Weldability of Metals
Prof. D K. Dwivedi
Department of Mechanical and Industrial Engineering
Indian Institute of Technology-Roorkee

Lecture-08
Weldability of Metals Strengthened by Grain Refinement, Dispersion Hardening and Transformation Hardening

Hello I welcome you all in this presentation related with the subject weldability of metals and we have talked about the weldability of the work hardenable metals and the precipitation strengthen the metals. And in both the cases what we have seen that the application of the heat for the fusion welding it causes the reduction in the hardness of the heat affected zone. In case of the work hardenable metal it is the loss of work hardening affect due to the inhalation and recovery of the dislocations.

While in case of the precipitation strengthen metal loss of hardness and loss of strength primarily takes place due to the reversion dissolution of the precipitates. Under which in turn causes the significance of softening of the heat affected zone but as far as the solid state joining of these work hardenable and precipitation strengthen metal system is concerned.

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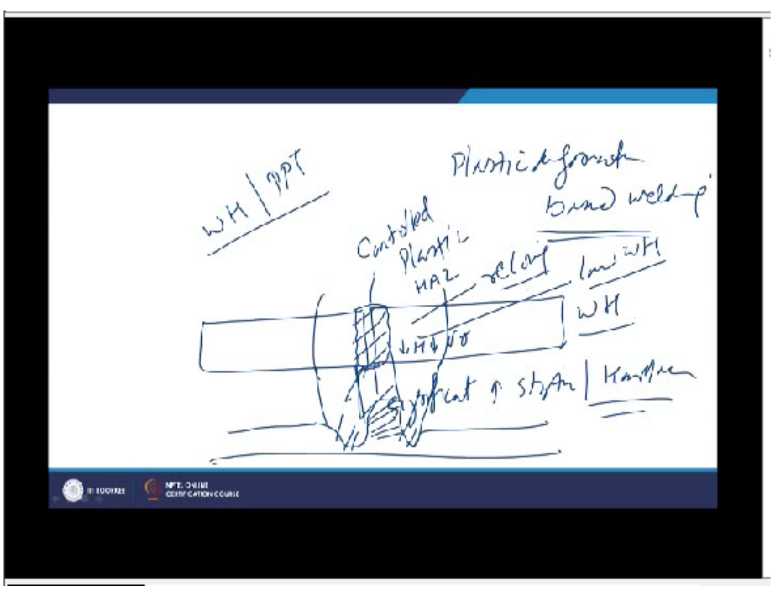

The response to the plastic deformation based welding process is quite different. If we see the work hardenable metal systems like this where controlled plastic deformation of the faying surfaces is used for developing the metallurgical continuity. So that a joint is made this controlled plastic deformation in case of the work hardenable metal systems causes the work hardening.

And, so significant increase in strength as well as hardness takes place in the region of the weld joint. While away from the weld joint in the heat affected zone if heat is being generated due to the plastic deformation or in course of the welding process. Then this will be leading to the recovery and loss of work hardening effect and this loss of work hardening effect causes the reduction in the hardness reduction in the yield strength.

So the typical pattern of the hardness variation which is observed in this case like in the base metal hardness is high. But as we approach to the heat affected zone hardness is reduced and as soon as we reach in the weld zone hardness is increased again. So this increase in hardness is in the weld zone is attributed to the plastic deformation and related work hardening effect.

While the zone next to the weld metal that is heat affected zone here the softening or reduction in hardness is occurring primarily to the recovery. And the loss of the dislocations which is taken place due to the heat generated in during the plastic deformation based welding processes.

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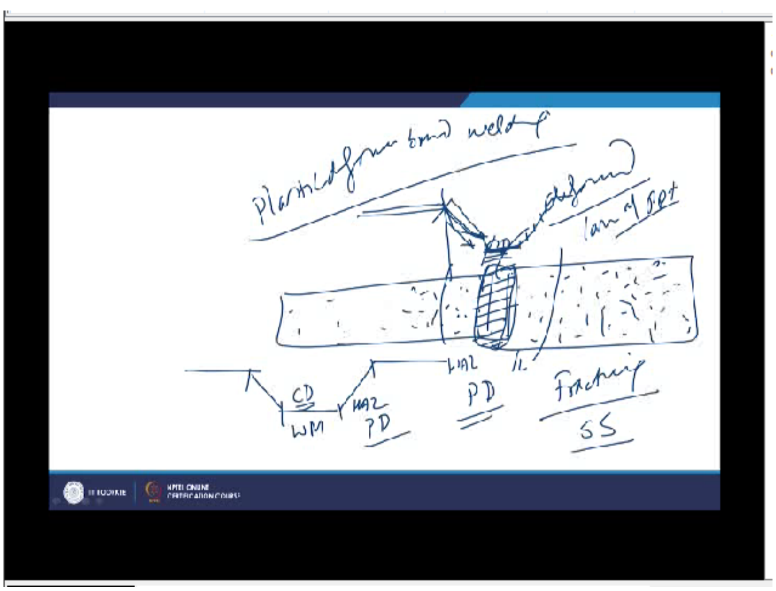

