Joining Technologies of Commercial Importance

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Lecture - 42
Weldability of Precipitation Strengthened Metals

Hello, I welcome you all in this presentation and so far we have talked about the weldability of the work hardenable metal and now in this presentation we will be taking up the weldability of the precipitation hardenable metal or precipitation strengthened metal systems. So, let us understand first how does this mechanism work, those metal systems like the A is the matrix and B is there as a solute. If B is having the solubility in A which is changing as a function of temperature then it helps to offer the precipitation It helps to develop the precipitates and these precipitates if these are hard and well distributed in the matrix. Then these help significantly in increasing the yield strength and the hardness of the material. So, the matrix having the fine well distributed hard particles in form of phases and precipitates. So, this kind of the fine well distribution of the precipitates helps in strengthening the metals, but these kind of the precipitates are formed.

in certain category of the aluminium alloys, ferrous alloys, copper alloys and the titanium alloys. So, if we see the details of the metal systems which can be strengthened by the precipitation strengthening. These are the aluminium copper alloys, aluminium magnesium silicon alloy, aluminium zinc magnesium alloy, copper beryllium alloy, magnesium aluminium alloys and some of the ferrous alloys. And whenever we give the controlled heat treatment of solutionising followed by quenching.

and then ageing. Then these fine precipitates as per the metal systems are formed and which in turn helps in increasing the strength and the hardness of the metal system. Whenever these precipitates are formed basically The mechanism which is helping to increase the yield strength of the metal is the increased barrier to the dislocation movement due to the presence of these precipitates. So, the mechanism of the strengthening depends upon the size of these precipitates. like in a material if the dislocations are moving then the dislocation barrier to the movement of dislocation will be offered by these precipitates.

So, if the precipitates are well distributed in the matrix then there will be lot of resistance for the movement of dislocation and which in turn will help in increasing the yield strength. There are 2 mechanisms which are there in which play a big role in strengthening of the metal strengthened by the precipitation hardening. One is the cutting of the precipitates and another is the bowing down around the precipitates. So, both these mechanisms contribute to the strengthening of the material as per the size of the precipitates. So, there are different types of the precipitates which are formed as per the type of metal system.

For example, aluminium copper is one precipitation strengthening metal system where Al_2Cu is one of the typical. precipitate which is formed in case of the aluminium magnesium silicon alloy Mg_2Si is the precipitate which is formed and similarly in case of aluminium zinc magnesium it is the $MgZn_2$ precipitate which is formed. And when these precipitates are well distributed in very fine size in the matrix then these contribute in big way towards the strengthening of the metal system. For development of these precipitates there are 3 steps which are used one is called solutionising where the alloy is heated to the temperature high enough above the solvus line, so that the homogeneous solid solution is formed. Thereafter from this after the heating it is quenched rapidly, so that we get the solid super saturated solid solution after the quenching we get the super saturated solid solution where alloying element will be present in the quantity or in the amount or in the solid solution much more than its quantity.

ability to get dissolved that is why it is supersaturated solid solution. And the third step is the ageing, now ageing can be performed at high temperature then it is called artificial ageing or it can be performed under the ambient condition then it is called natural ageing. In both the cases precipitates are formed. The few metal systems like aluminium, zinc, magnesium in this case the precipitates are formed slowly while in case of the aluminium copper systems the precipitation is very fast. So, these respond rapidly and to the heat being supplied during the welding or heat Subsequently during the ageing this will be hardened rapidly as compared to the aluminium zinc magnesium system.

So, aluminium zinc magnesium alloys that is why offers very good improvement in the strength and hardness even after the natural ageing while response of aluminium copper system is somewhat less for the natural ageing. And that is why artificial ageing is normally performed for strengthening of the aluminium So, these are the 3 steps for strengthening purpose and now we will see what are the different precipitates are formed. So, as I have said as per the size of the precipitates there are different strengthening mechanisms or the different way by which dislocations will be formed. the movement of dislocation will be resisted. So, as far as the contribution of the precipitates with respect to their size is concerned what we will see that when the particle size is small in this band, the bowing down of the dislocations around the precipitates contributes in much bigger way towards the strength as compared to the cutting.

