Advances in Welding and Joining Technologies
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Lecture – 17
Welding Metallurgy Part I

So, good morning everybody today will be discussing on the another module of this course Advances in Welding and Joining Technologies.

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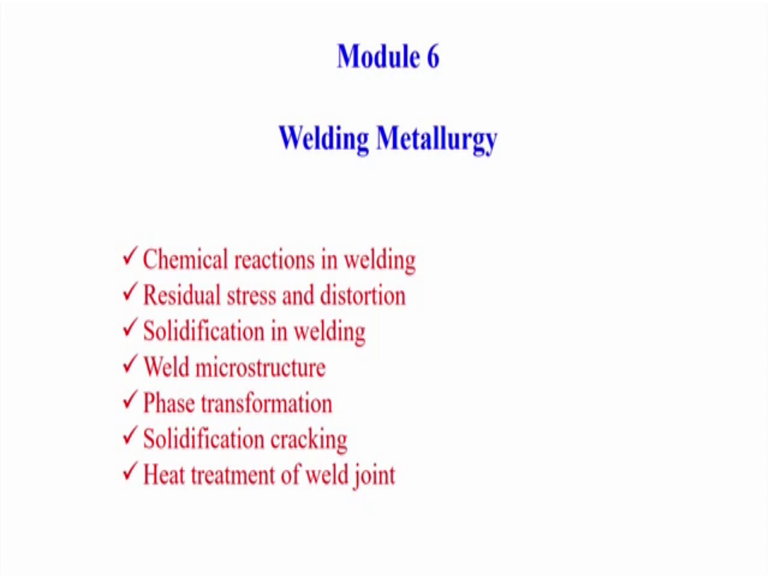

So, that that is related to that welding a metallurgy; This is also a part of the complete course and that purpose of this covering this welding metallurgy is that, probably some metallurgical understanding or some reaction happening during the welding is helpful to decide the type of welding processes or sometimes this critical analysis of this welding metallurgy also necessary, to avoid to produce some kind of defects in during the fusion welding processes or as well as other solid state welding processes.

So, we will try to get some basic idea; metallurgical aspects related to welding processes. So, this module welding metallurgy we will try to cover that; first is a we will try to look into that chemical reactions, that is happening in welding process. Second, is the one of the most integral part of welding that residual stress and distortion that is the most serious problem happens.

And of course, this is residual stress and distortion having the link with the metallurgical changes that happens during the welding process. And then we will try to basic fundamental understanding of the solidification and in specific to welding processes, and what are the typical microstructure and what is the nature of the microstructure actually developed the welding process and probably; how we can control this weld microstructure during the process, so that we can expect some desired properties in the final version.

So, that microstructure is more related to the weld joint property. So, it is very much it indeed is needed to know some idea basic idea about the weld microstructure. Then we will try to look into that phase transformation happens; it may be the solid test state phase transformation or what are the consequence of the when there is a solidification happens from liquid phase to the solid phase during the welding process, and how this phase transformation actually affects the final or influence the final weld joint, then will try to look into that specifically the formation of the cracking and in very specific to the solidification cracking, that is the most severe problem in the welding of a specific in presence of the specific components within the weld.

So, that is I will try to look up; try to look also try to look into that solidification cracking in that happens during the welding process. And finally, some basic idea that heat treatment of the weld joint; so we have the idea about the heat treatment processes, but we will that look into that basic things is heated, when how it is possible to apply in case of the in case of specific weld joint. So, with this I can start with the several components of this module; first will the what are the chemical reaction that happens during the early process.

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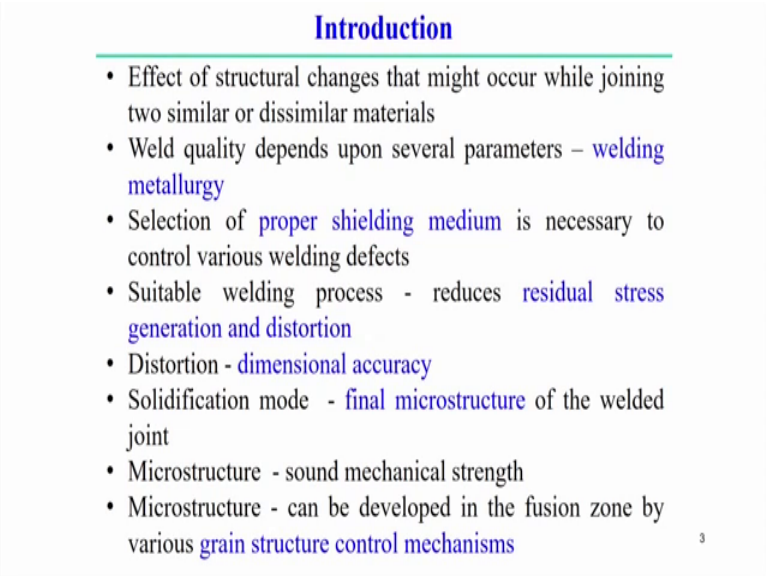

So, that if we look into that chemical reactions basically happens during the welding process. So, we will try to look into the basic aspects that, what are the effect of structural changes happens during the joining of the similar and dissimilar materials and that structurally changes due to presence of or using different type of shielding gas or any other kind of shielding to the molten weld pool, and then how it react with the molten weld pool and making whether it helps or into some helps in micro structure formation or it may not help in the micro structure for, but helps in other aspects also.

Second, that definitely we know that weld quality; that means, final weld joint in terms of joint strain, their mechanical properties of the weld joint that is a mostly were interested and the life of the weld joint that definitely depends on the welding metallurgy.

So, that; so it is necessary to study this welding metallurgy; and how this welding metrology depends on the several parameters involved in the welding processes, third point is that selection of the proper shielding medium it is also necessary that that selection of the shielding anyway shielding gas is obvious necessary to use in the welding processes, but proper shielding gases need to choose, because it actually finally, affects the formation of the different types of weld defects at suitable welding processes or suitable pre measurement of the workpiece sample.

So, that it will finally, try to reduce the residual stress and generation of any kind of the distortion. Anyway in fusion welding processes always it is subjected to some amount of the residual stress and distortion we cannot avoid this; only what we can do; that we will try to reduce the amount of the residual stress and distortion or if the residual stress is beneficial to some extent that will try to maximize that component, but most of the cases residual stress is basically not favoured in a life of the weld joint.

So, that is why our objective should be always to a minimize the amount of the residual stress generation and of course, the amount to reduce the distortion, because distortion is basically affect the dimensional accuracy of the two components when we are supposed to joint or all this aspect is mostly influenced by the solidification mode or maybe the final well structure or final microstructure of the weld joint.

So, therefore, microstructure actually formation of the microstructure is highly related to the whether we can get a very sound weld joint or not. So, therefore, that study and the effect of the different process parameter is actually necessary, because the microstructure can be developed in the fusion zone and that microstructure can be controlled. So, there are several control mechanism. So, that we can control the microstructure and indirectly this microstructure also affects the generation of the residual stress along with the other conditions, but the distortion residual stress also influenced by the presence of the micro structure.

So, that stress generation distortion and formation of the microstructure, they actually linked with respect to each other therefore, they are interactive phenomena is needs to investigate or needs to know here, but it is not possible to cover in details analysis of all the micro structural phenomena in this module, we will try to look into some basic concept that generally happens during the welding process.

So, that we have some idea that nature and type of the microstructure can be developed in the welding processes. And of course, that we can link the different type of the process parameters or microstructure what is the in terms of the or that influence the amount of the residual stress and distortion.

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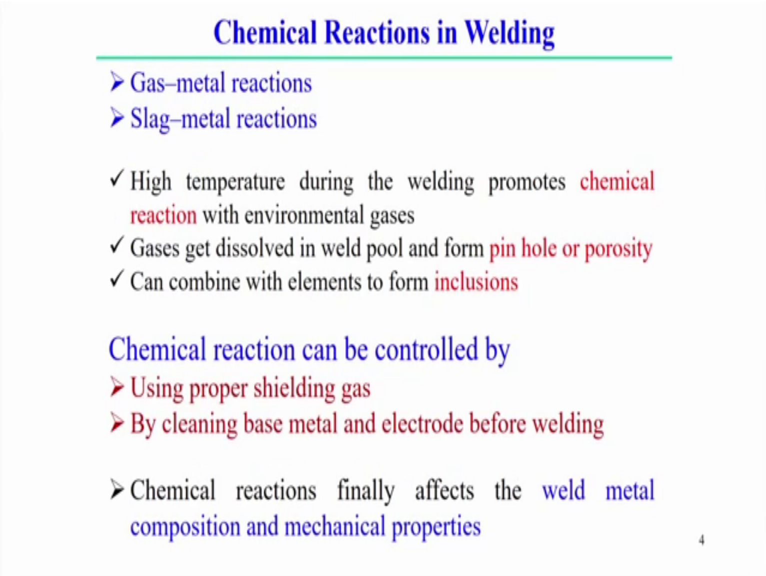

So, in that respect, first we look into that; what are the chemical reactions in welding is generally happens? So, broadly we can categorize is the during the overall, if you look into overall all the type of the welding processes. So, we can use that gas basically shielding gas to protect the molten pool.

