Joining Technologies of Commercial Importance
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Lecture - 08
Physics of Welding Arc

Hello, I welcome you all in this presentation related with the subject Joining Technologies for the Metals and this presentation is mainly based on the shielded metal arc welding process and the basic fundamental principles of the arc welding in general. So we will try to first of all understand that how the heat is generated and how it affects the quality of the weld joint in general.

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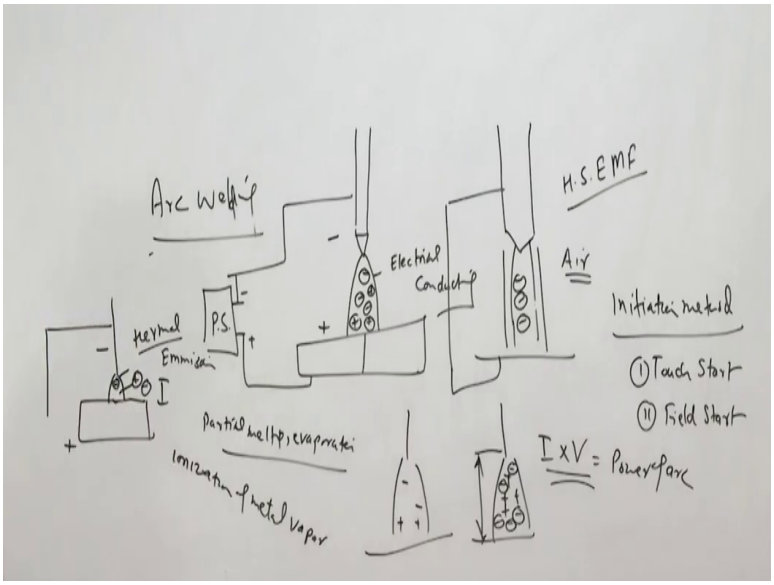

So here you know for - for establishing welding arc - arc for welding purpose what is important that the - the between electrode and the base metals to be joined stable arc is established and for this purpose normally the electrode and work piece are connected to the suitable power source say the work electrode is connected to the negative terminal and work piece is connected to the positive terminal.

And with the suitable power supply when the arc is strike the current flow takes place but we know initially when there is no arc the gap between the electrode and work piece is full of the

atmospheric gases and the gases or not or non-electrical conducting so this gap must be made electrical conducting and for that purpose only we have to use certain arc initiation methods.

And this arc initiation methods - arc initiation methods basically rely on developing the charged particle column between the electrode and work piece so that it can be made electrical conducting and these 2 methods - there are 2 methods which are extremely commonly used one is touch start method and another is field start method. In case of the touch start method electrode is brought in contact with the work piece for striking the arc or for initiating the arc.

And as soon as the touching takes place due to the short circuit high flow of the current results in the excessive heat generation at the contact points so increase in temperature at the contact points of the electrode and work piece and once this heating takes place due to the short circuiting in this very short period maybe sometimes partial melting - partial melting evaporation means metal vapor generation all this takes place in a very short period of time.

And once this short circuiting is over the electrode is taken away from the work piece so gap is created this gap is full of air, so here once the gap is created the open circuit voltage means the arc voltage is - is the potential difference between the electrode and work piece is established and in this situation what happens that due to the heating thermal ionization or thermal emission of the - thermal emission of the electrons from the electrode tip and work piece side.

At the same time ionization of the - ionization of the metal vapors takes place - metal vapors takes place which were generated due to the during the short circuiting period and this so as a result of thermal ionic emission electrons are produced and ionization of the metal vapors produces positively charged particles and negatively charged particles in form of electrons we had that connected the work piece and the electrode to the power supply with a particular kind of the polarity.

So here as per their priorities the electron anion will start moving towards the cathode that is the electrode and electron and electrons will start moving towards the anode that is the work piece, so this how the flow of charged particles movement of charged particles in the arc gap starts and

once sufficient charged particle density is available in the gap between the electrode and work piece it becomes electrically conducting.

And once the gap is has become electrically conducting the flow of current it starts so this is how the arc initiation takes place in case of the touch start method and in case of the field start method high strength electromagnetic field is established between the work piece and the electrode and so this high-strength electromagnetic field helps emission of the electrons from the surface of the cathode and this in turn produces the charged particles in the gap.