While when the particle size is big then the cutting of the dislocation means the movement of dislocation through the cutting of the precipitates. is accounted for much higher increase in strength with the large size particles. So, obviously there will be a combined effect if we see that how the size is affecting then combined effect we can see. Now with the for very fine size precipitates there is a significant drop in the reduction in the strength due to the bowing down of the dislocations around the precipitates while in case of the large size particles there is a increase of the the strength for the large size precipitate. So, if we will see the combined effect of both these that is what we can see in this diagram what we can see there is a particular critical radius at which both bowing down and the cutting mechanisms will be playing.

great role towards the strengthening of the material. So, this one will be offering the maximum increase in strength and thereafter for the large size of the precipitates will be leading to the reduction in the strength. So, this is the size range where which would like to have for peak hardening or the peak strength. So, now we will see as a typical example for the precipitation strengthened metal system like aluminium copper system where the $CuAl_2$ precipitates are formed. Named in different ways one is like Guinier-Preston precipitates these are stable as a function of copper content these are stable up to this temperature.

The temperature up to which these are stable can be shown by this line and similarly the theta double dash phase which is also known as Gp2. phase that will be stable up to the temperature which will be shown by this line as a function of the copper content. And then theta dash precipitate will be stable up to this temperature and thereafter it will get dissolved. So, if we see and how about the appearance of these precipitates, these precipitates are extremely fine in size. And that is expressed in angstrom.

So, these are the precipitates what we can see in form of disc shape. So, these disc shapes are precipitates are like they are of the different diameters and the different thicknesses like this, this is what we can understand. So, the finest precipitates are produced by are found in form of the GP zone, GP Guinier-Pristons precipitates and then theta double dust precipitates and further larger size of the theta dust precipitates. And these two precipitates are perfectly coherent with the lattice structure in the solid solution and that is why these lead to the significant straining in the lattice structure. And therefore, they contribute to increase in strength significantly by effectively reducing or reducing the movement of dislocations while theta dash precipitate is the semi-coherent.

So, its effectiveness for reducing the dislocation movement will be limited as the extent of strain in the lattice structure induced by the theta dash phase is somewhat limited and theta phase is the stable phase. which is incoherent. So, its contribution towards the strength is limited because it does not cause much of the strain in the lattice structure in the solid solution of the aluminium. the means in aluminium and copper alloys. So, that is what we will see the GP zones are the coherent precipitates with the lattice and these are extremely fine 4 to 6 angstrom and their diameter is 180 to 100 angstrom.

While theta double dash precipitates also called GP2, their size is found in thickness from 10 to 40 angstrom while the diameter ranges from 100 to 1000 angstrom. And theta dash phase which is semi-coherent, its thickness ranges from the 100 to 150 angstrom and the diameter varies from 100 to 6000 or more depending upon the time and the temperature of exposure for ageing which has been given. Now as I have said this is the solid solution where in the matrix the solutes are present here and there and when the precipitates are formed which are coherent. then these will be developing the strain in the lattice structure and which in turn helps in reducing the movement of dislocations. So, that yield strength and hardness can increase while on the other hand when the coherent the incoherent precipitates are formed.

The strain in the lattice structure caused by such precipitate is very limited and that is why increase in strength by the incoherent phases like theta precipitate in aluminium copper alloys is very limited. So, if you have to understand the way by which the increase in strength will be taking place during the ageing process. So, during the ageing as I have said in the first stage homogeneous solid solution is formed. after quenching supersaturated solid solution is formed and in the third stage when the precipitates are formed during the ageing. So, now ageing can happen at different temperatures means at room temperature as well as at elevated temperature.

So, as a function of time for at a given temperature definitely the number of the precipitates will be increasing as a function of time. So, that will be leading to the increase in strength that is what we can see here in the super saturated solid solution will have lower strength. But as soon as the, so this is the schematic of the super saturated solid solution where all solutes are. while dissolved in the matrix and there is no precipitate. But gradually as a function of time at a given temperature of ageing formation or the precipitation starts and it leads to the development of the So, initially there will be few precipitates and the number of such precipitates will keep on increasing with the aging time and situation will arise when it will be peak aged.