So, therefore, you need to know the interaction between the gas and molten weld pool or when the molten weld pool becomes solidified how the what is the reaction happens between the these two components that is also need to know. And this is the one way another way to protect the molten pool is the in terms of the using the some slag.

So, therefore, slag metal reaction also important to know analyse to know to finally, to that influence the weld joint strength. So, these two mode either using shielding gas or either using the slack probably the purpose is to protect the only the molten weld pool during the welding processes, but why it is important; because high temperature during the welding involves fussionally specifically the involve high temperature generation.

So, that high temperature the chemical actually it promotes the chemical reaction with the surrounding atmosphere. So, when the it reacts with the surrounding; the molten weld pool reacts with the surrounding atmosphere, because tendency increases even at room temperature to at very high temperature. So, that probability is the entrapment of the gas can be dissolved in the weld pool and they can create the porosity or kind of pool or kind of some other defects or there may be the they can form the some inclusions also, when it is react when the molten weld pool react with the outside atmosphere.

So, therefore, this type of interaction or this type of chemical reaction of the molten weld pool with the suddenly atmosphere can be controlled and by the way using the proper shielding gas or using the proper slag material, so that it will be able to protect the molten pool during the welding process. So, other way also that this chemical reaction can be reduced simply by cleaning the best metal, because most of the cases we can the we can find out the when you the layer of the metallic oxides and of course, we use the several electrode during the welding process.

So, before using that; if you clean the workpiece surface and the electrode material probably we can reduce some amount of the contamination of the molten weld pool. So, finally, because the finally, the chemical reactions is basically affects, the final weld joint properties or it can alter the weld composition, it becomes the part of the weld composition or becomes part of the final composition of the weld joint strength and that actually indirectly influence the affects the mechanical properties of the weld joint.

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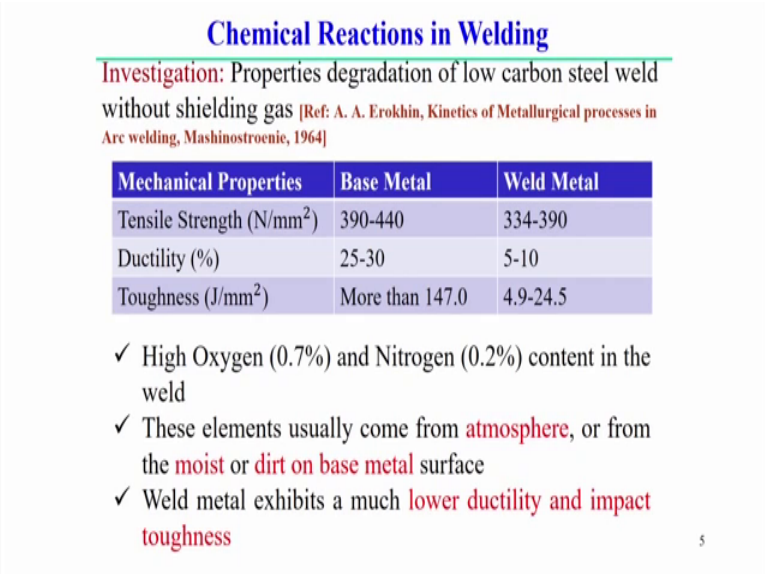

Mechanical Properties	Base Metal	Weld Metal
Tensile Strength (N/mm^2)	390-440	334-390
Ductility (%)	25-30	5-10
Toughness (J/mm^2)	More than 147.0	4.9-24.5

So, that chemical reaction find out that first some investigation has been carried out that, I think if you look into that reference Erokhin actually first actually investigated the what is the effect of the shielding gas and in welding processes. So, he conducted the experiments on low carbon steel without any shielding gas.

Simply creating the arc, but with no shielding gas the weld was conducted, and then the properties difference in the different properties we can tabulate it in the here that mechanical properties, if you see the tensile strength base metal, what is the range; I think Newton per millimetre square 390 to 440, but weld metal without any shielding gas found out that well there is a decrement of the joint strength 334 to 390. And there is a considerable decrement of the ductility of the weld joint and of course, toughness there is a huge reduction in the toughness of the weld joint.

So, there is a degradation of the weld joint properties as compared to the base metal, if we do the welding without any shielding gas. So, that is why shielding there is necessary to use some shielding gas to protect the molten pool. Here, if you see that main that high oxygen, nitrogen and mainly the oxygen and nitrogen content was found in the weld joint.

So, around 0.7 percent oxygen and around 0.2 percent nitrogen actually found out with the plain weld metal, if you do not use any kind of the shielding gas ; that means, during the welding process at this high temperature the molten weld pool actually react with the surrounding atmosphere, and then oxygen and nitrogen actually absorbed within the molten pool or mixes within the molten pool.

So, definitely this amount of the oxygen and hydrogen usually comes from the atmosphere or there may be other source of this contamination or present there is oxygen or nitrogen that cannot may come also in the moist, that moist air can come from the moist air or that that base metal surface and the dot on the base metal surface sometimes we use some chemical agent on the base metal surface.

So, that can be a source of this oxygen or nitrogen and finally, it reacts with this the oxygen. So, definitely weld metal exhibits a much amount of the lower ductility and the impact toughness also very low in this case. Therefore, this investigation tells us that of course, we can do the welding process welding process can happens in absence of the shielding gas, but we have to compromise with the degradation of the different weld joint properties.

So, in that case it is essential to use some amount of the shielding gas and even it is possible to using the shielding gas, that the weld joint properties is as maximum as of the basic properties of the parent metal. So, therefore, this investigation actually the indicates that there is a need of the using the shielding gas in the welding processes, what if you over if you look into the overall effect of the nitrogen oxygen or hydrogen on the weld joint quality.

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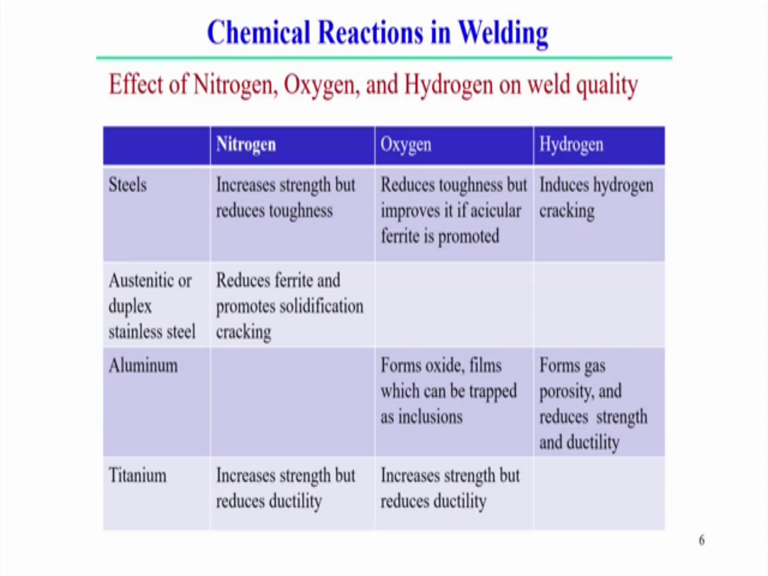

	Nitrogen	Oxygen	Hydrogen
Steels	Increases strength but reduces toughness	Reduces toughness but improves it if acicular ferrite is promoted	Induces hydrogen cracking
Austenitic or duplex stainless steel	Reduces ferrite and promotes solidification cracking		
Aluminum		Forms oxide, films which can be trapped as inclusions	Forms gas porosity, and reduces strength and ductility
Titanium	Increases strength but reduces ductility	Increases strength but reduces ductility	

Because these three components in the atmosphere or surrounding atmosphere mainly becomes part of the final weld joint. So, they are having some impact on the weld joint quality. So, in overall if you see that if you look into the steels that steel presence of nitrogen actually when he is contaminated to the nitrogen it increases the strength, but reduces the toughness. So, increases the strength presence of the nitrogen increases the stainless steels, because there is steel containing of the other alloying element.