In this case no direct contact between the - between the electrode and work which is needed but the development of high strength electromagnetic fields helps in emission of the electrons from the cathode and that is how the gap is made the full of the charged particles and the gap is made conducting, so the important thing for having a stable arc is that the gap between the - the there is a sufficient potential difference between the electrode and work piece.

And the gap is made conducting in the event when the gap is deficient with this charged particles in charged particle density is less than the reduced electrical conductivity will be leading to the pass leading to the extinction of the arc means arc may get extinguished in that situation and if it is really full of the charged particle means the charged particle density is high in the gap then it will be leading to the very good electrical conductivity and the flow of current through the arc will be very smooth.

So that will keep on so that flow current through the arc that is the welding current and that arc voltage potential difference means that is the difference between the - between the electrode tip and the work piece this is the arc voltage product of these two gives us the power of arc and this power of arc helps in generating the heat desired for the melting of the work piece so they are too methods for initiating the arc.

And these are the conditions which are necessary for emission of the for starting or starting the arc or initiating the welding arc and these two methods are used invariably in most of the welding processes.

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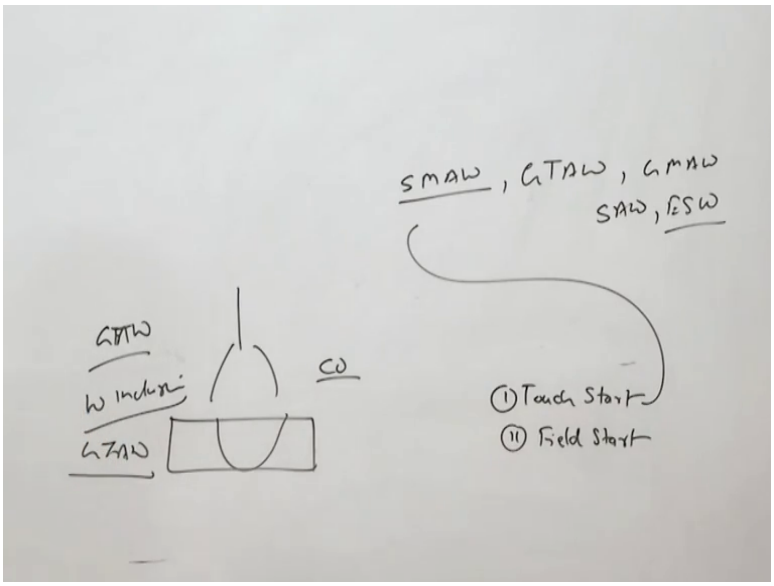

For example, touch start method is commonly used in processes like - like Shielded Metal Arc Welding process that is Manual Metal Arc Welding process also in the Gas Tungsten Arc Welding process and like the Gas Metal Arc Welding process and like Submerged Arc Welding process, Electro Slag Welding process in all these processes the touch start method.

But sometimes if it is felt that the contact between the electrode and the work piece is not good from the soundness point of view of the weld joints, in that case like say the tungsten gets transferred at that time when there is a contact between the work piece in case of the GTAW process, so the tungsten inclusion are formed - in tungsten inclusions are formed in case of the GTAW process if the tungsten electrode tip is degraded and gets transferred to the weld pool.

So the it will be contaminating to the weld with the tungsten inclusions and adversely affecting the mechanical properties and another possibility is that when we do not want that direct contact between the electrode and the work piece either not favorable due to the possibility of the contamination and inclusions of the weld or it is not practically possible to have the contact of the electrode with the work piece like in the plasma welding.

So in those situations the high-strength electromagnetic field is established for initiating the arc without so in that case the electrode is not brought in contact with work piece for initiating the arc.

