Marine Construction & Welding
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Module No. #01
Lecture No. # 32
Submerged Arc Welding

Well, continuing with this type of methods of welding, now, we will talk about submerged arc welding.

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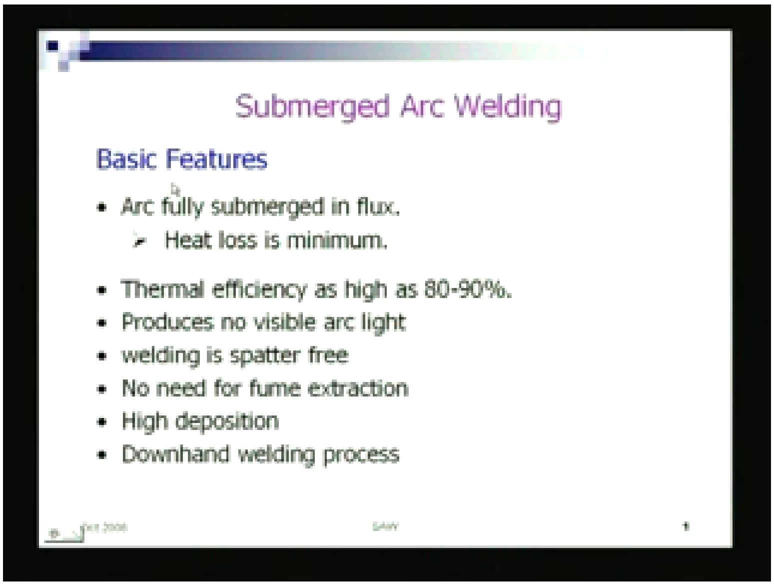

As you can see, submerged arc welding, also referred to as SAW, in simple also is referred to as SAW - Submerged Arc Welding. Well, just by the way, I mean submerged arc welding does not mean anything to do with under water welding; it has nothing to do with under water welding. This term submerged means the arc is submerged; note the entire welding process is submerged. When the entire welding is done, submerged in water, that, that is what is under water welding.

So, here, the welding is done above water. It has nothing to do with under water welding; only, the arc, molten pool - these are submerged in flux; that is how the name submerged arc. Previously, all the welding processes, till now we have seen, in all the processes, the arc is kind of exposed; it is not submerged. If at all it is submerged, it is submerged in gaseous medium.

So, it was visible always in all the previous welding processes one will have to use proper productive means in the eyes such that you do not affect your eyes because that is a very intense light source. A welding arc is a terribly intense light source. If you look at that, eyes will get damaged severely. Here, in this submerged arc welding, you do not see the arc because the arc is submerged in a pool of flux and there is a fundamental difference in this method. So, as we see that, what are its basic features?

First and foremost, as I see that, it is fully submerged in flux; thereby, what you get immediately? The immediate benefit is, heat loss is minimum.

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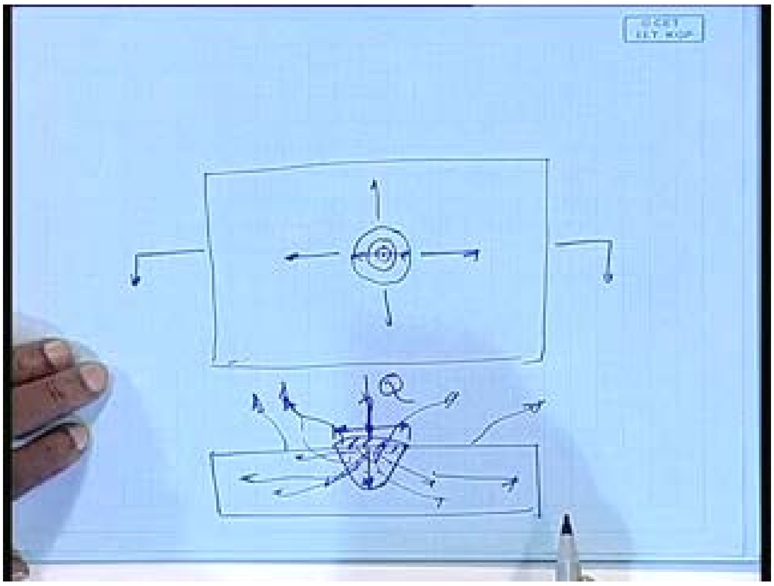

Heat loss is minimum. Like I had been just showing here by these arrows, these are basically radiation loss, convection loss. Whatever heat is coming in from the arc, part of the heat is getting conducted in the plate, thereby, your fusion is taking place and rest of the heat is getting lost by conduction. Some of the heat is getting lost through radiation, convection from the plate surface, from the molten pool surface.

Whereas here, in this case, that does not happen because it is all covered by a shield of flux and that flux, being an insulating kind of medium, means not a conducting medium, its thermal conductivity is very low. So, heat loss is minimized; that is one of the biggest benefit.

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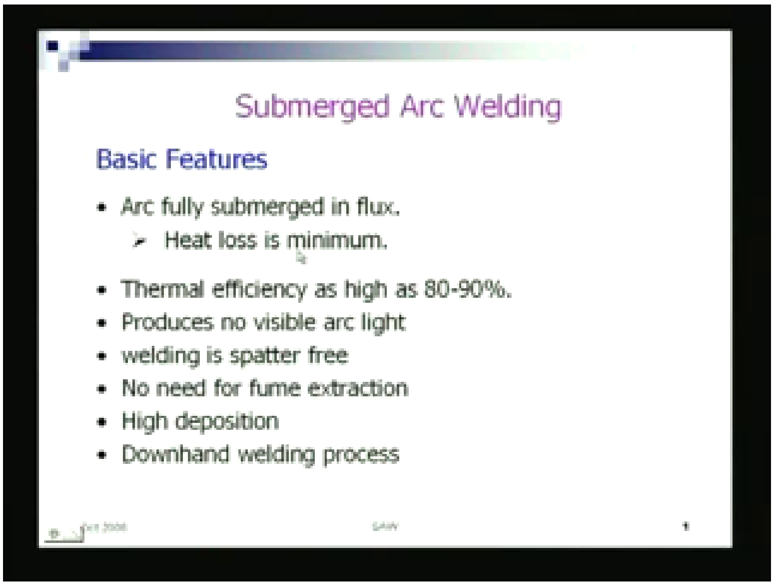

Another benefit obviously is to the welder; means that you do not see the arc; so chances of damaging your eyes are very is not there.

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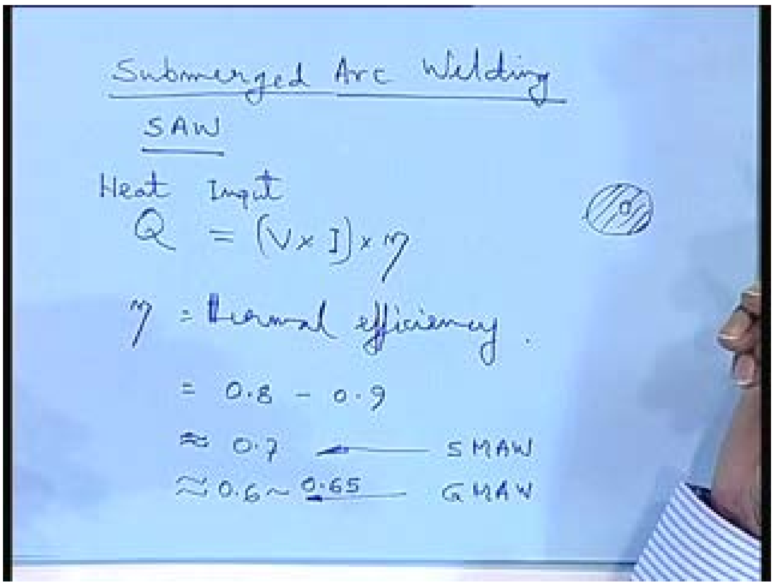

Thermal efficiency is as high as 80 to 90 percent. What is this thermal efficiency? It is you see when we talk about the welding heat, in welding, there is something called heat input, that how much heat were is going in the plate. That is given by Q. As I said, this is

V into I right, but the actual heat input is multiplied by some eta; that eta is the so called thermal efficiency of the process.

What is that? This is actually the heat which is… this determines the how much heat is actually going into the plate and how much is getting lost. So, eta for submerged arc welding, as here we have mentioned, is around 0.8 to 0.9 for submerged arc. Similarly, say for manual metal arc welding, it is of the order of well around 0.7 shielded metal arc welding.

Tell me, how much do you think it should be for gas metal arc welding? Why so less - 0.5? Well, tell me whether it will be more than 0.9 or less than 0.7, or will be in between? Why should it be in between, not less, or why it should not be more?

Well, straight away, cannot be more because here, we have seen that it is a process where I am saying, the heat loss is minimum, the arc is properly covered, and there, the heat loss is maximum because I am injecting a gas. You see, in shielded metal arc welding, the gas is generated by burning the flux. So, that kinetic energy of the flow of gas is not that high; the flux burns, gas is found and that gas is giving the shielding to the to the arc in manual or shielded metal arc welding. But in gas metal arc welding, I am pumping in gas. So, gas by force is going and going away. So, it is by convection, it will takeout lot of heat. So, heat loss is more. So, it is not that low as 0.5, but it is of the order of 0.6 to 0.65.

So, gas metal arc welding, there is a lot of heat loss because this is important; why important? because that much of thermal energy because I am burning the same amount of energy, but, utilization is less 30 to 35, 40 to 35 percent is going off, whereas the heat energy utilization is much better; 10 to 20 percent is only lost. Anyway, so this it has a produces no visible arc light.

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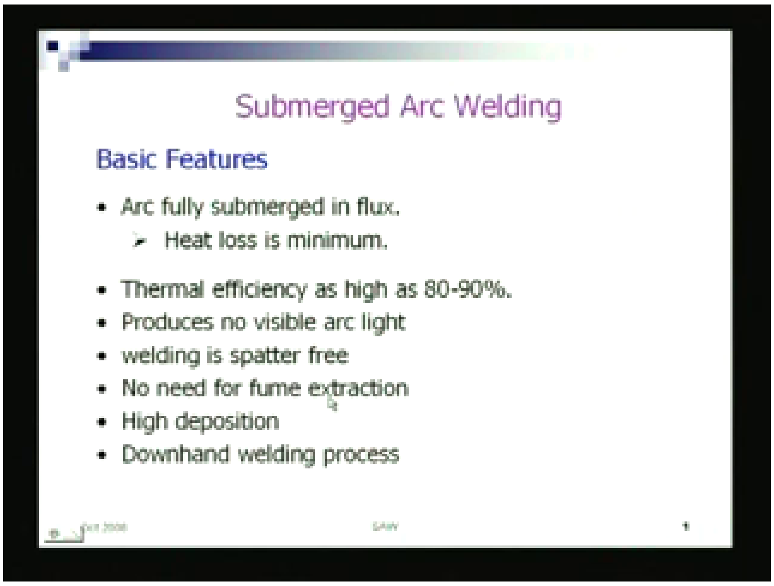

As I was saying, that is also one plus point of this submerged arc welding. It is very welder friendly; hardly any fumes; no need for fume extraction, as you can see.

In shielded metal arc welding, that shielding, that what you call, coating material over the electrode is so designed that it will produce a gas; it will produce a fume. So, you will have to have a fume extraction method as well. because that Otherwise, it will be hazardous for the operator. So, here, you do not need such any such thing because hardly any fumes is generated because we do not intend to generate any fume. So, the flux is also accordingly prepared that it produces minimal gas.

One can have a high deposition welding. Why? because this process is essentially automated process. And being automated process, I can give higher heat, higher current I can use. Once higher current, we can go for a high deposition process, and it is another feature - it is always a down hand welding process; means, it can weld only down arc; not those positional welding of vertical or over.

