Marine Construction and Welding

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Module No. # 01

Lecture No. # 28

Shielded Metal Arc Welding

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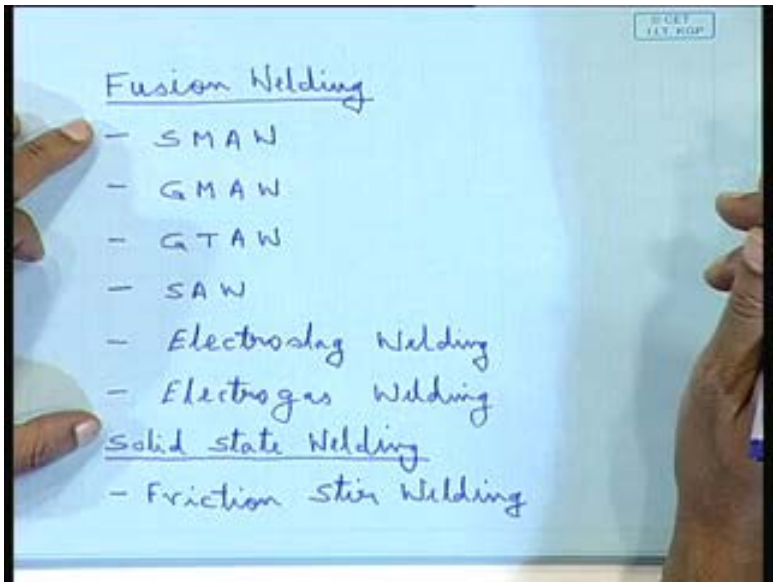

We will start with the welding processes. Welding processes has used in ship building industry. Primary we look into that. So, there as you can see, generally all the welding techniques involved. They are fusion welding processes. Here, I have listed some of them, which are more relevant as far as the ship building industry is concerned.

Among this fusion welding, fusion welding means, where fusion takes place by virtue of fusion. We would do the joining of two components. So, S M A W, that is shielded metal arc welding. Then, you have G M A W, gas metal arc welding. G T A W, gas tungsten arc welding. We will take them up little more in detail. Subsequently, just now highlighting what are the methods.

S A W, submerged arc welding, then you have something called electro slag welding, electro gas welding. So, these are as you can see 6 such methods, which are based on fusion welding process. Then, we have another welding process which can be referred to as solid state welding. By solid state, we mean that there is no fusion involved. It is no melting involved. That is how the name solid state.

So, under that, a welding technique which is referred to as friction stir welding, that is also slowly gaining so-called popularity and acceptance in that ship building industry. In this, we do not go for melting of the plates to be welded. So, that is how the name solid state welding. We will look into that later little more in detail. So, today we will look into this shielded metal arc welding little more in detail.

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So, you can see this shielded metal arc welding. Why it is called shielded metal arc welding? Essentially, it is the arc is shielded from the environment. As you can see in this schematic diagram, these dotted lines, they are actually shielding the arc as well as the primarily the arc from the environment, from the atmosphere, such that contamination, oxygen and nitrogen contamination does not take place, right.

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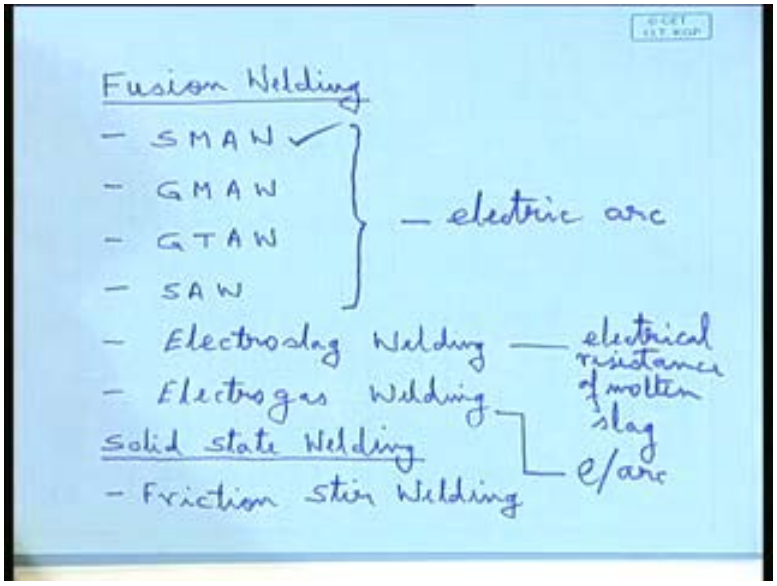

So, essentially these are fusion welding process. It required the, required heat is produced from an electric arc. Will this fusion welding processes, which I have just now mentioned of them, these first 4, the heat is generated from electric arc. So, there are, they are some form of electric arc welding. There are some forms of electric arc welding. Whereas, it is actually electrical resistance, the heat generated from the electrical resistance of molten slag. That is how the name electro slag welding because all these are fusion welding process. So, there you need to have some heat generated, which will melt the metal as well as the electrode.

So, in the first 4, the heat is generated from electric arc. In this electro slag welding, it is generated from the molten slag. Again, electro gas is from electric arc. It is also from electric arc here. Essentially, a gas shielding is there. We will see how it is different from gas metal arc welding later.

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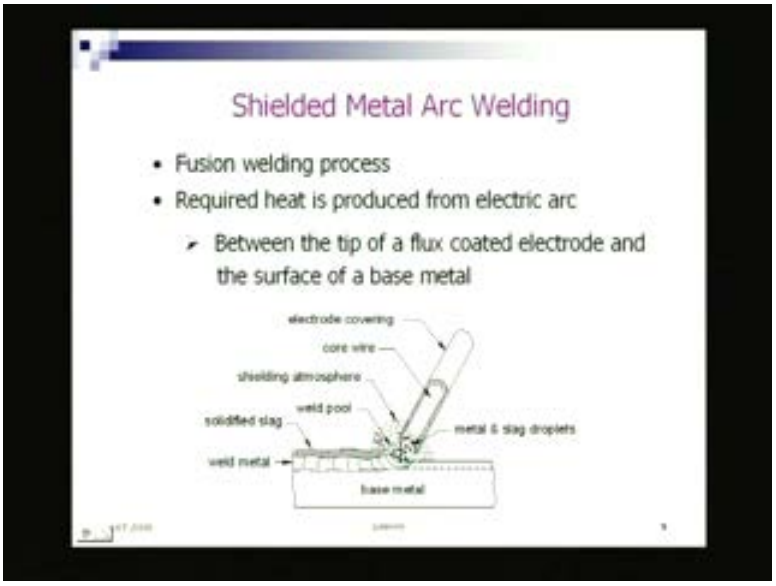

So, again going back to this shielded metal arc welding, as we can see that here the required heat is produced from the electric arc between the tip of the flux, coated electrode and the surface of a base metal. The electric arc we have between that obviously. So, here we can see that, the electrode as well as the filler metal is the, I mean that is one and the same. So, this is schematically shown. You must have done it in your first year workshop practice. So, here what do you see is, that this is our electrode, here we have the covering, the coating of the electrode, and the central part is the core wire, which carries the current and access the filler metal.

Here, you have the so-called welding arc, electric arc where schematically you have tried to show that the metal transfer is taking place. These black spots are as if what happens, the metal gets melted, and it gets transferred through the arc, through the arc column. So, here your molten metal from the electrode is getting transferred to the base, metal part of the base metal is getting melted. Also, there by you have the weld metal deposit over which you have a solidified slag. That slag is nothing, but the burnt flux. The flux, the coating what it has over the electrode, that burned flux is termed as slag, and the slag under that heat remains in a molten state. So, which floats over the weld metal and thereby, it provides a shielding to a molten metal.

Whereas, in that heat, the flux will burn and generate some gases. Those gases protect the arc column, the plasma column. Plasma column also needs to be protected from

atmospheric contamination. Why? It is because through the plasma column, you have the metal droplets getting transferred. Electrode tip is also there at that high temperature. So, if it is not shielded from that atmospheric environment, the metal getting transferred as well as the electrode tip will get oxidized.

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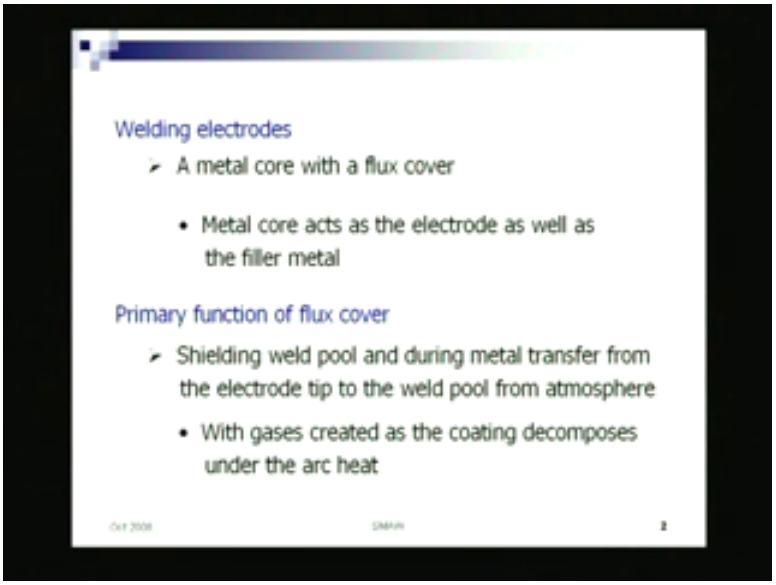

So, what you see in the shielded metal arc welding is, it is essentially a manual welding process. Also at times, it is referred to as MMAW, manual metal arc welding. Also, it is referred to like that. So, here what we have is the, one of the important constituent is the welding electrode depending on the different types of electrode, the welding quality, I mean end usage of the welding process also changes varies.

So, we will take a look at what are the kinds of welding electrodes, the broad classification. So, electrodes are nothing, but it has a metal core with a flux cover. Electrodes have certain standard length. Electrodes are available, so they have the required metal core. That metal composition will depend on, well depend on your usage. That means, of course if you are going to weld certain particular steel material or some metal object, you are going to weld.