On the other hand if we talk about the plastic deformation based welding processes of the precipitation hardenable metals where the presence of these precipitates is contributing significantly towards the increase in strength then as per the response of the metal like this. So, here the zone next to the means faying surfaces of the components which are subjected to the control plastic deformations for metallic continuity and developed the weld joint.

This zone which is severely deformed during the welding process experiences complete loss, loss of precipitates primarily due to the fracturing of all such precipitates. So basically we get the solid solution through the complete dissolution of the precipitate. While the partial dissolution due to the heat being generated during the plastic deformation based welding process can lead to the partial dissolution in the heat affected zone both the sides.

So, in this case the complete dissolution is taking place in the weld metal due to the fracturing and the complete reversion of the precipitates. While the partial dissolution or partial loss of the precipitates is taking place in the heat affected zone. So if we notice this and if we try to understand this with the respect to the hardness variation, then we will see that hardness in the base metal is high.

But as we approach in the heat affected zone and there will be a gradual loss of the hardness and the minimum hardness will be shown by the weld metal, where the hardness is where the complete dissolution of the precipitates have taken place. On the other hand again the gradual increase in the hardness will take place in the heat affected zone, where the gradually the means the partial loss of the precipitate is taking place.

So, wherever there is a gradient that will be zone where either increasing amount of the dislocation or precipitates is present or the decreasing amount of the precipitate is present. Like the maximum precipitate density will be here in the base metal and then it will keep on decreasing gradually as we approach towards the weld metal. So, it will be causing the gradual reduction in the hardness.

So minimum hardness will be shown by the weld metal then increasing hardness will be shown by the heat affected zone both the sides. And then the maximum hardness in the base metal, so this reduction in the hardness in heat affected zone is due to the partial dissolution. While in the weld metal minimum hardness is attributed to the complete dissolution or complete reversion of the precipitates. So, these are the complete different aspects from the weldability point of view of the work hardenable and precipitation hardenable metal systems.

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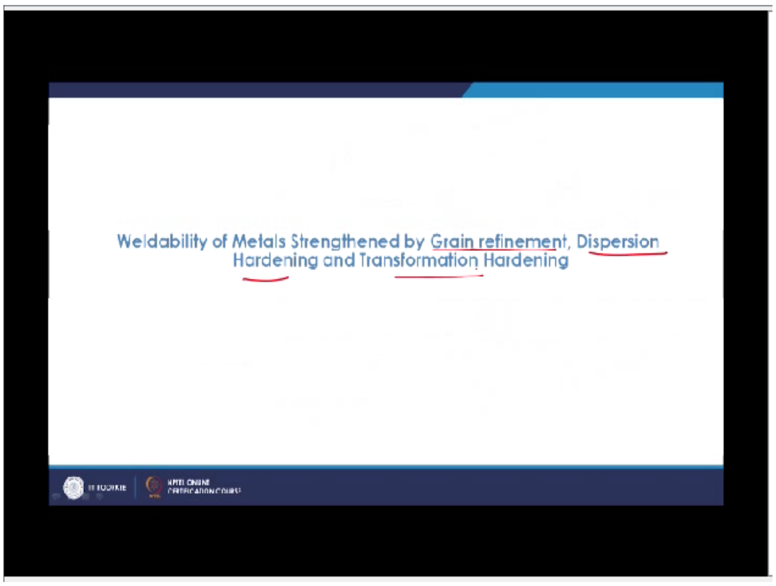

Now we will see the way by which the metals strengthened by the grain refinement, dispersion hardening and transformation hardening.

