Weldability of Metals

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Lecture-05
Weldability of Work Hardenable Metals

Hello, I welcome you all in this presentation related to the subject weldability of metals. And we have seen that there are different types of the metals which are strengthen by the different mechanisms like the work hardening grain refinement, transformation hardening, precipitation hardening, dispersion hardening. So, whenever these metals strengthen by the different mechanisms are welded there is lot of change in properties of the base metal.

And which in turn affects the ease of welding related with that particular kind of the metal. So, you know depending upon the kind of process that we are using for the welding purpose, you know the plates to be joined by the fusion welding needs to be heated and then they are brought to the molten state.

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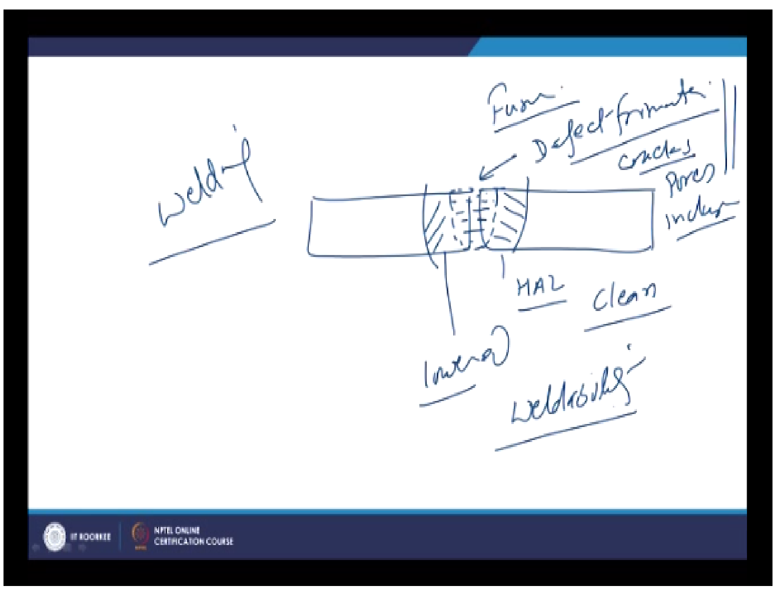

And was the molten state is realized subsequent solidification leads to the development of the joint. So in this process lot of heat is transferred to the base metal which in turn generates the heat affected zone. So, as for as the ease of welding or weldability of metal for fusion welding is concern, now will see the formation defect formation tendency of that particular metal is how clean weld is being made which is free from the impurities in form of the porosity or inclusions or other defects.

The defects in form of cracks, pores, inclusions, so if by taking proper care with the welding process and developing proper welding procedure maybe we can avoid these defects. But is still there will be the formation of the heat affected zone, so the way by which the Hz properties are affected due to the application of heat for fusion welding that significantly determines the ease of welding or the weldability.

If there is significant compromise with the properties of the heat affected zone means these properties are either lower or unnecessarily the hardness is increased material is in brittle. Then in that case the weldability of the metal will be reduced significantly.

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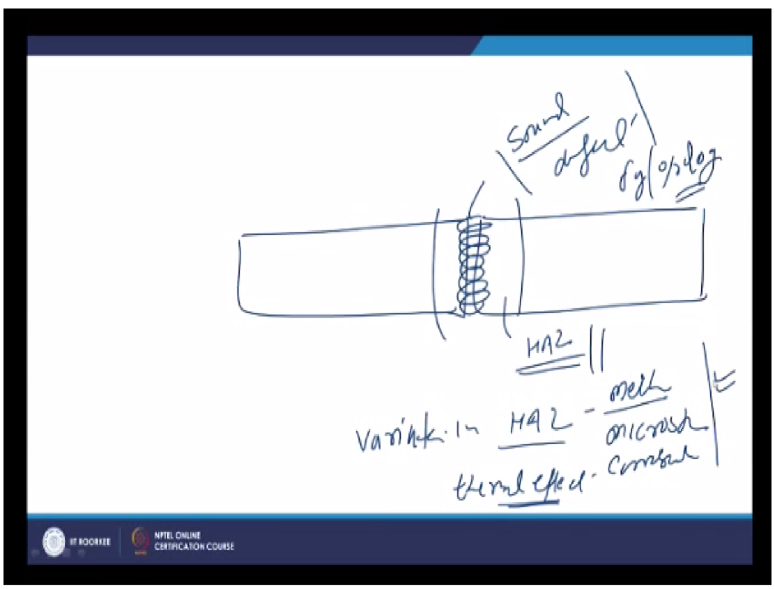

Likewise when the metal system when welded using the solid state joining process. So, the control plastic deformation of the faying surfaces will be leading to the metrological continuity. And in this process of the controlled deformation for development of the joint some of the heat will be generated and that will also be generating the heat affected zone however the heat affected zone with will be very narrow in this case.