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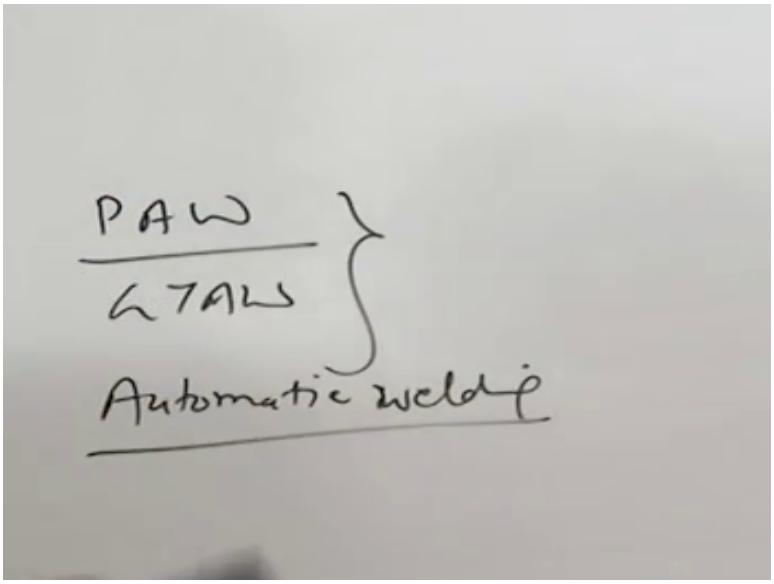

So plasma welding and all other automatic gas tungsten arc welding where ever we find that the contact - contact is not suitable or in automatic welding process where it is not feasible automatic welding where ever automation has been implemented so we want that arc is initiated without direct contact while feeding the work electro to the work piece for making the contact and initiating the arc.

So these are the 2 ways by which arc is initiated as for as so these basics applicable for entire range of arc welding processes.

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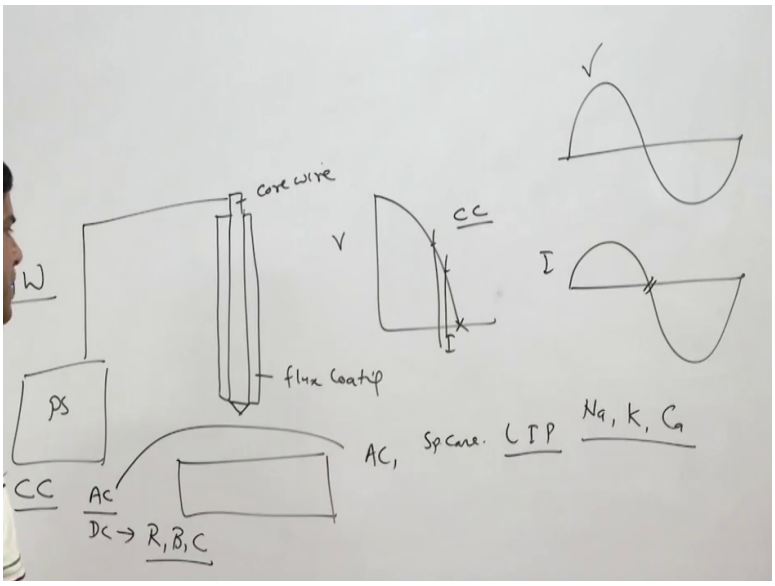

Now we will see the things related with the shielded metal arc welding process commonly abbreviated as shield SMAW, in case of the SMAW what we use - we use 1 electrode which is normally coated with a flux this plays a very big role in case of the shielded metal arc welding processes, here we have core wire of the electrode and this is flux coating on the electrode flux coating in the shielded metal arc welding process plays a very important role for success of the process.

And here in this case since the touch start method is used and mostly the process is controlled manually, so the power source we used with this processes is of the constant current type means even the short circuit stage it does not offer much higher much large current value like this is a kind of the V I - the V I characteristic or the static characteristic of the constant current power source here so the in short circuit stage the current is limited.

And also there is no major change in the value of current with the fluctuation in the arc length which will be changing the voltage so it despite of marginal change in the arc length the current does not change appreciably so it maintains the heat, it times the consistency in the heat being generated for uniform melting and a good quality of the weld joint, so it is preferred to have the constant current type of the power source.

And mostly the type of current as far as this process is concerned it can be AC or DC, DC is very commonly used to because it can be invariably used with all types of the electrodes like a rutile basic and is the cellulosic type of the electrodes, all these electrodes are extremely commonly extremely common in the industry for the welding purpose and these can easily be used using the DC welding current.

For using the AC what is required that the welding electrodes for AC needs the special care especially in terms of the low ionization potential elements, this low ionization potential elements must be present in the electrode in sufficient quantity like sodium potassium and calcium.