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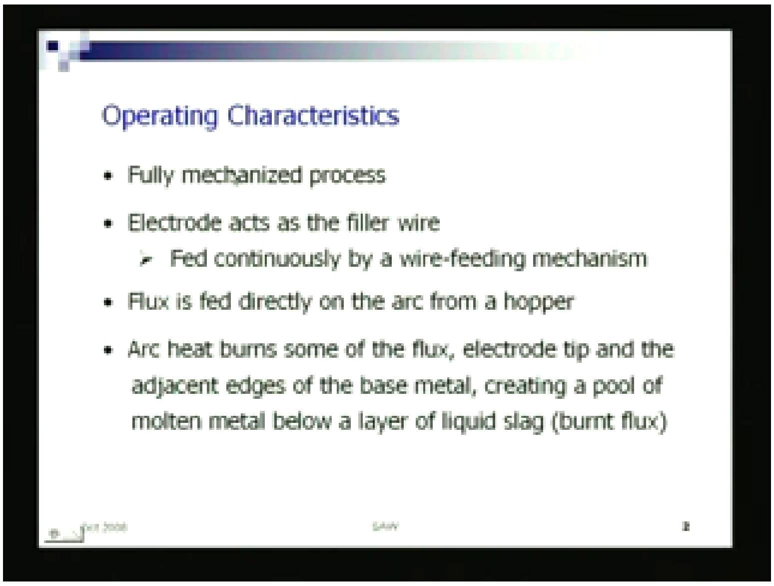

What are the operating characteristics? It is a fully mechanized process. Here also, the electrode acts as the filler wire, unlike arc welding like SMAW or GMAW. It is also the electrode; that itself is the filler wire; it is fed continuously by some feeder mechanism, like you have in GMAW.

Flux is fed directly on the arc from a hopper. From a hopper, the arc comes. This arc heat burns some of the flux. The electrode tip and the adjacent edges of the base metal are melted. Right It burns some of the flux. They will tip and the base metal, are melted; It creates a pool of molten metal just below the arc, which is covered by a liquid slag. That liquid slag is nothing but the burnt flux.

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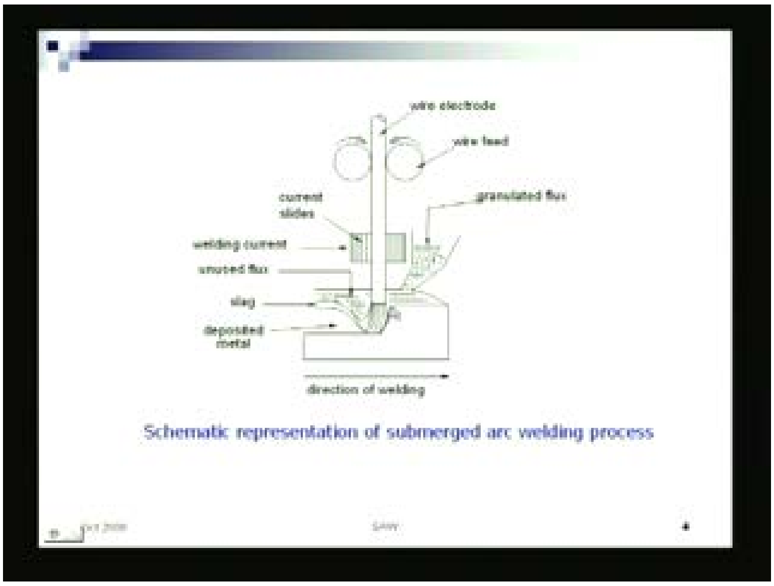

So, let us schematically, it is it one can show it like. This this is your electrode. Here, you have the arc. So, what I have shown? Of course, the diagram is not very perfect; this is the well this is the plate top surface. So, I have shown a very small arc length. This arc length is essentially to the bottom of the weld pool, as if this is my bottom of the weld pool, this is the deposited metal going (Refer Slide Time: 10:13).

Anyway, this is a continuous feeding mechanism. Power is fed here, through this bush. There is a hopper of width from where you put the granulated flux. That flux burns and forms a layer of slag. So, that arc heat will burn the flux; that burnt flux is slag. Now, that slag is in molten condition; it is a lighter than the weld metal. So, it will float up and provide a full protection from that Phosphoric Oxygen. And since the liquid metal is covered with a liquid, another liquid slag, you get a very smooth surface of the weld bead; the top surface of the weld bead becomes very smooth. So, that is also a very good property aspect of this process.

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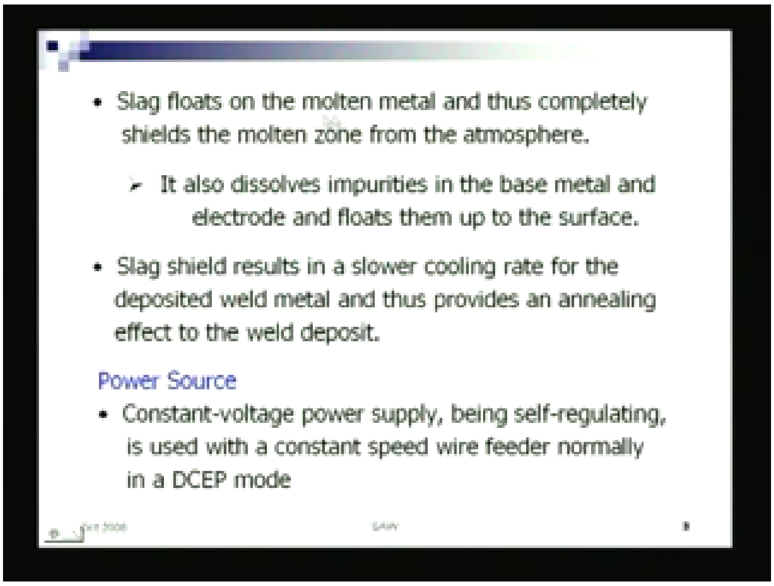

Slag floats on the molten metal and thus completely shields the molten zone from atmosphere as well as it dissolves impurities of the base metal and the electrode, and floats them on the surface. So, any impurity there, also get removed kind of gets removed. This slag shield results in a slower cooling rate; that is another aspect because when you are gradually welding it, so what is happening is, how the process goes something like this.

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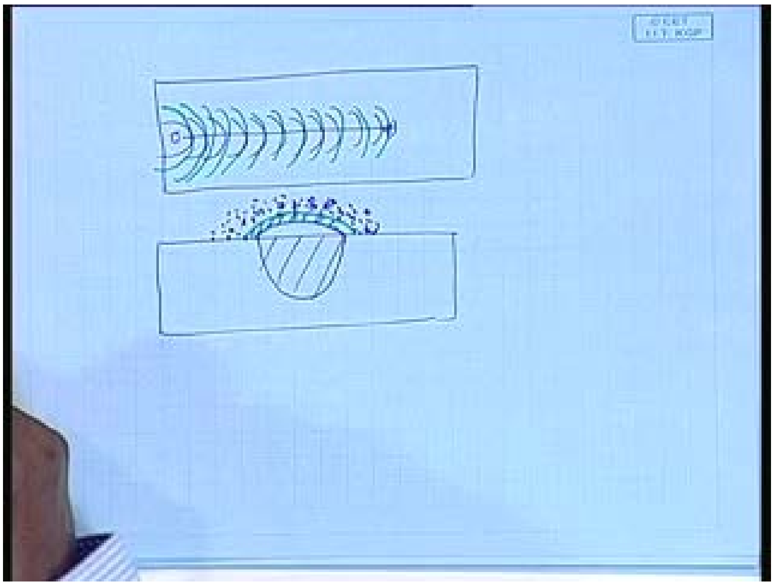

Suppose this is my plan view; the electrode is moving along this direction; so, the deposition is taking place. right And if I see in the cross section, suppose this is my fusion has taken place, this is the metal deposition at the top, and then you will have over that, a layer of slag like this. This is the slag; means, as you are going past these green lines, I am referring to the solidified slag. It is solidified. And then, on top of that, you will have these granules (Refer Slide Time: 12:40).

Because as you have seen, this is continuously being fed - those granules of flux, and now, some flux is burnt; not the entire amount; some of it is burnt. I mean when that arc hits, a part of it will burn and we will form the slag; that slag will float up on the above the molten metal and will form a solid crust. That will be again shielded with a un-burnt, unused flux. Later, you can recycle it, so, there but what is happening in the process? You have a total shielding of the molten metal; of the deposited metal, rather.

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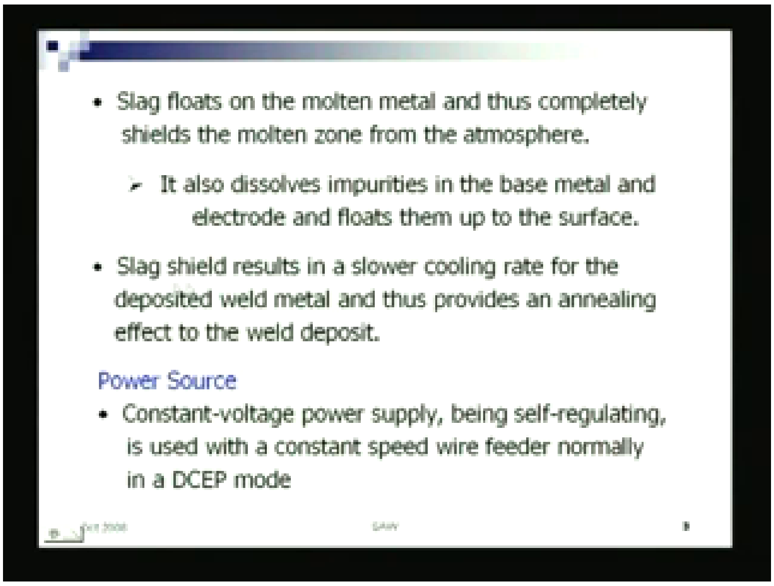

The molten metal eventually becomes the deposited metal, solidified metal. right So, the heat loss from here is minimal. It is having an insulated, a kind of shielding; is it not? So, this slag shields, along with the flux, in fact slower the cooling rate of the deposited metal. The cooling rate is reduced, and once the cooling rate is reduced, it provides an annealing effect of the weld deposit.

What will that annealing effect will help in? It will help in increasing ductility; chances of crack formation are less, lowered because welding is a thermal process. So, that there will be thermal stresses. So, if the material is ductile, then there are chances of cracks forming because of stresses, will be reduced.

So, that is the general feature of this process. What are the power sources used here? Generally, a constant voltage power supply is used with electrode positive. Why constant voltage because it is a constant feeder mechanism. Electrode is fed continuously in automated fashion. So, I can keep the arc length constant.

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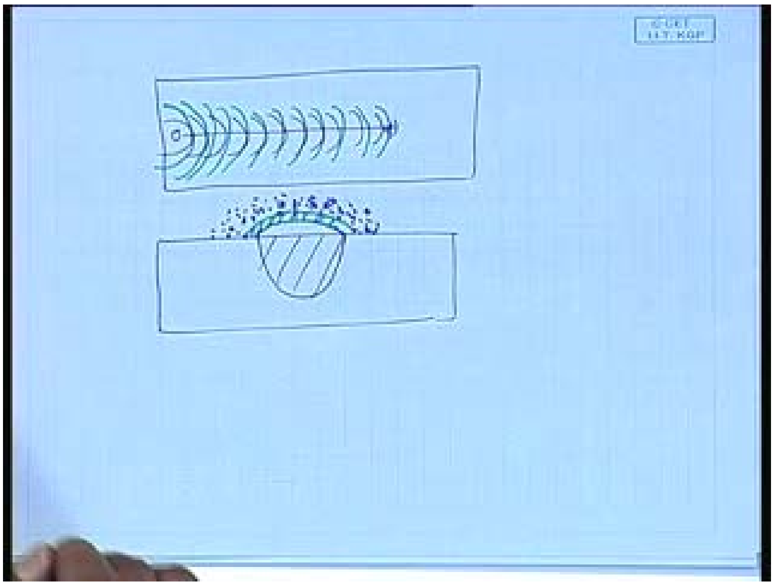

So, if that is so, then it is better to use constant voltage power supply and electrode positive mode. Why? I want to deposit more metal because increasing penetration; by making DCEN, I can increase the penetration, but that, I do by increasing current.

And keeping the electrode positive, I melt more electrodes, and thereby increase the deposition rate because if I have to increase deposition rate, I have to increase welding speed for increase in productivity. So, it operates its c v or constant voltage power supply with DCEP mode.