So, in this case if the joint which is being formed is sound and free from the defects which of course in case of the solid state joining process will depend upon the yield strength and the percentage ductility a percentage elongation of the metal. So, lower ductility, greater elongation will be leading to the easy development of the sound weld joint which will be free from the defect with the minimum energy requirement.

The minimum possible efforts which are required for developing a sound joint but is still some amount of the heat affected zone will be developed if the little bit heat is generated and the heat generated is negligible then and Hz will be absent. So, the variation in heat affected zone properties either in terms of the mechanical or the micro structure or the corrosion properties due to the either thermal effects due to the heat which is occurring due to the heat supplied for the fusion welding or the heat generated during the solid state joining process.

So these variations will significantly be determining the ease of welding or the weldability of the metal. Now will be going through the one particular kind of the metal system which is work hardenable metal system.

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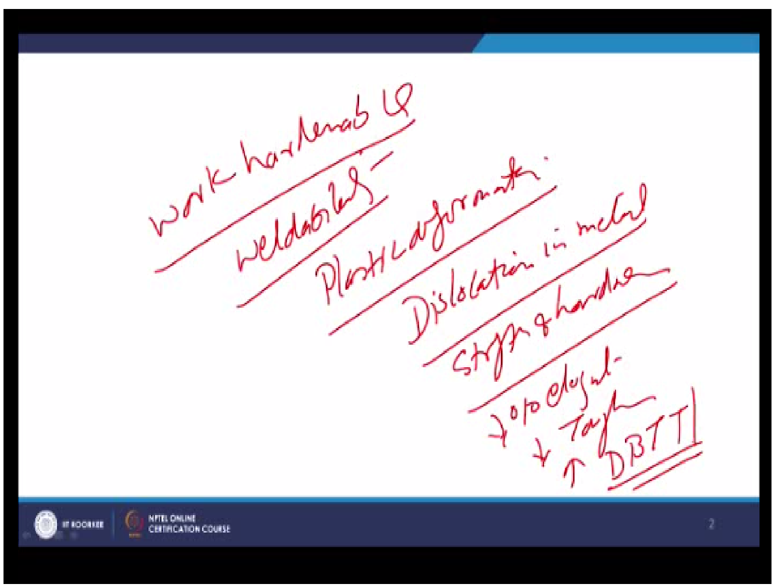

And the weldability associated with this kind of the metal systems, most of the metal systems whenever they are deformed, whenever they are subjected to plastic deformation or lot of the metrological changes takes place especially in form of development of large number of dislocations in the metal. And these dislocations tend to increase the strength and hardness of the metal however it happens with the reduction in the percentage ductility or reduction in the toughness.

At the same time it increases the ductile to brittle transition temperature which is also an undesirable effect because we want the ductile to brittle transition temperature is as low as possible.

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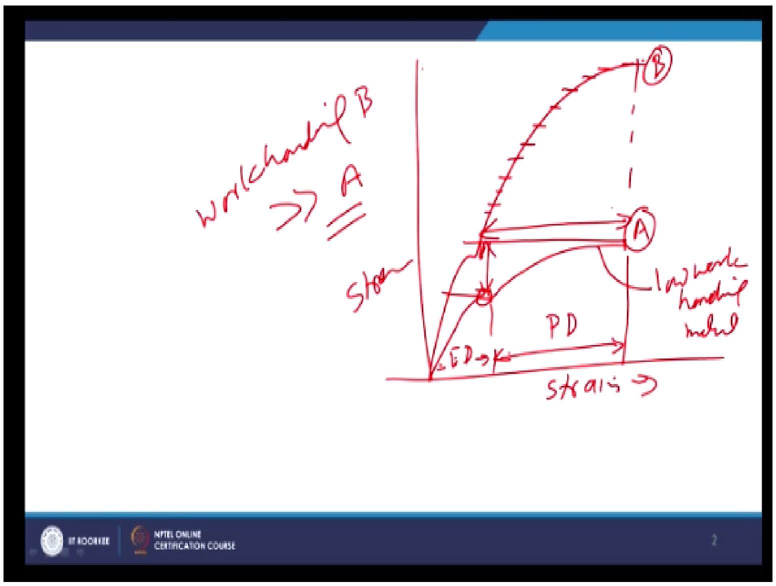

And effect it is effect we can easily see when we conduct a the tensile test. So, the metals which show very limited work hardening behavior they will be showing gradual change very gradual change in the strength of the metal or the stress requirement to cause the further strain in the materials is typical engineering stress. And the strain cure for a 1 metal which does not show much work hardenable behavior.

So, for such large strain plastic strain value say this is the elastic deformation or elastic limit and this is the plastic deformation zone and this is the elastic deformation zone. So, the kind of a stress requirement is increasing very slowly with the increase of a strain, so this will be considered as low work hardening metal. On the other hand there may be a metal system which may deform very rapidly like for the same strain value.