So, you will have to choose the suitable electrode for that purpose. Choosing suitable electrode means, we will have to look into the weld metal composition or the parent metal composition, which is to be welded, such that it matches with the welding electrode, and then, other aspects which concerns the flux, so that we will see. So, here

what do you see is, that the metal core acts as the electrode as well as the filler metal. As we have seen because for electric arc welding, you need to establish the arc. So, to establish the arc, you need an electrode. So, here the electrode is a consumable electrode. It generates the arc, generates the heat and in that heat, the electrode itself gets melted and gets deposited, thereby we do the welding.

So, primary function of the flux cover. Why the flux cover is there? The meat core, we can understand the flux. It provides shielding to the welding pool. Welding pool means, when you strike an arc under that action of that heat, the part of the best metal just below arc melts and forms like a molten pool of metal. That molten pool is referred to as the weld pool. So, the function of flux cover is one of the function is shielding the weld pool, and during metal transfer from the electrode tip to the weld pool from atmosphere, that means that molten pool has to be shielded as well as the arc column has to be shielded because metal transfer is taking place as I have already said.

So, that shielding is provided by that arc column, shielding is provided with gas is created from, where it is created? By the coating decomposes under the arc heat. The flux coating that burns and decomposes under the arc heat, and produce the necessary shielding environment. That is what is referred to as welding fume. When you do a metal manual arc or shielded metal arc welding, we will find lot of fumes getting generated. They are purposely generated, means the flux composition is such that those fumes are generated because those fumes are needed to give a shielding, to give coverage to the arc column as well as the electrode tip, whereas the molten metal is given a shielding by the molten slag.

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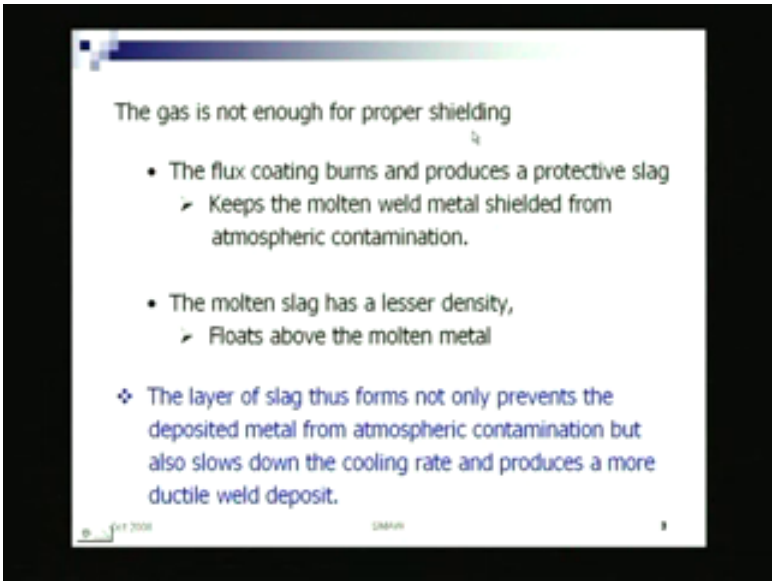

So, that is what has been said here, the gas is not enough for proper shielding, means the fumes, welding fumes which are getting generated or the gas which is getting generated, that does not give the entire shielding. So, what happens is, the flux coating burns and produces a protective slag. The flux after getting burnt, we refer it to a slag that keeps the molten metal, weld metal shielded from atmospheric contamination because atmospheric contamination is primary contamination is oxygen. It will get oxidized and also nitrogen, there is a nitrogen contamination also takes place.

So, to protect it from that, this protective slag or the molten slag acts as a protective coating. This molten slag has lesser density, there by it floats above the molten metal because when I am welding it, your metal is getting melted, flux is getting burnt forming slag, and that is also a molten state. So, both are mixed, but the molten slag being lighter, it will float up the molten metal. So, that is also important because it should have sufficient fluidity, the molten slag such that, it can float up because the molten metal, the weld pool in the molten state is not remaining for a very long time because you are moving the electric arc, you are doing the welding. Doing welding means, one of the motions is you are taking away the heat source, electrode is moving, so as you are taking away the heat source, means what the molten pool is also moving or in other words, the molten pool is getting solidified. So, the slag should be able to float up before it gets solidified.

They are in a mixed condition because under the action of the arc, there will be quite a substantial turbulence in the molten metal pool. In that turbulent environment, your molten metal as well as the molten slag, they are in the mixed condition. So, it should have the molten slag should have such property, such viscosity and density, that it can float up very fast and gives the protection and because if it cannot float up, then it remain in trapped within the molten solidified metal, which is then a defect in the welded joint.

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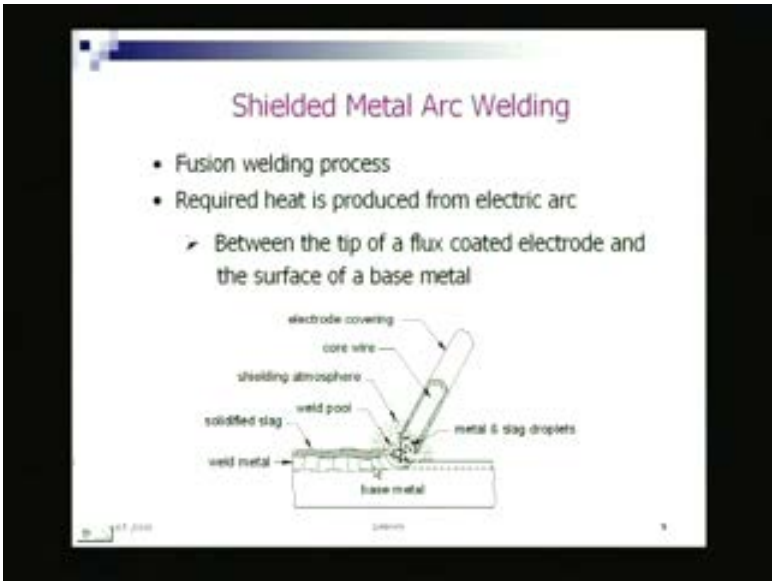

So, the layer of slag thus forms not only prevents the deposited metal from atmosphere contamination, it also does another work. As you can see, also slows down the cooling rate because what is happening, if you go back to here in this schematic figure, this is the solidified metal, say this is my solidified layer. Over that it is the solidified slag. So, when I am doing the welding, as I am progressing I will find there is a layer of slag remaining over the weld bead. What is the weld bead? That is nothing, but the solidified metal. That means, there where the metal deposition has taken place.

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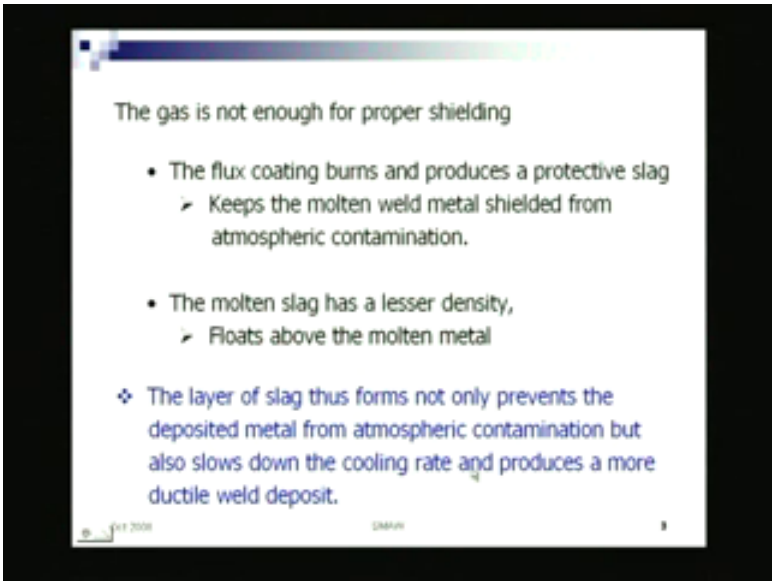

So, it does that additional work, that it slows down the cooling rate because as the solidified metal or the weld bead is covered with a layer and obviously, this slag which is formed, that we will have, that is a bad conductor of heat and it is covered with that. So, that leads to reduction of the cooling rate, and we know if the cooling rate is slower than it produces a more ductile material because steel as you know, if the cooling rate is very fast, that is what is referred to as quenching. You heat up a metal and dip it in water, it becomes hard, it becomes brittle, but you heat it up and allow it to cool very slowly, it is aniline. Some what that effect of aniline takes place.

So, there by the slag functions not only in terms of protecting it from oxidation, from atmospheric contamination, also it helps in positive sense, that it make the well deposit ductile because always is preferable to be to have ductile property than an arc in such fabrications (( )).

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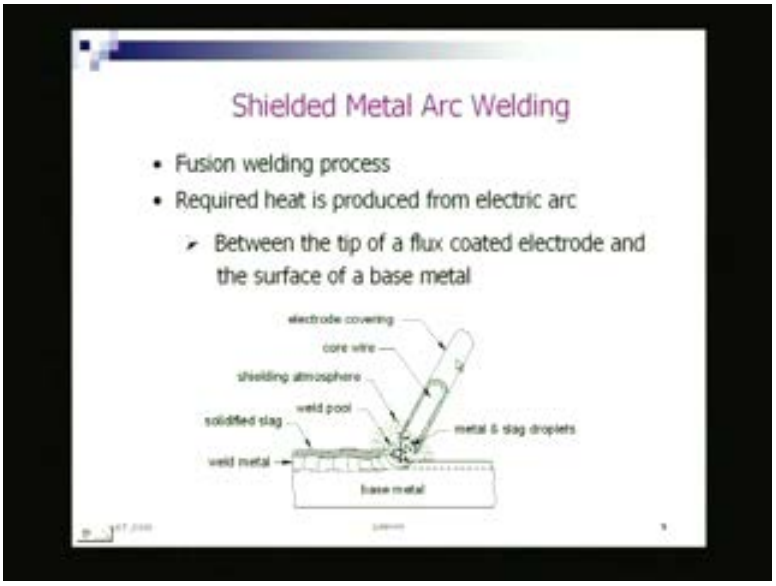

It is not solidified electrode. You mean to say, the electrode is something like this, a rod over which above the top coating is the flux. Then, we call it flux, like you can see here. The electrode covering what we have region, this shaded part. Electrode covering here it is a section taken. So, this covering is the flux, that is a solid flux, a solid coating over the metal wire. Suppose, you have a metal wire inside 3 millimetre dia wire, which is actually the electrode over which you have a coating. Another thick coating of few millimetre diameter, few millimetre thicknesses, so that is what the flux coating is. We will see what the flux is made up of.

