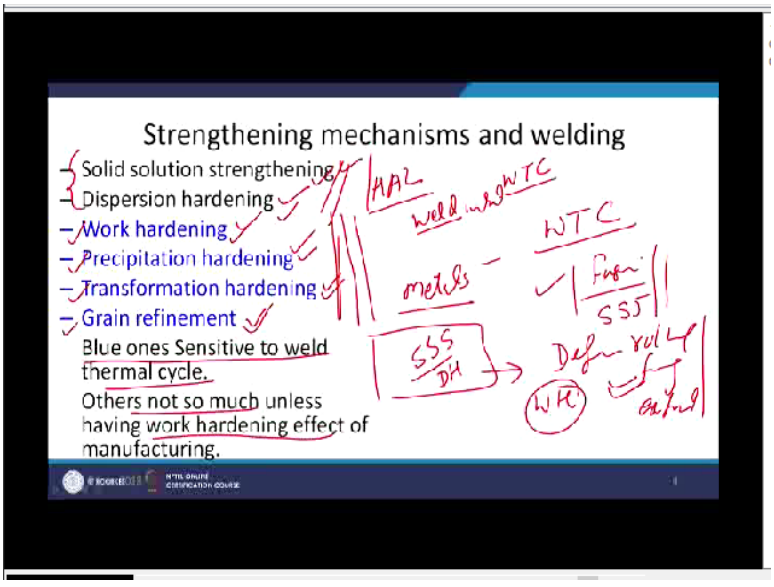

So, these were the all strengthening mechanisms like solid solution strengthening, dispersion hardening, work hardening, precipitation hardening, transformation hardening and the grain refinement. So, if we see the first 2 strengthening mechanisms like solid solution strengthening

and the dispersion hardening. The HAZ of the weld is not much affected by the weld thermal cycle, if the metal is strengthened by the dispersion hardening and the solid solution strengthening mechanism.

But in case of the weld, weld of these 2 the weld metal of the dispersion hardened and the solid solution is strengthen metal system will be of somewhat lower strength. And dispersion hardened metal in case of the fusion welding may have the defect formation tendency but the HAZ properties will not be appreciably affected on the other hand. All those which are highlighted in blue like work hardening precipitation, hardening transformation hardening and the grain refinement.

Properties of such kind of the metals which are strengthened by these 4 mechanisms, they are found to be extremely sensitive to the weld thermal cycle being imposed either during the fusion welding or during the solid state joining. The properties are going to be significantly affected because in case of workout there will be very loss of the of the dislocations. In case of the precipitation there will be loss of the precipitates.

In case of the transformation hardening there may be formation of the soft or the hard phases as per the type of metal system. And in case of the grain refinement is metal strengthened by the grain refinement the weld thermal cycle will be leading to the green coarsening and which in turn will be detracting the hardness and the strength of the metal. So, all the blue ones are sensitive to the weld thermal cycle while in other cases like a the solid solution strengthening and dispersion hardening.

The extent of the weld thermal cycle is very limited to the extent up to which they have the work hardening effect like whether the metal A is a developed by the solid solution strengthening or the dispersion hardening. These will be shaped through the deformation based approach is like a rolling, forging extrusion. So, if these metal systems are these products or the plates or the raw materials having the work hardening effect of the manufacturing stage.

Then this work hardening effects certainly be compromised due to the weld thermal cycle being experience during the welding. And that is what we write that in these 2 cases the effect of weld thermal cycle is not so much except that the work hardening effect being imparted in the solid solution strengthening metals or the dispersion hardened metals.

That will be reduced due to the weld thermal cycle which will be experienced by these metals in case of the manufacturing stage. Now I will summarize this presentation, in this presentation basically I have talked about the 2 important aspects related with the metals like the role of the mechanical properties on the weldability especially with regard to the deformation based joining processes or the welding process.

And the role of the strengthening mechanisms and the way by which these can affect the ease of welding. Because if the metal is strengthened by a particular metal and due to the weld thermal cycle it is being more severely affected and the performance is degraded badly. Then the weldability will be reduced and if the reduction in mechanical performance and the joint capabilities is very limited, then the weldability will certainly be better thank you for your attention.