The stress requirement may increase drastically , so with for each unit for per unit change of the strain the stress requirement is significantly high for this another metal system. So, with suggest that this is getting work hardened due to the deformation more rapidly, so if we compare the metal B with A then we will notice that the work hardening tendency of the B is much greater than that of the A.

For the same strain value stress requirement for the B metal will be much higher than the metal A . So, means the different metal get work hardened by the different magnitude for the same deformation or the for same strain value. So, considering this as a background for the work hardening metals now will go with the finer details of the work hardenable metals and the way by which these are affected**.**

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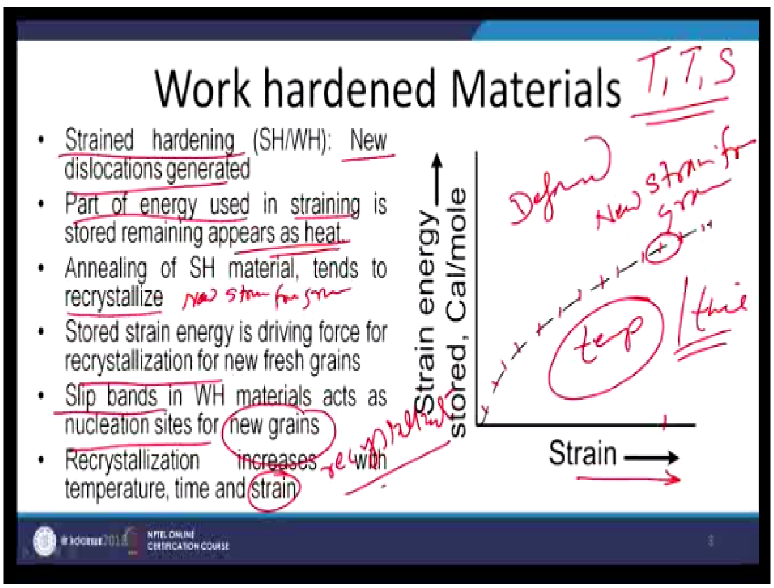

By the welding process whenever it is carried out either for either using the solid state joining process or the fusion welding process. So, you know that the whenever material is deformed new dislocations are generated and these dislocations interfere with the movement of further dislocations which in turn resist the plastic deformation.

So, there will be increase of the yield strength and there will be increase in the hardness of the material. And this is what is called work hardening or the strain hardening and it primarily occurs due to the generation of large number of the newer dislocations. And whenever metal is deformed plastically a part of energy consumed in deformation is left out in the plastically deformed metal.

So, part of the energy used in straining is stored in the metal while the remaining portion of the energy is converted into the heat. So, the part of energy which is stored in the metal that offers the lot of effects with regard to the the behavior of the material. And when such deformed metal subjected to the higher temperature exposure. It tends to get Anneal and by developing the newer grains by forming the grains which are new in geometry and the free from any kind of the strain.

So, if we see whenever the metal is strained plastically the amount of energy is stored in the material keeps on increasing with the strain magnitude. And this becomes the driving force for a recrystallization or the formation of the new screen free grains. So, whenever this plastically deformed metal is or you can strain hardened metals subjected to the higher temperature exposure above the recrystallization temperature it tends to recrystallized means forms the new strain free grains.

And as I have said whatever is the strain energy is stored in the plastically deformed metal that acts as a driving force for the recrystallization of a newer grain. Greater is the strain energy is stored is here will be the recrystallization of the metal. So, whenever the material is screened it produces the lot of dislocations and the slip bands are also produced in course of the plastic deformation.

And which acts as a site for nucleation of the new grain during the recrystallization . So, once these in new fresh strain free grains are produced the material properties are modified or change significantly. And the recrystallization means the extent up to which the newer grains which will be formed that will depend significantly on the temperature at which the plastically deformed component is being exposed.

And for how long means the time for which exposure is being given and how much is straining has been given how much strain has been imported to the plastically deformed metal, that will be affecting the strain energy stored. So, the temperature, time and the kind of strain energy stored.

These will be affecting how fast recrystallization and the extent of recrystallization which will be occurring due to the higher temperature exposure.

