Joining Technologies of Commercial Importance

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Lecture - 46
Weldability Consideration

Hello, I welcome you all in this presentation and you know that so far we have talked about the effect of the metal properties on the weldability and how the weldability of different types of the metal systems is affected if they are strengthened by solid solution strengthening, grain refinement, precipitation hardening, transformation hardening, dispersion hardening. And how the weldability will be affected if a metal system is having the combined effect of these strengthening mechanisms. Now we will be looking into the general aspects related with the weldability of the metals and what are the different things that we should look into instead of going into the metal systems. For example, if we have to identify or we have to study the weldability of the metals, we need to see that whenever a weld joint is made. how the weld metal properties and the heat affected zone properties are affected. So, like the metal the two parts of metal A are being joined either by the fusion welding or the solid state joining process.

A joint will be produced at the interface In case of the fusion welding it is typically called weld metal and nearby that zone always depending upon the process a zone which is affected by the heat or the deformation is produced In general when the zone in the base metal which is being formed due to the effect of heat it is called heat affected zone. So, we need to consider the properties or we can say the characteristics of both weld and the heat affected zone. If the weld metal, so what are the things that we have to look into the weld metal, weld metal properties. So the first thing is about its soundness because soundness whether it is free from defects and discontinuities or not and if it is free then what are its properties.

in terms of like mechanical properties, corrosion properties, wear properties or then what are the kind of the residual stress development in the weld metal and accordingly we will be saying whether the weldability of metal from the weld metal point of view is good or or it is poor. Apart from this the heat affected zone properties are also looked in to see whether the heat affected zone is sound means no cracks. and the kind of the residual stresses being present and the kind of the properties it is having in terms of the microstructure, mechanical properties and corrosion properties. Sometimes, hardening takes place which leads to the embrittlement, sometimes softening takes place in the heat affected zone which promotes the fracture, unfavourable metallurgical transformation in

the heat affected zone lowers the corrosion resistance and all these things happen due to the unfavourable metallurgical transformations means the development of microstructure. So, if we talk in the beginning about the weld metal.

the weldability of metal when we are looking into the weld metal related aspects. A weld joint of a given metal can be produced just say either by fusing the faying surfaces and so the metallurgical continuity is realized after the solidification. In this case no external metal is added. So, in this case there is no almost no change in composition of weld metal. So it is expected that this kind of the weld metal will have uniformity in composition like starting from base metal across the weld metal again into the base metal.

So there should be uniformity in composition of the base metal, but as far as the microstructure is concerned there can be lot of heterogeneity because the base metal may have the rot structure means the structure having the effect of the manufacturing processes. If it is like rolling or forging then those effects will be there in the microstructure and if it is the if it has been made by the casting then it will have the dendritic structure. But as soon as we approach or we reach around the heat affected zone, there we will see the various regions like partially refined heat affected zone, refined heat affected zone, coarse grained heat affected zone. coarse grained heat affected zone. And then in the weld metal of course we may have the planar grain structure, then cellular grain structure, then dendritic grain structure and equiaxed.

And likewise the similar kind of the structural variation will be on the opposite side. So despite of having the same composition since the melting has taken place, so subsequent solidification and the heat affected zone has experienced the weld thermal cycle, so it will also be having the different micro structural changes. despite of no change in the chemical composition of the weld metal. Whenever a base metal is welded by the fusion welding process there is always structural variation and depending upon the characteristics of the metal there can be softening or there can be hardening depending upon the kind of the metallurgical transformations which are taking place in the weld zone. For example, like the most of the metals like precipitation hardenable systems, work hardenable systems and dispersion hardened systems.

When they are welded by the fusion welding process mostly we see even for the autogenous welding where no change in chemical composition of the weld metal is taking place just the Faying surfaces are fused, the weld metal is found to be of the poorer mechanical properties due to the unfavourable metallurgical transformations as compared to the base metal. Now we will see that sometimes the autogenous welding is not possible due to the difficulties associated with the through thickness penetration. Like by using the laser welding and electron beam welding maybe we can weld the thicker

sheets and realize the through thickness penetration to ensure that the faying surfaces are brought to the molten state. But still in those cases even without change in composition lot of structural modification in the weld metal. results in the change in mechanical properties and which may be in form of hardening or softening of the weld metal.