So, that intimate of the strength actually depends on the nickel and chromium ratio presence in the different gradient a steels basically. So, that the this is the effect of the nitrogen only, but of course, there in presence of other alloying elements also important. In general presence of oxygen in steels basically, reduces the drastically reduces the toughness what improves it; that means, toughness can be improved, if acicular ferret is promoted.

So, we can control the solidification process in such a way that acicular variety is promoted, then probably the toughness can be increased even in presence of the oxygen; that means, even though it is contaminated with the oxygens.

Hydrogen basically the hydrogen the role of the hydrogen in steals machine during the welding processes try to induce the hydrogen cracking, that is normally you can normally we can say that it is a cold cracking process. So, basically this are the role of the nitrogen, oxygen and hydrogen and in presence of that what may be the, what types of the properties can be affected when you try to weld the steels; Now, austenitic or duplex stainless steel.

So, austenitic stainless steel and duplex stainless steel basically the most influencing parameter is the nitrogen here rather than oxygen and hydrogen. So, basically presents in presence of nitrogen the austenitic or duplex during welding of austenitic and duplex stainless steels, that actually reduces the ferrite content and provides the solidification cracking or we can say the hot cracking basically chances of the hot cracking actually enhances in presence of nitrogen during the welding austenitic duplex stainless steel. The aluminium definitely when you try to weld aluminium most serious problem is the formation of the react with oxygen and formation of the oxides.

So, that oxides can be trapped within the molten pool and becomes part of the final weld joint as an inclusion. Therefore, the in welding of the aluminium the contact with the oxygen is better to always avoid, because oxygen at the high affinity to react with the aluminium specifically and this affinity increases with respect to the temperature and so and forms the oxide. So, that is the one serious problem welding of the aluminium making the aluminium oxide. And other hydrogen is also having effect during the welding of the aluminium, that it actually forms gas ferocity and reduces the strength and ductility.

So, when there is a presence of the gas porosity within the final weld metal component or final weld joint that trapped porosity actually uses the mechanical properties like, the strength properties and of course, the ductility. And other material specifically the titanium , so titanium is also having when he interact with the oxygen and milli oxygen and nitrogen, so presence of hydrogen is little bit affected in the titanium joining of the titanium and they are alive, so that is more serious problem in case of welding of the titanium and we say very proper shielding is required to avoid the interaction with the oxygen and nitrogen from the atmosphere.

So, probably it is more serious problem that the shielding as compared to the steels or probably as computers normal steels component. So, sometimes in welding process also practically we have seen, the welding of the titanium means the extra shielding gas is sometimes required simply to protect the molten pool, because it is having very high affinity to from the to react with the oxygen and nitrogen and basically who need react with the nitrogen molten titanium that actually increases the strength, but reduces the ductility or we can say that sometimes it is it actually decreases the strength as well.

Even for oxygen also it increases or decreases the strength, but definitely it reduces the ductility. So, we can see that of course, almost all type of materials ferrous nonferrous, that during the welding process they are having the tendency to react with the surrounding atmosphere and most of the cases we can find out they actually reduces the mechanical properties since presence of this different atmospheric elements; so therefore, to protect this all these elements from the atmosphere, we generally use the shielding of this molten pool and the different way.

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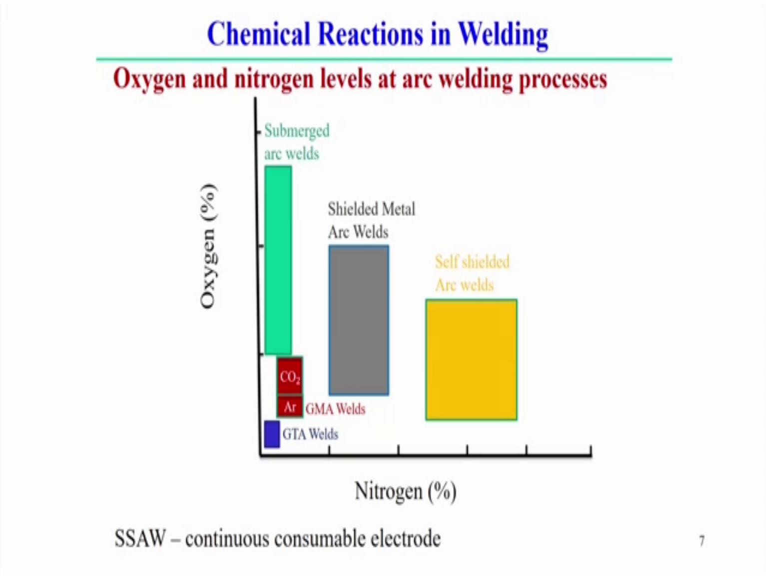

Some overview on these things the effect of the chemical reaction in oxygen in welding and here we can see that oxygen and nitrogen levels at the during the welding process we generally find out the different welding processes. Now, what is the x axis and y axis; x axis depends the nitrogen position and y axis represent oxygen component percentage of the oxygen component.

And here you can see that submerged arc weld, in case of submerged arc weld presence of nitrogen component is less during the welding process, but presence of oxygen content is more in here in the submerged arc welding process. Probably, in submerged arc welding process we can use the slag material or we can use the flux material and that flux one of the component of the flux may be the oxide, so that that oxide is a supplier of the merged amount of the oxygen presence in that weld pool.

But the nitrogen level is very less in submerged arc welding process, if we look into the gas metal arc welding process; here also oxygen content is little bit more as compared to the gas tungsten arc welding process, because gas metal arc welding process sometimes commercially we use the shielding gas as a carbon dioxide. So, that carbon dioxide basically react as the high temperature it come from the oxygen and that oxygen can be a form of part of the final weld joint.

So, GTA welding the relatively the oxygen level and nitrogen level is relatively less, because in this case we are do not use any slack and we use the inner type of the shielding gas in this case the inner type shielding gas actually protect the molten pool from the outside atmosphere, and even that inner gas also do not try to react with the molten weld pool. So, that is why argon shielding gas use in case of the gas tungsten arc welding process.

So, that the oxygen content and the nitrogen content in the final weld joint is very less in this case. Shielded metal arc welding we use the shielded arc welding in some coated electrode. So, here that molten weld pools basically protected by creating the slag as well as the formation of the fume of gas basically. So, that protect the molten pool, but in this case here the composition of the coated coating consists of coating on the electrode that actually that can be different composition and that that can also access the source of the oxygen also and that oxygen can be become part of the final weld joint.

So, it is a moderate type of oxygen or nitrogen content we can find out in case of shielding metal arc welding process, what; if we look into the self shielded arc welding process. So, in case of self shield shielded arc welding process, in this case the it is resembles that; it is creates the arc like gas metal arc welding process there is a continuous supply of the electrode in case of shielding metal arc welding from a self shielded arc welding process.

But this use not any kind of coating on the use the coating of the electrode and that actually protect the molten pool, but it is some very little different with respect to the shielded metal arc welding process as compared to the and as well as compared to the gas metal arc welding process. So, here shielding metal arc welding process we can find out that me moderate amount of the oxygen content may have, but nitrogen content becomes more in this courses, because of the process itself.

So, although we can use the shielding gas and different type of protection, we can use the flux also to protect the molten pool, but till and the final composition of the weld joint make may have some amount of the oxygen and the nitrogen and that different welding processes, what are the typical content of the oxygen or nitrogen some idea we can get here.

So, overall we can see that overall all this process we can find out the least amount of the oxygen, hydrogen content. Probably we can find out in case of gas metal arc welding process and we can find out what maximum amount of oxygen content we can find out this submerged arc welding process and maximum amount of the nitrogen can we find out the self shielded arc welding process.

Of course, this amount of the oxide nitrogen content not only depends only on the shielding gas, but it also to some extent depends on the what type of metals we are just trying to weld.