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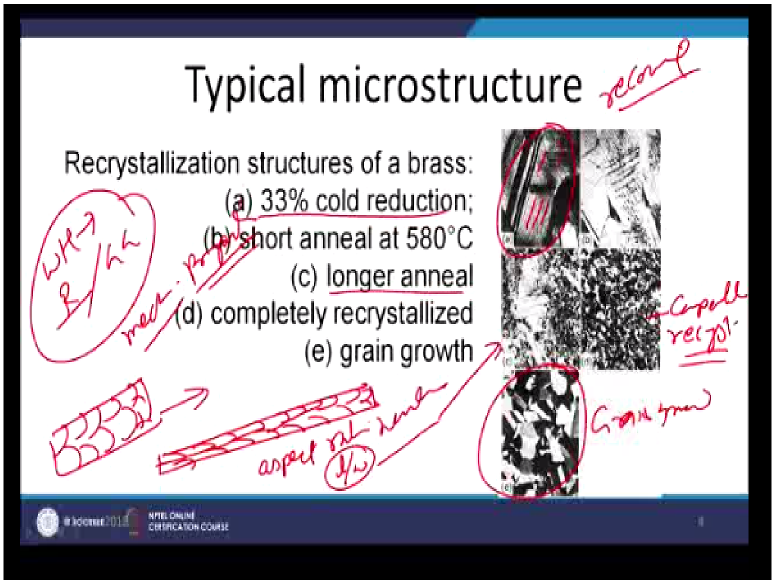

Say for an example a metal which is subjected to the plastic the formation by 30% cold reduction it produces lot of dislocations which we can see from these very thin lines all these are dislocations. And when we give the exposure to the higher temperature for a very short period sum of dislocations are annealed or you can say annihilated through the recovery mechanism.

So, the number of such dislocations will be reduced and when exposure is given for further longer period will see that newer grains will be formed. And further longer exposure will be leading to the complete recrystallization means all the grains which were deformed earlier during the plastic deformation stage. They will be vanished and newer grains will be developed.

So, the complete recrystallization will be happening with the further longer exposure of the metal. Say initially if the metal is having crystal structure of this kind which is (()) (14:44) when it is subjected to the plastic deformation. Then it will be leading to the change in aspect ratio and the change in strain state of all these grain. So, energy associated with the such grains will be more because of the strain energy stored.

And if you will notice aspect ratio which is the length to width ratio of such grains will be completely different. And once the recrystallization happens again will be getting the equast grains which will be having like aspect ratio certainly lower than what it was after the deformation. And if the high temperature exposure is continued for further longer period then this will be leading to the grain growth.

So, coarse grains are developed with the continued exposure of the work harden metal for longer period. So, these are the stages of work harden metal when subjected to high temperature exposure. First the recrystallization takes place followed by the grain growth and both these changes will be leading to the change in mechanical properties of the metal which is being subjected to the exposure to the higher temperature.

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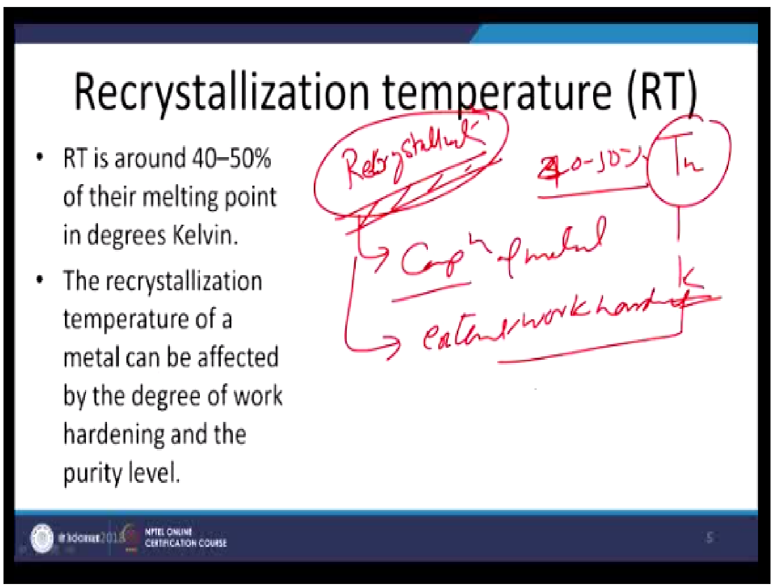

So, at what temperature such kind of the change in that plastically deformed metal takes place in form of the recrystallization. So as we can see plastically deformed metal at what temperature it will crystallized that is found to be around like say 40 to 50% of the Tm where Tm is the melting point temperature in Kelvin.

So, about 0.4 to 0.5 times of the melting point of the metal is the temperature at range in which the recrystallization of the metal will be taking place . However this will also be affected by the composition of the metal that like the presence of the impurities and the extent of work hardening which has been imparted work hardening or the definition which has been imparted. So greater the plastic deformation which has been given easier will be the recrystallization because the amount of a strain energy stored will be more which is the driving force for such kind of the recrystallization.