And this peak aged condition will be leading to the maximum increase in yield strength hardness and thereafter further ageing at a given temperature will be leading to the coarsening of the precipitates, so by consuming the fine precipitates the size of the precipitates will start growing. And when this growth of the precipitate starts we will be seeing that the reduction in the strength as well as hardness will start, so this stage is termed as when this stage when Increase in the ageing time at a given temperature starts coarsening of the precipitates this leads to the reduction in the yield strength and the hardness this stage is called over ageing. So, in case of the under ageing there will be few precipitates which will be although very fine and in case of the peak ageing there will be maximum number of the fine precipitates and in case of over ageing. So, the coarsening of the precipitates will start and that will in turn will be leading to the reduction in the strength. So, variation in the ageing characteristic as a function of temperature we will see for the varying ageing time precipitation hardenable aluminium alloy.

This is aluminium, silicon, magnesium alloy where both are approximately 1% in the coarsening So, after the formation of the supersaturated solid solution when the system is aged at 120 degree centigrade. Then what we see that increase in the strength takes place very slowly and it takes very long time to reach to the peak strength, but when aging is carried out at 150 degree centigrade The peak strength at 120 degree centigrade was achieved say after 1000 hours. But when it is performed ageing is performed at 150 degree centigrade then it is being realised at 100 hours. At 170 degree centigrade it is being realised at 10 hours. And at like say 205 degree centigrade when ageing is performed in 1 hour it is subjected to the peak ageing and thereafter we can see the reduction in the strength starts.

So, we can say when the ageing is performed at 205 degree centigrade then after 1 hour the over ageing starts which means the coarsening of the precipitates. will start and that in turn will be leading to the reduction in strength. So these are very important aspect as far as their implication with respect to the welding is concerned. Now we will see that a metal system when a metal system like this which is in the peak aged condition having very fine distribution of these fine precipitates in the matrix of the alloy. Now for the welding purpose when we apply external heat, so the material which is in the peak aged condition having very fine precipitates like this.

So these precipitates are subjected to the over ageing due to the application of the heat. So what will be happening will be supplying the additional heat. So obviously the part of the metal will be brought to the molten state and part of the heat being supplied for melting will be transferred to the base metal. So this will be causing the heating of the metal next to the fusion boundary and this heating actually causes the overaging. So, overaging leads to the either complete dissolution or partial dissolution of these precipitates.

or the coarsening of the precipitates, so these are the 3 effects. So, if we take this example at this location here we have large number of precipitates that is what we can see from this diagram. As we approach towards the fusion boundary there will be some loss of the precipitates, so that is what we can see here in this example this is the base metal. This is the heat affected zone and this is the zone next to the fusion boundary and this is the weld metal. So, if we observe the things closely these are the 3 micrographs corresponding to the 3 different locations.

in the weld joint which is showing schematically how the variation in precipitates take place when it is subjected to the welding. So, the base metal which is not affected by the heat of the welding will be having the large number of precipitates that is what we can see very high density of these fine precipitates present in the metal matrix. But as we approach towards the fusion boundary and reach in the heat affected zone we will see that number of such precipitates have been dissolved and further these precipitates also have been coarsened. And if we go further closer to the fusion boundary we will see that number of such kind of precipitate has been further reduced and there are in this case just 2 precipitates are left and here like say 5 to 10 precipitates are left and here may be having 50 to 100 number of precipitates. on welding a peak strengthened material like say this is the weld zone or the fused region, this is fusion boundary.

So, the base metal which is away from the fusion boundary will not be affected by the heat as we approach towards the fusion boundary this will be affected by heat and next to the fusion boundary there will be subjected to the very high peak temperature for longer time. So, the regions which are subjected to the significant amount of the heat high temperature exposure for longer time that will be experiencing the complete dissolution of these precipitates and slightly away from the fusion boundary dissolution will be partial. So, partial dissolution of the precipitates and since these metals were strengthened by the presence of these precipitates and if these are getting dissolved then of course the hardness and strength will be reduced. So, maximum loss of the strength and hardness will be taking place next to the fusion boundary Then on moving away from the fusion boundary there will be somewhat lesser loss of the strength and further away from the fusion boundary in the base metal there would not be any change in the hardness and the yield strength. So, these effects we can easily see in case of the welding through this diagram.

