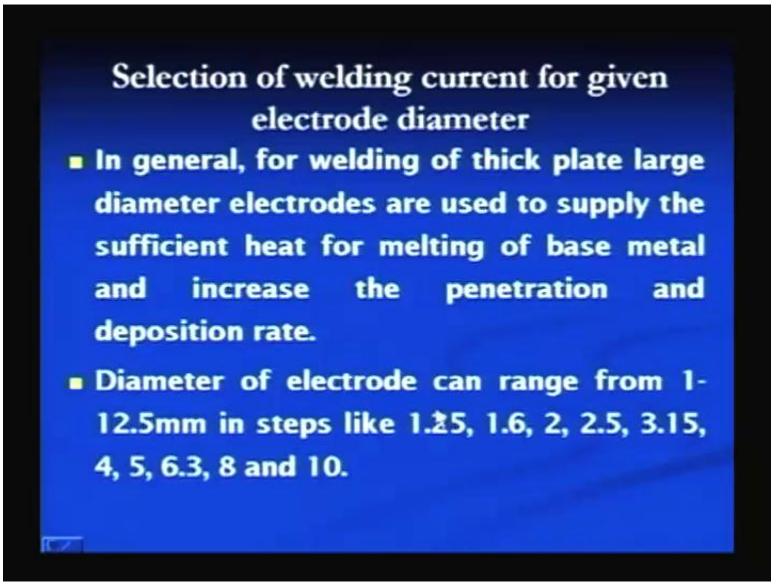
Manufacturing Process - I
Dr. D. K. Dwivedi
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Module - 3
Lecture - 7
Shielded Metal Arc Welding Part – 2

Welcome students. This is the second lecture on the shielded metal arc welding. So, the continuation of the first lecture on the same topic, and I have explained that the welding process parameters like welding current, welding voltage and welding speed significantly effects the soundness of the weld joint which is produced. So, by continuing the discussions related to the effect of the welding current and selection of the electrode diameter, I will continue this lecture.

(Refer Slide Time: 01:10)



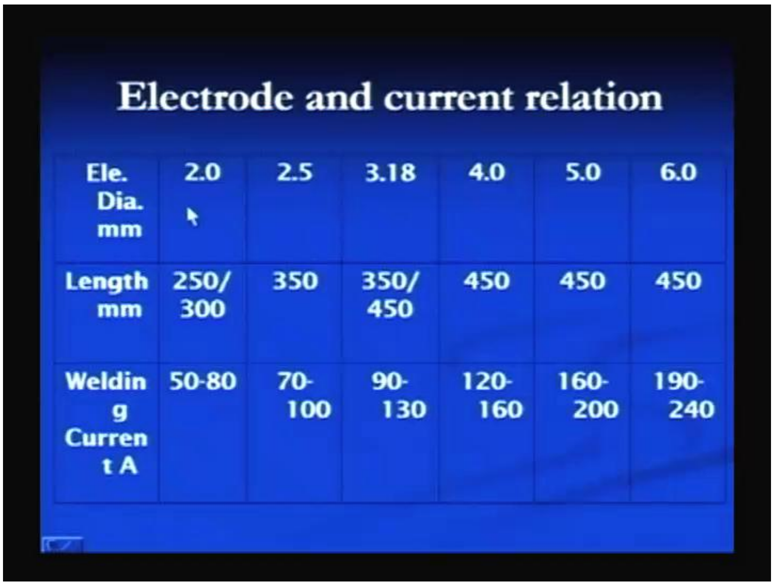
The selection of the welding current for the different electrode diameters is based on the application. Normally for the thick plates we need the higher heat input for perfect melting and proper penetration, and for that the use of high welding current is to be done. And for using high welding current it is required that large diameter electrodes are selected, so that higher heat can be generated for proper melting of the base metal and the electrode material. So, the joint can be completed properly in perfect manner.

In general, therefore, for welding of thick plates the large diameter electrodes are selected to supply sufficient heat. So, that the base metal can be melted properly with the desired penetration and also a higher deposition rate can be achieved, because high heat input generated in the arc region not only increases the rate of melting of the base metal but also increases the melting rate of the filler metal, which is coming from the electrode tip, and increased melting rate of the filler metal increases the rate by which the groove is filled.

So, we can say that higher welding speed increases the deposition rate, increases the penetration rate which is required for welding of thick plates. The diameter of the electrode which are available commercially in very wide range, and this diameter of the electrodes can be in range of 1 to 12.5 mm in a steps like 1.25 mm, 1.6 mm, 2 mm, 2.5 mm, 3.15 mm, 4 mm, 5 mm, 6.3 mm, 8 mm and 10 mm, and then it can also be up to 12.5 mm. So, the larger diameter of the electrodes are used for welding of thick plates, but when the low heat input is required for welding of thin plates, we normally select the small diameter electrodes. So, that desired heat input can be provided to the base metal and filler metal, and a desired penetration can be achieved.

So, on the basis of the electrode we set the current which is to be used for a given application; for the different electrode diameters we said different welding currents. So, the details of the welding currents which are set for the different diameter of the electrodes the different currents are certain; that detail we will see in the next slide.

(Refer Slide Time: 04:07)


Electrode and current relation

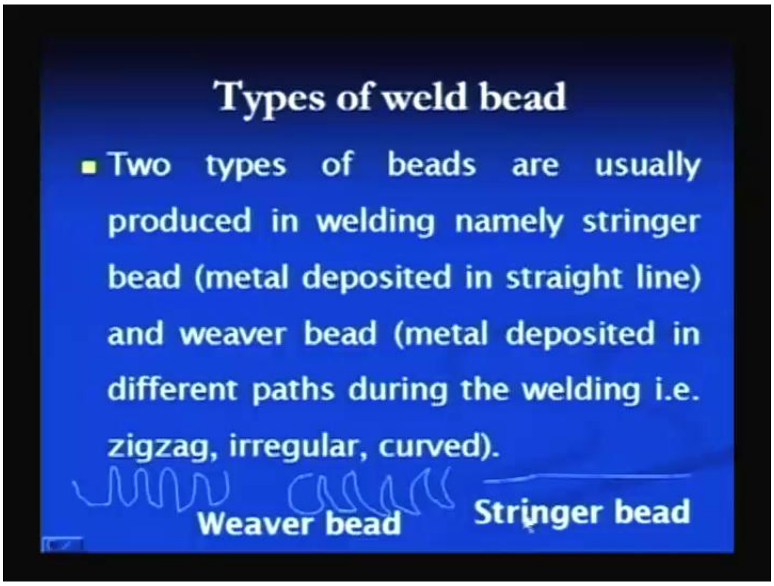
Ele. Dia. mm	2.0	2.5	3.18	4.0	5.0	6.0
Length mm	250/ 300	350	350/ 450	450	450	450
Welding Current A	50-80	70-100	90-130	120-160	160-200	190-240

The relation between the electrode diameter and the current is like this here. The electrode diameter in mm is mentioned in this row. Here 2mm, 2.5 mm, 3.18 mm, 4.0, 5.0 and 6 mm diameter electrodes. These can be of the different lengths, and they require different level of currents. The electrode of the 2 mm diameter can be of lengths 250 to 300 mm, and it requires the welding current in range of 50 to 80 ampere. 2.5 mm diameter electrode can be of 350 mm length, and it needs the current in range of 70 to 100 mm. So, greater the electrode diameter, longer is the length of the electrode here, and higher the welding current rating which can be used with the electrode.