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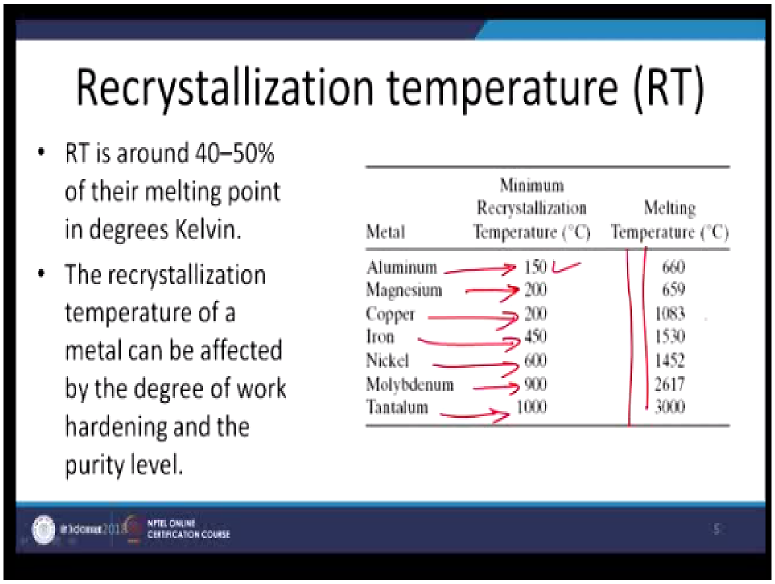

So, we can see here for the recrystallization temperature for the different metals become different like for aluminium it is for pure metals aluminium it is 150 degree centigrade, for Magnesium 200 degree centigrade, Copper 200, Iron 450, Nickel 600, Molybdenum 900 and Tantalum 1000 degree centigrade. And these temperatures are significantly lower than their respective melting temperatures.

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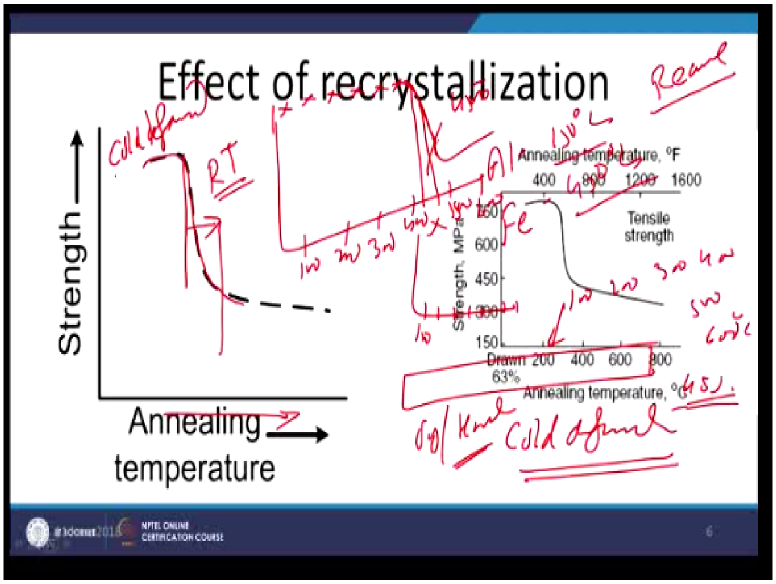

Now what is the effect of these recrystallization on the mechanical properties. So, we have seen that the different metals like aluminium recrystallizes around 100 degree centigrade while iron recrystallization temperature for iron is 450 degree centigrade. So, say the steel plate subjected to the cold deformation and after the cold deformed condition say with the reduction of say 40%.

If we measure it is strength will notice that is strength and the hardness of the metal is significantly high. Now this deformed plate when given the exposure of the different temperatures of say 100 degree, 200 degree, 300 degree, 400 degree, 500 degree, 600 degree centigrade. So with the exposure of the deformed plate of the iron at higher temperature if we try to plot this variation in terms of the hardness.

So hardness for 100 degree centigrade it will be significant it will not be reduces significantly. So if we plot this like say 100, 200, 300, 400, 500, 600 degree centigrade. And then variation in the either yield strength of the metal or the hardness if plotted as a function of the temperature at which exposure has been given to this cold deformed plate.

Then what will notice that there is no drastic change in the hardness of the metal until it is exposed to a temperature of the 400 degree centigrade. And then there is sharp drop in the yield strength and hardness of the metal takes place as soon as it is expose to the temperature above the 450 degree centigrade. And this is attributed to the recrystallization which means the formation of the new grains which will be eliminating all work hardening effect.

If it was there earlier eliminating all means reducing the dislocations from the plastically deformed metal and making it softer. So, this is what we can see here with increase of annealing temperature there is cold deformed metal subjected to the drastic reduction in the strength as soon as the annealing temperature goes beyond the recrystallization temperature.

So, increase in annealing temperature lowers the strength more specifically above the recrystallization temperature. And this is attributed to the formation of the new strain free grains recovery of the metal and the recovery will be leading to the reduction in the dislocation density as well as the formation of the new free strain grains as a result of a annealing above the recrystallization temperature.