But sometimes it becomes mandatory to prepare the edges of the plates to be welded through the suitable edge preparation and in that case it is required to fill up this gap using the suitable filler and in that case we have to use some kind of the filler. electrode welding processes are used or like non-consumable welding processes like gas tungsten, arc welding, plasma arc welding we have to use filler from outside. So, this filler or the consumable electrode can be of the two types, so filler or the electrode. composition can be almost similar to that of the base metal or it can be completely different than the base metal. Most of the cases when there are no major metallurgical issues and the weldability issues related with the base metal then mostly the matching filler or the electrode metal is used.

But if you want to address some specific technological aspects. with the poor weldability of the base metal then we choose the dissimilar or completely different filler metal or the electrode. Like say those high carbon, high carbon steel plates sometimes welded using the austenitic stainless steel or nickel based fillers in order to overcome the issues related with the high hardenability, lower down the residual stresses, reduce the cracking tendency or what we want that the weld metal is having the better combination of the properties then the base metal. So in that case we choose the suitable filler which will offer us the required combination of the properties which may be in terms of the good corrosion resistance, in terms of the required the tensile properties of the weld metal. So or it is having the required wear resistance, so we can choose.

the filler or the electrode composition suitably so that it is having the required set of the properties for the weld metal. So if we considering this aspect where at least we have the flexibility in case of the fusion welding processes where consumable. either consumable electrode is used or the filler is used from outside. We have the flexibility to select the suitable filler so that the weld metal composition can be regulated accordingly in order to have the required microstructure, mechanical properties, corrosion resistance, wear resistance. So that allows us to use either similar or the dissimilar metals to satisfy the requirement of the weld metal properties.

But if we talk of the heat affected zone related aspects then certainly whenever heat is supplied to facilitate the fusion of the faying surfaces one zone near the weld metal is formed And this heat affected zone, we cannot do much to eliminate the heat affected zone because in fusion welding processes it is always there. Whenever heat is supplied to

ensure the fusion of the frame surfaces, a heat affected zone is formed. Size of the heat affected zone certainly can be reduced by using the high energy. So, density welding processes like laser beam or electron beam but this zone will still be there size of the or the width of the heat affected zone certainly can be reduced. So, from the weldability point of view we have the luxury at least in case of the welding of the thick plates.

where we can use the filler or the electrode of one or other composition in order to adjust the properties of the weld metal. Certainly we can have a situation where either the corrosion resistance or the tensile properties of the base metal are very poor. Like corrosion resistance of the base metal in terms of the MPy is just like 5, MPy this is the typical unit to show the corrosion resistance or corrosion behaviour of the material and say tensile properties in terms of the yield strength is just 300 MPa and the percentage elongation is just say 20%. So, if we want that our weld metal is of the much better properties then accordingly we can choose the suitable filler metal or the electrode offering us the much better corrosion resistance like CR is having 1.

5 MPY. yield strength is of 500 MPa and the percentage elongation is 30%. So, this kind of the flexibility is available to regulate the weld metal properties at least with the consumable welding processes or those processes where we can choose the filler metal of either similar composition or of the dissimilar composition. There are some issues with the autogenous welding process as far as the weldability is concerned. Like a metal which is having the solidification temperature range of just 10 degree. Then the issues related with the weld metal are very limited especially with regard to the solidification cracking.

But when the solidification temperature range becomes very wide then even the autogenous welding does not help to eliminate solidification temperature range is very high like say 150 degree centigrade. Then even simple fusion welding, autogenous welding where just the faying surfaces are brought to the molten state and subsequent solidification sometimes lead to the solidification cracks at the centre of the weld. So, in order to avoid the weldability issues related with the higher solidification temperature range, sometimes the autogenous welding is avoided and we try to weld. the base metal using the suitable filler, so that the solidification temperature range can be reduced say from 150 to 25 degree centigrade. In that case the solidification cracking tendency will be reduced with the because of the reduction in the solidification temperature range.