So, as per needs of the heat input required and the deposition rates which are required, we select the desired electrode diameter. And accordingly, the welding current is set so as to get the desired heat input and proper melting of the base metal for perfect joining of the plates to be welded. Optimum welding current setting is important for successful welding, because without that we will not get a smooth stable arc; we will not get consistency in heat input and the penetration. So, the optimum heat input is important and if the welding current setting is not optimum or not proper, then it can lead to the number of problems like high current setting may damage the electrode coating material due to the electrical resistance heating of the core wire, because electrode extension length in shielded metal arc welding is significantly high.

So, the flow of high current through the long electrode extension portion generates lot of heat which can damage to the coating material. And decomposition of the coating material degrades the performance of the coated electrodes. So, it is always desirable to maintain the temperature of the core wire within the safe limits, so that coatings are not damaged by the heating of the core wire caused by electrical resistance heating. And on the other hand if the lower currents if the current is set on the lower side, then the optimum level, then it can create the problem of the arc stability; the arc may be unstable, and it may wonder here and there, and the penetration may be poor. It can lead to the lack of fusion or lack of penetration, and the fluidity of the molten metal may also be poor. So, these things will lead to the inconsistent weld and the weld of the poor mechanical strength and poor weld bead appearance. So, the setting of the welding current on the higher side or on the lower side will be undesirable; that is why setting of the welding current at optimum level is important.

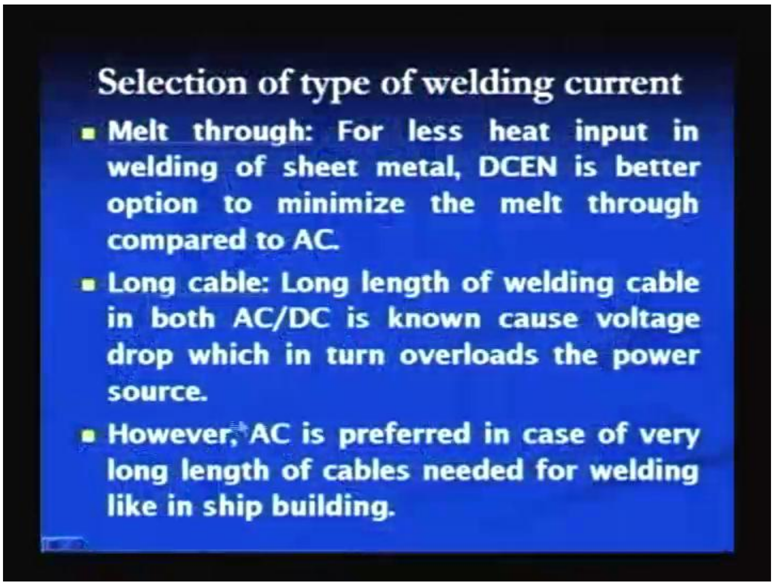
(Refer Slide Time: 07:45)



During the welding by using the proper current setting that the weld beads are deposited to fill the gap between the plates to be welded, and these weld beads are deposited in the two different ways. One method or one way is that in which the weld bead is deposited in a straight line that is termed as a stringer bead, and in other case weld bead is deposited in zigzag manner; we call it as weaver bead. So, the two types of the beads are usually deposited in welding. These are the stringer bead in which metal is deposited in a straight line, and the weaver bead which metal is deposited in different parts during the welding.

It may be zigzag manner, irregular manner or curved manner. Schematically it has been shown here that the zigzag manner or irregular manner beads can be deposited like this or like this when metal or the weld bead is deposited in this way. And these two patterns or some other irregular patterns, we call it as a weaver bead; otherwise, when weld bead is deposited along a straight line, we term it as a stringer bead.

(Refer Slide Time: 09:14)

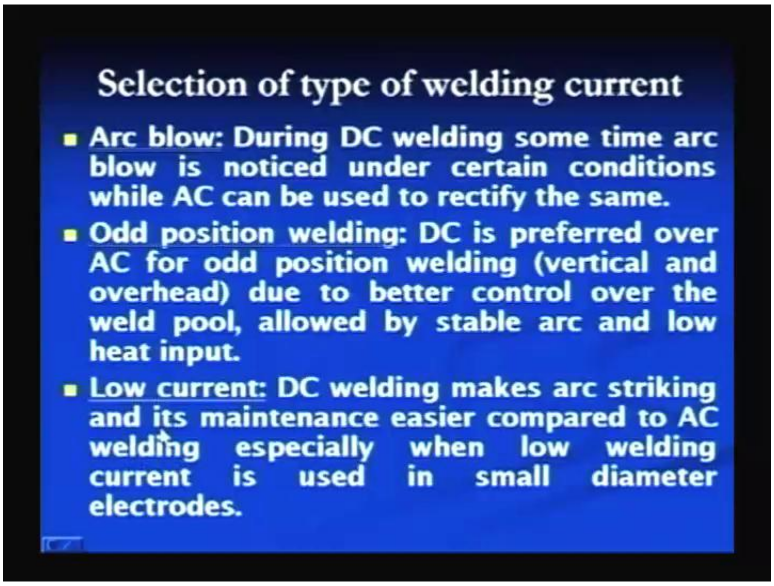


For proper deposition of the weld beads, it is necessary that the current of the proper polarity proper magnitude is selected, so that the free form joint is produced in such a way that it is free from the defects. So, selection of the welding current for producing the optimum bead is very important. And when selecting the current, certain points are kept in mind like the melt through problem can take place if the welding current is not set properly. So, for the cases where less heat input is required for welding of sheet metal or for welding of thin plates, normally DCEN is selected for the better weld joint which is free from the defects like melt through and the distortion and the residual stresses.

So, the DCEN will help to produce the weld joint and minimize the melt through problems compared to the AC or DCEP polarity. Here if for the welding purpose we have to use long cables, then use of the long cables causes the loading on the welding power source. Because long length of the welding cable in both AC and DC is known to cause the voltage drop and which in turn overloads the power source. This overloading is to be avoided, and if it is compulsory to use the long cables like in fabrication of the heavy components used in a ship industry.