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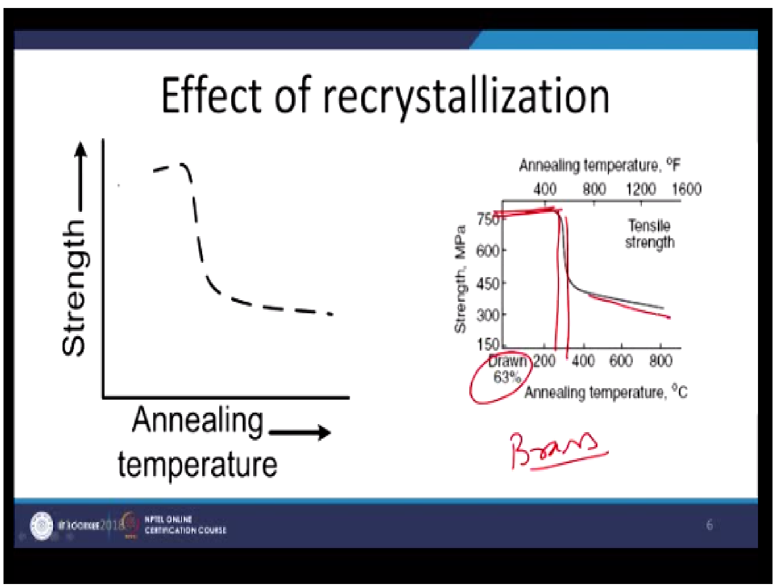

So, if we see this similar to the brass subjected to the cold drawing with the reduction of the 63% after the cold drawing it shows a significantly higher strength. And as the annealing temperature is increased, so as soon as it is annealing temperature goes beyond the recrystallization temperature. There is a sharp drop in the strength of the metal and thereafter this is strength reduces gradually. So the annealing or the heating of the work hardened metal above the recrystallization temperature lowers the strength and the hardness.

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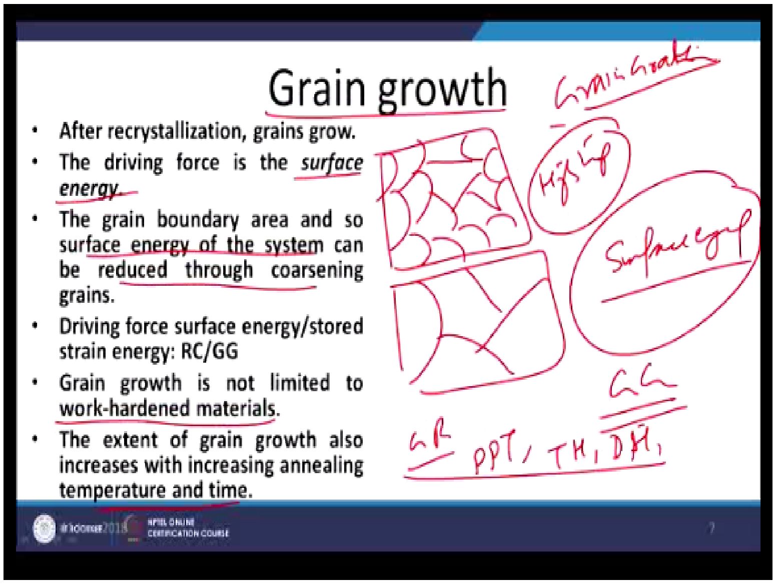

After the recrystallization another important aspect is the grain growth. So once the recrystallization is complete if the high temperature exposure of the work harden metal continuous for longer period then we will notice the grain growth or the increase in the grain size, grain growth. So the driving force for the grain growth is different from what it was for the recrystallization, driving force for the grain growth is basically the surface energy.

So, a metal system which is having the finer grains will be having the greater grain boundary area. So, more and so more a surface energy associated with the grain boundary areas. So, whenever the such kind of the system is the expose to the higher temperature this kind of the metal tends to achieve more established by reducing the surface energy and for that purpose in tends to grow in size. So, this is the main reason behind the grain boundary area driving force for the grain growth is the surface energy and the grain boundary area.

And so the surface energy of the system can be reduced through the coarsening of the grains. And the grain growth and therefore since it is not associated with the strain stored energy but it is associated with the basically the surface energy. So, any kind of the metal system whenever given exposure of the higher temperature because of this driving force the system tends to have the minimum possible surface energy.

And that it tends to realize through the reduction of the grain boundary area and which is possible through the grain growth or the coarsening of the grain. And that is why the grain growth is not limited to the work harden metal but green growth is observed in all types of the metals whether it is grain refined strengthened or the precipitation strengthened or transformation hardened, dispersion hardened yeah.