So this low ionization potential elements facilitate the easy emission of the electrons for striking the arc whenever current passes through the zero level or the changes the direction or the voltage is 0, so if this is the current cycle and this is the voltage cycle in case of V's, in case of the AC so it is important that when the current flow when using AC becomes 0 at this stage to have the gap conducting the sufficient charged particles has to be produced.

So that the gap can be maintained electrical conducting, and for that purpose low ionization potential elements or you see they are very important for good arc stability that is why the AC should be used keeping in mind the recommendation of the manufacturer for shielded metal arc welding electrodes so this is about the power source and the type of current which is to be used.

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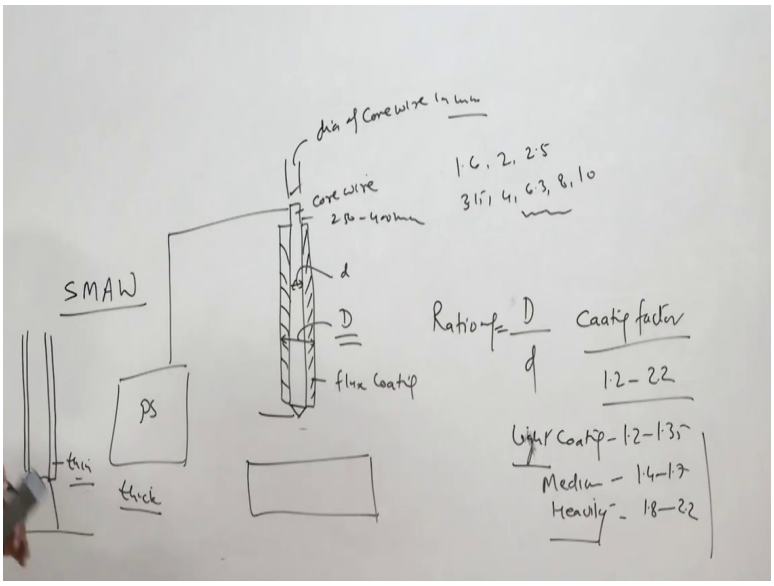

Now the role of the coating since if we see here bare electrode is open at the top electrode at the top end is bare where the we do not have the coating and the entire length otherwise it is coated this length maybe like say 250 to 400 mm and the diameter of the electrode is - is designated through the diameter of the core wire - core wire - core wire in mm like say so it is very common to have like 1.6, 2, 2.5, 3.15, 4, 6.3, 8, 10 mm diameter electrodes.

So all these are indicating the diameter of the core wire, so electrode diameter means the diameter of the core wire and this is the coating so the diameter of the electrode with the coating is if indicated by the letter D and the diameter of the core wire is indicated through the letter small d in that case the ratio of the core diameter of the electrode with the coating divided by the diameter of the core wire this ratio gives us the idea about the coating factor.

Coating factor is an indicator of the thickness of the coating layer which has been applied over the surface of the core wire, so this coating factor value generally varies from 1.2 to 2.2 Where in light coated electrode - light quoted electrodes means the coating is very thin light coated electrodes they have this value from 1.2 to 1.35, medium coated electrodes will have this value in the range of 1.4 to 1.7.

And then heavily quoted or heavily coated electrodes they will have value from 1. say greater than 1.7 to 1. 2.2, this is the general just to have the idea about the range, so now it is very easy

to understand the light coated electrodes will have very thin layer of the coating and this thin layer of the coating may not be enough to provide the sufficient shielding to the pool.

So - so for that we need to see that what are the roles been performed if the coating is thin or if the coating is really very thick so thickness and tennis of the coating will have the effect on the soundness of the weld joint, so far that how it will affect that is what we can see in respect of the - in respect of the kind of role which are we - which are performed by the electrode the coatings during the welding.