So, if we take an example like this is the base metal. And it has been produced by the fusion welding, so this is the weld metal. The zone which is next to the fusion boundary is 1 is this, zone slightly away from the fusion boundary is 2 is this, zone further away from the fusion boundary is this. And corresponding weld thermal cycles have been shown here and zone further away which is unaffected is this one. So, if we see the regions which are very close to the fusion boundary we are experiencing the much higher temperature and high temperature exposure is there for longest period.

While the zones which are away from the fusion boundaries they experience lesser temperature, lesser peak temperature and for shorter time. So, the temperature and the retention period, high temperature retention period. So, the temperature is increasing and retention period is increasing as we move towards the fusion boundary and its effect and as we move away from the fusion boundary this peak temperature as well as retention period is decreasing. So, the region which is away from the fusion boundary significantly away from the fusion boundary will not be affected by the heat. So, it will be showing the maximum density of the precipitates and it will be showing the maximum strength.

While the region which is slightly heated. by the heat from the fusion zone then it will be experiencing the partial loss of the precipitates. So, accordingly there will be partial reduction a little reduction in the hardness and yield strength. And as we move further away further closer to the fusion boundary then there will be further reduction in the number of precipitates and coarsening of the precipitates. So, this will be leading to the further reduction in the strength. And then next to the fusion boundary there will be complete loss of the precipitates.

So, it will be the weakest zone or the minimum hardness and strength will be observed in case of the precipitation strengthened material in the zone next to the fusion boundary because of the complete dissolution or complete loss of such kind of precipitates and the hardness variation we can see. So, this just immediately after the welding means in as welding condition the minimum hardness is next to the fusion boundary and then on moving away we will see that hardness starts increasing. So, this increasing hardness is indicating that this is the region where the partial dissolution has taken place and this is the zone above which the Precipitates have not been much affected by the heat of the welding and that is why strength loss was minimum. So, this is the zone where complete dissolution has taken place, this is the zone where partial dissolution has taken place and this is the zone where which has been unaffected by the base metal unaffected by the heat from the welding. Now if the zone which has been completely has experienced complete dissolution like one which is next to the fusion boundary like this one.

So this will be having the aluminium copper or aluminium magnesium silicon or aluminium zinc magnesium in the solid solution stage. So if the metal shows the tendency for ageing after the welding then we will notice that again formation of the precipitates in form of Mg_2Si or $ZnMg_2$ has started. So if we allow after the welding. Immediately after the welding if we check then the hardness next to the fusion boundary will be minimum. But after some time if we check then zone next to the fusion boundary will start experiencing the aging like this and then like this.

And after significant if you perform artificial ageing then we find that hardness variation is by enlarged uniform and the strength has been restored that is what has been shown in this diagram. So if the natural ageing is performed the region which has experienced the complete dissolution will be responding very rapidly for the formation of the precipitate and it will be showing the increase in strength. So, this is the zone next to the fusion boundary and if we perform the artificial aging. So, in case of the artificial ageing the zone which has experienced the partial dissolution that will be subjected to the over ageing. While the zone which has been subjected to the complete dissolution that will be experiencing the formation of the fresh precipitates.

And that is why the zone which has experienced the complete dissolution leading to the over Formation of the precipitates on artificial ageing will be leading to the maximum improvement in hardness and strength. While the zone which has experienced the partial dissolution will be subjected to the over ageing effect and that is why this will be showing a little bit dip. So, little bit dip is experienced away from the fusion boundary that is primarily due to the over ageing effect and then again will have the hardness maximum hardness due to the in the base metal. So, now I will summarize this presentation. In this presentation basically I have talked about the mechanisms which will be leading to the increase in strength of the precipitation hardenable metals and how the precipitation strengthened metals are affected by the heat from the welding. Thank you for your attention.