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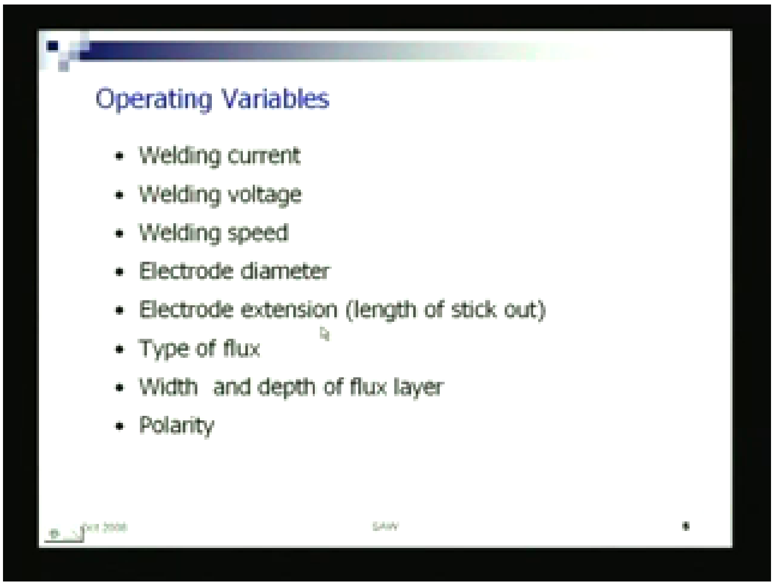

This is a schematic representation. Operating variables are again, see: the current, voltage, speed, electrode diameter, electrode extension, length of the electrode.

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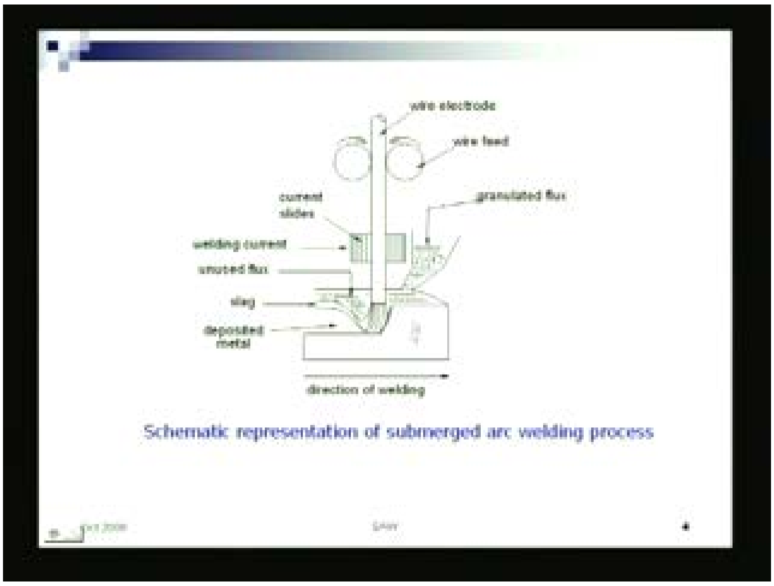

We have talked about it - type of flux width and depth of flux layer. That is also important; too deep a flux layer again is not good; that means, here, that hopper height. How? If the hopper height is much above, then too much flux will fall.

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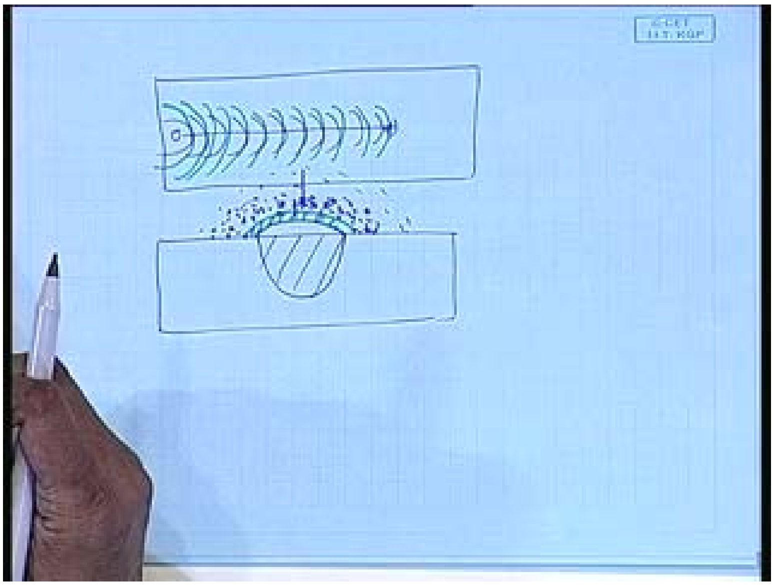

That means, say, if this flux layer is very huge (Refer Slide Time: 16:32); that is also not good because that will add weight to the molten metal. So, there will be contamination of the flux. Is it not? Because, the molten slag should float up, but if it is loaded with un-burnt flux too much, it will add pressure. So, the molten slag will not be able to come up. That will give rise to slag inclusion, a defect called slag inclusion, and then finally, polarity also is important because of that heat generation.

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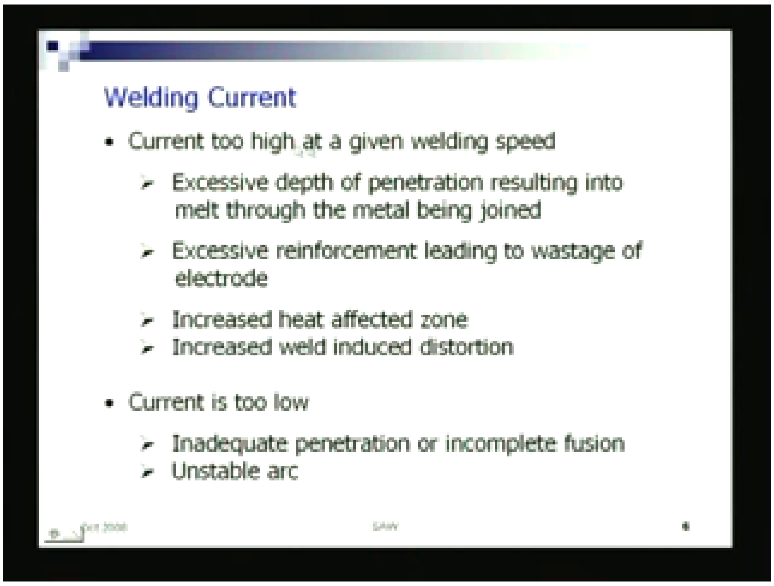

Here, you see the welding current is too high, then obviously excessive depth of penetration; too high a current will lead to excessive depth of penetration, excessive reinforcement leading to wastage of electrode either.

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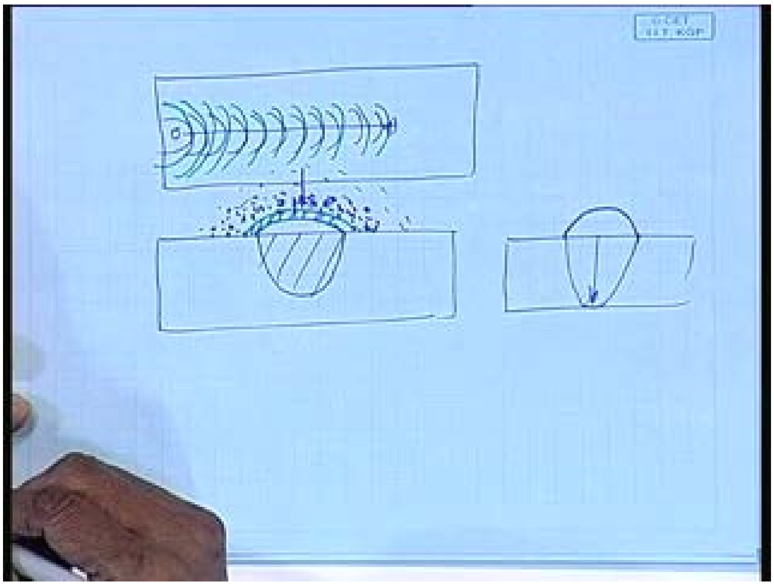

I mean high current will have a much bigger penetration. If the speed is low, then again have we will have too much of melting; both are not… I mean nothing excessive is desirable; that is the thing; these are only what we are trying to show here is, current too high means, we are taking all other parameters remaining constant; all other parameters remaining constant, If you increase the current too high, then you will have all these effects: increased heat affected zone, increased weld distortion. Whereas the current, if it is too low, obviously, inadequate or incomplete fusion; also unstable arc. That means arc going on and off, that is unstable; it is getting on, it is getting off.

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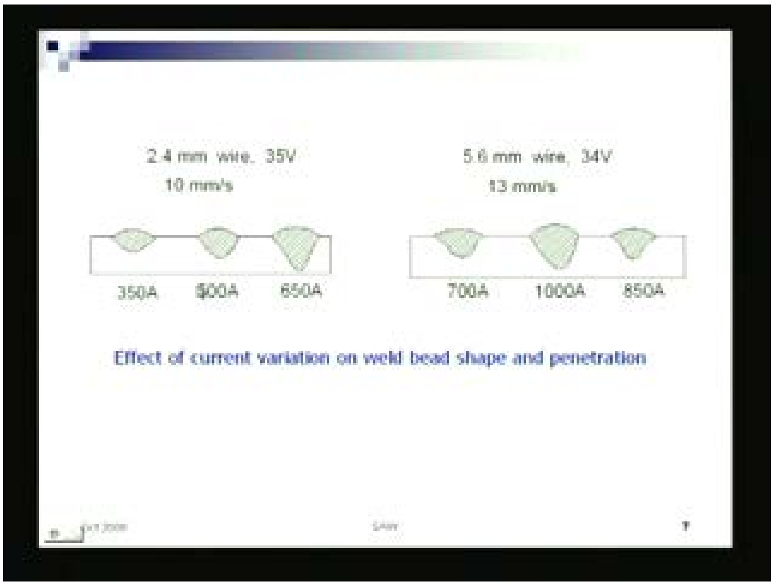

So, this is somewhat schematically, we can see that with this wire diameter, this speed, and this voltage, arc voltage for a lesser current. And as we increase the current,

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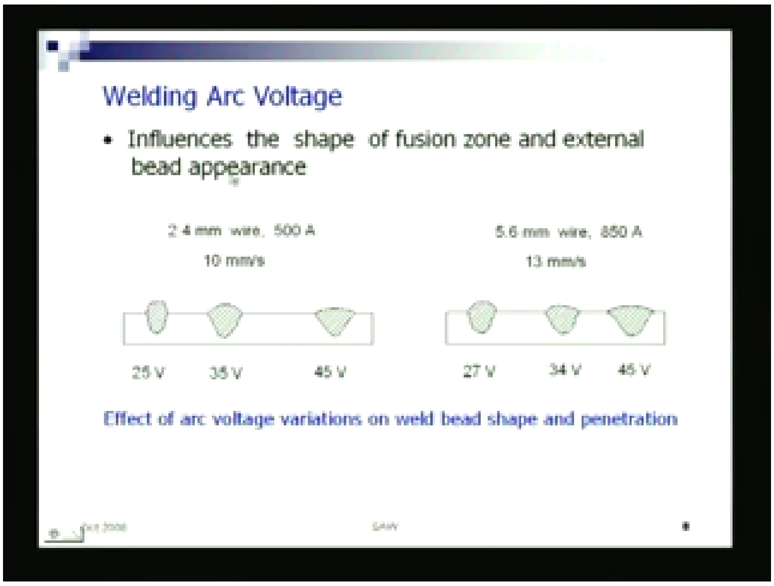

It is nothing but, that means increasing current keeping all other parameters constant, it has the primary effect on depth of fusion. So, if depth of fusion has to be certain depth of fusion has to be achieved, then you will have to change that current; either you will have to increase it or decrease it, or voltage influences the shape of fusion; primarily, the external bead appearance.

Right So, what do you see? If the voltage is low, you have a narrow bead; if the voltage is high, you have a wider bead, for all other parameters remaining constant, say, the diameter, ampere, speed, constant. So, less voltage - narrow; higher voltage - wider; depth of fusion - more or less same.