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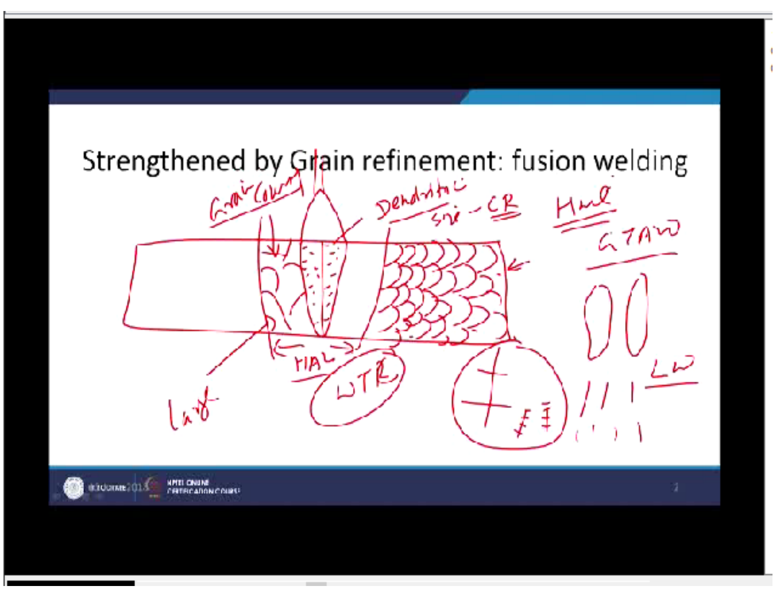

When they are subjected to the welding by the fusion welding or by the solid state welding process like those which will be involved in the plastic deformation, like say the metal system which is primarily strengthened by the grain refinement, no other mechanism is working in anyway. So the component is like this and when subjected to the welding through the application of heat.

So, on the zone will be brought to the marten site with the application of heat and in this process, so this zone will not be having any effect of the prior grain refinement. Because the grain structure here it will be completely dendritic and the size of the grain will be governed by the cooling rate experienced by the weld metal during the welding. And which in turn will depend upon the heat input which is being given.

If the heat input is high like in the case of the GTAW process then the grains will be coarse . And if it is the laser welding process where heat input is very less the grains will be extremely fine and they will be well distributed. So in case of the since that is as cast structures, so grains are very coarse for the gas tungsten arc welding. Well in case of the laser welding these will be very fine, in case of the dendritic structure.

Now apart from the formation of the dendritic structure or the cellular structure in the weld metal the part of the heat will also be transferred to the base metal. And it will be developing the heat affected zone both the sides, since these kind of the metal system has been strengthened by the grain refinement. So, grain size is fine and we know all kind of the metal systems when they are exposed to the high temperature.

The metal tends to attain, the larger grain size so that the associated surface energy can be reduced. So, the zone which is experiencing the effect of heat of the fusion welding that will be subjected to the grain coarsening. Because through the grain coarsening the surface energy associated with that particular metal will be reduced. So all the grains tend to get coarse and so that the associated energy can be reduced through the reduction in the grain boundary area.

While in case grain size is fine the grain boundary is more associated surface energy is more. So, simple it is very simple that whenever heat is supplied the grain tend to grow and that will depend upon the kind of the well thermal cycle experienced by the heat affected zone.

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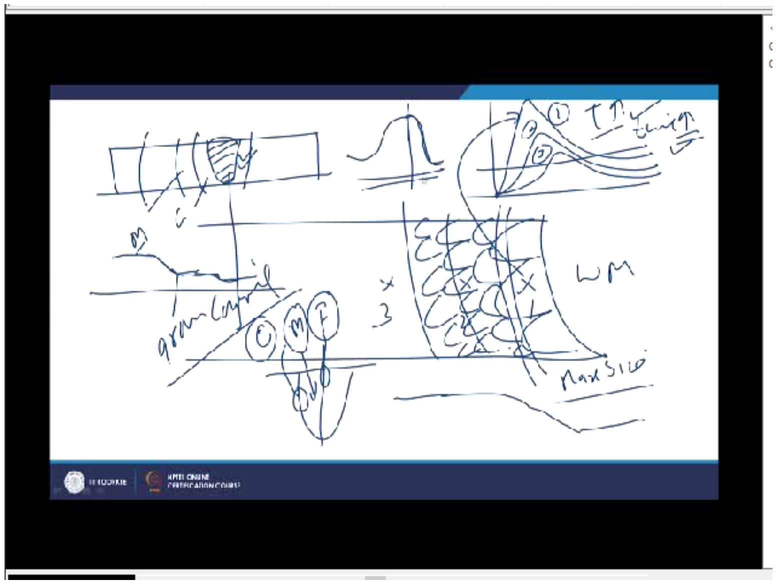

So, if we take an example like this is the weld metal, this is one zone this is another zone increasing distance from the fusion boundary. So, weld thermal cycle of the each zone will be experiencing the different thermal cycle. Peak temperature will be maximum for location one and then peak temperature will be somewhat lower for location 2 and for the lower for location 3. So, if we take up any particular temperature above which recrystallization is taking place.