So, under those conditions if it is necessary to use long cables, now the long cables are preferred with the AC welding, because it does not cause that much overloading on the welding power source. So, AC is preferred in case of very long length of the cables is to be used for welding of the components in the ship building or in the ship industry.

(Refer Slide Time: 11:46)



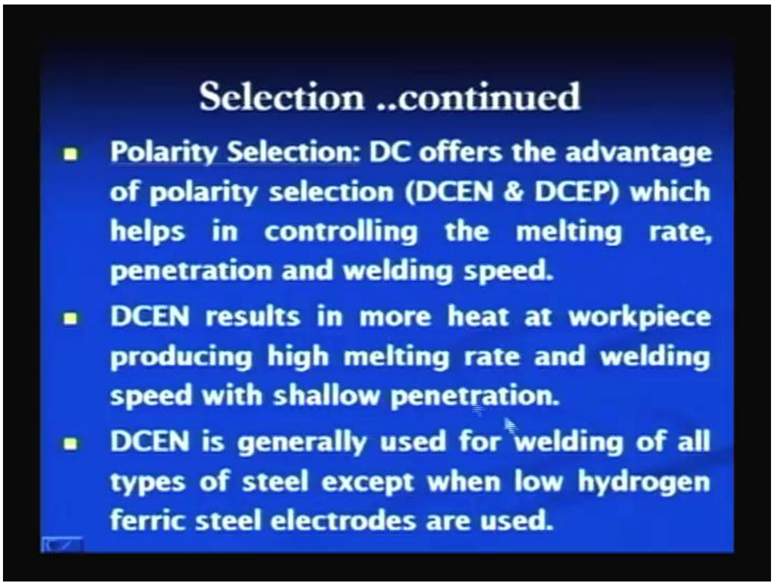
The arc blow is the another problem which is noticed in case of DC welding particularly when the plates are welded near the edges, or the angle of the electrode is not proper then under those conditions during the DC welding, the arc tends to wander away from its intended direction, or it tends to deflect away or in the directions where it is not required. So, that deflection of the arc from the path which is required is known as arc blow, and this problem is encountered during the DC welding particularly. So, this problem can be overcome by using the AC.

So, if the problem of the arc blow is significant, then use of AC can help to overcome the problem of the arc blow. And if the odd position welding is to be done like the welding is required or welding is to be done in overhead position or in vertical positions. Then there will be tendency of the molten metal to fall down, and under those conditions it is required that the heat input to the weld metal or the weld pool is controlled properly. And for better control over the heat input and better control over the weld pool, it is preferred to use DC as compared to the AC.

Because DC allows to have a better control over the heat input in the base metal side or in the electrode side by selecting the proper polarity. Because heat input in case of AC is equal in both electrode and the base metal side. At the same time the application of the DC in odd position welding also helps to or gets the better arc stability and the lower heat input by selecting the DCEP. So, the heat generated in the base metal side is reduced. So, the DC allows the better control over the heat input and better control over the weld pool helps to weld successfully in odd positions.

Low current if is required like a the DC welding makes the AC striking makes the arc striking and its maintenance easier compared to the AC, and especially when the low current is used with the small electrode diameters. If for a given application if we have to use the small diameter electrodes for controlling the heat input, because small diameter electrodes can work with the low welding currents, but the problem with the low welding currents can be of the poor arc stability and its maintenance. So, under such conditions if AC is used, then it will impose the problem of the poor arc stability with the low welding current even in case when small diameter electrodes are used. So, to overcome the problem of the arc stability DC is preferred over the AC particularly when the low welding currents are to be used with the small diameter electrodes.

(Refer Slide Time: 15:44)

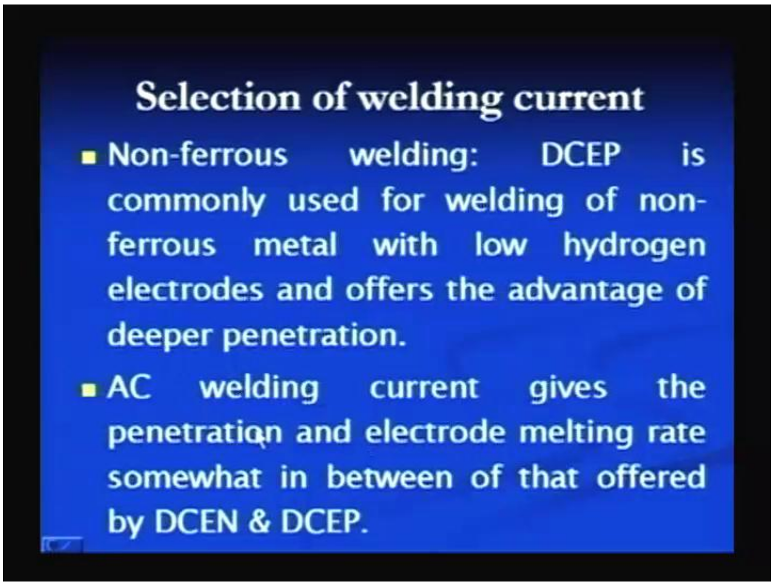


The polarity selection, this advantage is available with the DC only as per needs we can generate higher heat in the base metal side or the lower heat in the base metal side; as per needs the polarity can be selected, and that polarity selection advantage is available only with the DC not with the AC. So, DC offers the advantage of the polarity selection like DCEN or DCEP which helps in controlling the melting rate penetration rate and the welding speed. So, as per needs these parameters can be controlled by selecting the proper polarity. So, that the polarity selection advantage is available with the DC only.

The DCEN results in more heat at work piece side, and which in turn results in higher melting rate and the welding speed with the shallow penetration. Because in case of DCEN, one-third of heat of the arc is generated in the electrode side and two-third of the heat is generated in the base metal side. So, this huge difference in the heat generation in the base metal side produces the advantage of the higher melting rate of the base metal and the higher welding speed with the shallow penetration.

This DCEN particularly in steel welding also helps to increase the life of the tungsten electrode, but here in shielded metal arc welding, the advantage is mainly related with the increased melting rate of the base metal. DCEN is generally used for welding of all types of the steels except when low hydrogen ferric steel electrodes are used. So, there DCEN is normally used in steel welding.