So, now when the arc is struck in that heat, the core electrode, this core wire that is the electrode. That core wire melts. At the same time, the coating which is the flux, it burns. Coating is not melting, that is burning because it is in the atmosphere environment with oxygen burning and after burning like this, inside core wire is melting and forming a molten deposit, flux is burning and forming a slag flux burnt flux is refer to as slag (( )).

Yes, the slag is forming and that slag is in molten state, and also because of the burning spot of the flux gets decomposed and forms fumes gases. Yeah, not actually molten slag is not forming any gas. This flux is forming molten slag plus gas, like you burn a piece of coal. What you get? You get some gases as well as some ash, some residue. So, here the residue is the slag and some part is the gas.

So, the gas what we are getting here, that is to our benefit. When the coal piece of coal is burnt, the gas it goes in the atmosphere. It does not benefit us in anyway, but here it benefits us because that gas, it protects this arc column because through the arc column, when you have the electrode, it is not touching the metal. There is a gap. Through this gap, the molten metal is getting transferred, electrode tip is melting and getting transferred. So, while getting transferred, it will get oxidized because there it is not protected by the slag, it is only on the above the molten pool.

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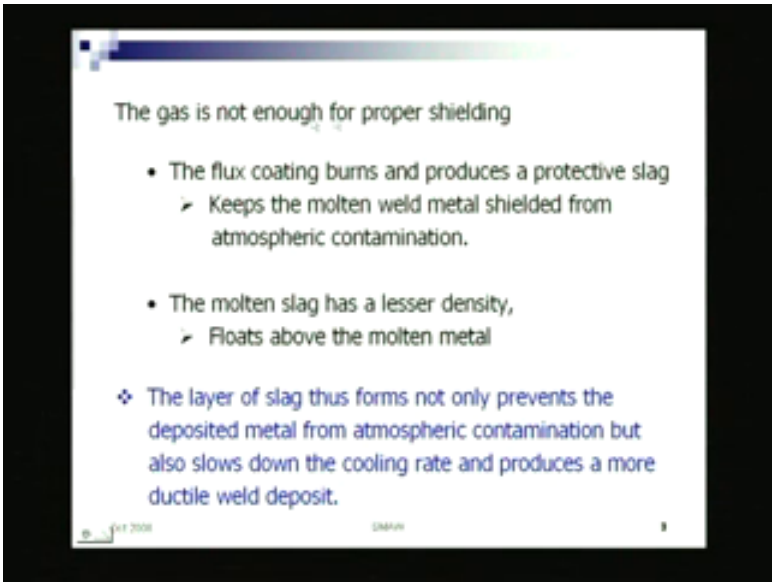

So, this is exposed as well as the tip is exposed. So, the fumes coming out that is protected in it. That is how it is said that, this gas gives the shielding for the arc and then, here we are talking about, that there is not enough, so flux slag also provides the necessary shielding anyway.

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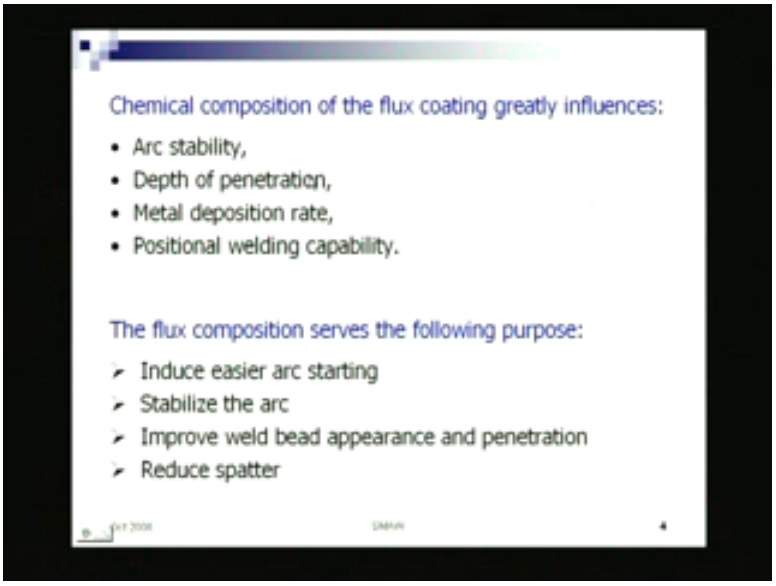

So, what do you see? That the chemical composition of the flux, we have seen that there is some flux coating on the electrode. Now, that chemical composition of the flux coating that has a great influence on the performance of the welding, on the end quality of the weld deposit, and also on the process, on the performance, like it influence the arc stability. Arc stability means, what that means? The arc is nothing, but it is a plasma column. That gas in between that gap, between the metal plate, or the job plate which is being welded and the electrode tip.

There what happened, gas is there to start with its only air atmosphere. Now, unless until you have the circuit closed, current will not flow. So, if I just hold the electrode like this, nothing will happen. You may have observed, what you do, you just touch it, and then lift it up by touching and lifting up. What essentially I am doing by touching? I am completing the circuit. It is a high ampere is power source. So, momentarily that touching will generate an enormous heat here and by lifting it what happens. That heat itself will as well as the arc created because of just breaking the circuit by lifting it.

You may have observed when you switch off a switch. There is a spark kind of a thing. That means, when the electrical connect, when it gets disconnected, there is an arc. I mean a kind of an arc jumps between the two poles. So, when I am touching it, lifting it, two things are happening. The momentarily touching, huge current is flowing because there is a momentary short circuit in the entire welding circuit. That a current will heat

up with the electrode as well as the best metal at that location. Second thing, the moment I am lifting it up, that there will be an arc between the electrode and the plate. So, both the action of the arc and heat will ionize the air column there to start with. It will ionize those things. It will happen in a millisecond, nanosecond time. It will ionize the air column, and once the air column is ionized, it is no more non-conducting. It becomes a conducting column.

So, the circuit is completed and current flows. Current flows means, what flow of electron takes place or bombardment of electron takes place in the process. That heat is generated in that plasma column. That heat then keeps on melting the metal, as well as the electrode. Now, that will keep on melting, provided the arc is stable. If the arc gets extinguished, then there is no heat. Again you will have to strike the thing, create the arc.

So, that is what is the arc stability. That means a stable arc will give you a stable heat now and then. If the arc is getting extinguished or arc is getting deflected, arc power is reducing, increasing, fluctuating. Then, what happens, your heat generated is fluctuating because at the end, we are interested in the amount of heat generated. We are not truly interested what is happening to the arc or interested in heat generated. Why? Because that heat will determine how much metal is getting melted. Heat will determine how much the best metal is getting melted, what is the rate of deposition. All those things will depend on heat. That is number 1.

So, to get that heat uniformly all through, I need a stable arc. To get a stable arc, I need a suitable composition of the flux coating. Why? Because initial staring, I said the plasma column is formed by the ionization of the atmospheric air, but subsequently, that atmospheric air is replaced by those gases which are being generated by burning the flux. So, the flux composition is becoming important. That means, what gas is getting released, their ionization potential becomes important and that leads to the question of arc stability.

So, you see that the chemical composition of the flux coating, it influences the arc stability. Next, it influences the depth of penetration. Depth of penetration means you are striking the arc, that heat. How much it is penetrating in the metal plate? How much it is penetrating in the metal plate, means till what extent it is melting the plate. How much depth? That of course, also will depend on the thermal conductivity of the plate material,

but also will depend on the arc characteristics. Arc characteristics means, what whether that arc has a certain kind of kinetic energy force, the jet, the arc jet into the metal plate, whether it creates turbulence, where by the conduction process is enhanced kind of metal movement. You assume a molten material zone, where you have some molten material and the molecules are moving in this direction. That means, the metal is coming and going down, again going through the side up and going down or in other word like this.

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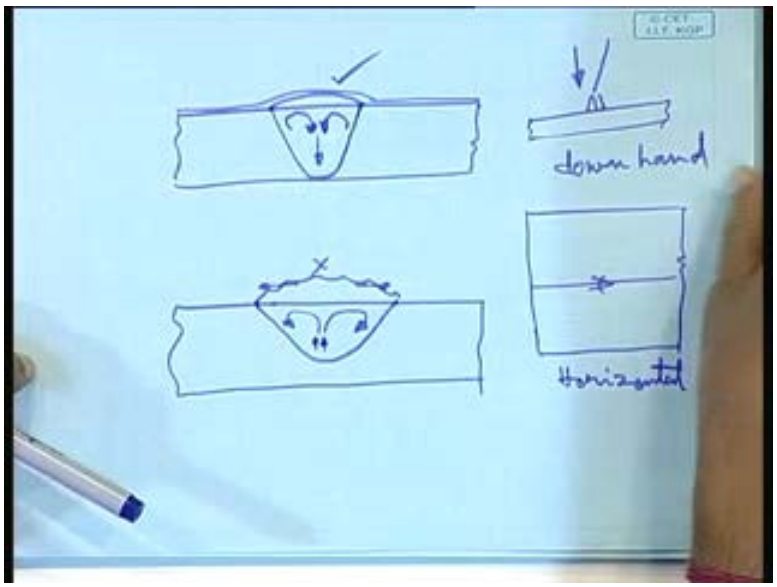

Suppose, the fusion zone is this, and what I was saying is the movement is something of this order, of this nature, then what happens, it as a kind of a penetrating force, conduction of heat will be more. So, your depth of penetration increases, whereas if the movement of the molten particles are like this, just the opposite as if it is going from bottom and taking an outward motion, then I have the heat is conducted more on the sides. The wall fusion is more. It is becoming wider, whereas in this, it is becoming deeper, narrower and deeper. So, all those again will depend also on the chemical composition of the flux because this will depend on what kind of forces is generated.