And then grain growth is occurring, so for the location one the peak temperature will be high, temperature will be high as well as high temperature retention will also be high. And both these factors will be promoting the maximum grain growth in the location 1. While somewhat lesser grain growth will be occurring in the location 2. So, the regions which are experiencing the maximum grain coarsening.

These will be experiencing the higher peak temperature for longer time and so the region which have experienced with the maximum grain size. Maximum size of grain that will be the softest one where partial grain coarsening has taken place that the hardness will be somewhat high. And where grains are still find that zone will be having the higher hardness.

So, if we plot the hardness variation for the weld metal for the weld joint which has been weld joint of the grain strength and grain metal strengthened by the grain refinement. In that case the weld metal will have the strength corresponding towards the dendritic size. But in case of the heat affected zone the area next to the fusion boundary will be coarse are there is somewhat final in the slightly away from the fusion boundary.

So, this will be somewhat medium grain size and fine grain size for the away from the fusion boundary. And this effect will simply reflect from in the hardness variation and if the hardness variation is plotted maximum hardness in the base metal somewhat lower hardness, in the slightly coarsened grains. And further lower hardness in the very coarse grains and then the base and then the weld metal.

So, this reduction in hardness in the heat affected zone is primarily attributed to the grain coarsening. Now as far as the weld metal is concerned, in general the weld metal also shows lot of variation in the grain size. The finest grains are observed at the centre of the weld and then maximum grain size is observed at the grain boundary. So, the coarse grain size at the grain boundary and weld centre will have the fine grain size.

And medium grain size will be available in between, so again there will be variation in the hardness in the weld metal itself like this. So the maximum hardness at the centre and then reducing hardness at the up to the fusion boundary and this is also attributed to the changing grain sizes. So, when the metal is strengthened primary by the grain refinement in case of the fusion welding, weld metal heat affected zone will be showing the reduction in hardness due to the grain coarsening.

While the weld metal will be showing the variation in hardness as per the grain size, hardness grain will be minimum at the centre. So, hardness will also be maximum at the centre and then it will be reducing either side as per the grain size of the metal.

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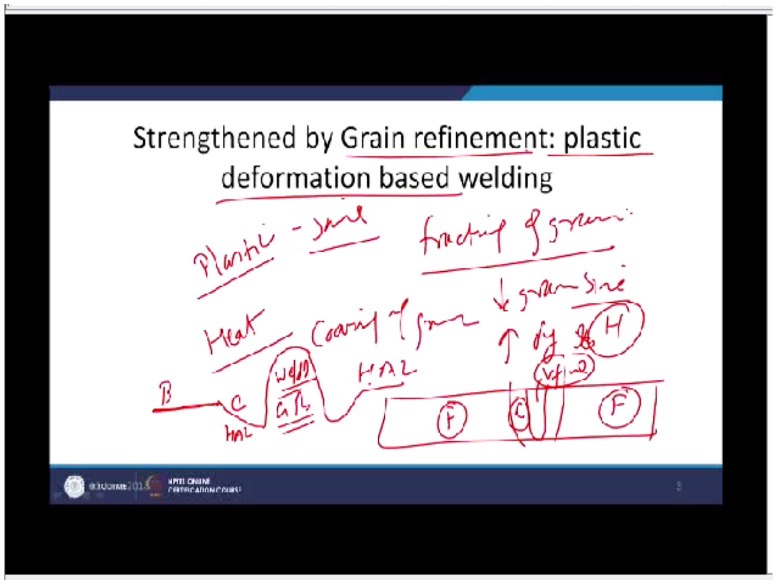

Now will see when the metal system strengthened by the grain refinement subjected to the welding through the plastic deformation approach. So, whenever material is subjected to the severe plastic deformation for development of the joint lot of fracturing of the grains is involved. And which in turn lowers the grain size, under reduction in grain size increases the strength yield strength and also it increases the hardness of the metal.