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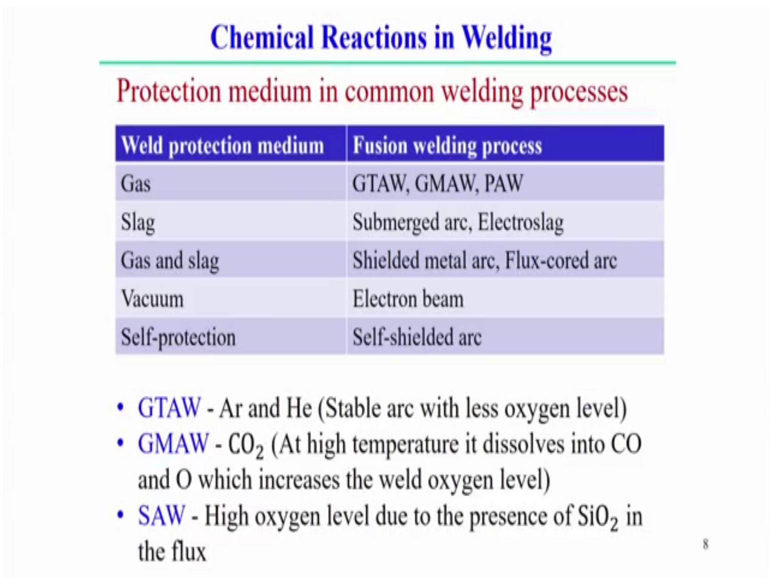

Now, protection medium in common welding processes we can use the different protection medium for the different type of the welding processes. So, first the gas protecting or shielding gas we can use normally in case of the gas tungsten arc welding process, gas metal arc welding process, and plasma arc welding process. Slag we can use that submerged arc welding process the weld production medium slag actually there when using the some flux metallic oxide and other composition and after welding the lighter weight slag is comes onto the upper side of the weld pool.

So, slag this actually protect the molten pool, in case of submerged arc welding and electron slag welding processes. And we can use both shielding gas as well as slag, both we this type of protection we can find out in the shielded metal arc welding process and flux core arc welding processes and of course, we use the of protection medium in vacuum in case of the electron beam welding process. So, when the electron beam welding process has been done this under the vacuum; so not necessary to use the use any kind of at the shielding medium. So, that under the vacuum there is no chance of the reacting the surrounding atmosphere.

So, electron beam welding process we can use the vacuum. So, that is the I think the most efficient protection medium in case of electron beam welding that is that considers the under vacuum. Another case is the self protection and that in that case the self shielded arc welding processes, we can use the self protection medium. So, that also comes the simply coating from the creation of the arc and there may be some coating on the wear , but if you look into the laser welding also some laser only we use the shielding gas also. Normally, we use the organ shielding gas even in case of laser welding also.

So, all type of welding processes to some extent we can use some protection medium. So, overall look into that gas stress arc welding, we can use the either argon and helium, because using this under this shielding gas they can clear the arc should be stable. So, argon and helium in case of gust will the most suitable shielding gas and, because it produces the stable arc and of course, the contaminated are the less oxygen level the contamination with the oxygen less using this type of the shielding gas.

In case of gas metal arc welding process, we can use normally commercially we use the carbon dioxide and, but difficulty of the carbon dioxide that carbon dioxide can be decomposed into carbon monoxide and oxygen. And of course, finally, it actually increases the oxygen level in the final weld joint, because of the using ha carbon dioxide. Carbon dioxide is most commercially used, but we can use the inert type of gas also in case of gas metal arc welding process work we need to know the stability of the arc under this you under the shielding gas.

And shielded metal arc welding here normally you use the high oxygen level and, because shielded metal arc welding is early submerged arc welding process we can mostly find out the high level of the oxygen, because of that we can use the silicon oxide also as a composition in the flux material.

So, that is how oxygen level is high in case of the submerged arc welding process. So, apart from all this type of slag or flux or gas shielding gas it is also possible to combine the different composition of the shielding gas, they may also affect not all the shielding purpose, they can affect the other aspects of the welding, probably sometimes we use the using the mixing with the other shielding gas, what type of the shielding gas that mainly on the purpose of the stabilizing the arc constant concentrating the arc that is also and sometimes we intentionally we use the other oxygen also and that can be used as a surface active elements during the welding process.

So, the purpose of the using shielding gas not only the shielding of the molten weld pool, maybe to enhance the performance from the welding processes sometimes best we can choose the composition of the shielding gas or we can mix the two different types of the shielding gas or we can mix the oxygen or with the shielding gas. So, that with the specific purpose of the taking the effect of the surface active elements and to get some benefit in the surface using the using the oxygen in the with mixing with the shielding gas.

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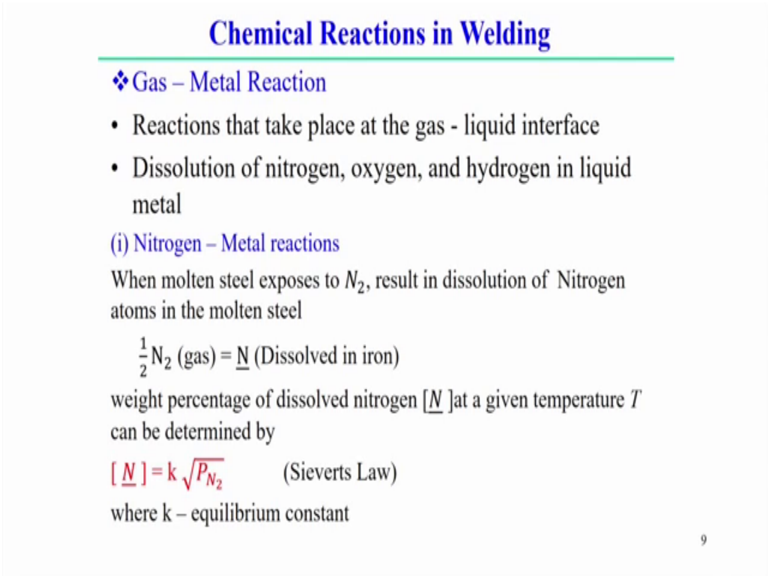

So, if we look into that that now gas metal reaction little bit that chemical reaction in the welding process. so. Firstly, the reaction takes place between the gas shielding gas and the liquid sub interface or liquid metal. So, the reaction happens between these two and during this reaction there is a dissolution of the oxygen nitrogen and hydrogen in the liquid metal, but in basic way we will try to discuss some that how this reaction happens. So, first we look into the reaction between the nitrogen and metal, so how they react with respect to each other.

So, when molten steel is actually exposed to the nitrogen that results in the dissolution of the nitrogen atoms in the molten pool. So, what percentage of the dissolved nitrogen at the given temperature can be represented by the Sibert's law here we can see that in equal to k into root over of P N 2. So, here the k is not some constant parameter or constant term that is called the equilibrium constant on here.

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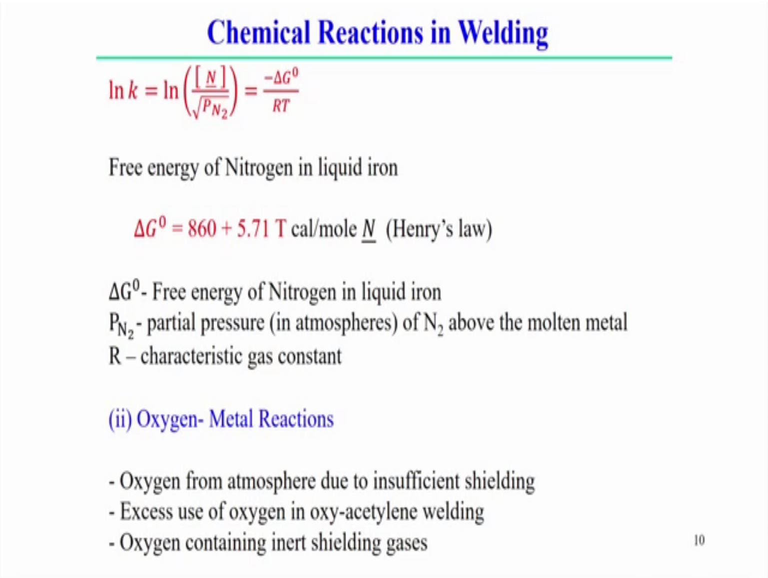

So here you can see that this k can be linked with the other free energy of nitrogen in the liquid state a liquid iron, and that the free energy of the nitrogen in the liquid iron can also be represented by this equation you can see there is some linear equation with respect to temperature.