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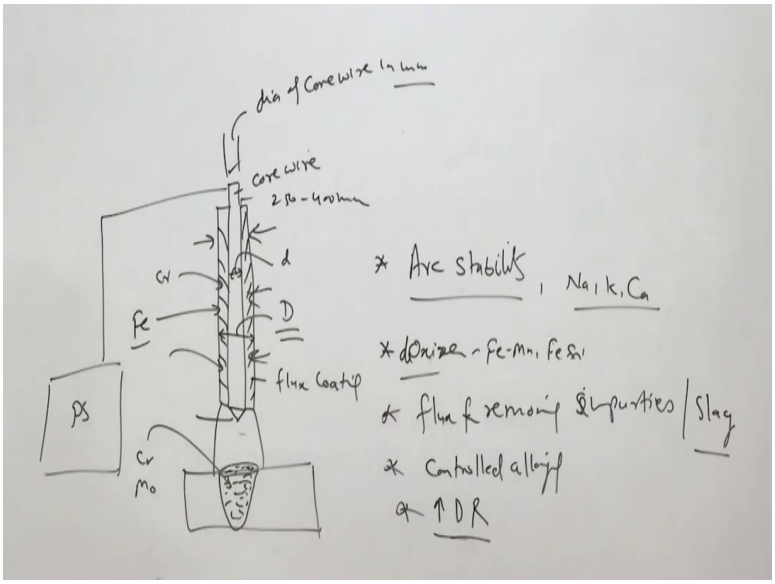

So as far as the role is concerned the bare electrode we know, bare electrode like of the iron or aluminium they are having higher ionization potential, so the electron emission capability is limited, so they do not provide very smooth and stable arc due to limited electrical limited connectivity of the gap between electron and work piece so the arc is unstable mostly in case of the bare electrode.

And that is why the electrodes if they are coated with the if they are coated then the coatings of the low ionization potential elements voting with the low ionization potential elements will provide the arc stability, so the first role of the providing which is very important the purpose of providing the coating is first to see that arc is stable.

So and this is achieved through the incorporation of the low ionization potential elements like sodium potassium calcium in the coating these elements have very low ionization potential and that is why and during in the welding conditions during the welding they emit the electrons very easily and provide the conducting gap between the electrode and work piece easily so the arc stability improves.

And the second purpose is to - is to provide the de oxidizes de oxidizes say common like Ferro manganese and Ferro - Ferro silicon kind of things are added what they will be doing then they will so this whatever oxides are being formed it will help to separate out the metal which has got oxidized and help to save the metal work and then also to provide the - the flux for removing the impurities - removing the impurities like the flux is designed in such a way that the ingredients or constituents of the flux interact with the impurities and forms slag.

And this slag is designed to - slag is designed to be lighter than the weld metal, so whenever the weld metal the weld is brought weld pool is formed the slag which is formed due to the interaction between the flux and the impurities the slag becomes lighter and it starts floating over the surface of the metal at the same time this the coatings are also provided for controlled alloying - controlled alloying if it is required to the have a specific set of the properties in the weld metal.

And we want to incorporate some special elements like chromium or molybdenum in the weld metal then these elements are incorporated with the coating and when in the powder form and when this - when this will and then this will be transferred to the weld pool, so this is what is called controlled alloying, so the alloy - alloying elements which we want to incorporate in the weld metal they will be added in the coatings.

So that during the welding this get transferred after the fusion into the weld pool, further this is also used for increasing the deposition efficiency - increasing the deposition efficiency and how it is achieved like the iron powder cell if the steel is being welded to increase the deposition efficiency, iron powder is incorporated with the coating and when this iron powder melts, it gets transferred to the weld pool.

So coating efficiency because is calculated from the weight of the core wire and when the iron powder is added with the flux it helps to increase the weight which is being deposited in unit - unit time and thereby it helps to increase the deposition efficiency or the deposition rate, rather it is deposition rate, in unit time we are able to deposit more quantity because iron powder will be getting transferred after melting into the weld pool.

And the iron powder which was incorporated with the coating in that way it helps to increase the transfer of the transfer in that way it helps to increase the deposition rate there are few more functions which are performed by these coatings which includes like in odd position welding or in vertical welding.