So while if the heat is generated during the plastic deformation then certainly it will be causing the coarsening of the grains in the heat affected zone. So what we may notice that the weld zone is very fine due to the fracturing of the grains and the constituents while the heat affected zone is coarser and the base metal is again final because it has been strengthened by the grain refinement.

So fine grain size in the base metal, coarse grain size in the heat affected zone and very fine grain size in the weld metal. So we will find a situation where the base metal is retaining it is hardness, loss of hardness is taking place in the heat affected zone due to the coarsening. So in HAZ zone and then again high strength is being realized due to the fracturing and refinement of the grain in the weld zones.

So we may find a trend of variation in hardness of this kind, so this is a weld zone having the higher hardness primarily due to the grain refinement. So, as per the change of the welding process as per the approach of the welding process there can be significant variation in the yield strength and the hardness. Because of the changing grain sizes in case of the grain refined metal system.

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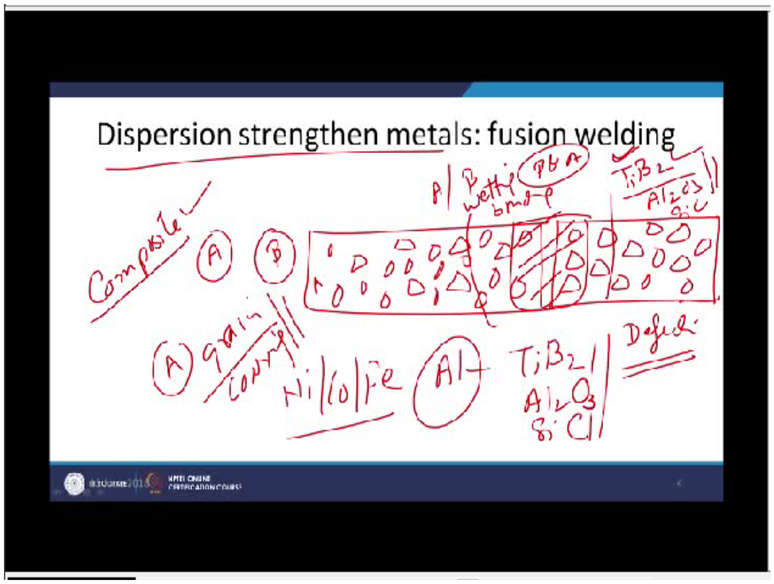

Now if we take the dispersion strengthened metal system dispersion strengthened metal systems are primarily this mechanism is primarily used for developing the composites means metal A is not having the desired characteristics. So, another constituent is brought in and incorporated with the A. So that the required combination of the properties can be realized to achieve a particular purpose.

So, in this case both A and B materials retain their identity like matrix A is reinforced with the constituent B in the matrix like this. In order to achieve the desired combination of the properties which otherwise cannot be realized through the any of these constituents individually. So this approach of reinforcing the constituents in the matrix, so as to achieve the required combination of the properties means such kind of the systems are joined.

Like typical example of this in aluminium we are reinforcing like TiB2 or Al2O3 or silicon carbide all these are refractory items we reinforced in the aluminium matrix. Likewise we may use nickel cobalt or even iron to reinforce such kind of the constituents. So, when the metal material of metal system strengthened by dispersion strengthening approach where in reinforcing agent has been incorporated in the metal matrix to develop a unique kind of the properties means such kind of the systems are welded by the fusion welding process.

Then what will happen since the B and A are not compatible, so on fusion welding the A will be fused completely because it is metal matrix. But there can be thermal damage to the reinforcing agent which has been incorporated in form of Al2O3 or TiB2 or SIC. So these can be thermally damaged due to the external heat supplied for the fusion welding. This is one problem thermal damage to the reinforcing agent.

Second is the since the metal matrix A may not be very much compatible with the B. So there can be various issues like the wetting and bonding between them. So these may be missing, so poor wetting, absence of the metallurgical bonding between A and B in the molten state can lead to the development of the number of defects in the weld joint. So, this is one of the issues as far as the fusion welding is concerned.

So the particles this reinforcing agents may lose their identity and, so their effect in the weld metal may also be lost or it may be compromised badly. While the variation in the properties in the heat affected zone of the dispersion strengthened metal system may not be appreciable except that the metal matrix may get coarsened. So, grains of the metal A may get coarsened due to the application of the heat. So such kind of the coarsening of the metal matrix may lower down the hardness. However such kind of the reduction may not be appreciable.