So, that also follows the Henry's law, so here delta G actually represents the free energy of nitrogen in the liquid iron and P N 2 is the basically partial pressure of nitrogen above the molten metal and R is the characteristic gas constant. So, if we put the appropriate value here, and of all this reaction basically we see it say we are representing the reaction is in as a function of temperature.

So, therefore, having that the reaction that happens during the molten pool with the atmosphere that entirely is strongly dependent on the temperature. Similar way we can find out the reaction between the oxygen and metal reaction. So, here we can find out that oxygen from atmosphere and what will be the source of the oxygen.

So, one source of the oxygen and during the welding process it comes from the atmosphere that may be due to the insufficient shielding process sometimes in oxy-acetylene welding processes of the excess use of the oxygen in oxy-acetylene processes that can be a source of the oxygen, sometimes we can use the oxygen that actually containing the inert shielding gas.

So, sometimes the shielding gas may content or oxygen, either it is inherent properties of of the shielding gas for example, CO 2 or sometimes intentionally we can use mix with oxygen with the shielding gas. For example, activated tig welding process; we can use oxygen with the shielding gas. So, that other depends source of the oxygen is generally presence in the shielding gas.

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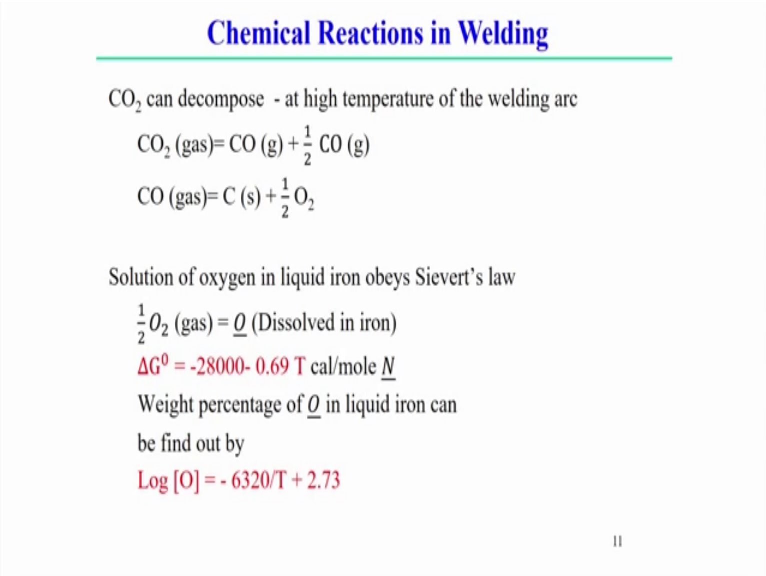

And here when we use the CO 2 as a shielding gas and we can see the reaction happens at the very high temperature, during the welding process, CO 2 gas is decomposed into carbon monoxide gas plus half of CO, and we feel it in the balance of the equation and finally, it can produce the carbon and oxygen.

So, that carbon and oxygen can be a can take part in the can be a part of the carbon also react with the steel or using the base metal and it fall it may from the carbide, but oxygen can be a part of the weld metal molten weld pool, but here also the absorption of the oxygen also depends follows the Sievert's law and we can see the similar way that free energy of oxygen absorptions delta G that is also a function of the linear function of the temperature.

And here we can see that weight percentage of oxygen in the liquid iron can be found out by forming that, again it is a logarithm scale oxygen and the it is also a function of the temperature here also.

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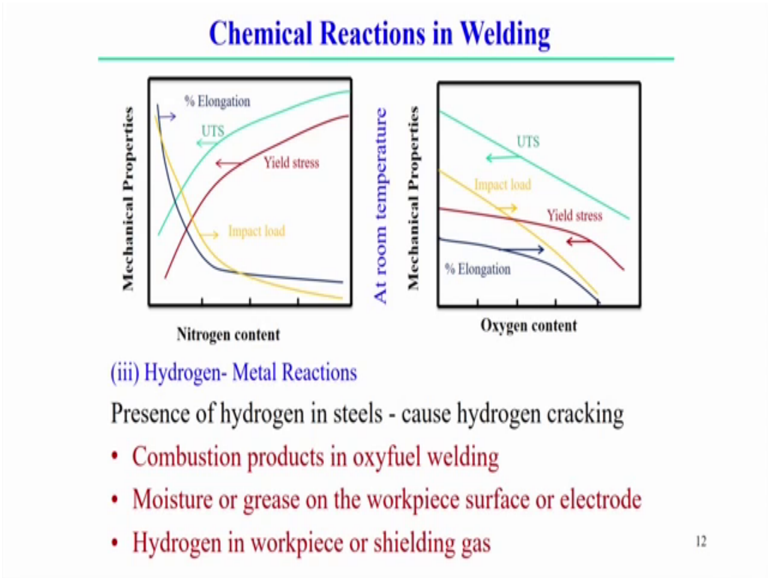

So, overall that type of reaction that type of equation can be Sievert's law or may be useful here to roughly estimate the or what is the amount of the oxygen can be dissolved in the molten pool or it becomes a part of the welding system. So, overall if we look into that, what are the properties that actually impact in presence that with the presence of the oxygen of nitrogen content here the to graph source that nitrogen content how the mechanical properties can vary, and with respect to the oxygen how the mechanical properties vary; whether it can be used beneficially or not.

Now, if we look into the first figure the nitrogen content here you can see that nitrogen with the increment of the nitrogen contact with the weld pool, molten metal of the or maybe the weld joint we can see that there is a considerable document of the percentage with the elongation and impact low by increasing the nitrogen content.

When in other way also we can find out that ultimate tensile strength and the yield strength that actually increases with increasing the nitrogen content. So, in that sense presence of nitrogen sometimes used the beneficially to increase the amount of the ultimate tensile strength of the joint or maybe the; we can if you try to improve the yield strength, then nitrogen is helpful in that sense.

But of course, if you look into that oxygen content here you can see that probably with increasing with increasing the oxygen content in the weld joint that almost all types of the properties actually decreases.

Here can see the ultimate tensile strength, impact load, yield stress elongation all actually decreases in presence of the oxygen. So that means, understand that mechanical properties at all not beneficial in presents on the or if oxygen content is high in this case. So, objective can be sometimes that to avoid the has minimum oxygen content and maybe, but some moderate amount of the nitrogen that actually helps to the improvement in the at least the weld joint strength in case of the fusion welding process.

Now, we can look into the effect of the other components of the weld joint that is the hydrogen or how hydrogen and metal actually react and we can see the first we look into that, what are the source of the hydrogen, in welding processes that; first is the presence of hydrogen in stores that what is the consequence effect of the hydrogen, the presence of hydrogen in still basically creates or suspect ability to the hydrogen cracking or cold cracking phenomena can be increased.

So, therefore, it is beneficial to avoid the presence of the oxygen a hydrogen, in case of the welding. So, what are the source of the hydrogen here; the combustion products in oxy fuel welding, that combustion product they may contain the hydrogen, moisture or grease sometimes used on the workpiece surface or maybe we can find out the moisture in the electrode also, that can be act as the source of the hydrogen also and hydrogen presence in the workpiece or hydrogen presence in the shielding gas.

So, these are the typical source of the hydrogen in case of the welding process, but if you want to avoid these things we can carefully visa dista can be reduced the hydrogen level by simply avoiding the hydrogen hydrogen containing shielding gas that is a straightforward.

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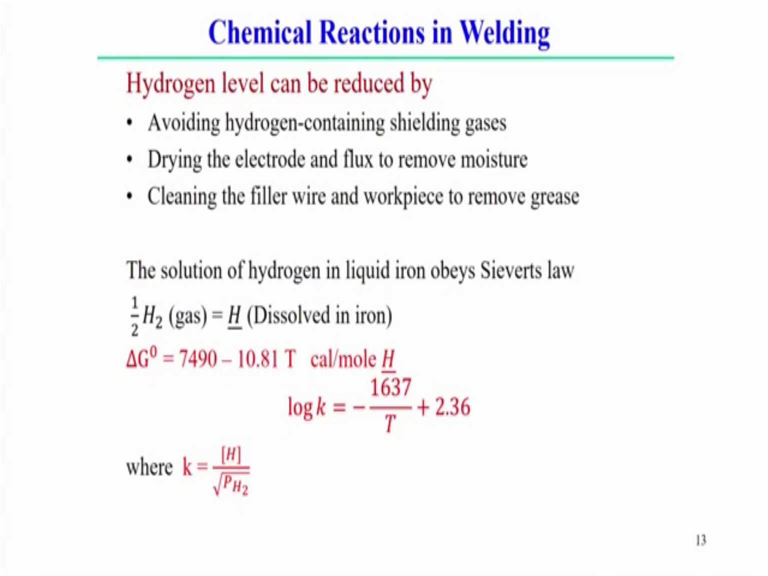

Next, is that if you the moisture may content some hydrogen; a moisture in presence of moisture is the source of the hydrogen also in the electrode. So, before using that, we can dry the electrode and the flux drying the flux to remove the moisture from that. In that way we can remove the hydrogen content in that type of the source during the welding process. And of course, cleaning the filler wire and the workpiece is necessary also to remove the grease, because that grease chemical that greases can be act as a source of the hydrogen also.