So, in all kind of the metal systems grain growth is observed because the driving force here is the surface energy. And the extent of to which grain growth will be taking place that will also that will be increasing with the increase of annealing temperature.

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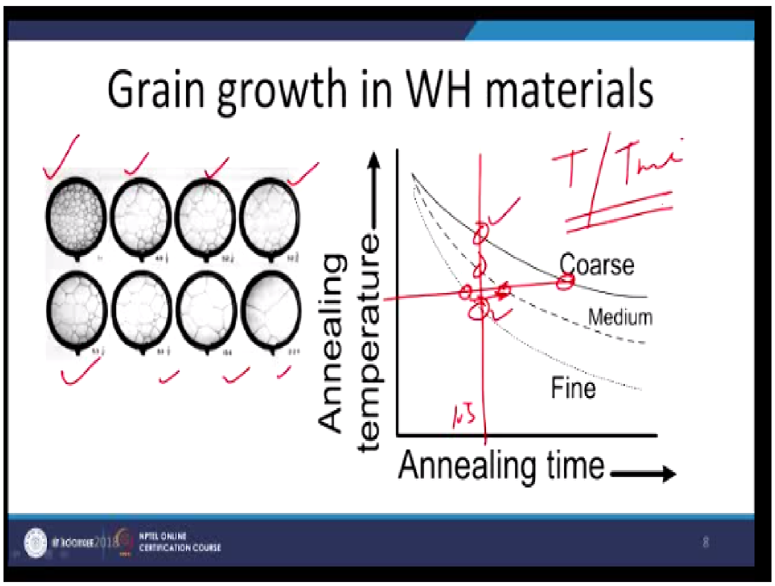

So, what we can see here wind exposure is given for the shorter period the grains are very fine. And with the continuous say these are the recrystallized grains which are equates and of the different sizes. But these are still find when the exposure is given for longer period will notice that grains are growing continuously and the grain will continue to grow significantly with the increase of the exposure period.

This is what we can understand from this diagram like for a given exposure time increase of the annealing temperature leads to the coarsening of the grains like annealing time is fix say for 10 seconds. So, if the 10 second exposure is given at lower temperature than the grains will you fine. And otherwise increase in exposure temperature you will be leading to the coarsening of the grains.

Likewise exposure of the metal for a given temperature and varying time or varying exposure period will also be leading to the change in the grain size. What we can see here with the for a given annealing temperature or exposure temperature increase of the annealing time increases the grain size. So, the exposure temperature and the exposure time both will be affecting the grain growth in the work hardened as well as in the other metal systems. Greater is the work hardening or other plastic deformation of the metal the greater will be showing the tendency for the grain growth as come.

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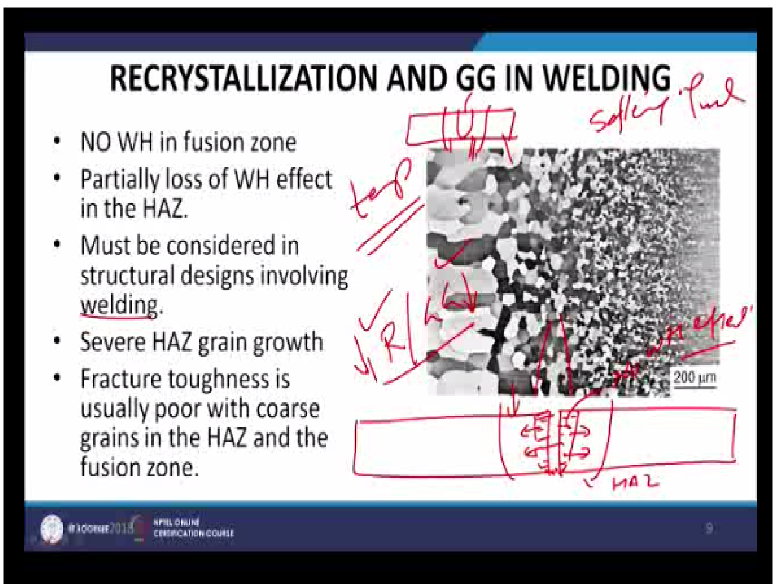

Now we will see what happens in case of the welding when the work hardened metal is subjected to the fusion welding. Like say is the plates subjected to the additional source of heat from the outside and the fusion is facilitated. So, the zone whatever zone is subjected to the fusion definitely that will have no work hardening effect, all effect will be eliminated.

And that is while the zones where heat will be transferred to the base metal due to the thermal conductivity of the metal a heat affected zone is formed. In this zone also due to the rise in temperature of the metal or work harden metal this zone will also be experiencing the recrystallization as well as grain growth depending upon the amount of heat which is being supplied for fusion during the fusion welding process.