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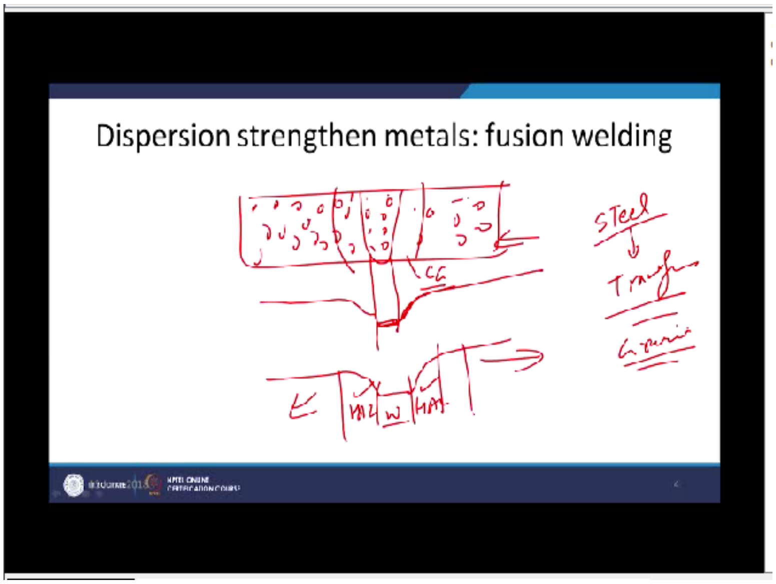

So, if we try to understand the variation in the hardness in such kind of the composites subjected to the fusion welding say this is the composite material it is developed through the dispersion strengthening mechanism. So here particles may be dissolved or may be thermally damaged and poor bonding may be leading to the defective weld joints.

So this under the heated affected zone may be having the coarse grain structures. So, the properties in the heat affected zone may be shortly lesser but this may be significantly lower in the weld zone. Because of the poor interactions between the reinforcing agent and metal matrix then only thermal damage to the reinforcing agent. So the properties may be significantly lower in the weld zone.

While on the other side again the properties may be compromised in the heat affected zone due to the grain coarsening. So the there can be soft zone formation in the heat affected zone as well as the well known and then gradually increase in hardness in another side. So this is how we can understand the weld zone HAZ zone both the sides and then the base metal. So, this is how the dispersion strengthened metals can behave.

Now depending upon the kind of the metal matrix it may respond in different ways to the weld thermal cycle, say if the reinforcing agent has been incorporated in steel which also response to the transformation hardening. Then there may be significant increase in hardness of the heat affected zone due to the transformation hardening. But if it is simply strengthened by the grain refinement. Metal matrix is simply strengthened by the grain refinement then grain coarsening will be leading to the softening in the heat affected zone.

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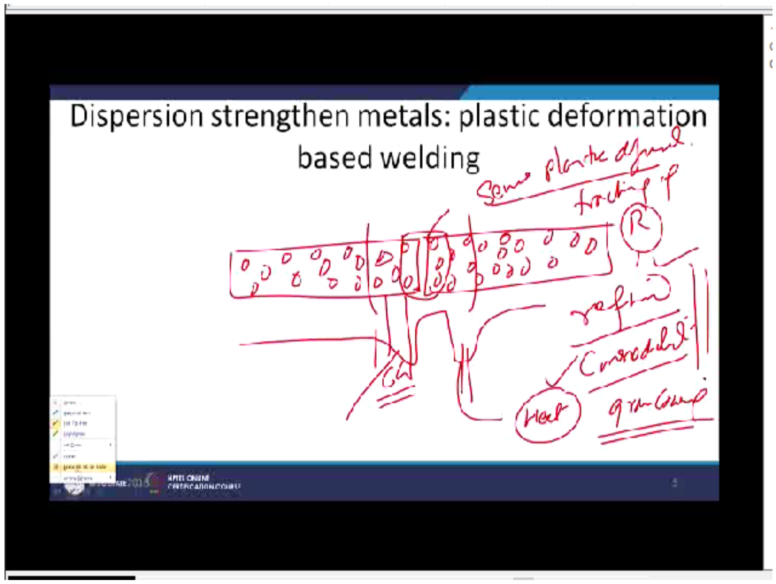

Now will see when the plastic deformation based approach is used for developing the weld joints of the composite materials. So, in that case what will happen will try to see the composite material or the metal strengthened by the dispersion hardening through the suitable reinforcing agent. When such kind of the metal systems subjected to the plastic deformation for developing the weld joint.