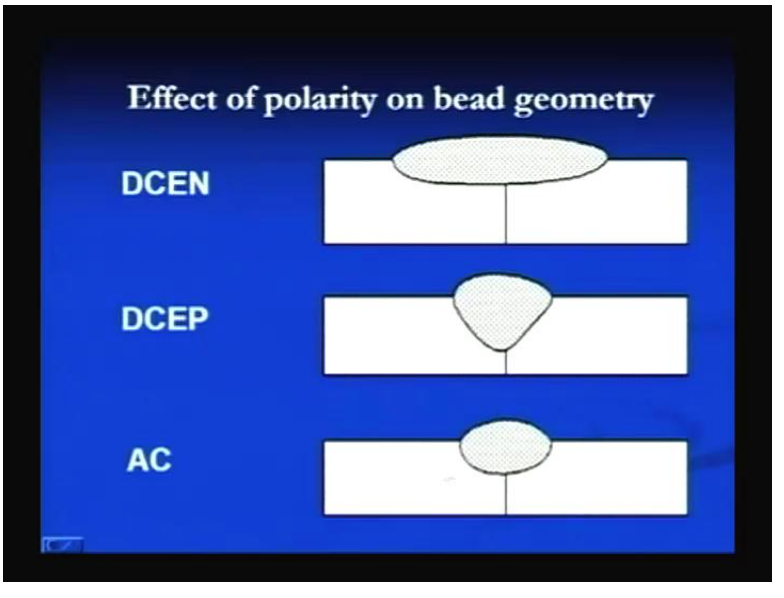
(Refer Slide Time: 17:51)



Then non-ferrous welding, for the non-ferrous welding normally we use a DCEP, because it offers the advantage of the cleaning action, because when DCEP is used electrode is made positive and work piece is made negative. And electrons are emitted by the work piece itself which helps to get the advantage of the cleaning action particularly in the welding of the aluminum when magnesium kind of metals where cleaning action is important, because refractory oxide films is found on the surface of the aluminum or a stainless steel or the magnesium materials. So, for the welding of the non-ferrous metals particularly DCEP is used.

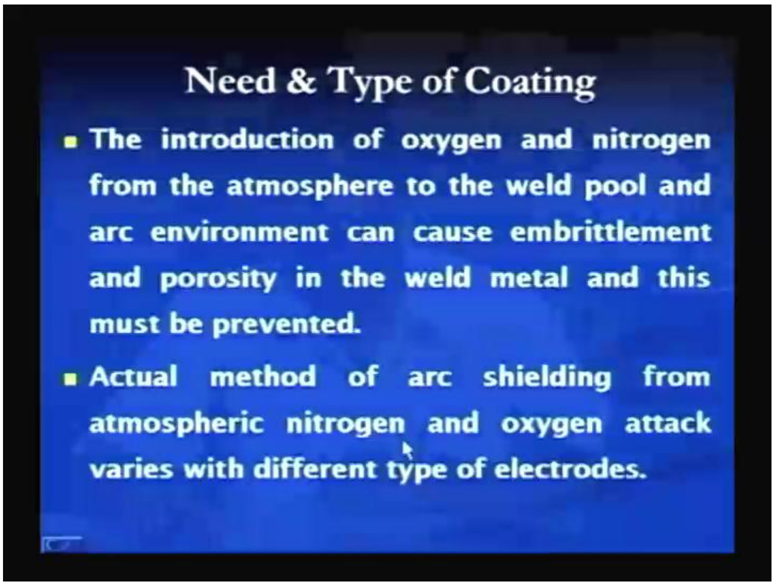
And also it is used with the low hydrogen electrodes as it offers the advantage of the deeper penetration in the weldment. The AC welding current gives the penetration and the electrode melting rate somewhat in between of that offered by DCEN and DCEP, because polarity is continuously changing in AC. So, whatever the melting rate and the penetration is obtained in case of AC that is found in between of the DCEN and DCEP.

(Refer Slide Time: 19:30)



The polarity significantly affects the weld bead geometry here with the DCEN when the less heat is generated in the electrode side and more heat is generated in the base metal side, we get the wider weld bead with the shallow penetration. And when DCEP is used, electrode is made positive; we get the deeper penetration and shallower weld bead or the weld bead width is a smaller one, and the penetration depth is more. And in case of AC it is the combination of the both, we get the optimum weld bead width and optimum penetration. So, as far as weld bead geometry in terms of the bead width and penetration is concerned, the penetration and bead width lie somewhere in between of DCEP and DCEN.

(Refer Slide Time: 20:35)

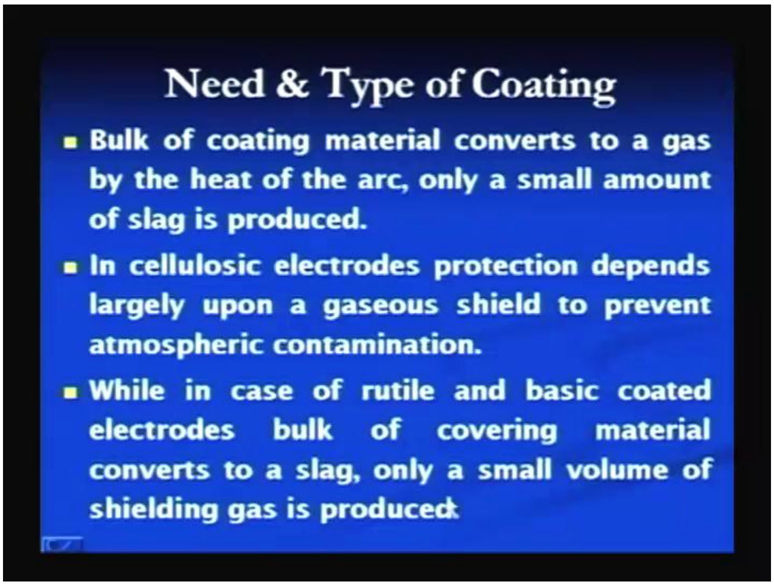


In shielded metal arc welding, the coated electrodes are used, and these coated electrodes help to produce the sound weld joints. Coatings in these electrodes are used for specific purposes; the functions are performed by these coating materials in very specific manner. So, what is the role of the coating in the shielded metal arc electrode and what are the different functions performed by the coating constraints or the coating materials; that we will see in detail one by one.

Because during the welding of the metals, the oxygen and the nitrogen can enter into the arc zone or into the weld pool which can get dissolved and react with the molten metal of the weld pool. And the entry of the oxygen and nitrogen in the arc zone from the atmosphere and then in to the weld pool can damage the soundness of the weldment. Because these oxygen and nitrogen can lead to the formation of the oxides or nitrites, or these can also be present there as a gaseous medium which can produce the gaseous defects in the weldments.

So, to reduce the adverse effects related to the entry of the gaseous like oxygen and nitrogen coming from the atmosphere in to the weld pool, it is desired that the effects of this gases in the weldment is reduced. And under the adverse effects on the performance of the weldment caused by the oxygen and nitrogen or hydrogen are reduced by application of the suitable coatings on the electrode. The actual method of arc shielding from the atmospheric nitrogen and oxygen depends on the different types of the electrode materials, which are used. Means to control the adverse effect of the oxygen and nitrogen on the weldment, the different methods or the different constituent in the electrode coating material can be used. And these coating materials are of different kind, and these will be discussed one by one in the coming slides.