It will also affect the metal deposition rate. Obviously, the heat, how much heat is getting generated? How much heat is getting generated is not only from the point of view of how much power is being spent, but also ionization potential of gas. That also determines how much heat will be generated like in helium environment, some amount of heat organ environment, some another amount of heat will be generated.

So, that will then decide on the, will have the effect on the metal deposition rate because metal deposition rate is nothing, but the melting rate of the electrode which is getting deposited. Then, positional welding capacity, positional welding capability means, you know welding. I mean if we see welding situations, the best welding situation is like this. That means down hand. Down hand welding metal transfer is taking place in the direction of gravity. This is called down hand welding, say this is my welding electrode, this is what is down hand welding. There can be a situation, say this is a vertical wall, and you are welding in this direction, say the vertical wall and you are welding on the vertical wall.

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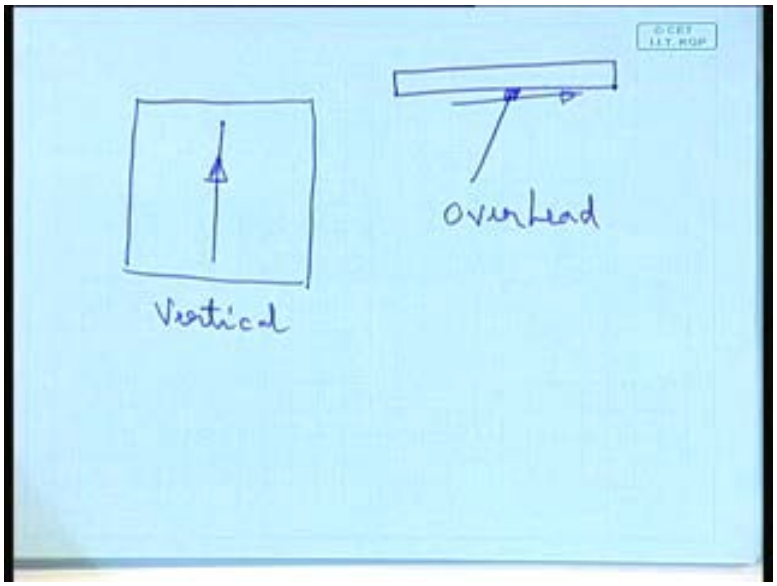

So, this is a horizontal welding. It is in horizontal welding. You may have such the same thing, another vertical wall, and you are going up vertically. So, that is a vertical welding, and the worst is the overhead and you are doing the welding. This is overhead. That means taking the electrode, and doing the welding overhead. So, this is the worst metal transfer is taking place against the force of gravity. In the next, worst is vertical welding metal transfer is taking place against the force of gravity. So, there is a tendency of metal dripping little better than that. When I am doing a horizontal welding also metal transfer against gravity, but uniformly all along best is down hand.

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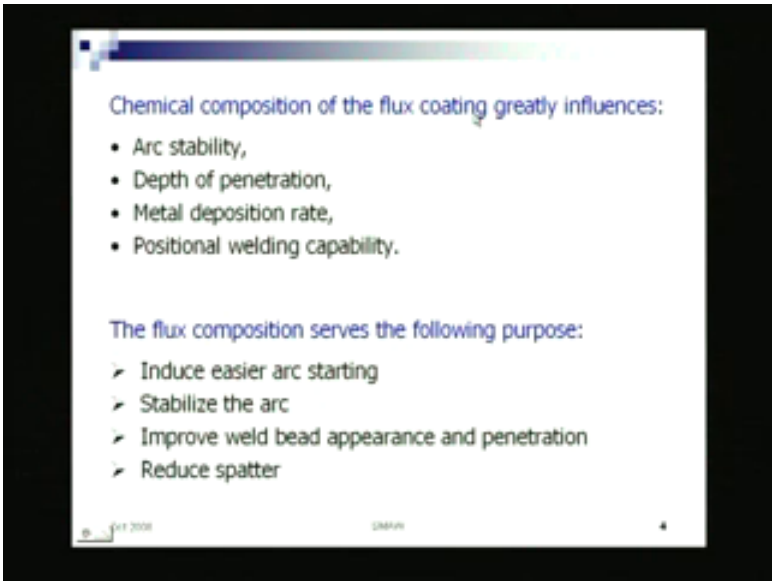

So, these are called positional welding. Taken together, it is referred to as positional welding. So, what it says that the capability, positional welding capability also will depend on the flux coating composition. These we are talking for manual metal arc welding for shielded metal arc welding. So, that means a particular type of electrode may be suitable for down hand welding, may not be suitable for overhead welding. If I have to do a positional welding, means where generally by positional welding, it means any welding position, other than down hand.

Other than down hand, that means where your metal transfer will be acting somewhat against the gravitational force. So, these are the aspects. Arc stability, depth of penetration, metal deposition, positional welding capability, they depend; they are influenced by the chemical composition. So, the flux composition of what it serves, what are the purpose, it induces easier arc, starting induces easier arc. Starting means, what it is easy with the suitable flux composition. You will have favourable gas is generated, which gets ionized more easily, such that the electric arc is initiated very easily.

If you recall your work shop practice days, you may recall that many a time you had difficulty to initiate the arc. It is not, it just changed the electrode take a suitable electrode arc is initiated very easily, means with the same hand, and you take some other electrode. You may have difficulty in initiating the arc. Well, that may have other advantages that coating; this coating may have other disadvantages, but one of the things

is that a suitable composition may help you in easier arc starting. This is nothing, but depends on the ionization potential of the gases stabilize the arc. That also is there, so that you get a fairly stable arc.

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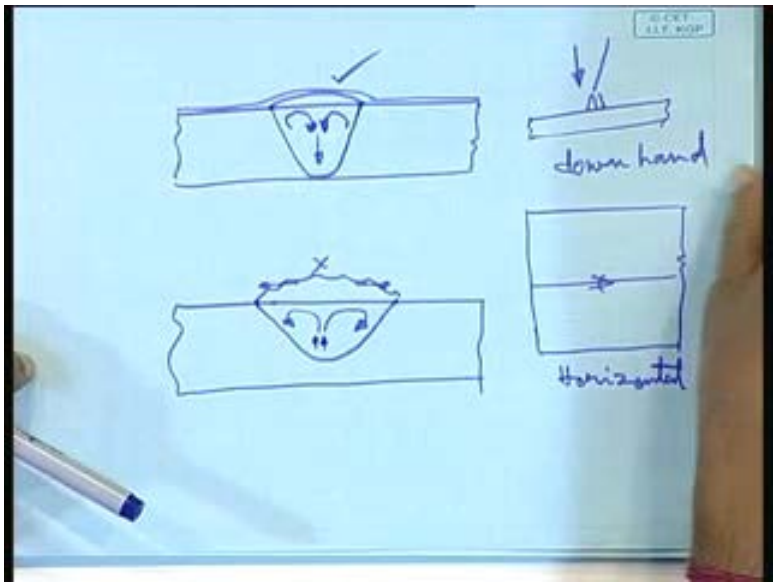

Then, improve weld bead appearance and penetration weld bead appearance means nothing, but when you do a welding, this is what is the appearance bead appearance. That means, the bead profile it has to be smooth. If it is very rough, this is not a good bead. This is a better bead have a smooth surface. Why it is important to have a smooth surface? Because you should remember that at the end, you will have to give a coating of paint to protect it from corrosion.

When a ship hall, I mean or the offshore platform, we working in a marine environment, you will have to give protection. If the surface is rough, and the protection will not be proper, the paint fill life of the paint fill will not be, will be less. So, it is preferable, it is desirable to have a smooth bead surface. That is what is referred to as bead appearance and penetration. Well, such that proper fusion takes place along the thickness.

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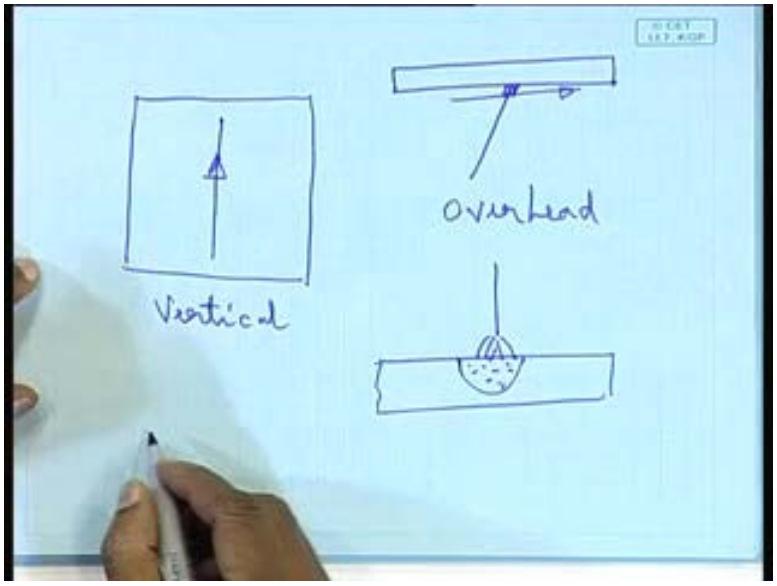

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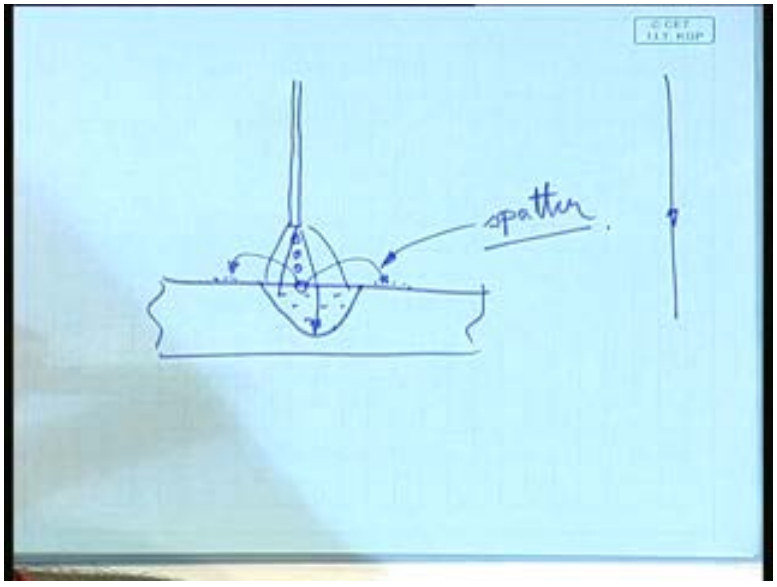

Reduce spatter, what is spatter? Spatter is essentially when you are doing welding. A molten pool has formed is not under the action of the arc. A molten metal pool has formed and the metal is getting transferred little in an enlarged few. Suppose schematically it is like this. Here, you have the molten metal molten pool, you have the arc and the metal droplets are getting transferred. So, as it drops here, there can be a case of spattering. It is not exactly spatter. That is a different phenomenon. Just it is something like when on a molten in a cup you have water, and you drop something, some water gets splashed, something similar. The molten metal is getting splashed out.