The mechanism of the solidification cracking I will be talking subsequently. But, what I am saying is like direct melting of the base metal may also not be or may not always be feasible if the metal is having the wider solidification temperature range or it is due to the high hardenability it is leading to the embrittlement of the weld metal. So, it will be better to use the electrode or the filler metal of the base metal. lower hardenability like the

austenitic stainless steel or the low carbon steels filler can be used. So, it may not always be favourable to have the autogenous weld through the melting of the faying surfaces and subsequent solidification of the weld metal development for producing a weld joint.

So, it is sometimes it is good to have the fillers and the electrodes either of the matching characteristics or of the completely different characteristics. As I have said we have the option to regulate or adjust the composition as well as the weld metal properties by choosing either the matching filler metal or of the completely different kind of filler metal. the weldability related issues of the base metal can be reduced. But we cannot do much as far as the heat affected zone development is concerned because it is directly affected by the amount of heat being supplied. for fusion of faying surfaces.

So, like low energy density processes like gas welding or shielded metal arc welding, these processes will be supplying the higher heat, higher amount of heat, so heat input will be more and that in turn will be leading to the wider heat affected zone. So, in order to reduce the adverse effects associated with the heat affected zone it is always favourable to work with the high energy density processes like electron beam welding or the laser welding or the plasma. arc welding these processes will require lesser heat input. So, the heat affected zone HAZ width in that case is reduced and that in turn will help in addressing the issues to some extent which are associated with the heat affected zone. heat affected zone issues cannot be eliminated but certainly they can be reduced and it to a great extent means the HAZ characteristics to a great extent depends upon the kind of weld thermal cycle being experienced by the base metal in the heat affected zone.

Like heat affected zone is the zone up to it is the zone or the width up to which the base metal properties are being affected metallurgically and the mechanically. is called heat affected zone and it will directly depend upon the amount of heat being supplied, heat input. So, if we in the heat HAZ if we take the 3 different locations 1, 2, 3 then each location will be showing us the different weld thermal cycle which means the different peak temperatures and the different cooling rates. So, heating rate is high if the point this is for 0.

1, 0.2 and 0.3. So, we will see that peak temperature is decreasing and it is taking longer time to reach the peak temperature that is what we can see the shift towards the peak. right this is time scale and this is showing the temperature and this is what is typically called weld thermal cycle. Weld thermal cycle to a great extent affects the HAZ characteristics whether it will be causing the means which kind of the transformation in the HAZ will be taking place and whether it will be causing the softening or the hardening of the heat affected zone, development of the residual stresses or cracking tendency accordingly, embrittlement also is caused by these HAZ transformation. There

are ways to regulate the weld thermal cycles associated with the HAZ. affected zone during the welding process and for that purpose we use preheat.

Preheating will be increasing the peak temperature of a particular location but it will be reducing the cooling rate being experienced. So preheating of the base metal during the welding will help to change the weld thermal cycle favourably. However, it may increase the HAZ width but it will reduce the cooling rates. Since the cooling rate especially in welding of steels are more troublesome. And that is why it may be considered that preheating sometimes help in reducing the residual stress development.

And it also helps in reducing the cracking tendency, reducing the embrittlement as far heat affected zone is concerned and this happens through the control over the unfavourable metallurgical transformations. In some of the processes what we see that thermo mechanically affected zone is also formed. This is the typical characteristic of the processes where the plastic deformation, controlled plastic deformation is used for welding purpose. So all those solid state joining processes like friction welding, friction stir welding, ultrasonic welding, explosive welding in all these welding processes localized in these 2 processes macro scale plastic deformation is used and while in these 2 processes ultrasonic explosive welding process micro scale plastic deformation is used. So, whenever this kind of deformation occurs we will notice that at the interface is deformed like this.