(Refer Slide Time: 23:46)

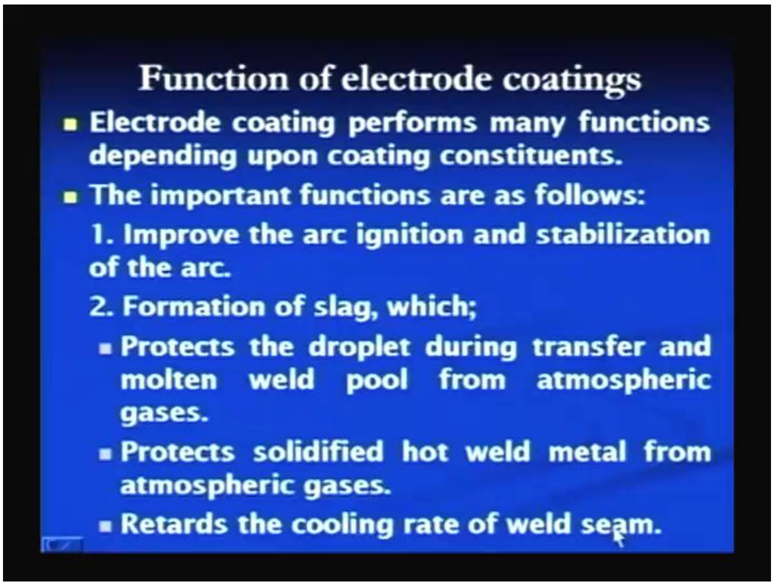


Like the coating materials can be of the different types, the common coating materials which are used for coating the electrodes in the shielded metal electrodes which are used in shielded metal arc welding process are like rutile electrodes or rutile type of the coatings are used, cellulosic coating, basic coating, acidic coatings are used in electrode materials. And the bulk of the coating materials is converted into the gas by the heat of the arc, and the small amount of these coating materials is used to produce the slag.

Whatever coating material is present that works in the two ways. One is it gets decomposed into the inactive or the shielding gases to provide the desired shielding to the weld pool and the arc during the welding to protect the same from the atmospheric gasses. And part of the coating material is also used in formation of the slag by reacting with the impurities. Like in case of cellulosic electrodes, the protection depends largely on the gaseous shield to prevent the adverse effects related to the atmospheric gasses. So, the cellulosic electrodes largely provides the inert or shielding gasses to protect the weld pool from the atmospheric contamination, while in case of rutile and basic coated electrodes, most of the material of the coating is used to form the slag.

Only a small volume of the coating material is used to produce the shielding gasses which are generated in form of the inactive or the inert gasses. The different functions are performed by the coating materials to produce the sound joint, and these functions arrange from the better arc stability to the better control over the protection or better protection of the weld pool during the welding.

(Refer Slide Time: 26:24)



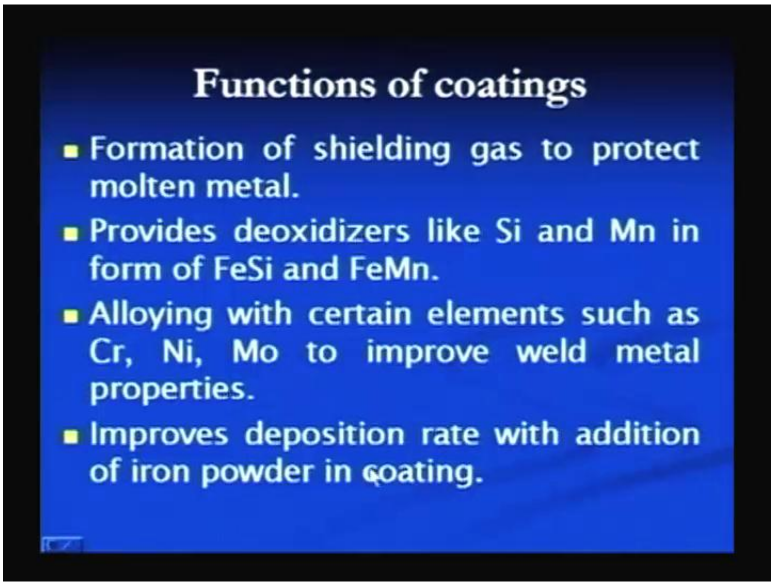
So, these functions will be covered one by one like they improve the arc ignition and stabilization of the arc. Coating materials are frequently added with the elements like calcium and potassium which helps to strike the arc easily and also help in maintaining the arc. Because these elements help to release the electrons easily during the arc, and the presence of arc helps to maintain the arc easily. Another role which is performed by these coating materials is the formation of the slag. The coating materials acts as I have just told you that it performs the two function.

It performs in two ways. One is it releases the shielding gases by the effect of the heat of the arc, and it reacts with the impurities present in the molten weld pool to form the slag, and the formation the slag intern acts in different ways. So, one is when slag is formed it becomes of the lower density than the base metal. That is why it floats on the surface of the weld pool, and it takes longer time to solidify; weld metal solidifies first, and that is why it normally covers the slag which is formed covers the solidified weld pool.

And therefore, the slag which is formed protects the droplets during the transfer and the molten weld pool from the atmospheric contamination. When droplets are being transferred from the electrode tip, at that time also thin slag layer covers the molten metal droplet, and when it is transferred to the weld pool at that time also the molten slag layer floats over the surface of the molten weld pool. So, thereby it protects the weld pool from the atmospheric gasses. And further, it also protects the solidified hot metal from the atmospheric gasses because it forms continuous layer over the solidified metal.

It also retards the cooling rate of the weld bead which is deposited, because it is non-conducting in nature. And thereby, it decreases the rate of heat transferred to the atmospheric gasses from the weld bead. And therefore, it allows the lower cooling rate or it makes sure that the weld bead cools slowly after the welding.