So, the severe plastic deformation next to the faying surfaces will be leading to the you can say severe plastic deformation . In the region next to the faying surfaces will be leading to the fracturing of all reinforcing agent and these particles which have been reinforced in the metal matrix. These may get refined and may get from consolidation in the metal matrix. And these favourable variation in the properties may lead to the improvement in the hotness.

On the other hand heat generated due to the during the plastic deformation based welding process may cause the coarsening of the grains in the heat affected zone. So, what will be having the base metal will be having the high hardness somewhat lower hardness in the heat affected zone due to the grain coarsening. And thereafter further higher hardness in the weld zone due to the refinement of the reinforcing agent.

And from consolidation of the metal matrix with the refined particles these may lead to the increase in hardness then again drop in the hardness in the heat affected zone. So this softening of the heat affected zone can primarily occur due to the heat being generated or heat being supplied during the plastic deformation based welding process to the heat affected zone. And which is causing the grain coarsening, so as per the behaviour of the metal system the responses will be different like say.

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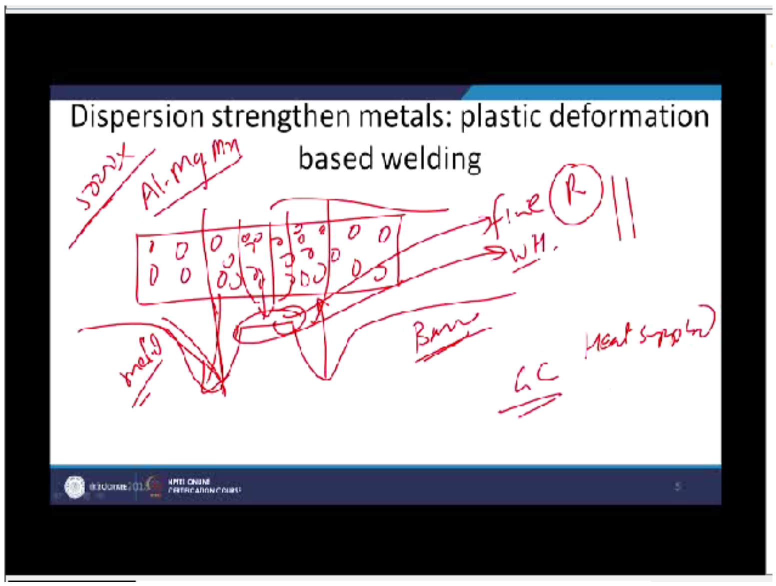

If the reinforcing dispersion strengthened metal system is work hardenable like aluminium, magnesium, manganese alloy, this is 5000 series aluminium alloy. When and this is work hardenable metal system and which has been strengthened by also strengthened by the reinforcement of the second phase political science. When such kind of the metal system is subjected to the welding by the plastic deformation.

Then certainly the plastic deformation in the weld zone is going to cause the work hardening, at the same time refinement of such kind of the reinforcing particles, reinforced particles due to the fracturing and breaking that will be leading to the further improvement in properties. So, the fine reinforcing agent work hardened metal matrix, both these will be contributed to the significant increase in the hardness.

So, much higher weld metal of the much higher hardness then somewhat lower hardness for the heat affected zone due to the grain coarsening like this. And then again rise in the hardness of the of the base metal like this. So, this increase in hardness is primarily attributed to the base metal where you have the particles reinforced in the metal matrix. So, higher hardness in the weld metal in this case is attributed to the work hardening as well as the grain refinement.

While softening of the heat affected zone is attributed to the grain coarsening due to the heat supplied during the plastic deformation based welding process or heat generated during the plastic deformation based welding process .