So, therefore, cleaning is required for the workpiece surface. So, that is a safeguard to minimize or to reduce the amount of the source of the hydrogen normally in case of any case of welding system, but of course, presence of the some amount of the hydrogen that also follow during the welding process simply the Sievert’s law; here you can find out that similar kind of equations here also.

So, here you can that all the equations are also given and here we can represent that free energy in this case in this reaction also that depends on the also the temperature and partial pressure of the hydrogen. So, apart from this reacts chemical reactions on the shielding gas and different oxygen hydrogen and nitrogen they are impact on the weld joint properties discussing this things.

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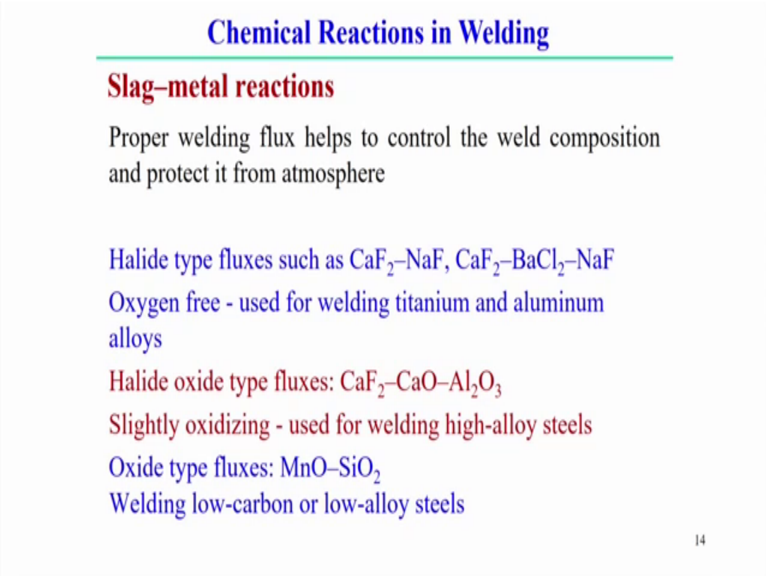

Now, will try to look into that; what are the sale; slag metal reaction? Basically presence of the slag, this is also another way of protection of the molten pool, but proper welding flux, actually helps to control the weld composition as well as the protected from the atmosphere.

So, dual role can also play, using the slag also they protect the molten pool at the same time they actually control the final well composition or. So, they becomes part of the well composition. So, what are the typical type of the slag; basically used the first is the halide type of the flux such as CaF 2-NaF, CaF 2-BaCL 2-NaF, these are the typical halide type of the fluxes are normally used and oxygen free flux is basically this type of the halide flux we can see that it is oxygen free.

Therefore, this oxygen free flux is basically very much helpful for the welding of the titanium and aluminium alloys, because the titanium, alloy and aluminium having the tendency to form the oxides and that is this tendency or reaction rate with the oxygen is more as compared to the other component for example, other as compared to the steels basically; so that is why it is always beneficial to use the halide type of the fluxes in case of the welding titanium and aluminium alloy.

But other type of the flux that is the halide oxide type of the flux CaF 2-CaO-Al 2 O 3 and this type of the flux is simply slightly oxidizing component are also there. So, this type of the flux is suitable for the welding of the high alloy steel. Oxide type of the flux;

that means, in this case the MnO and SiO 2, so both are having the oxides , so that type of the oxides is basically suitable for the welding low carbon steel or low alloy steel; so these are the typical type of the flux basically we choose depending upon the type of material.

And here in details to know, that what the reactions is happening; this what way the reactions is happening; during the welding process, when is the molten weld pool actually interacting with this type of the fluxes.

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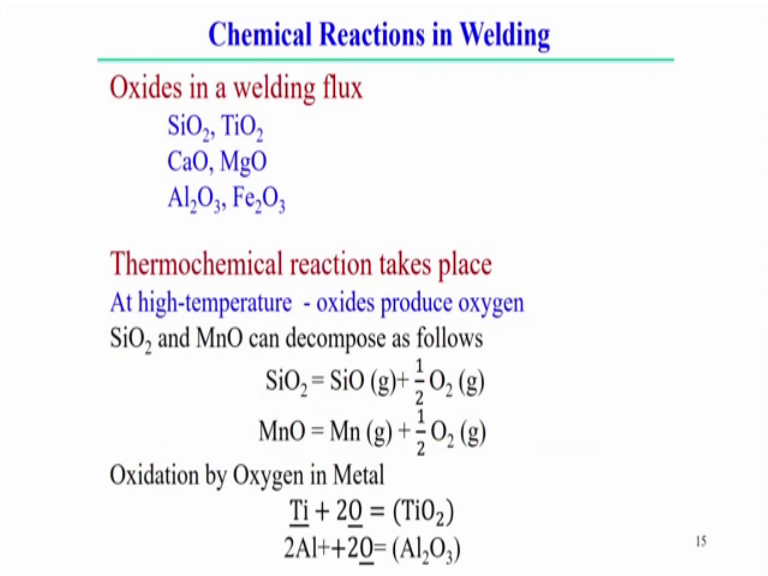

So, somewhat an idea basic idea that; what a couple reactions may happen here. So, oxides in the welding flux, we normally use the welding these are the types of the oxide flux we use the welding that is, SiO 2, TiO 2, CaO, MgO, Al2O3, and Fe2O3 these are the typical oxides in welding flux we used, and what are the typical thermo mechanical reactions basically takes place.

At high temperature oxides definitely try to produce the oxygen and SiO 2 and MnO 2 can decompose in the following way you can find out that SiO 2 produce oxygen and MnO also is a produce also oxygen, and that oxygen also react with the metals and they basically titanium it produces a titanium oxide and aluminium it will try to produce the aluminium oxides.

So, this way that this therefore, ultimately it is always it will try to create the titanium oxide and aluminium oxide, but welding of the titanium and aluminium, it is better to avoid the using some oxide type of the praxis, because it is having good affinity with the oxygen; it gets specifically welding for the aluminium a titanium and they are alloy.

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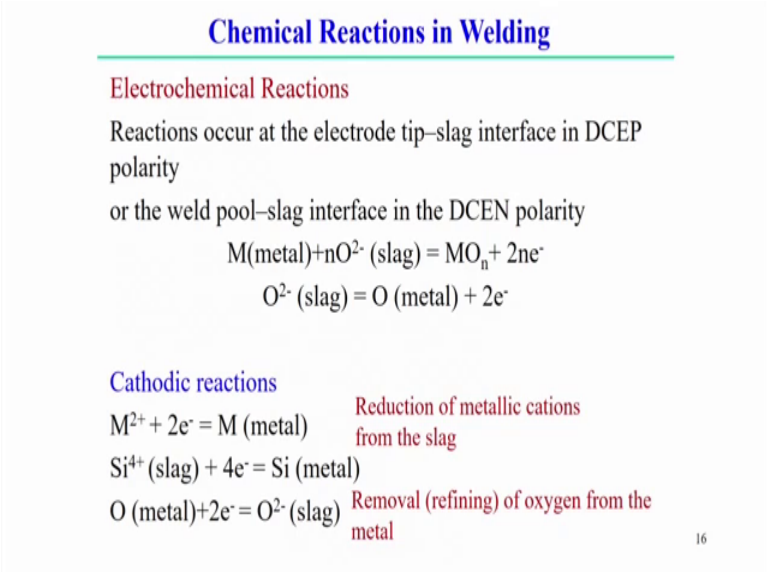

So, now there is may be the another type of reaction may also happen; that is the electrochemical reaction. So, that reactions occurs at the electrode tip and the slag interface, because that electrode tip and the slag also in that interface, in case of the direct current electrode positive DCEP direct and electrode positive polarity or in that weld pool; molten weld pool and the slag interface that in that case molten a little slag interface in case of the direct current electrode negative is that reaction is; so therefore, what we can predict here that DCEP that a direct electrode positive; when in that case the reaction between the electrode tip and the slag interface is more important, but when using the DCEN polarity, the molten pool and the slag interface the reaction is more important here.