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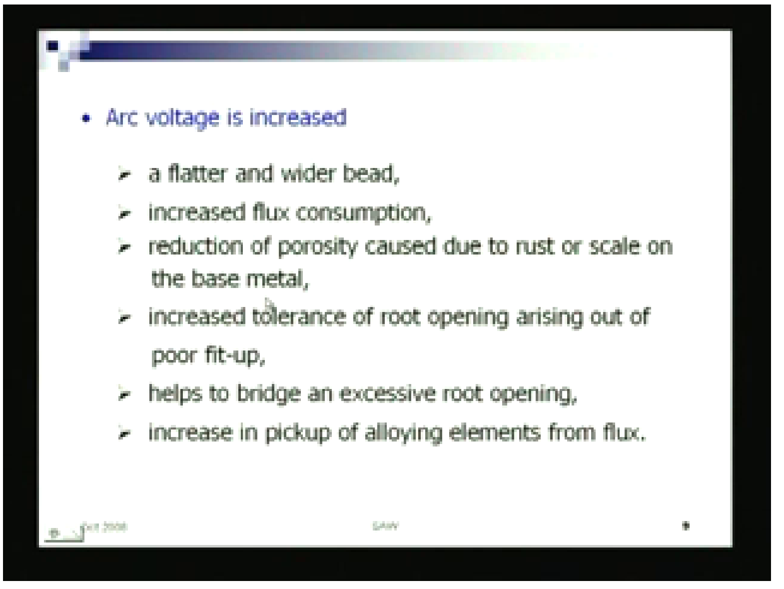

So, if arc voltage is increased, you have a flatter and wider bead. It will have increased flux consumption. That is also another important… because wider bead means more flux is getting burnt.

Reduction of porosity caused due to rust or scale on the base metal. This is the advantage; increased tolerance of root opening; that is one thing. When we do welding, if the root opening is not very uniform, then a wider bead is preferable because where the gap is more, I cover that. So, when it gives as a higher tolerance level of the root opening, that is what helps to bridge an excessive root opening.

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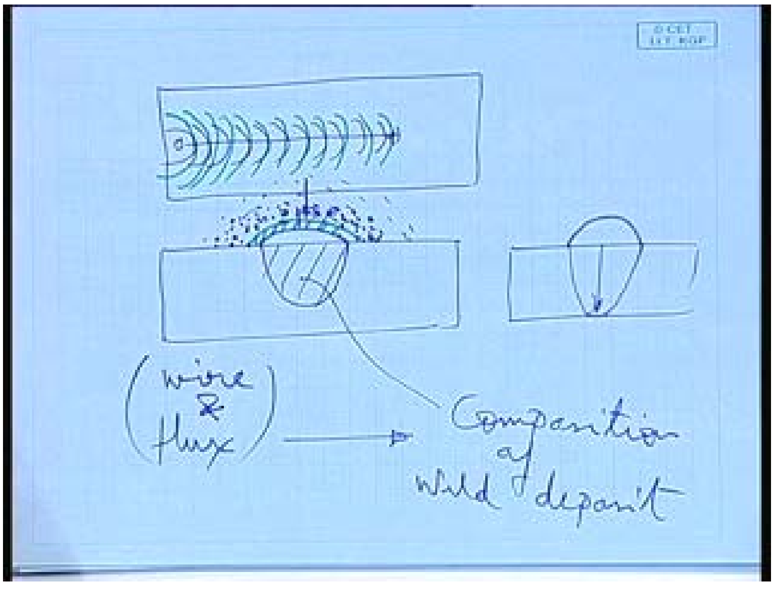

Increase in pickup of alloying elements from flux: This is one aspect in submerged arc welding that that is not available in other process. Here, the composition of the weld deposit, this composition of the weld deposit can also be altered Right by choosing a suitable flux. By choosing a suitable flux, that means a suitable wire flux combination; wire flux combination means wire is the electrode and the flux; particular wire flux combination. I can change the composition of the weld deposit.

There can be cases that you are welding a certain type of steel and you have very stringing requirement of the joint, welded joint, that it should have so much of tensile strength, so much of impact strength, and so on, so forth.

So, you may need in the process, you have such an alloying elements, more in this to achieve those desired properties, say, you want somewhat higher level of silicon. So, what you do? I choose a wire which has silicon; I choose a flux which also has a higher level of silicon such that in the process, some silicon from the flux will defuse in the molten metal. So, that is what is, pickup of alloying elements from flux.

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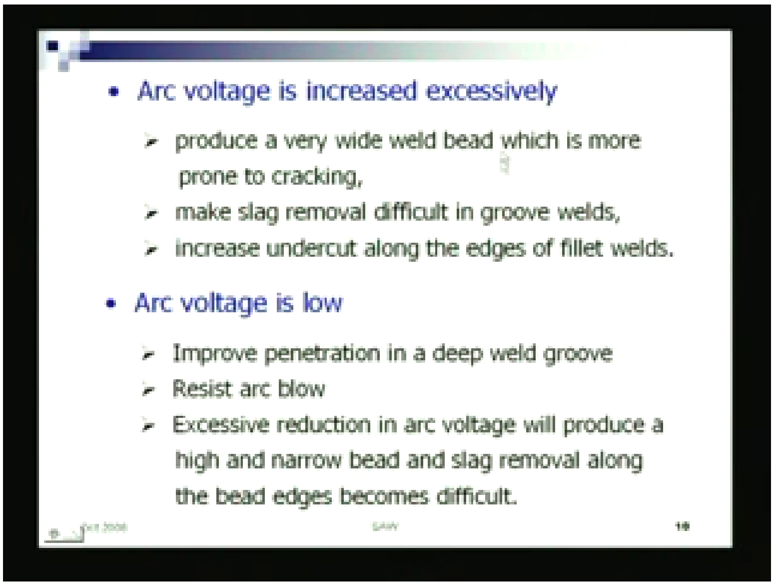

If arc voltage is increased excessively, increasing arc voltage excessively means what? Increasing the arc length; this becoming the distance between the electrode tip with the job is increasing.

So, what will happen? It will produce a wide weld bead. It may make slag removal difficult in grooved welds; means, in re-grooves, they are welding it. The slag may remain sticking to that; increase undercut along the edges. There is a defect called undercut; as we have seen, this undercut sump at the side, there will be a I mean lack of deposition at the side of the weld bead referred to as undercut (Refer Slide Time: 22:44). If the arc voltage is too low, too low means what? That the length, distance between the electrode tip and the job is too low. It gives improved penetration in a deep weld groove. It increases penetration; resist arc blow. What is arc blow? Arc blow is wondering of the arc; means, if the arc length is more; arc blow is essentially because what is that arc is a conducting medium. Right It is a kind of a conductor through which current is flowing. So, if a conductor is there through which a current is flowing, if I hold a magnet, this will get deflected. If I put in a magnetic field, that conductor will try to deflect. If the conductor is a steady copper wire or a steel wire, it will not move, but if a thin copper wire, it will deflect. Same thing, that plasma column is totally flexible; it does not have any rigidity. And now, when you are welding, you are connecting the positive terminal at one point, I mean the ground terminal at one point and the electrode there. So, it causes a magnetic field because high current is used 800 ampere, 1000 ampere. So, in that magnetic field, that the arc column may deflect; longer it is chance of deflection is more. That is called arc blow.

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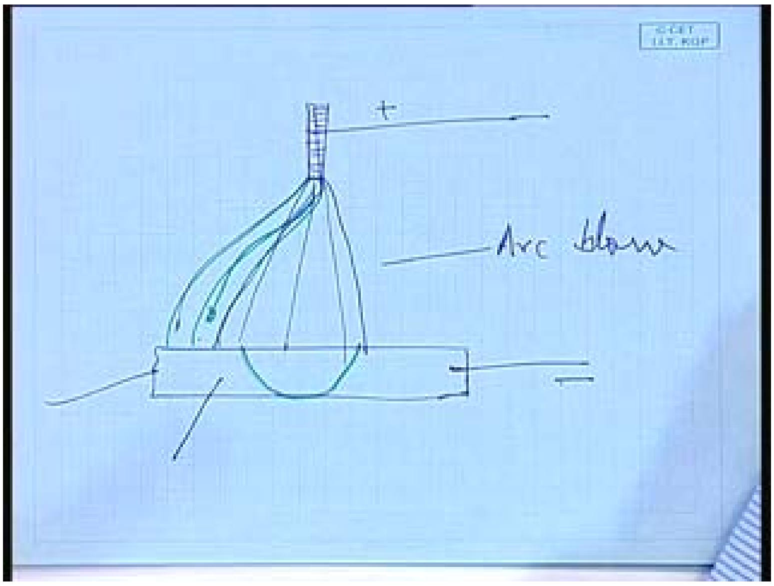

If the arc column deflects, means, suppose, say purposely I am drawing a much… I mean well this is my electrode, a very as if long this thing in the magnetic field. It may get deflected like this. The whole arc column may get deflected. Now, if the arc column gets deflected, the metal transfer also will get deflected. So, you will have to deposit here; it will not be deposited there properly. So, metal deposition becomes erratic. So, this phenomenon is called arc blow. Then, what you will have to do is, you will have to recheck that, where the other I mean I mean the terminal… suppose you have the electrode positive here (Refer Slide Time: 25:18), here is the negative terminal connected; so, you will have to connect at several places, I mean such that undesirable magnetic field is not formed. Anyway, but if the arc length is smaller, then chances of arc blow reduces; that is what it is saying, its raised arc blow.

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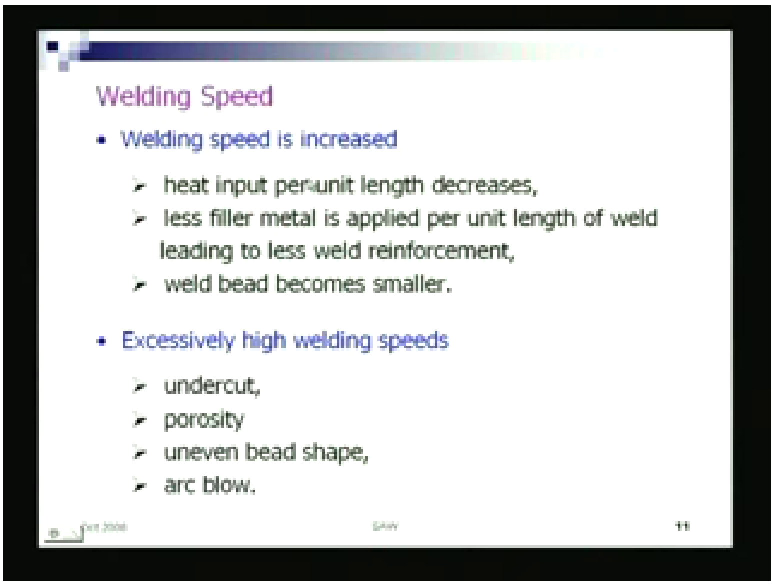

Now, excessive reduction in arc voltage will produce a high and narrow bead, a high and narrow bead as slag removal may become difficult.

Welding speed: As speed is increased, heat input per unit length increases sorry decreases. What is that? What does that mean?

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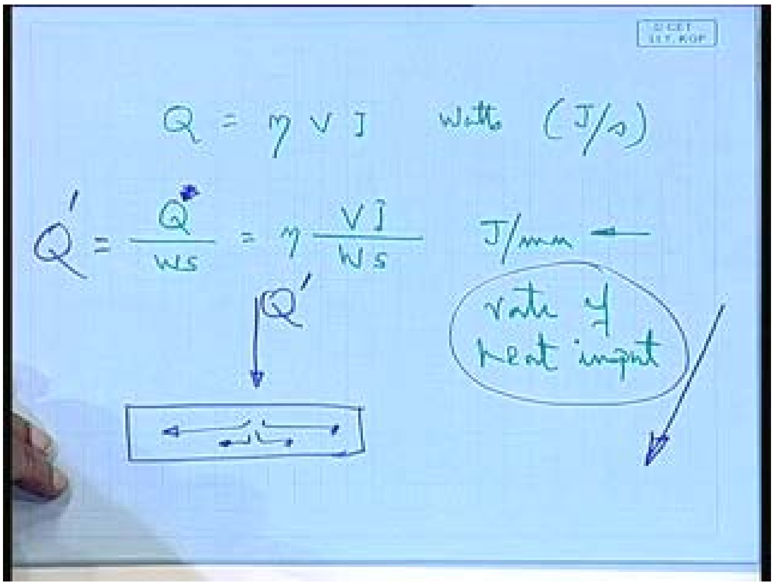

We have seen I have talked about the heat input. I said that is V into I. What is this? This is so many watts or joule per second; so many joules per second. And now, if I divide this by speed, welding speed, then then it becomes rate of heat input. So, if speed is millimeter per second, then it becomes joules per millimeter. So, this is referred to as rate of heat input.