So, that is how what is referred to as spatter. Obviously, this spatter is not a good aspect to happen. Why? Because if the moment it is getting splashed, means that metal is getting wasted. It is getting out of the molten pool, and getting deposited on the side which has to be eventually removed. It cannot leave them as there because they will form otherwise small beads that to be removed. So, this spattering is not a good thing. So, a suitable composition will reduce the spatter well.

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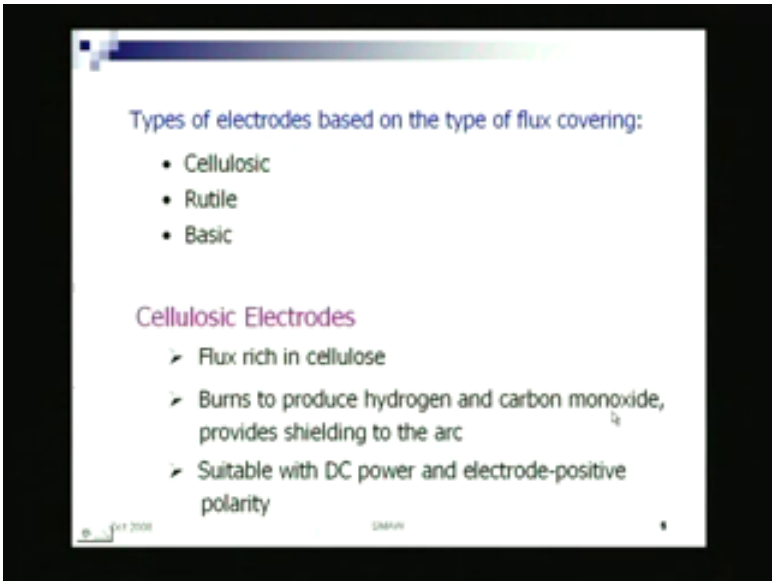

So, that is what it does and what purpose it serves about the flux composition. So, we see what the basic different types of flux covering are. So, the different types of electrodes, they are either referred to as cellulosic electrode or rutile or basic electrode. They are broadly under 3 heads. The electrodes are classified based on their flux coating, composition of the flux coating.

So cellulosic electrode. What is that the flux is reaching cellulose? The flux composition is reaching cellulose; it burns to produce hydrogen and carbon monoxide which provide shielding to the arc. So, you can see the welding fume which is generated. The person who is welding is not very healthy for him because there is a carbon monoxide revolution is there. So, that is why whenever the manual welding is there, you have a proper means of extracting the fumes, such that the welder does not get much expose to the fume, such that there is a section system because as the welding arc is moving, the gas is generated there giving the necessary shielding.

Then, it is getting dispersed in the environment and in that environment, the welder is sitting and that environment is not very healthy. It is a carbon monoxide, so it has to be extracted. That is another issue. Anyway, we find cellulosic electrode. Because of its organic compound primarily based on carbon, so it produces a carbon monoxide as well as the hydrocarbons. They decompose and forms hydrogen which provides a shielding to the arc.

So, these are suitable with DC power, and electrode positive polarity. So, a cellulosic electrode if you are using, they are suitable for using with DC power. DC power means, when you are doing the welding electric power source is needed, so it can be the DC or can be AC. So, that is what it is suitable with DC, and with a configuration of electrode positive polarity because as we change the polarity, the performance changes. If I am using DC, keep the electrode negative, the performance will be different. We will see those aspects later.

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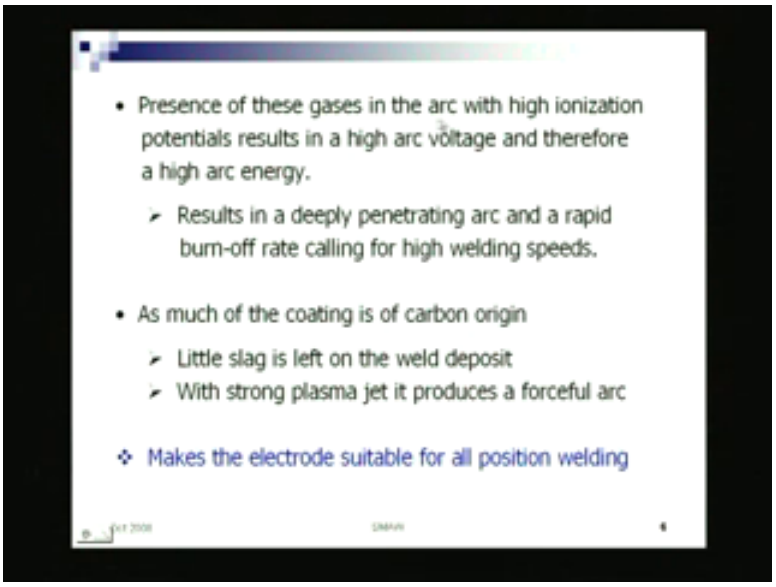

So, presence of these gases in the arc with high ionization potential, this hydrogen and carbon monoxide, they have a high ionizing potential. It results in high arc voltage. So, you can see how it is effecting the heats generation. The hydrogen and carbon monoxide, they have a higher ionization potential which results in high arc voltage, and therefore, high arc energy is increasing. That results in a deeply penetrating arc, means a cellulosic electrode where you need to have a higher penetration depending on the plate material to

be welded, depending on the situation because you know how much will be the weld fusion. The penetration means this depth of fusion.

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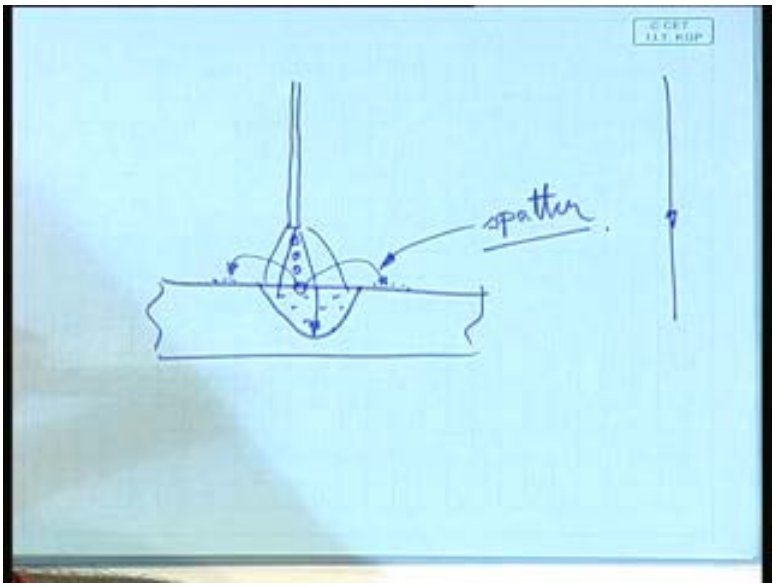

This depth of fusion to increase that primary driving force is the current. You increase the current; more heat is generated because heat is directionally propositional to the square of the current. More heat is generated, so more mean penetration should be achieved, but these are other aspects which also help in improving penetrations. That means to achieve a final control on the deposition pattern. On the fusion pattern, you will have to take a cumulative effect of all the welding variables. So, one of the welding variables is, what is the flux? What is the shielding medium? What kind of shielding medium? What properties it has? So, that also affects the deposition rate, the deposition pattern, the fusion pattern.

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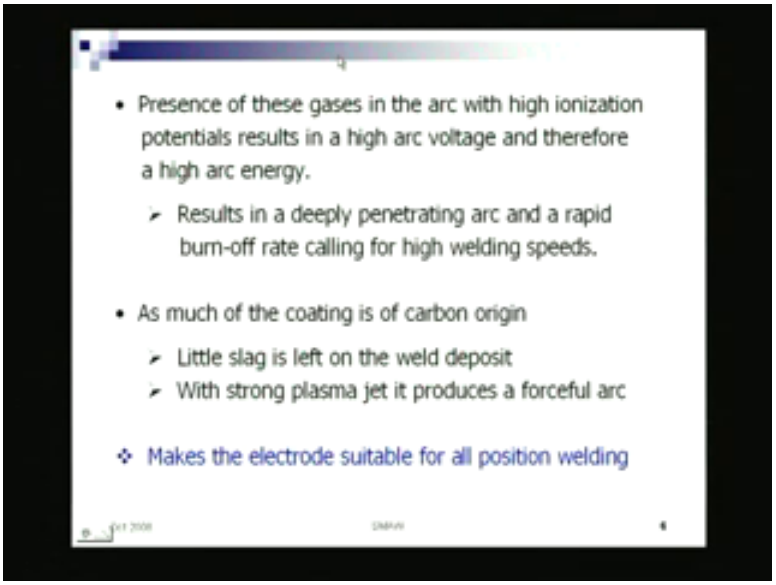

So, that is what you see here in cellulosic electrode. It results in deeply penetrating arc, and a rapid burn off rate. Rapid burn off rate means, what it is essentially there is a term used burn off. It is not burning off; it is melting the electrode calling for higher welding speeds, means what higher heat is generated because of high ionization potential higher energy we have, I am getting arc energy. That means higher heat. If higher heat, then it gives me a deeply penetrating arc as well as higher melting of the electrode, thereby I can increase the welding speed.