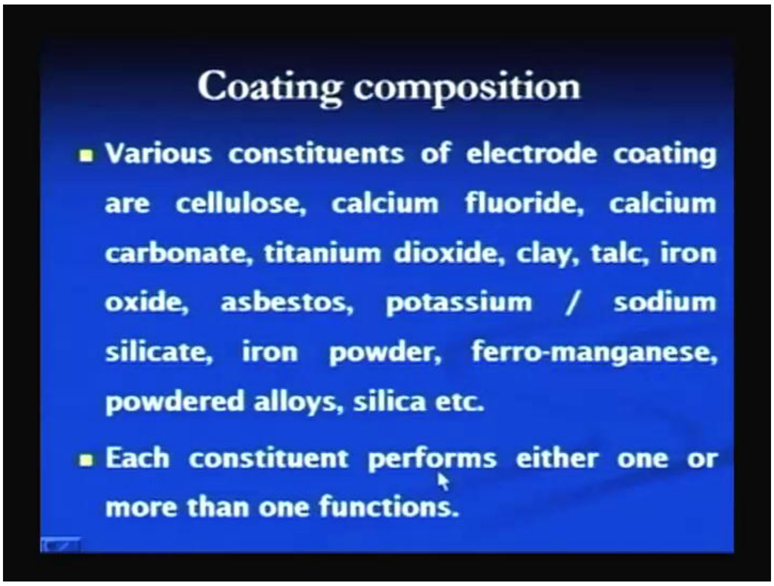
(Refer Slide Time: 29:29)



Other functions of the coating materials are like the formation of the shielding gasses to protect the molten metal; I have just explained in detail about this. The coating materials also provided with deoxidizing elements likes silicon and manganese in the coating material helps to deoxidize the weld pool during the solidification, because if any oxygen is present in the weld pool that oxygen reacts with the silicon or manganese. So, the silicon and manganese thereby goes along with the slag and oxygen is removed. So, the presence of deoxidizers helps to remove the oxygen from the weld pool.

Alloying elements also can be added with the coating material to get the certain alloying elements added in the weld pool for achieving the specific properties. Like many times to increase the corrosion resistance chromium nickel or to increase the hardness, the molybdenum or carbon can be added to improve the weld metal properties. So, in order to achieve the specific properties, certain alloying elements can be added through the coating materials in the weld pool to get the desired results. Sometimes to increase the deposition rate also iron powder is mixed with the coating materials. So, that presence of the iron powder with the coating material helps to increase the deposition rate, and that in turn helps to increase the deposition efficiency during the welding.

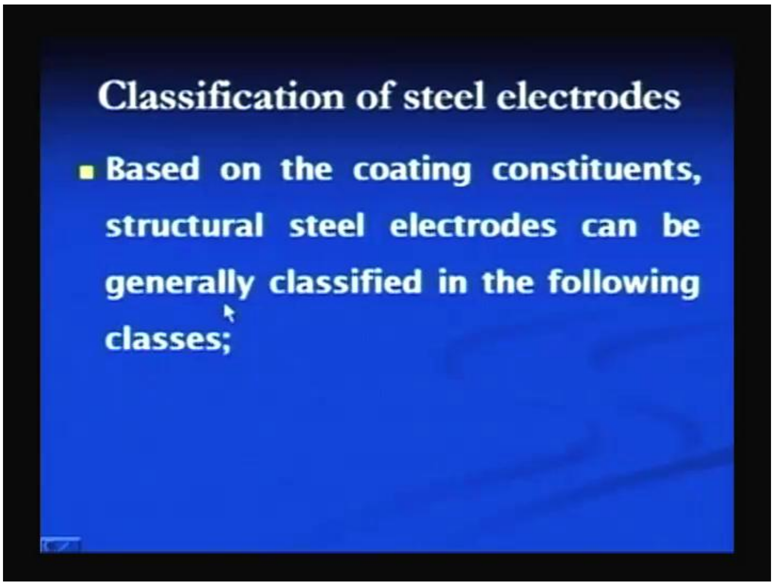
(Refer Slide Time: 31:37)



Different constituents are added in the coating materials to perform specific functions, and these coating materials are of the different types. Like the electrode coatings can have the cellulose, calcium fluoride, calcium carbonate, titanium dioxide, clay talc, iron oxide, asbestos, potassium and sodium silicate, iron powder, ferromanganese powdered alloys and silica. Each constituent is supposed to perform a specific function or more than one function.

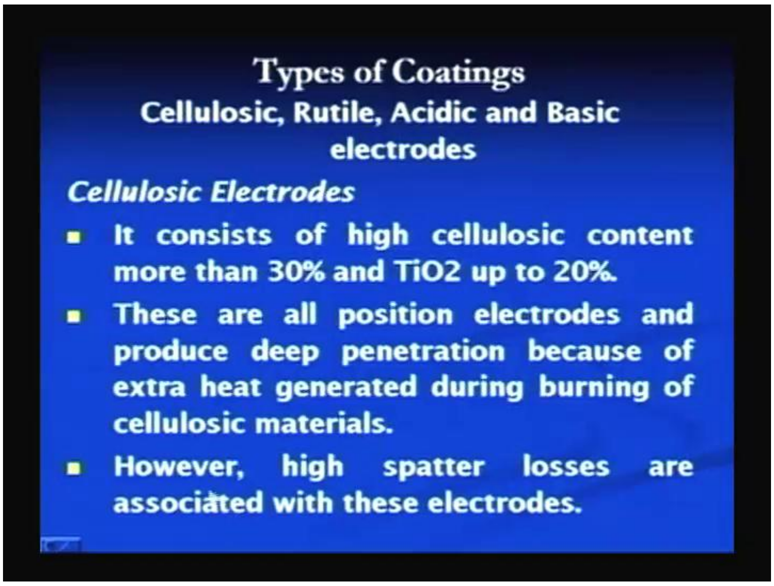
These steel electrodes are classified in a specific manner, so that one can understand the kind of electrode which is there and what kind of properties it will be offering after the weld bead is deposited. So, as per the Indian standards the two standards, I shall be covering one standard on the electrode classification was given in 1974, and another classification was given in 1991. So, first of all I will take up the electrode classification according to the IS Indian standard given in 1974.

(Refer Slide Time: 32:43)



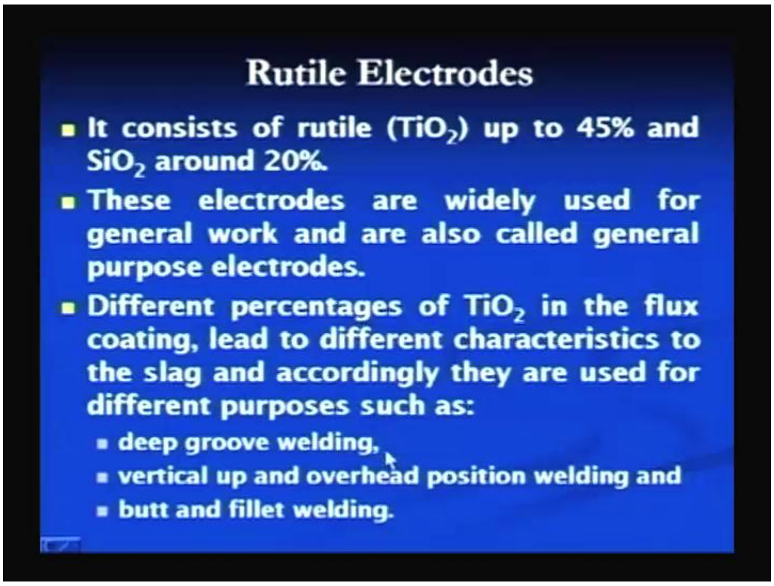
Based on the electrode coating constituents, structural steels can be classified in the different ways, and how this classification is made we will see now.