That means, at what rate heat is going in the plate? How many joules per millimeter I am putting? Because we are interested on what amount of heat is going in the plate at what rate? Rate means not in terms of time, but in terms of the length of the weld because we are interested in the total amount of heat going in the plate, not at what per second type, but at what per millimeter type or per meter, whatever way. So, rate of heat input is an important sort of a parameter or aspect in welding, which determines if how much heat per millimeter is going in. If that is going more, what does that mean?

That means this is my Q dash. There are so many joules per millimeter. So much of joule per millimeter is going; if more is going in means, more heat conduction. If it is less, then it will be less; simple. More joule per millimeter means it has to get dissipated; isn't it? That means more heat, more part of the plate will get heated up, and more part of the plate getting heated up means we have higher stresses, higher deformations, higher heat affected zone, higher melting zone, starting from, the fusion zone will be more heat affected zone will be more. Your more heat is going in. So, more thermal stresses, more deformations.

So, another aspect is that if I increase the speed, this decreases - the rate of heat input decreases. So, if I want to reduce distortion, first and foremost is to see that, how can I implement a welding process which has a low rate of heat input. That rate of heat input has to be reduced.

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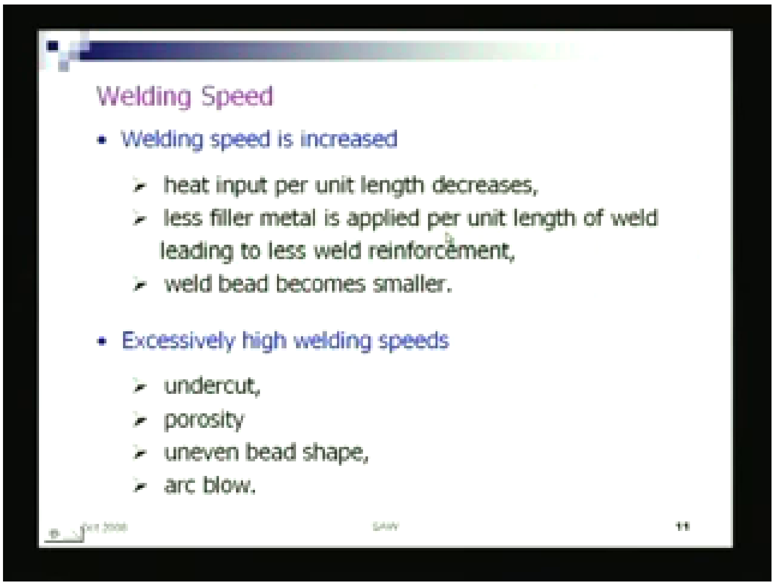

So, that is what, we see here that heat input per unit length decreases; rate of heat input is decreased as we increase the welding speed. So, welding speed not only benefits from the point of view of productivity, but also it will benefit from the point of view of quality of the final structure; your residual stresses will be less; your distortions will be less. Less filler metal is applied per unit length of weld leading to less weld reinforcement.

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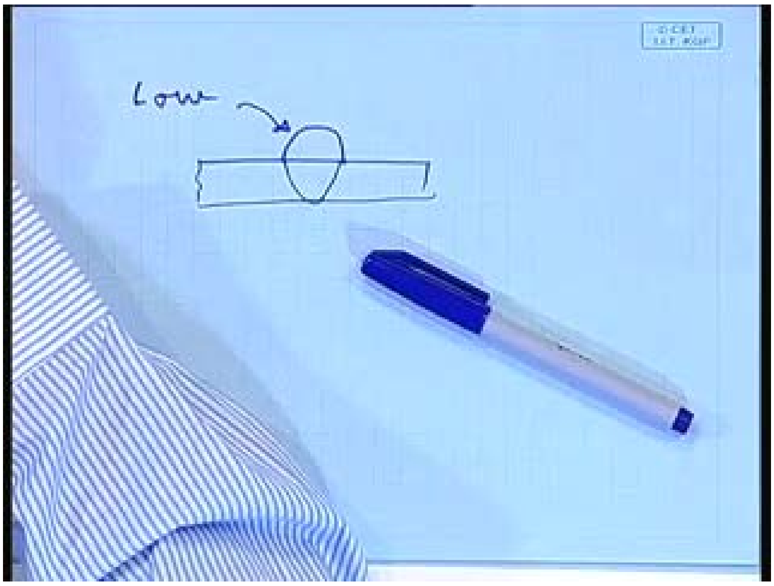

If the welding speed is low If the welding speed is low, then it may lead to over deposition. This is what is over deposition if the welding speed is low. If the speed is low, then obviously more metal is getting melted and getting deposited to place.

Well, if the speed is now excessively increased and I want to have more productivity and increase, then that will lead to undercut lead to porosity, uneven bead shape arc blow.

Why porosity because the gases will not be able to come out. It will not have enough time to come out. Before that, the metal will freeze. I am moving the heat source faster, means what? The cooling effect is faster; the molten metal will get solidified before it can the gases can float out. So, may lead to porosity.

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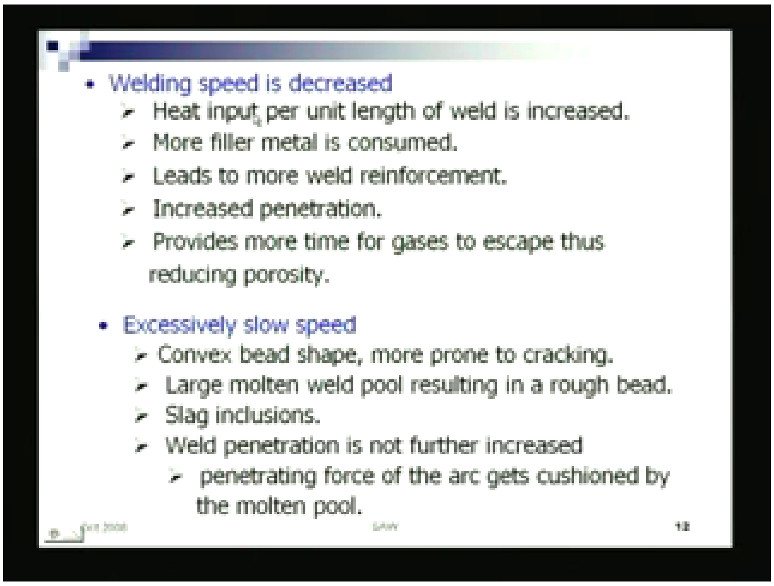

Now, the reverse; if we decrease the speed, then heat input per unit length is increased; that is the first foremost effect. More filler metal is consumed leads to more weld reinforcement, increased penetration, but not much. It is not a direct effect because the same phenomena will work; the same cushioning effect of the molten metal will work, but provides more time for gases to escape, thus reducing porosity. Chances of porosity will be much less; further, if we reduce a very convex bead shape, more prone to cracking; large molten weld pool resulting in rough bead; slag inclusion might take place; weld penetration is not further increased as we have talked about; penetrating force of the arc gets cushioned by the molten pool.

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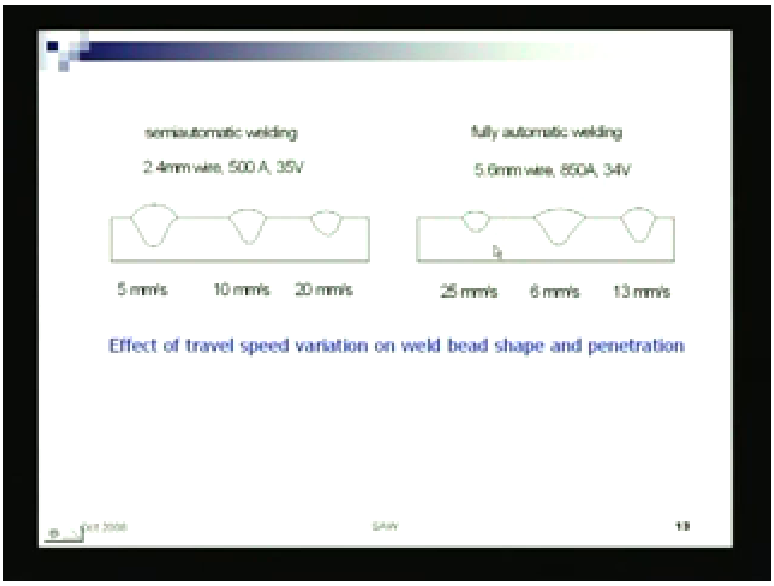

So, this schematically tries to show that, say, here is the 25 millimeter per second, 13, 6, I mean how, for the same, parameter is changing like that depth just by doubling this. Here, it was 13; it is 6, as if the speed is half. So, what has happened? It has become wider, but depth has not increased.

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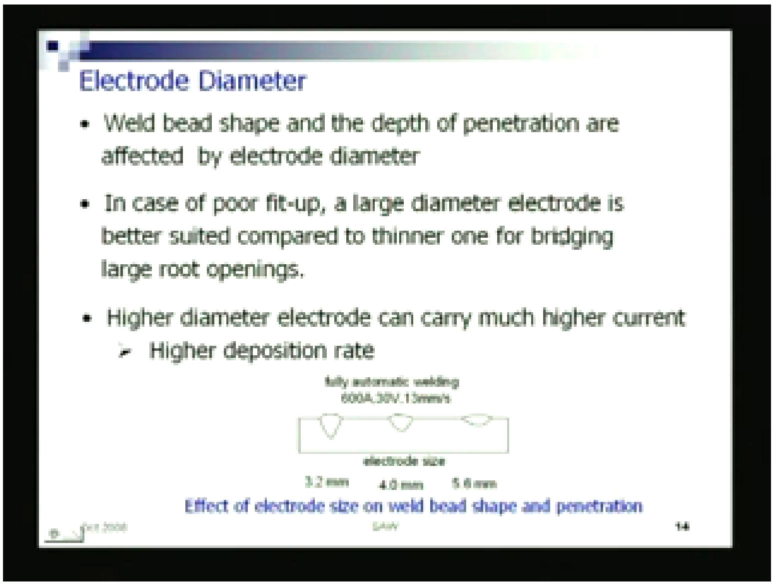

Electrode Diameter: Here, it is a high deposition welding. So, one can use much higher di-electrode. As you can see, you can go even 5.6 millimeter di-electrode, more thicker electrode. So, you can deposit much more metal. So, what do you see? That weld bead shape and the depth of penetration, are affected by electrode diameter; whatever electrode diameter is used. Higher diameter electrode can carry much higher current; so, thereby high deposition rate.

Now, in this, what we have tried to show? That other parameters keeping constant because when I use a high diameter electrode, essentially, I should increase the current also; because otherwise there is no… I mean the purpose is not served. it Once the electrode dia is high, it is capable of carrying more current. If that is so, I increase the current, thereby melt more metal; I deposit more metal by per unit time and thereby increase the welding speed; I increase my productivity.

Now, if I do not do that, I keep all parameters same and just increase, change the electrode dia, then the effect is this. Whole idea of showing this diagram is that with lesser dia, you have a higher current density. Lesser dia electrode, current density is higher. For the same current condition, say here, this example is for 600 ampere current, 30 volts and 13 millimeter per second speed with 3.2 dia, I find more penetration; with much higher dia, I find less penetration, but wider bead; what does that mean? That means a higher current density increases penetration; a higher current density increases penetration.