Also, other aspect is what as much of the coating is of carbon origin, so little slag is left on the weld deposit. That means not much of slag is left there. So, that has other effects. One of the good effects of the little slag left means, there is a less chance of slag inclusion. What it was telling that the slag should get floated up. It should float up, such that it does not get trap in size. So, less possibility of such thing happening. That is number 1. Again at the same time, a thinner layer of slag coating, so that annealing effect will not be, will be little less. It will be somewhat little less.

So, on one side, you have advantage, other side you may have a little disadvantage. It is not a pure disadvantage because you may not need that level of annealing. Whatever it is shielding, it is giving from heat dissipation good enough, but the idea is to know that a little slag is left from the weld deposit. Why? Basically, it gets burnt out, and it forms carbon monoxide. Well, with strong plasma jet, it produces a forceful arc, fine.

So, mix the electrode suitable for all position welding, so there by we see, since it results in a deeply penetrating arc, a forceful arc, deeply penetrating arc. Forceful arc means, it will fuse. The fusion power will be more along the thickness direction having strong plasma jet means, throwing up the molten metal also will have with a force. So, it can overcome the gravitational pull, and the metal can be deposited even in overhead condition. The molten droplet should be able to travel against the gravitational force.

So, that is happening because of this strong plasma jet. So, that is how it makes suitable for all position of welding. So, if I have to do over head welding, then it will look for a cellulosic electrode one of the solution.

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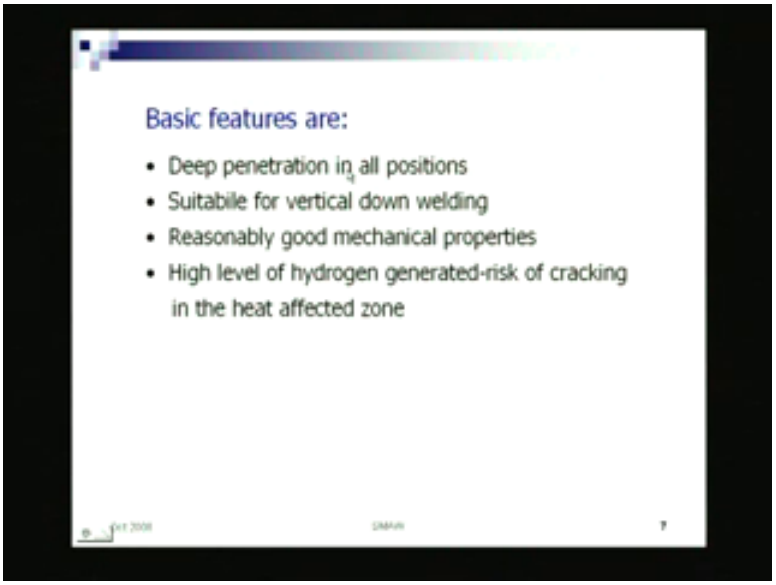

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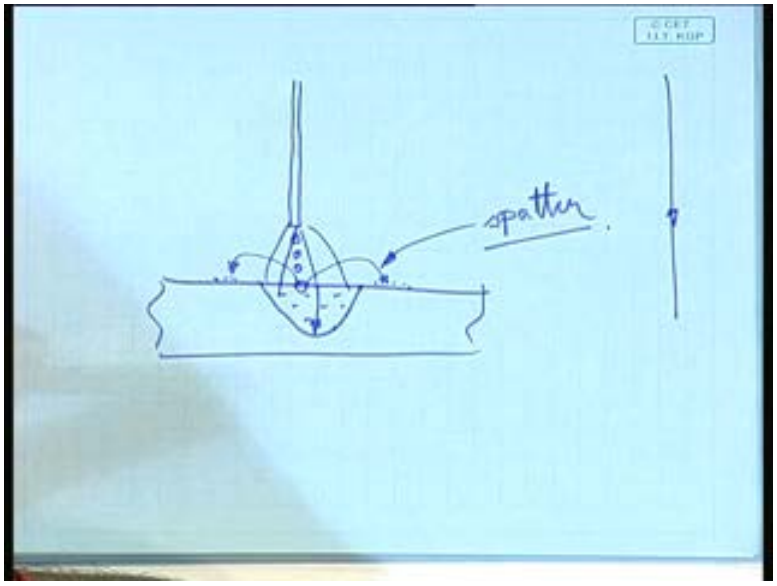

The basic features of this cellulosic electrode, just to summarize deep penetration in all position suitable for vertical down welding. Vertical down welding means, when you are coming down vertically from the top, coming down vertically because going up is easier in positional welding. When you weld from bottom and going up, it is easier. Why? Because continuously the solidified metal is giving you support, you understand.

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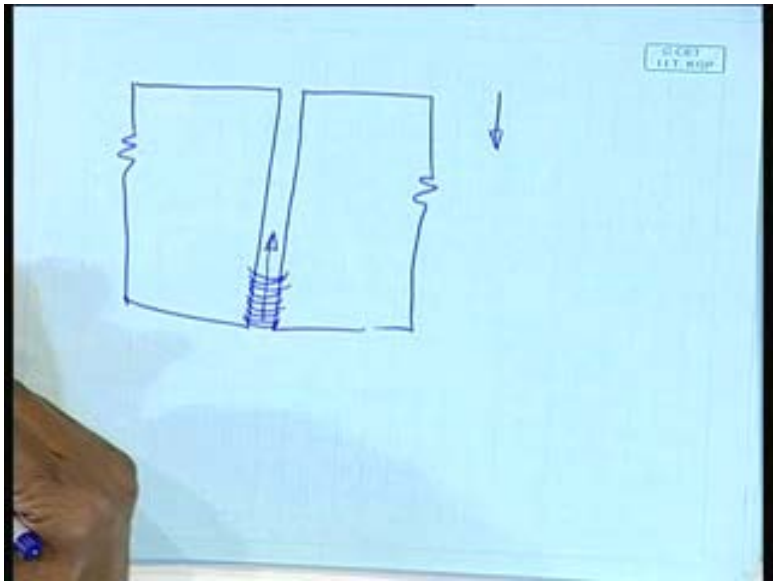

Suppose, a vertical up welding you are doing means, you have suppose two plates. They are sending vertically, and you are doing the welding up. So, what is happening is

gradually, I am progressing like this. So, this solidified metal itself is providing me support. The metal is getting transferred. It is getting a support, the solidified metal below, but when I am coming down from top, that is a different thing. The molten metal will tend to fall off because there is no support below.

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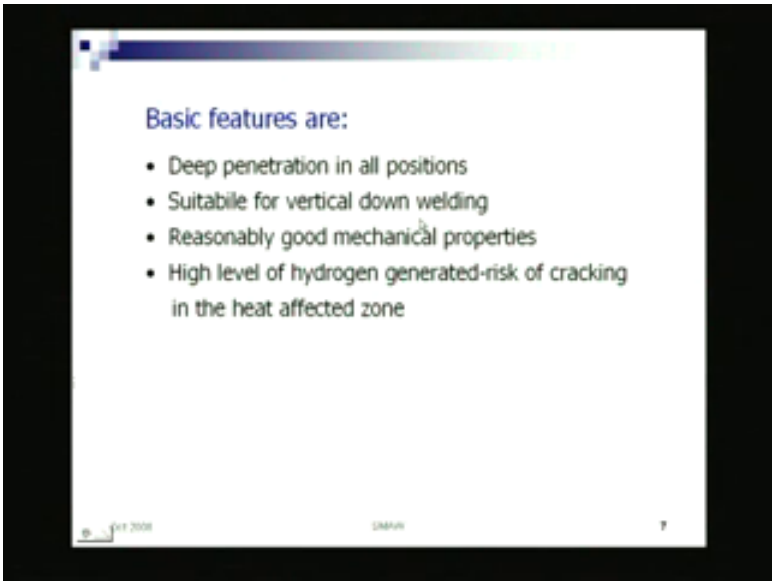

So, here it says, that it is also suitable for vertical down welding because there can be situation, where I cannot go from bottom up. I have to come from top to bottom. So, it is not only has a good penetrating power in all position welding, also suitable for vertical down welding, reasonably good mechanical properties. That means, well the weld property, what we get I mean, these are all you know qualitative reasonable good, we are saying high level.

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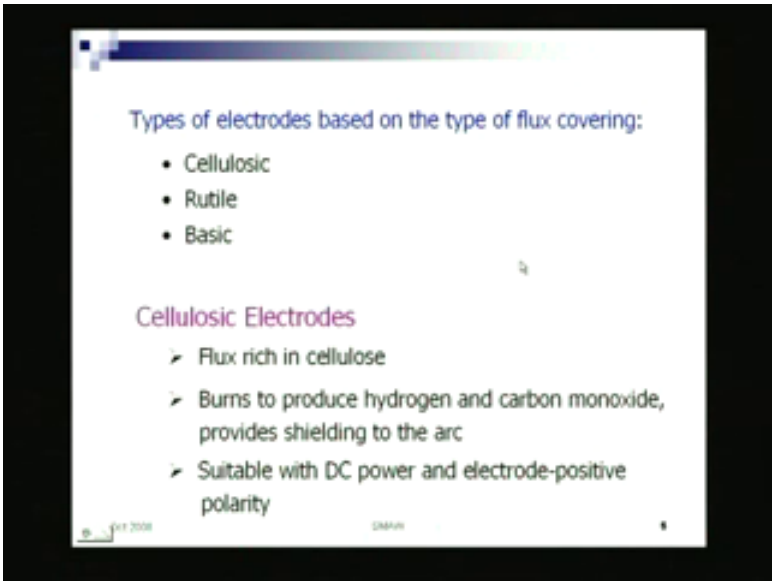

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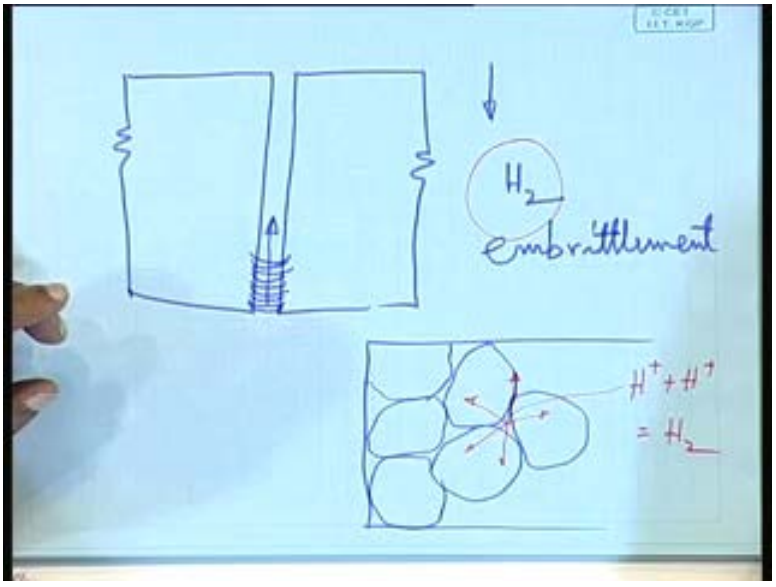

Well, here another aspect as you can see that the gases it was generating is hydrogen and carbon monoxide. Now, hydrogen is one aspect which causes a phenomenon called hydrogen embrittlement. Hydrogen embrittlement means that means, as if hydrogen is causing is rendering the material brittle. Suppose, steel you are welding, and what actually happens is the hydrogen embrittlement effect of that is after the welding is over. Then, you will find some portion, it is cracked.