So, we will try to look into that what type of reactions may happen here? What type of electrochemical reaction basically happened it happened it happens in this process. So, here you can see the metal actually in case of DCEN polarity. So, metal and the slag is that oxides in the slag, they can form the metallic oxides and produce the free electron.

So, that oxides also from the slag that oxides oxygen in the slags oxygen from there the oxygen becomes part of the molten pool and it also creates the amount of the free electrons. So, that in case of DCEN polarity that free electron is basically actually accelerated to go to the workpiece and that actually I am generated the amount of the heat.

So, in that case this is the reaction happens in case of DCEN polarity, but if you look into the cathodic reaction, what is the that reaction. So, fast if you see the it creates the molten metal that freak electron, basically clears the molten metal that by the reduction of the metallic cations from the slag. So, that that free; this slag also absorb the free electrons and it becomes the; it produces the Si.

So, this type of reaction is basically is called the reduction of the metallic cations and that reduction happens from the slag. In other way also remove up removal of the refining of the oxygen from the metal, because that free electron removes the oxides from the oxygen from the metal, and then ions oxygen ions becomes part of the slag. So, this type of reaction also called the removal or refining of the oxygen from the metal.

So, that type of chemical reactions electrochemical reaction normally happens in the welding process. Now, we come to that apart from the reaction with the shielding gas.

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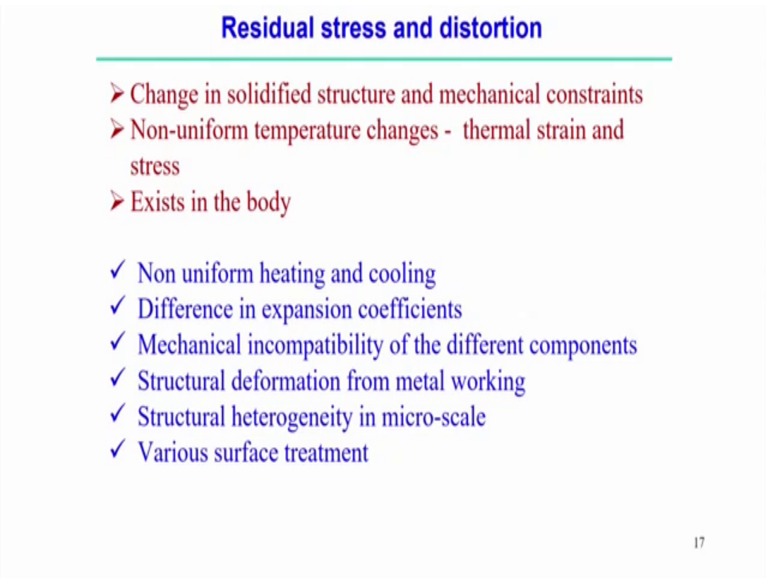

Now, we look into that; what is that that next topic of this module is the residual stress and the distortion. But, what way the residual stress may happen in the welding processes. So, residual stress is basically generated, during the welding process there are several factors.

So, one factor may be the some methodological changes; that means, the residual stress may generated due to the thermal strength and thermal contraction may be the volumetric strain, some metallurgical transformation, structural changes and boundary constant; all actually impact is a very complicated way the generation of the residual stress.

So, that amount of the stress becomes the final part of the weld joint after solidification of the weld joint to the room temperature. And then as a consequence of the residual stress, there may be some generation of the amount of the residual distortion. So, when you try to actually analyze the residual stress and distortion. So, that probably look into that mechanical constant, that is responsible generation of the amount of the stress, but mechanical constant if we look into that can be explaining the continuum scale, what the micro structural changes all this thing in the microscopic scale.

So, that different length scale, if we analyze this thing. So, source of the residual stress or generation with residual stress can be better explained. Now, broadly in general the residual stress happens due to the in case of material after the solidification. And mainly the change in the solidified structure and any kind of mechanical constant that actually applied during the welding process and related to that residual stress and distortion generation that non uniform temperature change basically happens that is called thermal strain. And strain it creates and that equilibrate the amount of the residual stress over the whole body we say over the volume of the body so not only on the limited to the surface.

So, therefore, the typical cause of the residual stress and distortion in an in any kind case of weld shield is that; Non uniform heating and cooling subject to different position the heating and cooling rate are different. Difference in the expansion coefficients specific specifically it is the more serious, when you try to look into the two different types of the material.

So, they are in that case the depends expansion compare need to follow the different expansion coefficients. Mechanical incompatibility of the different types of the components, so different types of types of the components the incompatibility mechanically may also exist. Structural deformation from the metalworking, so already please stay substation conditions we use the sometimes for the samples for the welding purpose.

So, structural are heterogeneity in micro scale. So, structurally it may not be the homogenous, but in the when you look into the microscopic scale the structure may not the homogeneous that also is also responsible for the generation of the residual stress and distortion.

And of course, that various before use using the welding process sometimes the material base metal can be sometimes, now it follows some various heat treatment process. So, that during the heat treatment process, it can also clear some amount of the residual stress during the residual stress also and that materials we use for the further processing.

So, that during the processing of the already heat treated surface they can create a some non uniformity in terms of the expansion coefficient in homogeneity within the structure and all these are responsible for that generation of the residual stress and distortion.

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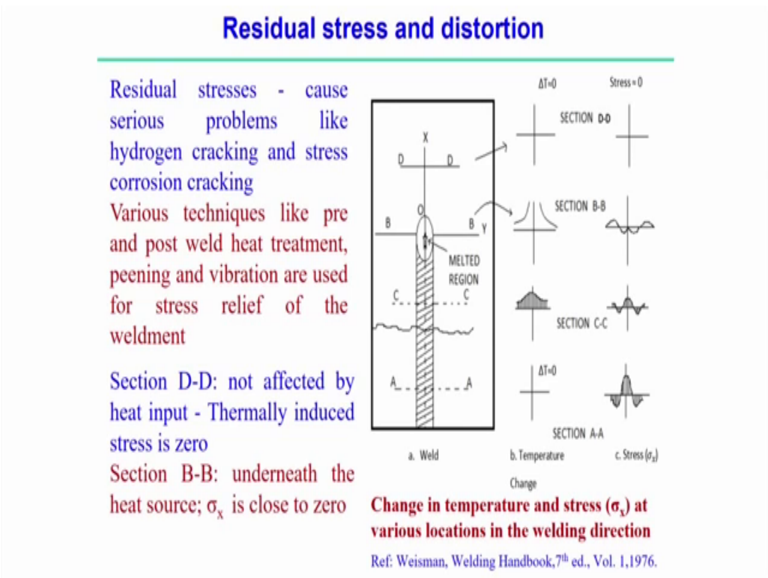

So, if we look into that one how to understand the residual stress; we look into the one welders at hand of course, these understanding is very specific to the welding process. So, we take a simple schematic picture of the welding process. Here you can see that welding process the figure; we can start weld process and it starts it is moving along the x axis and the heat source is moving along the x axis. So, is a continuously welding for the sample? Now, then we try to look into the different sections at the different time different section, they are having their temperature conditions are different in the different positions or temperature distribution are different in the different section.

So, in the first case if you look into the section D-D; here you can see that section D-D that in this case there is no temperature change, because this is about was supposed to joint, but not done yet. So, temperature distribution no change in the temperature distance; so we can say that there is no generation of the residual stress at the section D-D, but before no generation residual stress, but if we look into that typical aspect of the residual stress that residual stress actually creates the serious problem, residual stress cause the serious problem like hydrogen, cracking and the stress corrosion cracking.

Here, we can see that each actually residual stress impact on the hydrogen cracking a stress course I am taking by at the same times it; in fact, to the life of the weld joint, when there is a more serious when the weld joint component is subjected to some kinds of the fatigue loading condition. So, in that case the residual stress is the more serious problem. So, objective can be reduced or as low amount of the residual stress generation.

