Joining Technologies of Commercial Importance

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Lecture - 43

Lecture 43 : Weldability of Metals Strengthened by Grain Refinement and Transformation Hardening

Hello I welcome you all in this presentation and we have talked about the weldability of the work hardenable metals and the precipitation strengthened metals. And in both the cases what we have seen that the application of the heat for the fusion welding causes the reduction in the hardness of the heat affected zone. In case of the work hardenable metals it is the loss of work hardening effect due to the annihilation and recovery of the dislocations. While in case of the precipitation strengthened metals loss of hardness and loss of strength primarily takes place due to the reversion, dissolution of the precipitates and which in turn causes the significant softening of the heat affected zone. But, as far as the solid state joining of these work hardenable and precipitation strengthened metal system is concerned the response to the plastic deformation based welding process is quite different. 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 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.

is attribute in the weld zone is attribute 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 due to the recovery and the loss of the dislocations which is taking place due to the heat generated in during the plastic deformation based welding processes. On the other hand if we talk about the plastic deformation based 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. So, here the zone next to the means faying surfaces of the components which are subjected to the control plastic deformation for metallic continuity and develop 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 precipitates while the partial dissolution due to the heat being generated during the plastic deformation waste 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 then there will be 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 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 precipitates is present or the decreasing amount of the precipitates 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. Now we will see the way by which the metals strengthened by the grain refinement, dispersion hardening and transformation hardening when they are subjected to the welding by the fusion welding or by solid state welding process like those which will be involving the plastic deformation. Like say the metal system which is primarily strengthened by the grain refinement, no other mechanism is working in any way. So, the component is like this and when subjected to the welding through the application of heat, so the zone will be brought to the molten state with the application of heat and in this, 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 it is as cast structure so dendrites 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, 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 the metal is, since this 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 coarsened so that the associated energy can be reduced through the reduction in the grain boundary area while in case when the grain size is fine the grain boundary is more associated surface energy is more. So, it is very simple that whenever heat is supplied the grain tend to grow and that will depend upon the kind of the weld thermal cycle experienced by the heat affected zone.

So, if we take an example like this is the weld metal, this is one zone, this is another zone, increasing distance from the So, weld thermal cycle of the each zone will be experiencing the different thermal cycle. Peak temperature will be maximum for location 1 and then peak temperature will be somewhat lower for location 2 and further 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 1 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 regions which has regions which have experienced the maximum grain size.

maximum size of grain that will be the softest one, where partial grain coarsening has taken place the hardness will be somewhat high and where grains are still fine that will be 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 strengthened, grain metal strengthened by the grain refinement in that case the weld metal will have the strength corresponding to its dendritic size but in case of the heat affected zone the area next to the fusion boundary will be coarser than somewhat finer in the slightly away from the fusion boundary. So, this will be somewhat medium grain size and fine grain size further away from the fusion boundary. And this effect will simply reflect from in the hardness variation and if this hardness variation is plotted and 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 wild 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. 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 primarily by the grain refinement in case of the fusion welding. Weld metal, the 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 or the grain size 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. 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. And 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 finer because it has been strengthened by the grain refinement.

in the base metal, coarse grain size in the heat affected zone and very fine grain size in the weld metal. So, we may find a situation where the base metal is retaining its hardness, loss of hardness is taking place in the heat affected zone due to the coarsening. So, in HAZ zone and then again higher strength is being realized due to the fracturing and refinement of the grain in the weld zone. So, we may find a trend of variation in hardness of this kind. So, this is the weld zone having the higher hardness primarily due to the grain refinement.

As per the change of the welding process or as per as 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. 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 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. When such kind of the systems are joined like typical example of this in aluminium we are reinforcing like TiB_2 or Al_2O_3 or silicon carbide. All these are refractory items being reinforced in the aluminium matrix. Likewise we may use nickel, cobalt or even iron to reinforce such kind of the constituents.

When the metal material or 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 when 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 Al_2O_3 TIB_2 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 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 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 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.

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 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 and the heat affected zone may be having the coarse grain structures. So, the properties in the heat affected zone may be shortly lesser, but these may be significantly lower in the weld zone because of the So, poor interactions between the reinforcing agent and metal matrix there will be 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, there can be soft zone formation in the heat affected zone as well as the weld zone and then gradually increasing 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 responds 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 and grain coarsening will be leading to the softening in the heat affected zone. Now we 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 we 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 system 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 firm consolidation in the metal matrix.

And these favourable variation in the properties may lead to the improvement in the hardness. On the other hand heat generated 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 this reinforcing agent and firm consolidation of the metal matrix with the refined particles this 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 if the reinforcing, if the dispersion strengthened metal system is work hardenable like aluminium magnesium manganese alloy, this is 5000 series aluminium alloy and this is work hardenable metal system and which has been strengthened by also strengthened by the reinforcement of the second phase particles and 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 contributing 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 base metal like this.

So, this increase in hardness is primarily attributed to the and 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 the softening of the heat affected zone is attributed to the 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. Now we will see 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 ones 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 bainite or martensite. Formation of such kind of the phases means transformation of such kind of the phases will be leading to the increase in yield strength and the hardness. So, there are various metal systems which show this kind of behaviour and which is exploited to strengthen the metal system.

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. Then we have the titanium alloys where alpha titanium when it is transformed into the beta titanium it shows the improvement in strength. Similarly some of the copper alloys. Alloys also show the martensitic transformation like phases which under controlled 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. as well as the plastic deformation waste welding processes respond to the transformation significantly when such kind of the metal systems are subjected to the welding either by the fusion welding or by the plastic deformation waste welding process. I will summarize this presentation, in this presentation basically I have talked about the way by which the precipitation strengthened 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 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.