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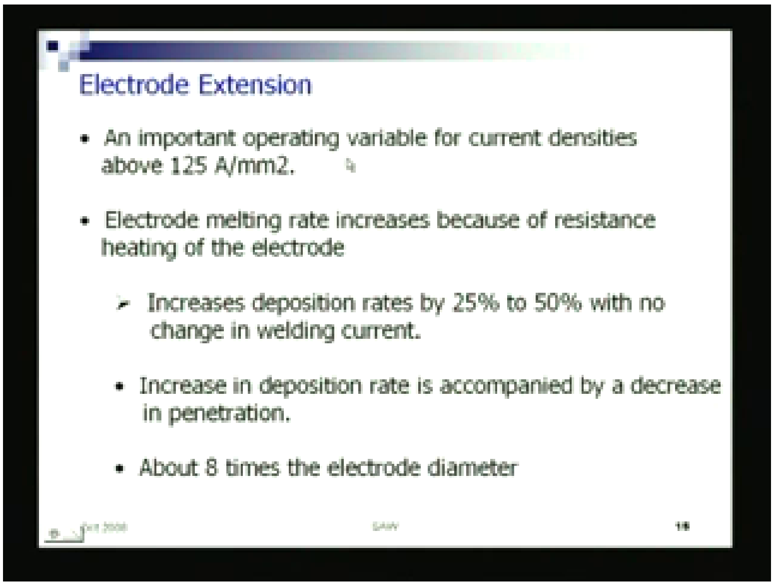

Electrode extension: That is nothing but we have talked about it. It is the length of the electrode beyond the from where the power is; from the tip to the point, from where it takes power.

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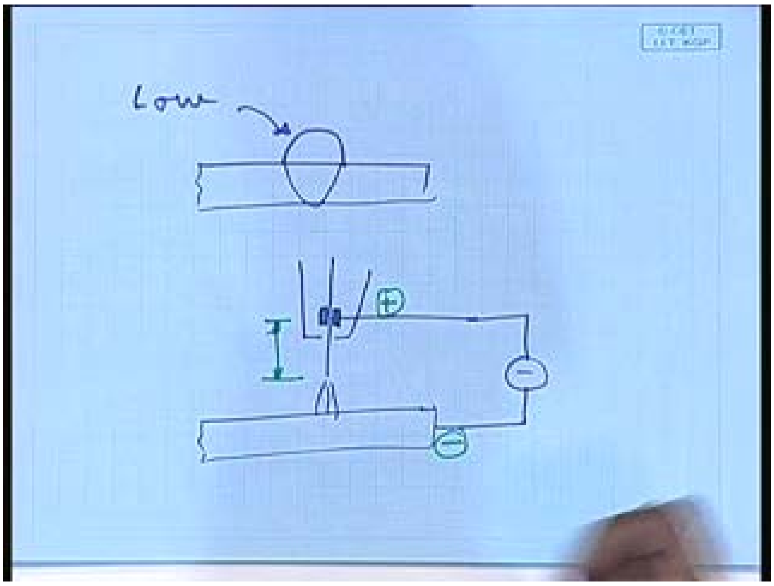

Schematically, it can be seen like this. Here, you have the shoes where the power is fed; that means the electrode passes through this shoe where the power is fed and this is my electrode tip. So, this distance is the electrode extension. This distance is the electrode extension (Refer Slide Time: 35:44). So, if the electrode extension is high, then we tend to, then then it results in higher deposition rate. For same, all other parameters remaining constant, I just increase the electrode extension; my deposition rate increases. Why? Because of the additional joule heating of that, but this will be predominant or it will have more significant effect provided the current density is above 125 ampere per millimeter square.

That means at lower current level, increasing electrode extension does not make much difference, but if my current density is above 125 ampere per millimeter square, then even deposition rates can be increased as high as 50 percent with no change in welding current. Deposition will increase without changing the welding current; that means what? Essentially, penetration will decrease; more heat will be generated in the electrode; more power will be consumed in the electrode; there by, more electrodes melting will take place.

Electrode extension for all practical purpose: Essentially thumb rule is eight times the electrode diameter; say, the electrode you are using is 4 millimeter dia electrode; it generally keeps 30 to 35 millimeter long. This extension, because it goes on increasing, it does not mean that this 50 percent will go to 80 percent. No, because then what happens? The electrode length becomes too long; It becomes unstable. The electrode is getting heated up; so, it will not come straight. It will get unstable; again, the same thing; it does not mean that the deposition rate will go on increasing with increase in weld total length; No. Up to a certain point it will work; then again, whole process will become unstable.

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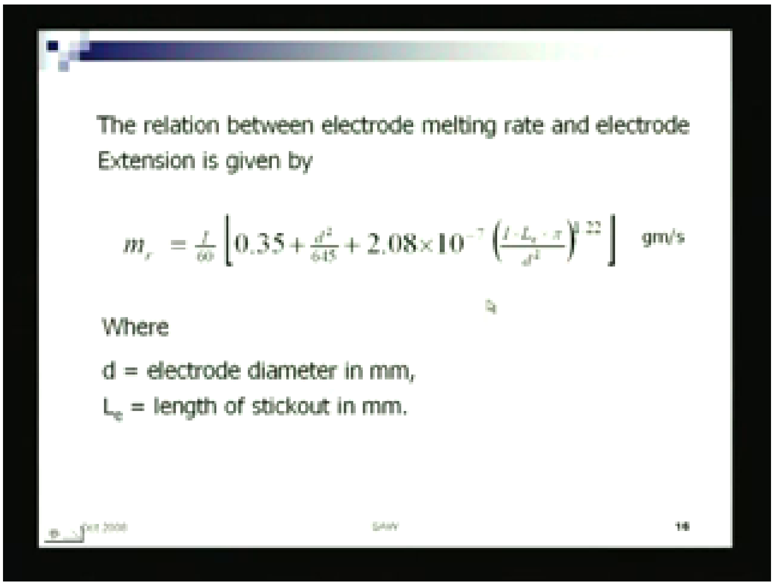

Here is some relation through which, one can find out approximately, this is some empirical relations. So, this is, how much should be the electrode melting rate for a given electrode extension; how the electrode extension is changing?

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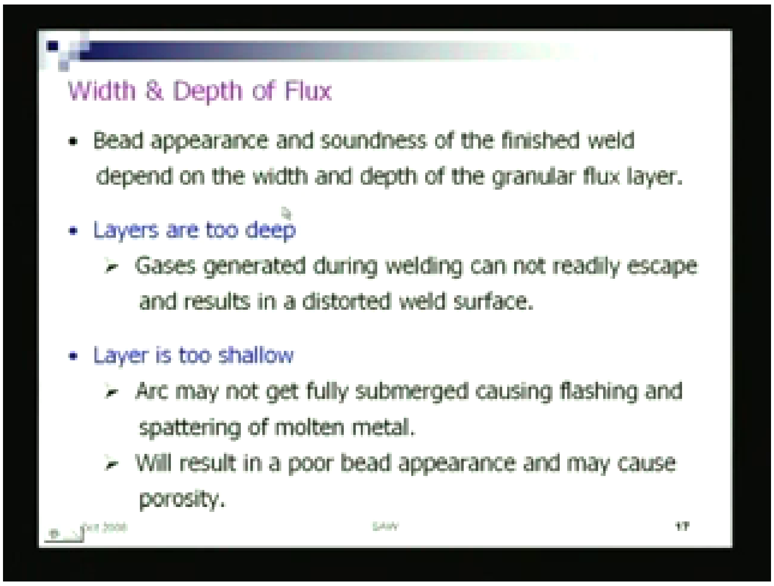

Width and depth of flux: Bead appearance and soundness of the finished weld also depends on this - width and depth. If the layer is too deep, too much of flux has been poured. That hopper position is not fixed properly, not aligned properly; too much of flux is pouring over weld deposit. Then, gases generated during welding cannot readily escape and also the molten slag will be under pressure of the weight acting over it by the flux. So, you will get a distorted weld surface too shallow - if the flux is too shallow, then what will it have? Sparking will be visible. That means proper shielding will not be there. You will be able to see sparks in between. That means the layer is too shallow; that means too little flux is coming. The flux chamber is jammed or whatever, also will result in a bead appearance, poor appearance.

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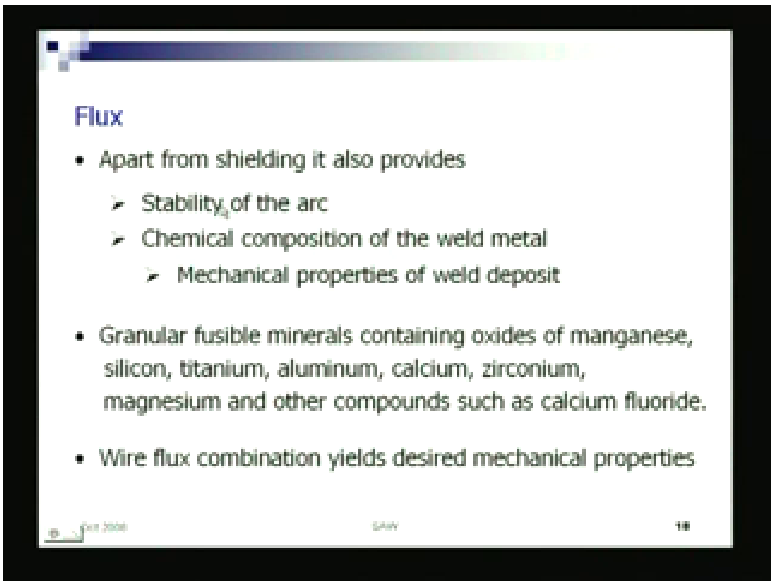

Now, the flux: The type of flux; what it does? Apart from shielding, it acts as stability of the arc. The chemical composition of the flux acts towards the mechanical properties of the deposit. This this flux is basically made up of oxides of Manganese, Silicon, Titanium, Aluminum - all those. It is essentially a mixture of all those oxides and then you have the so called wire flux composition; I mean for a certain welding of certain material, whatever mechanical properties are desired, use a suitable wire flux combination, as we have already talked about.

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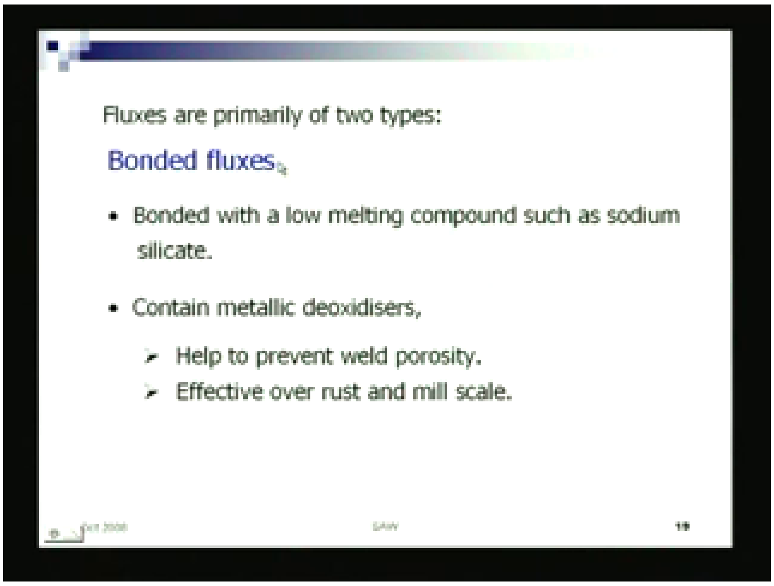

They are generally two types. This just we can go faster. There is a bonded flux, bonded with a low melting compound; as is a fused flux. This you can see later.

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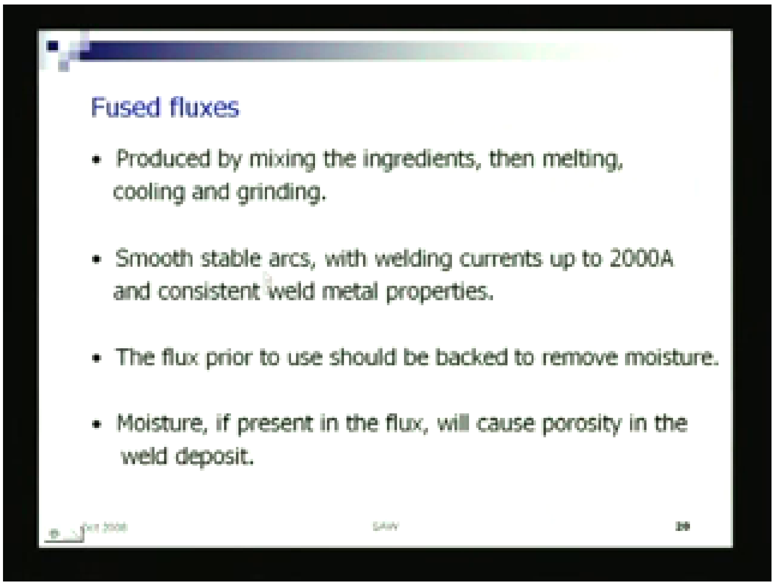

This fused flux they are they can be used for very high current operations; also gives a consistent weld metal property.