So, various techniques generally; we follow in straightforward way to reduce the residual stress; one is the post will hit genuine some most of the cases after doing the welding process we follow the heat treatment process; So, that where that heat treatment process also try to reduce the amount of the residual stress within the body. Then pinning and the vibration these are the two mechanical processes and for the stress relief of the weld joint also sometimes followed to reduce the amount of the residual stress. But, to do that now we will try to look into the; what is the what way the residual stress can be generated that.

Now, if you look into the section B-B. So, section B-B is exactly at the position that is under the heat source and at this support certain point of the time. So, it creates some molten weld pool and the behind that it clears the some amount of the already solidified weld pool. So, in that position what way the what can be the temperature distribution, if you see the section B-B; that we can see the temperature distribution is from the center to the maximum is around the center. And then gradually it is decreasing, but of course, it is the molten state and at the same time the molten pool is separated by the surrounding solid content of the metal.

So, that includes the distribution of the residual stress. So, section B-B that heat source here the sigma x that amount of the stress along x axis is close to 0 yeah is exactly at the center point close to 0, but further away from the heat source of stress are compressive in nature.

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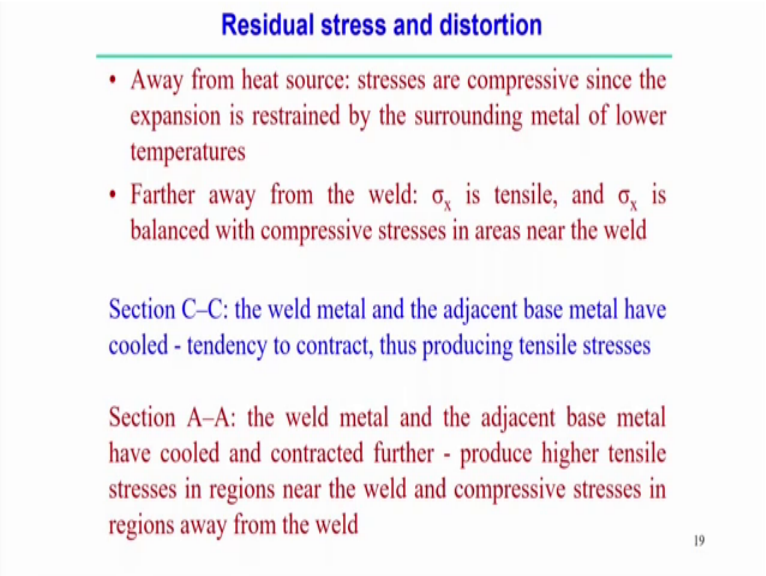

Since expansion is restrained by the surrounding metal of the lower temperature. So, if we look into further away from the weld joint, the sigma x becomes the tensile and the sigma x is balanced with the compressive stress areas near the weld pool. So, here you can see exactly center point is the amount of the residual stress is 0, if away from this thing it becomes compressive in nature in further away it becomes tensile in nature. So, that tensile is basically balanced by the try to balance the compressive nature of the residual stress.

So, that distribution of the residuals stress to the (Refer Time: 56:29) the temperature and what way it is interacting with the surrounding? What is the nature of the surrounding of the molten weld pool. Based on that whether nature; the type nature of the whether distance cell or compressive and their distribution has been decided. Now, if we look into the section C-C the weld metal and the adjacent base metal have actually cooled.

So, if we section C-C in that case it is already cooled and that metal is adjacent the base metal have cooled, but tendency to contract that actually produces the amount of the tensile stress. So, here the section C-C is the is already cooled, but the surrounding is not exactly in the room temperature, some hot environment is hottest body is also they are surrounding.

So, based on that the stress distribution with the centre is basically tensile nature and the further away from that thing; there is a compressive nature and again it becomes a tensile in nature. So, in that we will try to equilibrate the state of the stress between the varying between the tensile to the compressive.

Now, if you look into the section A-A. In this section, the weld metal and the adjacent base metal act already pulled down and already contracted further therefore, produced the high amount of the tensile stress. So, similar analogy that at the center is already contracted; So, it gives the high amount of the tensile stress at the center point and further a produced the further away from the weld joint it creates a compressive amount of the stresses from the weld joint.

So, this is the typical nature of the stress distribution normally happens in case of that welding process.

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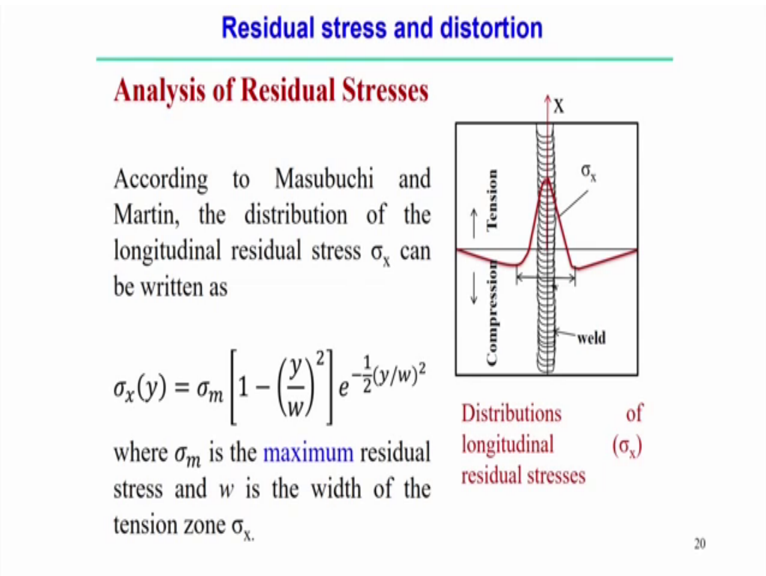

Now, if we look into that analysis of the residual stress in basically; here you can see that his longitudinal residual stress then we will simply longitudinal residual stress is that along x axis; so what is the amount of the longitudinal residual stress, how it varies with respect to transpire direction with respect to y. This way we can find out the sigma x, y is a function of the maximum amount of the stress and here we can find out the distribution.

So, the distribution of the stress is source that long distribution of the longitudinal residual stress is on the along the weld line that the center point; center it is a maximum tensile and away from these things it is a it becomes the compressive in nature.

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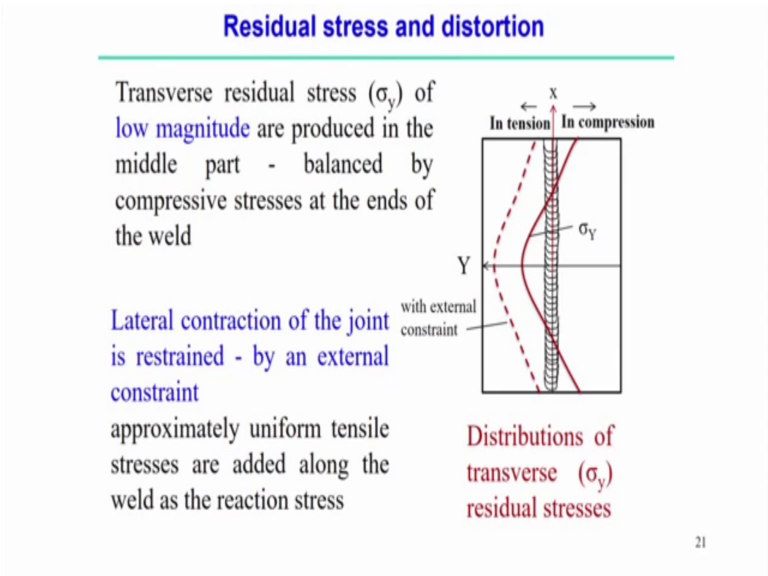

So, this is the typical nature of the longitudinal residual stress. Similarly, if you can find out the transfers residual stress, here you can find out that transfer residual stress is basically low magnitude are produced in the middle part. So, middle part transfer residual stress is almost very low magnitude, and balanced by the compressive stress is basically at the end that is the typical nature of the residual stress, but if the lateral contraction is restricted of the weld joint by some external constraint.

So, in this case we can find out that uniform tensile stress is basically added, so all are in similar nature; maybe all are in the tensile strength, tensile in nature and, but the at the center point the maximum amount of the residual stress is basically increases to some extent, but pattern remains the same, if there is no any constant applied to the welded

welded played. So, this is the typical distribution of the transfers sigma y. The transfers amount of the residual stress and that distribution, we are representing with respect to the X direction.