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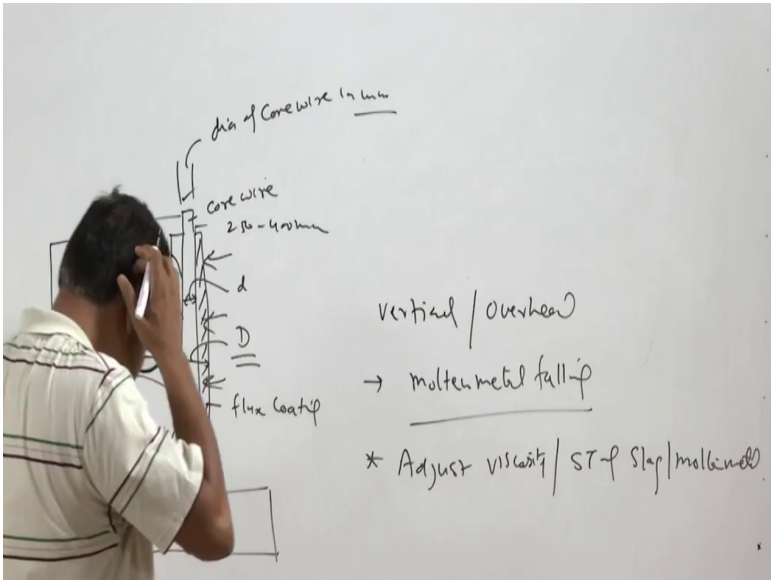

Like this vertical or overhead welding conditions where there is a heavy tendency of the molten metal - molten metal falling from the weld pool, so in this case it is desired that viscosity of the weld metal is high so the slag which is slag is actually the flux is designed in such a way that the slag which is formed is thick and viscous.

So it is the falling tendency of the weld metal can be reduced, so basically the purpose is to purpose of the coating can also be to adjust the - the viscosity and surface tension of the slag and molten metal so that the flux falling tendency of the weld metal during the welding can be

reduced, so these are the important functions which are performed by the fluxes- fluxes which are applied in the coating.

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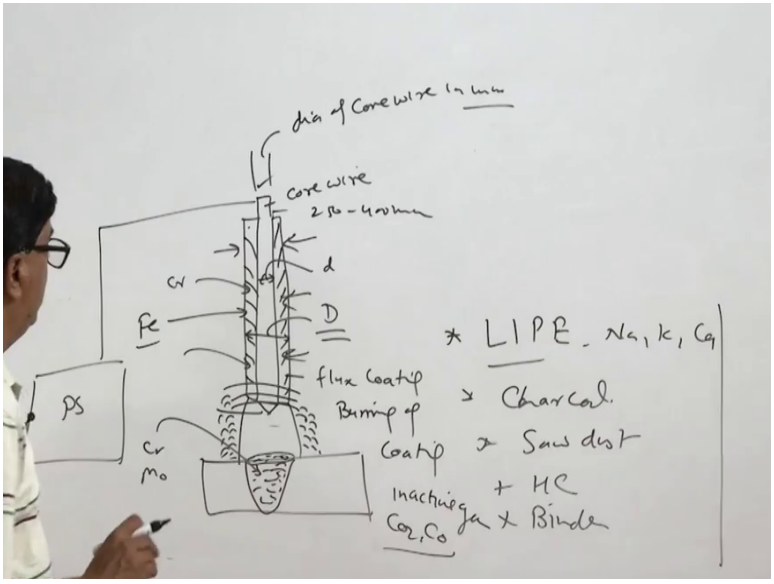

There are different - there are different types of the constituents which are added in the coatings and these are commonly used as a low ionization potential elements like sodium potassium calcium there is a charcoal which is commonly added and then sawdust is also used various hydrocarbons and commonly used is a binder these are sodium or potassium silicates. There are number of constituencies which are added for performing the specific functions during the welding.

And that is what we can see from this slide, where in this list shows the different elements and which are added into the flux for a performing the specific functions.

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Constituents and their role

Item	Formulation	Role
Quartz	SiO_2	Enhance current carrying capacity
Magnetite	Fe_3O_4	Refining transfer of molten metal drops
Calcium carbonate	$CaCO_3$	Lower arc voltage and release inactive gases
Fluorspar	CaF_2	Increasing viscosity of molten metal
Ferro- manganese and Ferro-silicon	Fe-Mn, Fe-Si	De-oxidants
Cellulose	-	Releases shielding gas
Potassium water glass	K_2SiO_3, Na_2SiO_3	Bonding agent
Rutile	TiO_2	Increasing slag viscosity and easy re-striking of arc

For example, quartz is added for increasing the current carrying capacity, magnetite is added for refining the transfer of the molten metal drops means that it helps in achieving them split transfer and the calcium carbonate is helps in reducing the arc voltage and providing the inactive gases so that the arc can be weld metal can be protected and the fluorspar for increasing the viscosity of the slag and molten metal.