Another important aspect is the flux prior to use should be baked. This spelling is probably wrong; it is baked; the c is should not be there; should be baked to remove moisture because as you know, moisture should not be there in a weld environment because that will lead to Hydrogen embattlement. The hydrogen will go in the micro structure. So, moisture, if present in the flux will cause porosity in the weld deposit as well as the Hydrogen embattlement.

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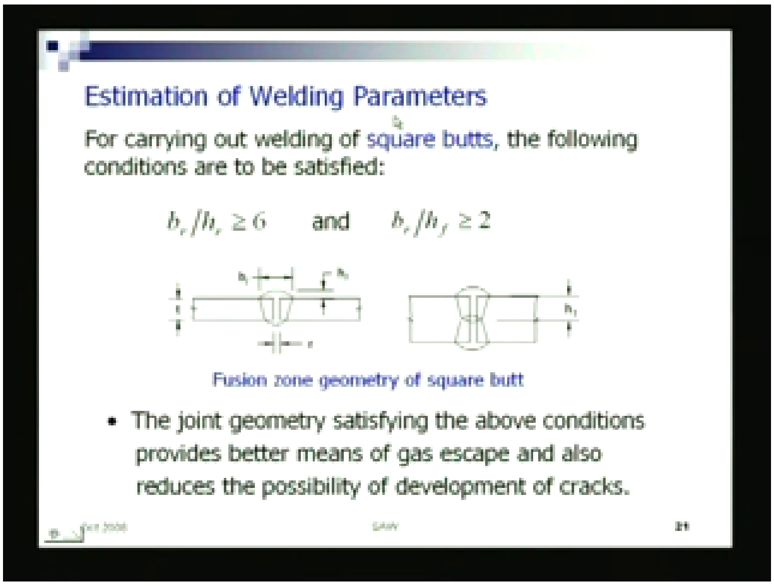

Here are some of the aspects of how to estimate the weld parameters.

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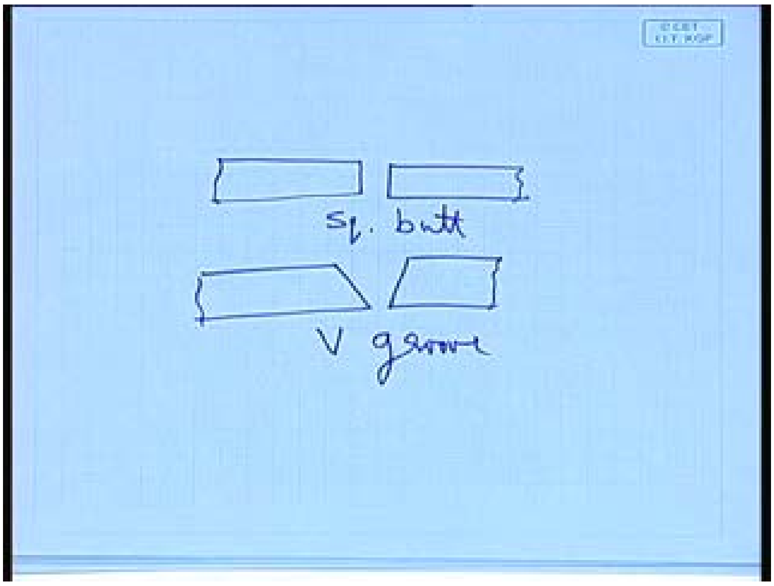

So, if it is a square butt, square butt means that two flat plates being welded having rectangular edges; this is what is referred to as square butt. When it is welded like this, then it is called V groove. This is square butt; this is V group; these are the edge preparations, where we have the edge preparations are done depending on requirement. So, generally, when welding is done, as you see, the breadth of the reinforcement to the depth of fusion, this ratio should be around greater than equal to 6. These are some of the thumb rules.

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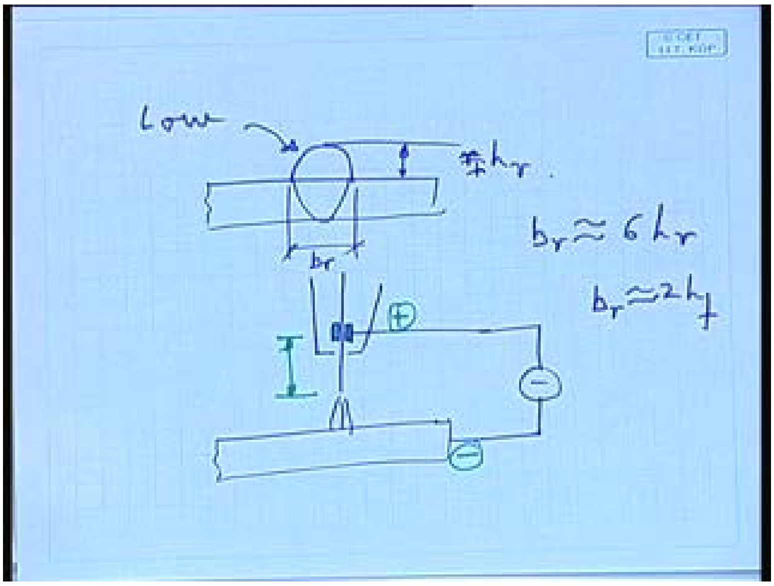

Breadth of the width of the fusion zone to the depth of fusion zone should be around 6 times and also, sorry, this get to the height of reinforcement that means how much metal to be deposited? What should be the reinforcement height? This and this width (Refer Slide Time: 42:25) breadth of the reinforcement and height of reinforcement. This is hr, this is the breadth of reinforcement to height of reinforcement; that is generally 6 times the hr, and also the breadth of reinforcement is around two times the depth of fusion.

If that can be achieved, then generally the cracks will not form. The joint geometry satisfying the above conditions provides better means of gas escape and also reduces the possibility of developing cracks.

Of course, when we will weld, it is difficult really, to assess how much will be the breadth weight and how much will be the reinforcement depth, etcetera. These are well, if one does some analysis, some critical calculations prior to selecting the welding parameters, then one can use these conditions to see what are the suitable parameters. Of course, in real life case, you do not actually go for calculating the parameters; you take from standard codes but, why because the welding are generally standardized, but when you have a nonstandard situation, then all these factors come in to play.

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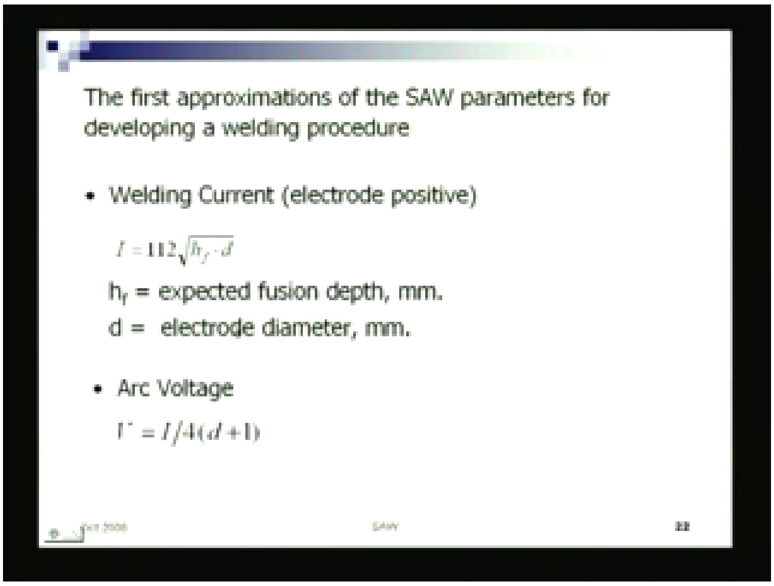

So, for that, I have given some. This you can see later, once you have the entire material how to estimate the first approximations of submerged arc welding parameters.

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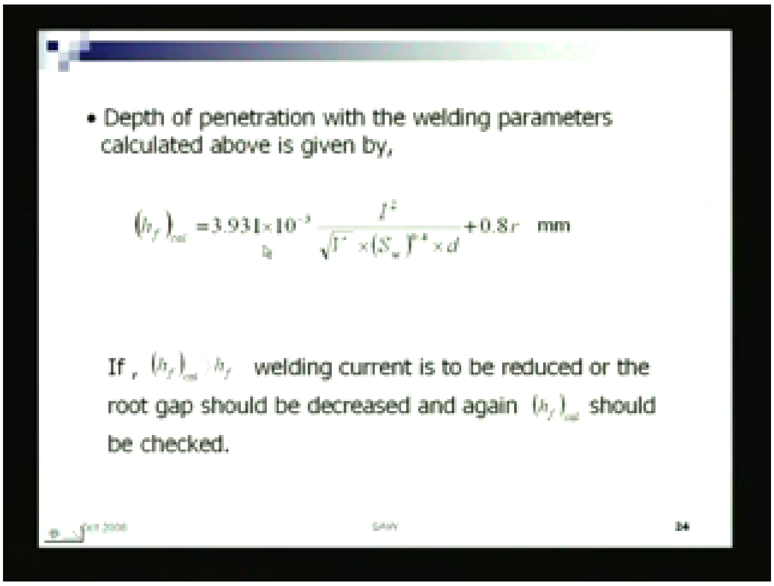

If you have to go for a nonstandard case, where you want to assess what should be the welding parameters, there are certain thumb rules given, from which you can… certain empirical relations are given, where in you can get what would be the depth of penetration for a given current, for a given speed, etcetera.

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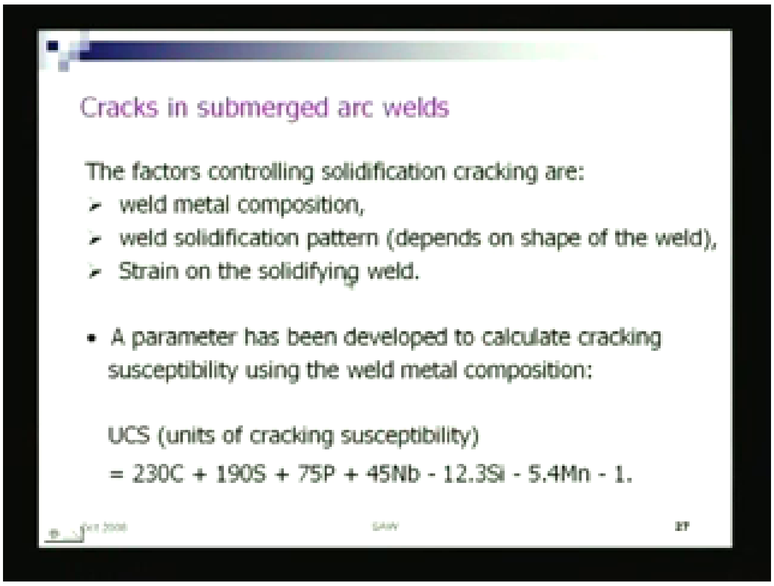

Well, cracks in submerged arc welding: because in any So, what do we see in the submerged arc welding? This is a high deposition welding process. High deposition welding process is an efficient welding process and also it provides welding of good quality; that means the weld bead profile is smooth as well as since the I mean it is automated process, you can achieve a higher speed of welding, higher productivity. At the same time, there can be a risk of cracks developing in this.

Why because it is also a high heat input welding. Though as I said, making it automated, I can increase the speed. But depending on how much deposition rate you want, deposition rate again depends on the speed. So, if you want to have a higher deposition, then again you will have to reduce the reduce the speed. Once you reduce the speed, your heat input rate increases. So, that increases the chances of cracks forming in the weld bent. So, that is how you see the factors controlling solidification cracking are. By means of solidification cracking means what? The metal gets solidified and you find your welding, this progressing arc going there and you find it has cracked and to back after solidification.

So, that depends on weld metal composition, weld solidification pattern, how it is solidifying? That means, what is the micro structure forming inside. Strain on the solidifying weld. What kind of thermal stresses are forming? So, a parameter has been developed to calculate the cracking susceptibility, depending on weld metal composition because all these cracks, I mean, which are connected with a welding process, they are essentially because of thermal stresses on one hand, and on the other hand, lack of ductility of the material.