(Refer Slide Time: 33:10)



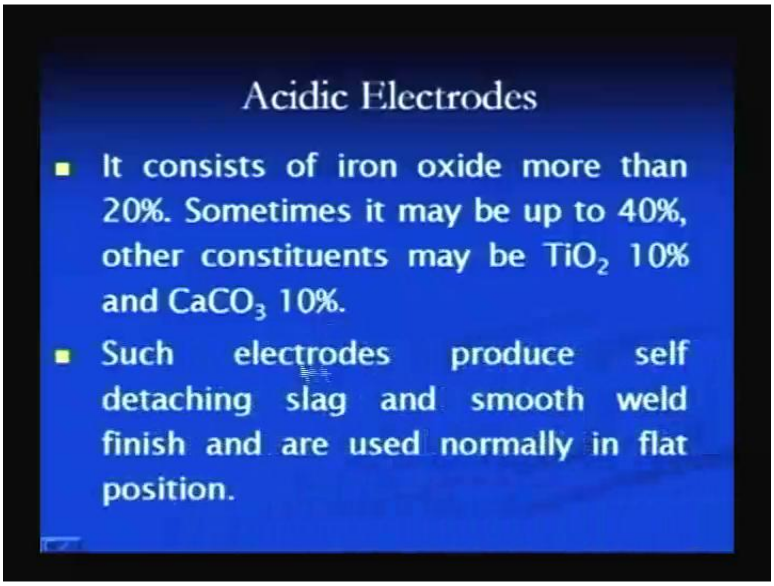
The different types of the coatings which are there are the cellulosic coating, rutile type of coating, acidic coating and the basic coating electrodes. In detail, the cellulosic coating electrodes consists cellulosic material about 30 percent and the titanium dioxide or titanium up to 20 percent. And these are all position electrodes or means cellulosic electrodes or all position electrodes and produce deep penetration because of extra heat generated during the burning of the cellulosic material. However, high spatter losses are produced by the cellulosic electrodes.

(Refer Slide Time: 33:49)



Rutile electrodes are other important types of the electrodes. It consist the rutile or titanium up to 45 percent and the silicon dioxide around 20 percent. And these electrodes are widely used for general purpose, and therefore, these are also termed as the general purpose electrodes. And the different percentage of the titanium in the flux can be there which in turn results in the different characteristics to form slag, and accordingly, they are used for the different purposes. So, the difference in the percentage of the titanium leads to the different performance of the rutile electrodes. And accordingly, these are used for the different purposes such as for the deep grooves welding, vertical up and overhead position welding and butt and fillet welding.

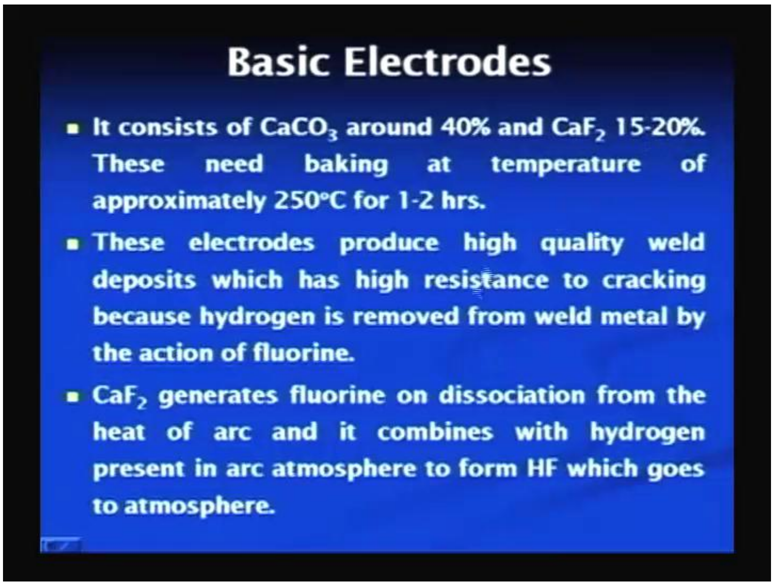
(Refer Slide Time: 34:48)



Acidic electrodes are another important kind of the electrodes; it consist the iron oxide more than 20 percent. And sometimes iron oxide can be up to 40 percent, and other constituents may be there as a titanium dioxide up to 10 percent and calcium carbonate up to 10 percent. And with such electrodes produce self detachable slag. This is important aspects, because many times it becomes difficult to detach the slag from the coating or from the weld bead.

And if the slag is not detached properly, the undetached slag can be left there as a inclusion which can deteriorate or degrade the mechanical properties of the weldment. So, that is why if the slag is self-detachable, it will help to produce the weld joint easily. And at the same time these electrodes also produce the smooth weld bead, and these are normally used in flat position welding.

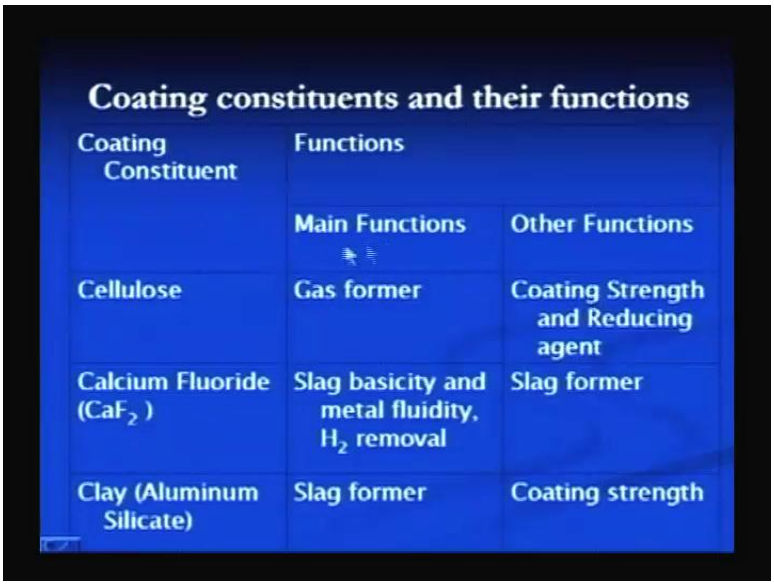
(Refer Slide Time: 36:00)



Basic electrodes consists calcium carbonate around 40 percent and the calcium fluoride 15 to 20 percent, and these electrodes need baking before using, because these are hygroscopic in nature; these absorbs moisture from the atmosphere. Therefore, proper baking as per the manufacturer's instructions is important, and normally, this baking is carried out at a temperature of 250 degree centigrade for 1 to 2 hours. And these electrodes produced high quality weld bead deposits which are having great resistance to the cracking particularly hydrogen induced cracking resistance is good in the weld bead produced by the basic electrodes, because hydrogen is removed from the weld bead by the action of the fluorine which is present in form of the calcium fluoride.