So, this kind of the deformation at the interface this will be leading to the formation of a zone which will be having the effect of deformation as well as heat and that is why it is called thermo mechanically affected zone. So, this is the typical characteristics of the ultrasonic welding and the explosive welding. explosive welding. But in case of the friction stir welding the complete recrystallization of the weld nugget takes place while next to the weld nugget we find a very little zone which will be having the effect of the heat as well as the deformation. So, the zone which is completely deformed, fractured, refined is called weld nugget in case of the FSW.

The weld nugget is the zone which experiences both effect of heat and effect of the deformation, so that is why it is called thermo mechanically affected zone, this zone is very narrow And thereafter region is formed which is affected only by the heat being transferred from the weld nugget to the base metal, so the heat affected zone. So, sometimes we get the thermo mechanically affected zone apart from the heat affected zone also. So, now we know that heat affected zone which experiences various weld thermal cycles. As per the metal system it may experience the recovery and recrystallization in case of the work hardening metals, grain refined metals, dispersion hardened metals, even transformation hardened metals.

solid solution strengthened metal. So, this is very common that like the heat affected zone due to the weld thermal cycle will be experiencing the recovery as well as recrystallization. But thereafter the metallurgical transformations in the heat affected zone like in form of the reversion. or dissolution of the precipitates or the transformation in form of like ferrite and pearlite transformation into the martensite or bainite. These will be so the reversion and dissolution will be causing the softening while the transformation hardening will be causing the hardening of the heat affected zone. Sometimes so that will depend upon the kind of the strengthening mechanism which is involved.

Apart from these the heat affected zone also experiences in case of the fusion welding processes. Heat affected zone experiences the tensile residual stresses, so if the metal system is hard brittle low percentage elongation then tensile residual stresses sometimes leads to the cracking in the heat affected zone. It also leads to the loss of toughness. So, it is important more to consider the way by which heat affected zone properties are being affected due to the weld thermal cycle being imposed during the welding to assess the weldability of the metal. Since the weldability of the metals considers the properties of the weld metal as well as the heat affected zone.

So, we need to consider the 3 aspects whether the weld metal is clean or not. Clean means it is free from the slag or the flux inclusions or not. That will depend upon the kind of the affinity a weld metal is having with the material. with atmospheric gases. The metals which are having the greater affinity with the atmospheric gases there will be greater tendency for formation of the oxides and nitrides and so to take care of them more slag is being formed and increased amount of the slag formation means increased tendency for their entrapment in the weld metal and that in turn will be reducing the cleanliness of the weld metal.

So those metals which have less affinity to the atmospheric gases they will be cleaner and they will pose lesser issues related with the weld. Likewise, the heat affected zone the way by which heat affected zone properties are affected like there are some of the metals which are not much affected by the heat of the welding in the heat affected zone. So, they will be offering the better weldability as compared to the metal systems which either experience the softening or the hardening or increased cracking tendency or reduced corrosion resistance. So, if the weld if the heat affected zone properties are being adversely affected then they will experience the or they will be having the lower weldability as compared to the others whose properties are not much adversely affected due to the heat being applied during the welding. Likewise the weld discontinuities, weld discontinuities can happen in the heat affected zone as well So, in the weld metal there can be inclusions, there can be porosity, while there can be the solidification cracks,

while in the heat affected zone there can be liquation cracking, there can be underweed cracking, there can be lamellar tearing.

So, there are various types of the crackings which can occur in the weld metal as well as in the heat affected zone and which can reduce the weldability of the metal. So, what we have to see for assessing the weldability of the metal is you have to see how clean the weld metal is, how the HAZ properties are being affected. and the kind of the discontinuities being formed when a metal is welded, so that we can have the fair idea about the weldability of metal. So, now I will summarize this presentation, in this presentation we have seen that the So, what are the different aspects that we should look into to assess the weldability of the metals and there are 2 main areas as far as the property consideration is involved in assessing the weldability. One is the properties of the weld metal and another is about the properties of the heat affected zone.

Apart from the cleanliness and the discontinuity cleanliness of the weld metal and the discontinuities formation in the weld metal as well as heat affected zone and the heat affected zone properties. Thank you for your attention.