Now, why cracked as if the metal become brittle? So, it cracked under the stress, thermal stress. So, it has been found that what happens is during welding, this hydrogen in the atomic state, it gets defused in the micro structure. I would not say, it is getting trapped in the molten metal. No, that is a different issue. It is going in the micro structure in the atomic state and then, as the temperature is coming down, those atomic hydrogen's, they are coming to form the hydrogen molecules. It is not 2 molecules combining, it is to form helium. It is hydrogen atoms combing to form hydrogen molecule.

Now, what happens, 2 atoms and 1 molecule, there is a difference of volume. So, that exerts a tremendous force that exerts a tremendous force. So, schematically, it could be seen something like this. Suppose, these are your crystals, or you see under high magnification the micro structure, these are the grains. Now, these locations if we think, they are the kind of voids where in your hydrogen has gone in.

So, they join together to from hydrogen molecules. So, thereby they exerted tremendous force in all direction, and that force, if the micro structure of the metal cannot sustain the crack, will form a crack, will form that means, a crack initiation will take place. Then, under the action of the external forces, all forces due to thermal stresses because we have welded. It got heated up and getting cool down, so kind of thermal stresses are forming.

So, under the action of that, that crack further gets propagates and a failure takes place. That means, a long crack forms. So, this phenomenon is referred to as hydrogen embrittlement. So, the culprit is hydrogen. So, to avoid hydrogen embrittlement, you will have to avoid hydrogen in the welding source, in the welding place, in the weld metal, but unfortunately, here the flux cover is that it evolves hydrogen.

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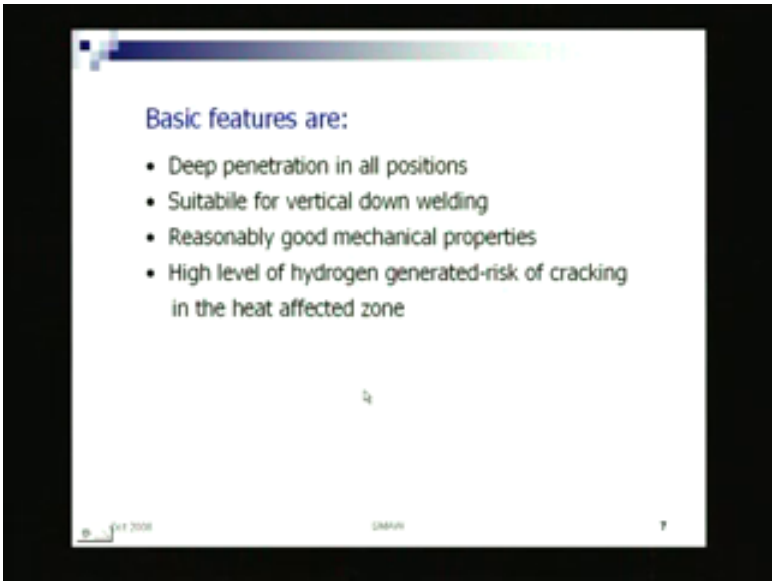

So, this is one of the bad aspects of cellulose electrode. That means high level of hydrogen generated risk. High level of hydrogen is generated. That risk of cracking in the heat affected zone increases. Well, heat affected zone means that is the weaker zone. So, possibility of cracking developing there it increases. So, that is one of the bad aspects of cellulosic electrode.

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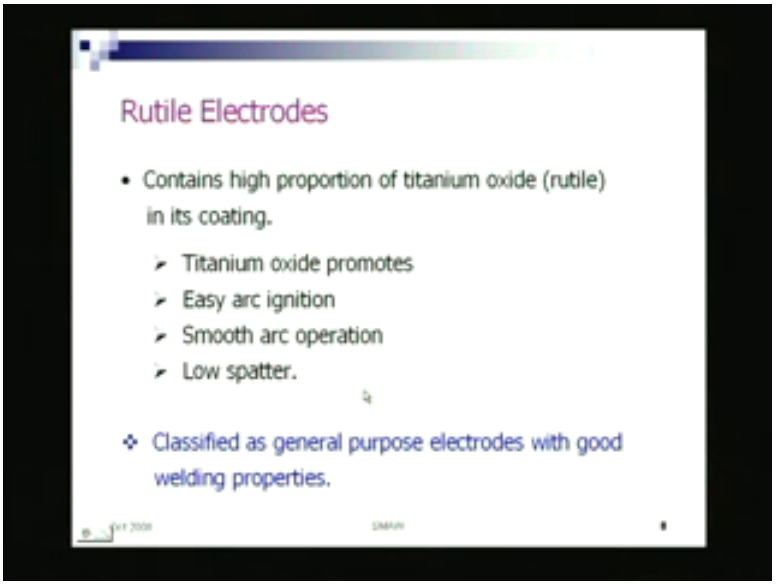

Then, you come to the rutile electrode. What are the rutile electrodes? This contains the high proposition of titanium dioxide. The titanium dioxide is another name of rutile. That is how the name rutile electrode. So, the flux contains a high level of titanium dioxide.

This titanium oxide promotes, well this promotes easy ignition, smooth arc operation, and low spatter, all that we saw in cellulosic electrode also. Similar things we find that titanium dioxide is actually a titanium dioxide. Anyway, it does not matter. Titanium oxide or titanium dioxide, that promotes easy arc ignition by virtue of platinum oxide being there in that flux coating. Arc ignition is there. It leads to smooth arc operation means, stable arc and also low spatter.

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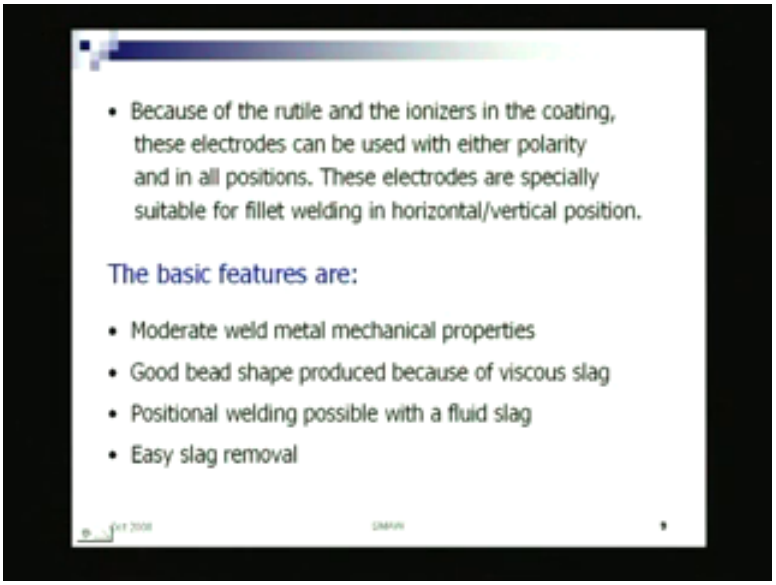

So, classified as general purpose electrode with good welding properties. So, this is a rutile electrode are the so-called general purpose electrodes means, in a wider range of field, wider range of requirement purpose, it can be used. Because of the rutile and the ionizers in the coating, some ionizers are added in the coating. This electrode can be used with either polarity, and in all position. There you talked about cellulosic electrode, positive polarity, and preferably DC power source. There was a limitation DC power source with electrode positive.

Here, you find that it can be used with either polarity, and in all positions and the moment, it becomes either polarity, means I can even use AC source. That means, for general purpose welding, you can use that, but definitely for ship building or where you

want a superior quality of a weld property etcetera, naturally you have to, well I mean you will have to look for whether this gives you the required mechanical properties or not.

So, these electrodes are specially suitable for fillet welding in horizontal and vertical positions. So, the basic features of this to summarize, it has the moderate weld metal mechanical properties. As you can see, these are more generalized kind of electrode which can be used over a general wider range in all positions, everywhere, but it gives moderate kind of mechanical properties. As you can note of high order good bead shape produces because of viscous slag. Bead shape is, bead profile is good because you have the slag viscous, means it forms a viscous covering over the molten metal. There by you get a good bead profile, positional welding possible with fluid slag like substantially fluid enough.

All position welding is possible. Slag removal is also easy. This also is an important aspect. After the welding, the slag has to be removed. It should be able to remove easily. If it cannot remove easily, there will be a possibility of small pieces of slag remaining on the weld bead, and if you have to do multi-run welding, that remains in trapped because that will not float up a solidified slag. So, slag removal is also another, which should be looking to while designing the coating.