So, if the greater is the amount of heat is being supplied greater will be the width up to which there will be rise in temperature greater will be the width up to which recrystallization and grain growth which will be taking place. And we know that if the recrystallization is taking place up to the greater width and more grain growth is taking place then this will be leading to the softening of the metal.

So, depending upon the amount of heat which is being supplied to the heat affected zone of the work hardening effect, loss of work hardening effect can be partial or complete. So, as we approach towards the fusion boundary the extent of a work hardening effect will be decreasing while going away from the fusion boundary. The extent of the work hardening effect which will be left will be more because of reduced recrystallization and reduced grain growth tendencies.

And we know that whenever such kind of the weld joint whenever made by the fusion welding process. So, it will be leading to the development of the heat affected zone which will weaker or the weld zone which will be weaker. And these aspects must be considered in development of the suitable structural design not just the strength of the base metal is to be considered.

But we need to consider the strength of the weld zone or the heat affected zone whichever is weaker for development of structural designs involving the welding. And the regions which are very close to the fusion boundary means the regions next to the fusion boundary which are which will be experiencing the greater temperature for longer period.

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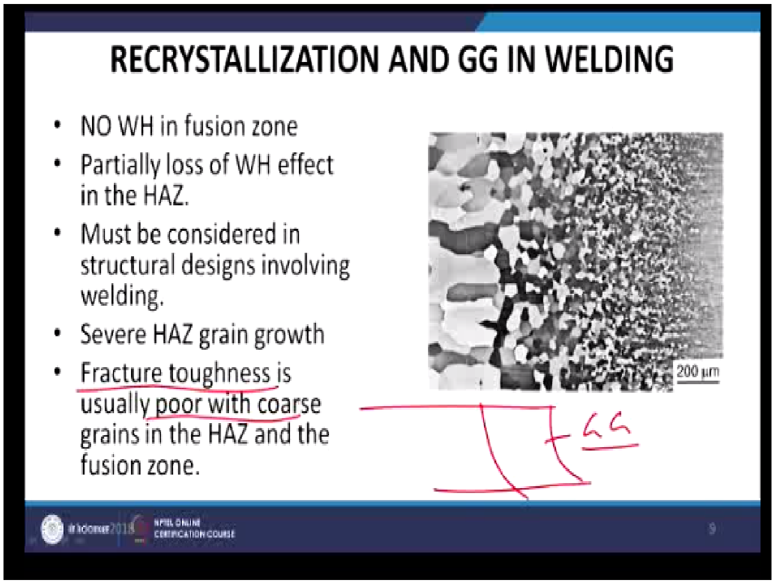

They will be experiencing the significant grain growth and complete loss of the work hardening effect and complete recrystallization followed by the grain growth. And therefore the extent in the strength loss will be maximum next to the fusion boundary and somewhat less away from the fusion boundaries. That is what will be seeing in the next slide.

And such kind of the grain growth is considered harmful from the mechanical properties point of view especially the fracture toughness, hardness and the tensile strength of material is reduced with the coarsening of the grains in the heat affected zone as well as in the fusion zone.

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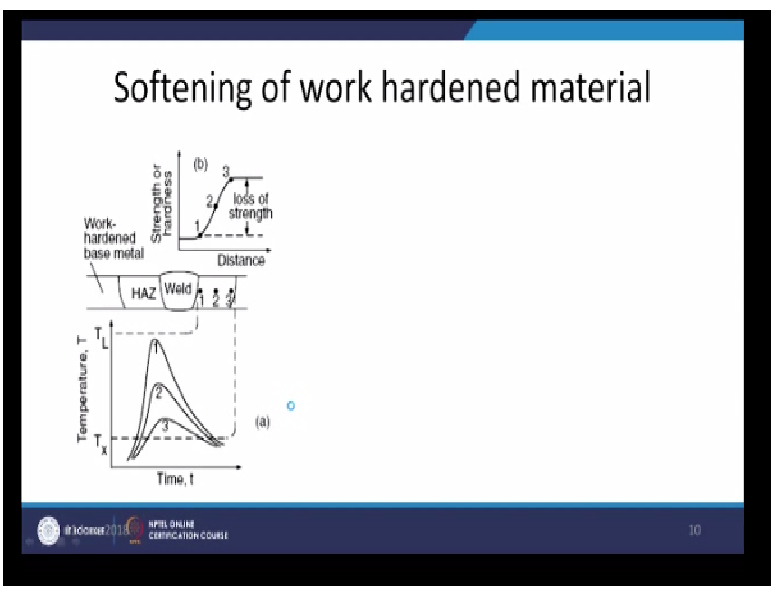

So, this is what we can see here, now I will summarize this presentation. In this presentation basically I talked about the concept of the metal and the way by which the working of the metal will be leading to the change in mechanical properties. And whenever high temperature exposure is given to the work harden metal in which way the properties of the work hardened metal are affected, thank you for your attention.