Ferro manganese and Ferro silicon are commonly used as a de-oxidants and the cellulose for releasing the shielding gases and potassium water silicate these are the bonding agents and the the rutile is also one of the common element which is added in form of the titanium oxide for increasing the viscosity and the since it has very good arc emission capabilities so it helps in re-striking of the arc.

So one of the important functions of this flux is also is that when this coating - this coating when approaches to the arc in course of the welding it is burnt out, so burning of the coating produces burning of the coating or competition of the coating material produces lot of inactive gases - inactive gases in form of CO_2 and CO, so these gases are released due to the thermal decomposition of the coating constituents and combustion.

So these gases from actually very loose cover of the CO of CO_2 around the welding arc and thereby it helps in protecting the weld metal from the atmospheric contamination, so this is very

important role of - of providing the coating in the shielded metal arc welding processes, since the protection provided in this process is not very good because it forms very loose cover, so there is every possibility that the atmospheric gases will be able to interact with the weld metal during the shielded metal arc welding process.

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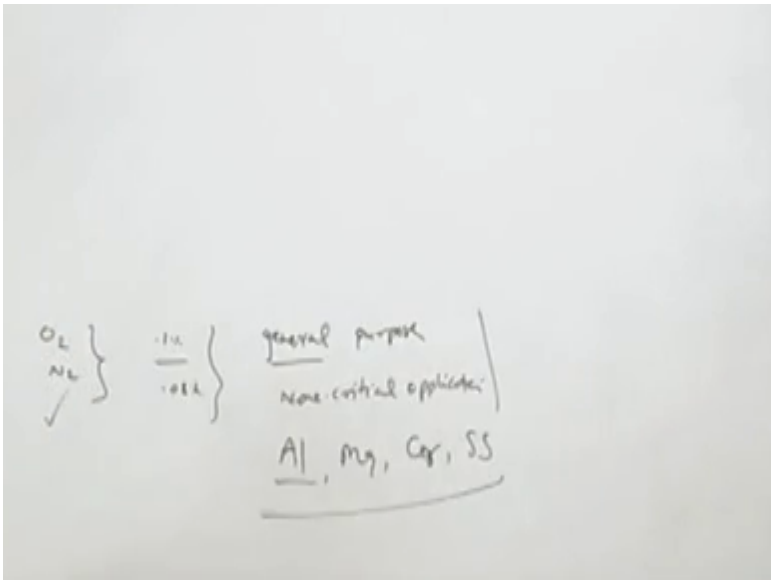

And that is why are usually the concentration of oxygen and nitrogen in the weld is on the higher side and normally say these are found say 0.1% to 0.08% on side, so the higher concentration of the oxygen and nitrogen in the weld metal they tend to degrade the properties of the - of the weld joint, and that is why these are good for like say for shielded metal arc welding process is good for the general purpose welding and wherever you see non-critical applications of the welding.

Because the quality of the weld joint is not that good and high due to the higher concentration of the gases only this process cannot be used for the purpose of the welding of all the reactive metals like aluminium, magnesium, chromium or the stainless steel because these metals easily react with the oxygen and form their oxides which are refractory ignitor nature and these oxides do not melt easily therefore they interfere with a melting of the best material. And so and these oxides also get mixed up with a weld metal to form the inclusions.

So the problems are number there are many problems associated with the welding of the reactive metals using shielded welding metal arc welding process that is why they are not normally

welded with a shielded metal arc welding process. And more those process which provide more effective protection to the weld pool are normally prepared for the welding purpose of this reactive metals like gas metal arc welding process or gas tungsten arc welding or the plasma welding process like those.

So this is now I will - I will conclude this presentation, in this presentation I have talked about that how the arc is established. And how the arc is initiated what are the conditions necessary for striking the arc and having this stable arc and what is the role of the different coatings and the electrode in the shielded metal arc welding process and what kind of metal systems which can be welded using this process, thank you for your attention.

In the next presentation I will talk about the other welding process like submerged arc welding process and gas tungsten arc welding process thank you for your attention.