Suppose, a material is put under tension, because cracking will not develop due to compression, it will be always because of tension, and as you know, when you do the welding, the residual stress in the weld zone is always in tension. So, the weld metal zone is under tension always. And now, the weld metal, if it is ductile enough, then it will take that tension and may be you will get elongated thereby the residual stress will get consumed and no crack will form. But if the material is brittle, means if the material is hard, then under that tension, either it will withstand, it being too hard you cannot do anything whatever tension thermal tension forces are taking place, or it will crack.

So, that is how, what happens, whether it is ductile or brittle, that means it is soft or hard will depend on metal composition; will depend on the cooling rate. Why? Because these two - the composition of the metal as well as the thermal cycle, it is undergoing that; means the cooling rate determines the micro structure and steels property is determined by the micro structure. How the micro structure is, the size of the grain, size of the composition of the grains, orientation of the grains - all these three together determines. Actually they determine the mechanical property of steel; not the composition alone; it is the composition along with its micro structure. How the micro structure will depend? It will depend on the composition; so, thereby, a parameter that is referred to as UCS - Units of Cracking Susceptibility.

It is as we see that, well, it is a statistically it is done. It is depending on Carbon, Sulphur, Phosphorous, Nibian, Silicon, Manganese contents. So, as you can see, that SUCS is reducing with increasing Silicon and Manganese, but increasing heavily with Sulphur as well as Carbon. That is why high strength low alloy steels has very low Carbon percentage, whereas high yielding steels has a higher Carbon percentage and is very difficult to weld. What does that mean - Difficult to weld? means, you weld; it cracks; there is a difference.

Why? because of this C, as well as Sulphur and Phosphorous as you can see they are very parameters which contribute heavily towards cracking susceptibility. That is why a ship welding quality weldable steel should have as low as these, as low as possible. Sulphur and Phosphorous general requirement is, it should be less than 0.05 percent.

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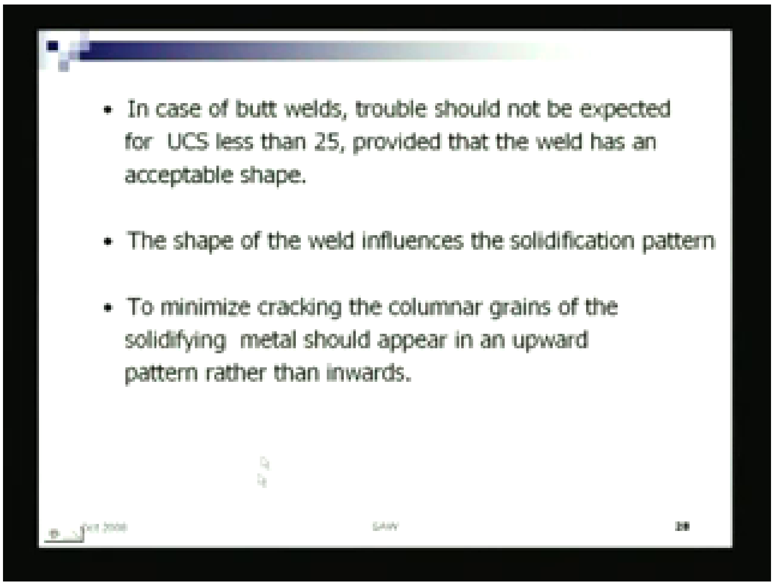

So, what we see, in case of butt welds, troubles should not be expected for UCS less than 25. These are some of the thumb rules. If you have within say 25, then for a butt welding, it should not crack should not develop. The shape of the weld influences the solidification pattern. To minimize cracking, the columnar grains of the solidifying metal should appear in an upward pattern rather than inwards. These are actually the grain structure; how the grain structure should be.

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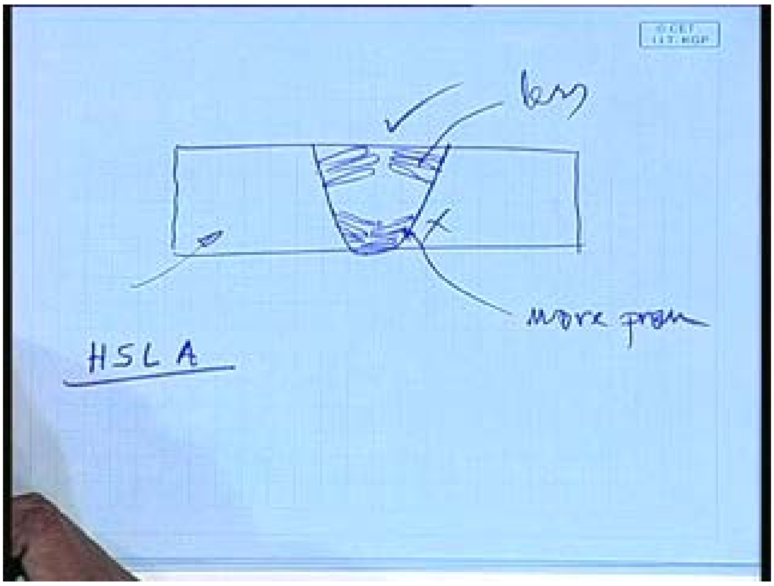

What happens is, you see, when a metal solidification takes place in welding, generally, well, let us assume, the fusion zone is like this. So, the metal solidification takes place from the molten metal. It forms a kind of what is referred to as columnar grains; that means grain like this; grains like this elongated type. So, it should have an upward sort of pattern. This upward pattern rather than downward, if the solidification pattern is like this, like this, then it is more prone to cracking.

It is more prone to cracking and this is less; that means this is preferable; this is not (Refer Slide Time: 52:11). How that I mean How that will happen? That will again depend on, partially depends on, the composition and also it depends on the parameters, right depends on the speed.

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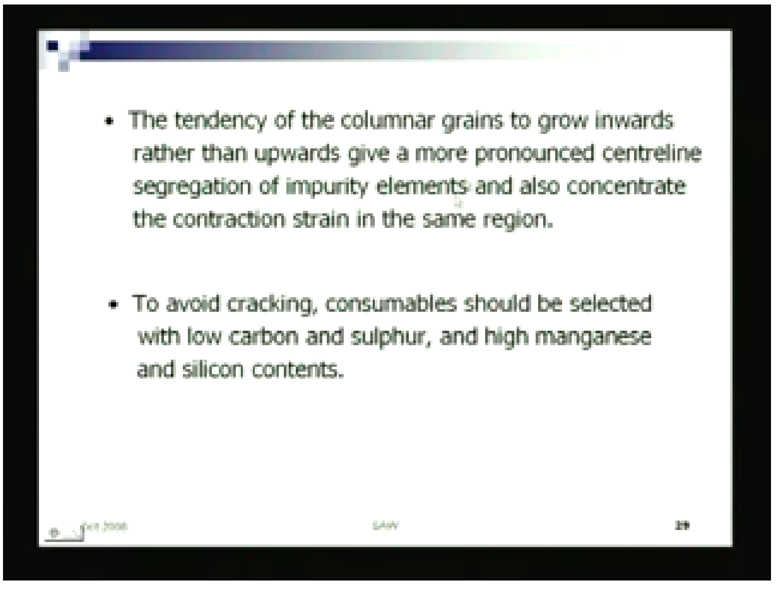

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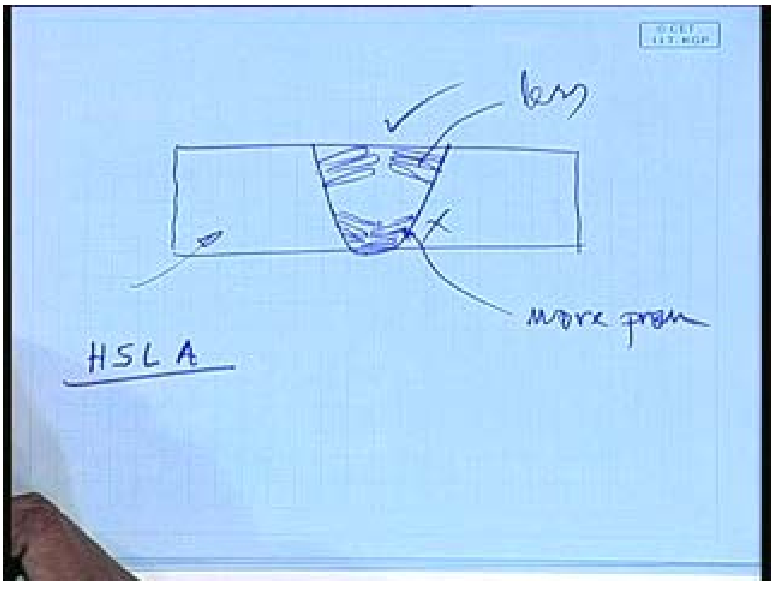

So, the tendency of the columnar grains to grow inwards rather than upwards, give a more pronounced centerline segregation of impurity elements. This is some of the (( )) aspects, how it happened, but it is nice to know. That is what basically happens and also concentrate the contraction strain in that region. In these forms, if it forms, then as if all the impurity elements, they get concentrated in that central region.

Impurity elements, means what? Those Phosphorous, Sulphur - those are the impurity elements. So, if they are in higher percent, they will get segregated and get concentrated in the middle portion. This segregation impurity will take place and contraction strain in the same region. To avoid cracking, consumables should be selected with low Carbon and Sulphur. I mean So, what is happening? Your base metal may be with low Carbon and Sulphur material has been used, say that that that what you call HSLA steel is being used; High Strengths Low Alloy Steel; automatically it has a very low carbon percentage and also low alloying; other alloying elements is also low, but by the process of rolling and heat treatment and the production process, they achieve a very high strength. That means suitable micro structure is achieved.

Fine. Now, that is being welded. So, welding consumable has to be so chosen, that is what is mentioned, so, welding consumable that means the if it is a submerged arc welding, your electrode as well as the flux should be so chosen that it should have low Carbon and Sulphur.

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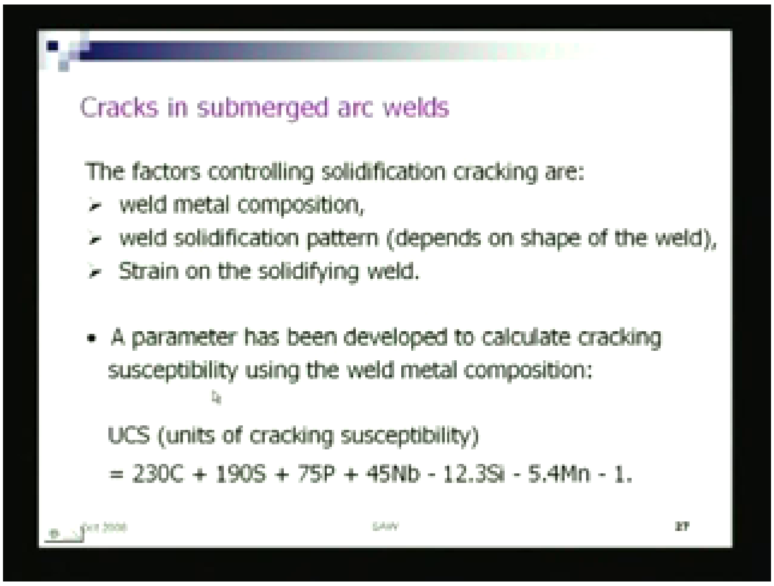

And with high manganese and silicon contents, because here you see, they are the negative terms. So, if I have higher Silicon Manganese, it is better for me; it reduces the UCS that is Units of Cracking Susceptibility that parameter reduces. So, this is what.

So, that is how, we see that this particular process the submerged merged arc welding is a high efficiency, high deposition process, but one of the biggest drawback is a down hand process. Down hand process means it cannot do any positional welding. However, as you see that, to achieve a good weld quality, one should try to maneuver it, the necessary the job, such that you convert all the positional welding to down hand welding.

So, thereby, this submerged arc welding can be, I mean, in shipyards. In fact, one should try to maximize the use of this particular process, welding process because it gives you a good high productivity as well as highest quality of welding. So, we stop here, today.