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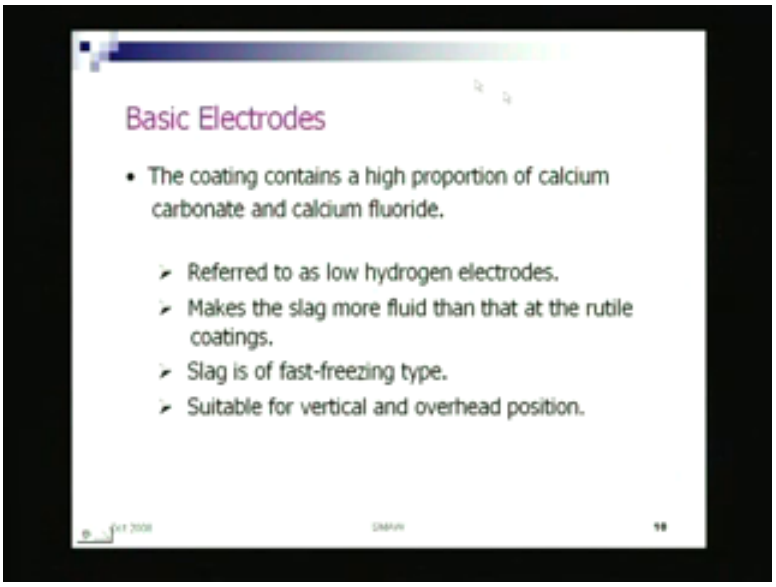

Then, basic electrodes, these contains high proportion of calcium carbonate and calcium fluoride. These are referred to as low hydrogen electrodes. We had just now talked about hydrogen embrittlement. So, these are low hydrogen electrodes, means here you can achieve an environment where hydrogen evolution is minimal.

So, it makes the slag more fluid than that in case of rutile coating. It is more fluidic slag. Slag is a fast freezing type, suitable for vertical and overhead position. Why? This slag gets frozen and that provides support to the molten metal also, so it is more suitable for vertical overhead position.

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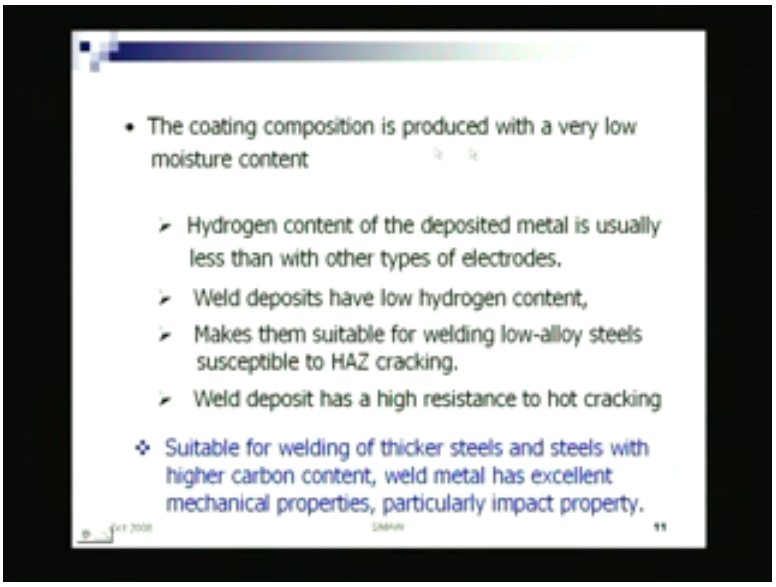

The coating composition is produced with a very low moisture content. Why? Because they are low hydrogen electrodes, so will have to control the moisture content also, otherwise it may generate the hydrogen in cellulosic. The composition is such, that the hydrogen evolution was there, but here the question of hydrogen is not there. It comes from the atmosphere moisture if the coating has observed. So, we will have to see the hydrogen content of the deposited metal is usually less than with other type of electrodes. Weld deposits have hydrogen content. It makes them suitable for welding low-alloy steels susceptible to hydrogen heat affective zone cracking.

So, these basic electrodes are suitable for welding of low-alloy steels, means higher tensile strength steels. If you have to weld, you will have to use basic electrodes for high tensile steels because low alloy steels are generally high tensile steels. It has a high

resistance to hot cracking. Hot cracking means because of the thermal stress, the crack takes place. Steel, when the weld metal is in hot condition, suitable for welding of thicker steels, and steels with higher carbon content, the moment it has higher carbon content, the possibility of harder phase not in side phase formation increases. We have talked about this.

So, weld metal has excellent mechanical property in the rutile. We have seen moderate in cellulosic. We have said good here. We say excellent mechanical property, particularly impact property. So, in ship building, that says that in ship building applications, it is preferable to use wherever manual welding use a basic electrode.

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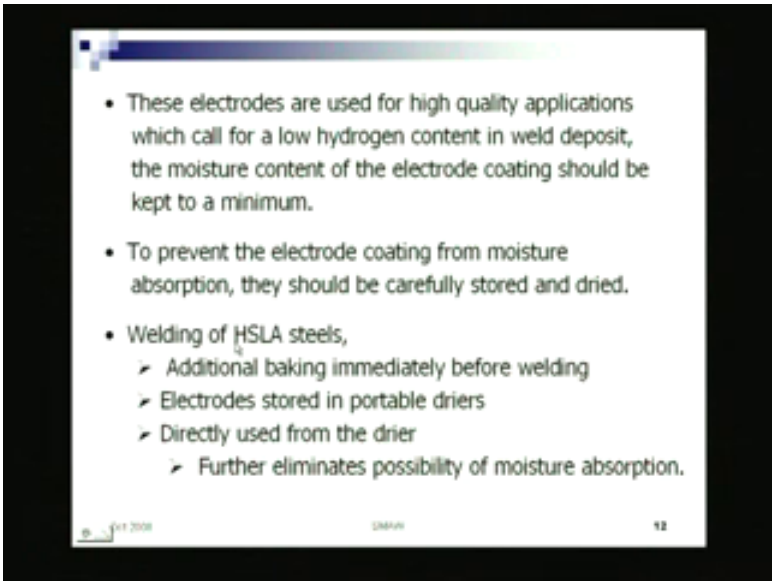

So, these electrodes are used for high quality applications, which calls for low hydrogen content to keep, prevent electrode coating from moisture absorption. They are to be properly stored and dried. Like for example, when you are welding HSLA steel, HSLA is high strength low alloy steels. They are additional baking immediately before welding is needed. Immediately before welding, you bake it.

So, what is done is, they directly use from a drier. The welder carries a portable drier, a kind of a flux as if which is electrically heated. You keep the electrodes. Inside is something like, if have seen Ramayana and all that, Rama used to carry the arrow, the container of the arrow something similar, exactly similar. That kind of a thing, instead of an arrow, you keep the electrodes. They are that is the electrically connected, such that

you continuously keep them at an elevated temperature and just take out the hot electrode, and start welding, such that you minimize the possibility of the moisture absorption.

Baking is that, baking is heating of a certain item at a certain temperature level for certain time, that is baking. You hold that thing at a certain temperature level, so it is to drive out the moisture.

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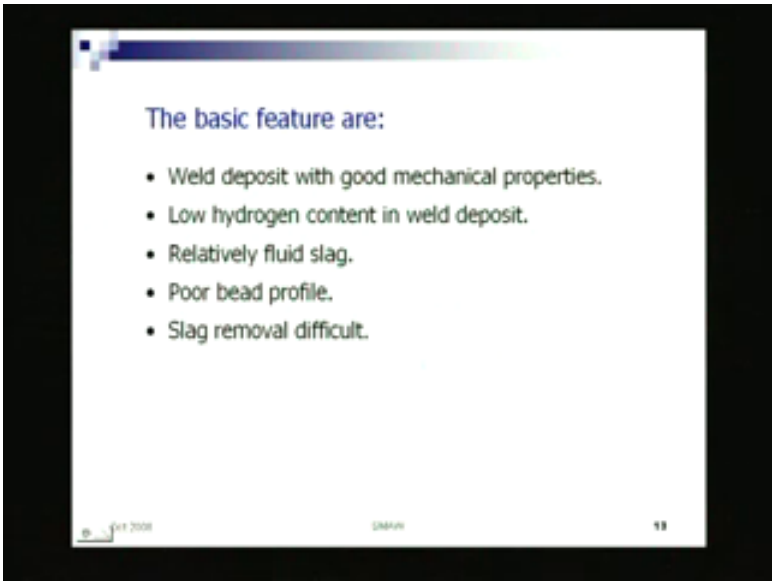

So, the basic feature are the weld deposit with good mechanical properties, low hydrogen content in weld deposit, relatively fluid slag, but you see everything is good, but this is bad poor bead profile. Generally, the bead profile becomes somewhat more rough. Slag removal is difficult. They are two negative aspects. So, that that is all about the shielded metal arc welding. Next, we will look into gas metal arc welding.

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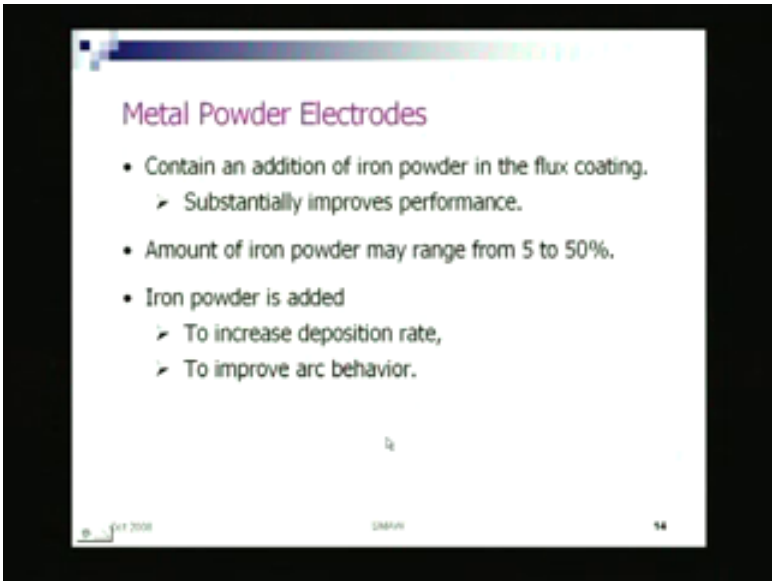

Well, there is something about metal powder electrode. That also may be, we will talk it about in the next class.