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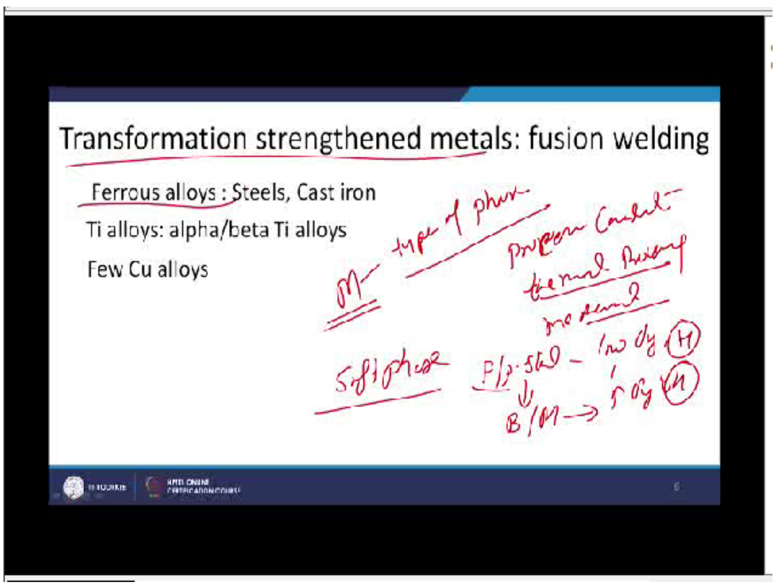

Now I will see the another metal system transformation strengthened metal system means the metal is showing the different types of the phases with the change of the processing conditions. These processing conditions may be in terms of the thermal processing or mechanical processing, so metal in normal condition may be having the soft phases like the ferrite and pearlite in simple low carbon steel which are softer one.

So, they offer somewhat low yield strength and the low hardness but when these are processed either by thermal processing or also by the mechanical processing these lead to the change of phases from ferrite to pearlite it may get change into the bernette or martensite formation of such kind of the phases is transformation of such kind of the phases will be leading to the increase in a yield and the hardness.

So, there are various metal systems which show this kind of behaviour and which is exploited to strengthen the metal system. So, the metals which show the transformation from the soft phases to the hard phases and this concept is exploited to achieve the required strength. The ferrous alloys are the most common types of the transformation strengthened metal system.

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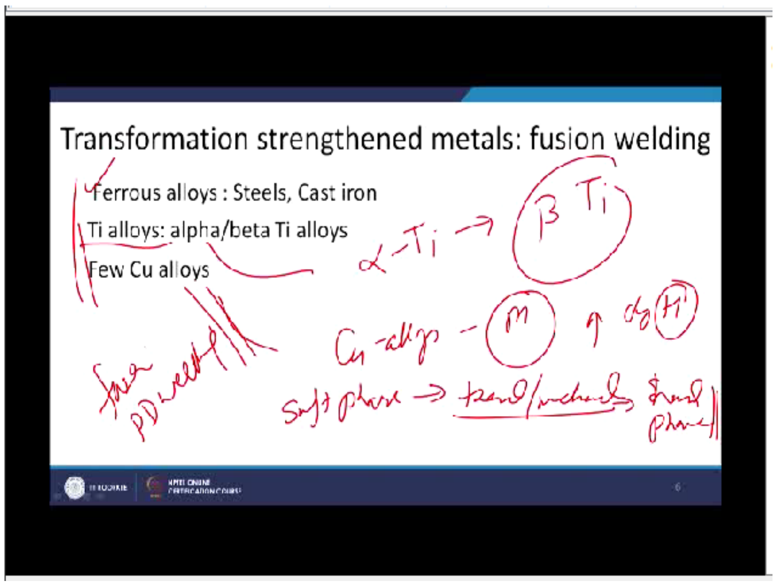

Then we have the titanium alloys where alpha titanium, when is transformed into the beta titanium it shows the improvement and strength. Similarly some of the copper alloys also show the martensite transformation like a phases which under control thermal conditions. Formation of such kind of the phases show improvement in the yield strength and the hardness, so all those metal systems where under a given conditions may be having the soft phases. When they are subjected to the thermal or mechanical processing in one controlled condition they lead to the formation of the hard phases.

And which in turn causes the significant change in the properties of the metal, so both fusion welding as well as the plastic deformation based welding processes respond to the transformation significantly. When such kind of the metal systems are subjected to the welding either by fusion welding or by the plastic deformation based welding process, so I will summarize this presentation.

In this presentation basically I have talked about the way by which the precipitation strengthen metal system metals strengthened by the grain refinement, metal strengthened by the dispersion hardening will respond to the fusion welding and the plastic deformation based welding process. And the way by which there will be variation in the properties of a such kind of the metal system with the application of the fusion welding and the plastic deformation based welding process, thank you for your attention.