The calcium fluoride generates fluorine on dissociation form the heat of the arc, and it combines with the hydrogen present in the arc environment to form HF which goes to the atmosphere. So, the hydrogen is taken care by this calcium fluoride which is present in the amount of 15 to 20 percent, and thereby, reduced percentage of the hydrogen in weldment helps to control the hydrogen induced cracking.

(Refer Slide Time: 37:35)

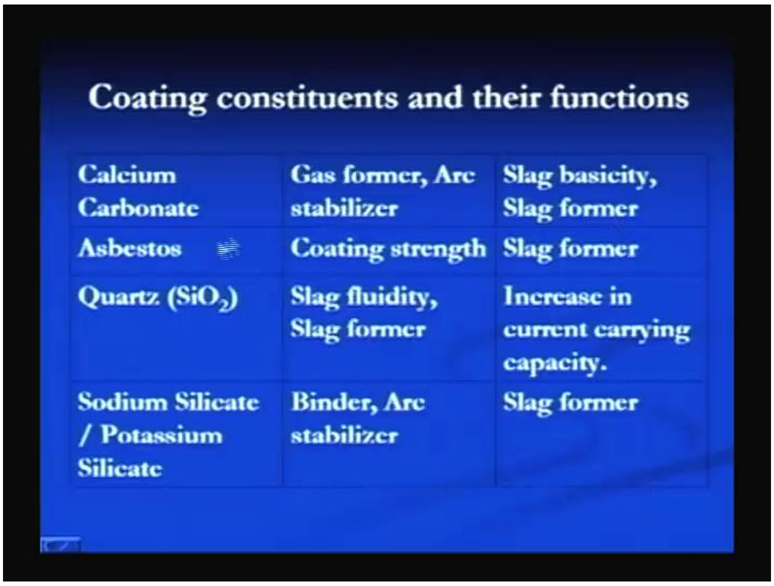


The different coating constituents and the specific functions performed by them can be seen here from this table. There is one main function and some other functions also performed by the each constituent like cellulose act as a gas former for protection of the weld pool. At the same time it also helps to coating strength and as a reducing agent. Calcium fluoride acts as a slag basicity and metal fluidity under the hydrogen removal, and it also acts as a slag former. The clay or aluminum silicate acts as a slag former and also increases the coating strength.

Refer Slide Time: 38:15)

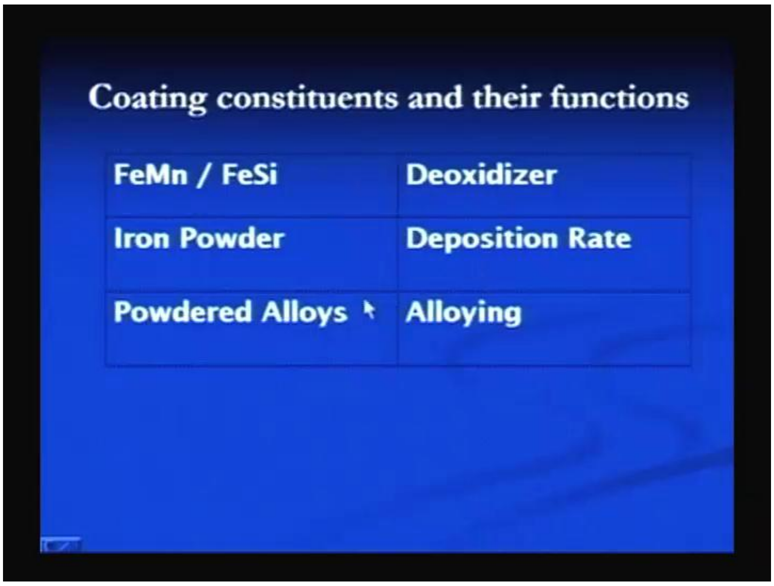
The talc or magnesium silicate acts as a slag former and arc stabilizer. Rutile or titanium dioxide acts as arc stabilizer, slag former and improves fluidity. And it also helps to remove the slag and improves weld bead appearance. Iron oxide improves the fluidity and acts as a slag former, and it helps to stabilize the arc acts as an arc stabilizer and improved metal transfer.

(Refer Slide Time: 38:48)



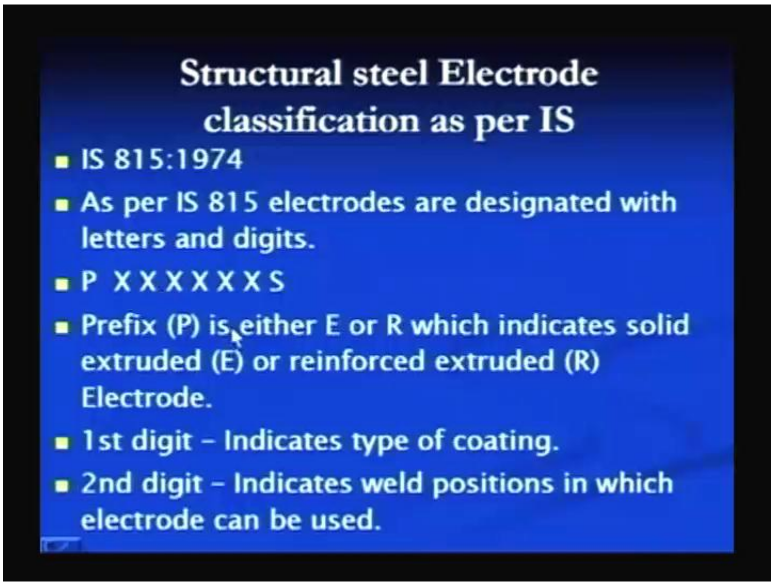
Other constituents like the calcium carbonate acts as a gas former and arc stabilizer, other functions are slag basicity and slag formers. Asbestos is there for improved coating strength and also acts as a slag former. Quartz is there whose slag fluidity and acts as a slag former. It also increases the current carrying capacity of the electrode. Sodium silicate and potassium silicates are used as a binder, and these also helps to improve the arc stability, because these are having the low ionization potential elements. At the same time these silicates also acts as a slag former.

(Refer Slide Time: 39:31)



Other constituents which are added in the coating materials like FeMn and FeSi acts as a deoxidizer. Iron powders have used to increase the deposition rate. And the powdered alloys are used at the specific alloying elements in the weld metal to achieve the desired characteristics.

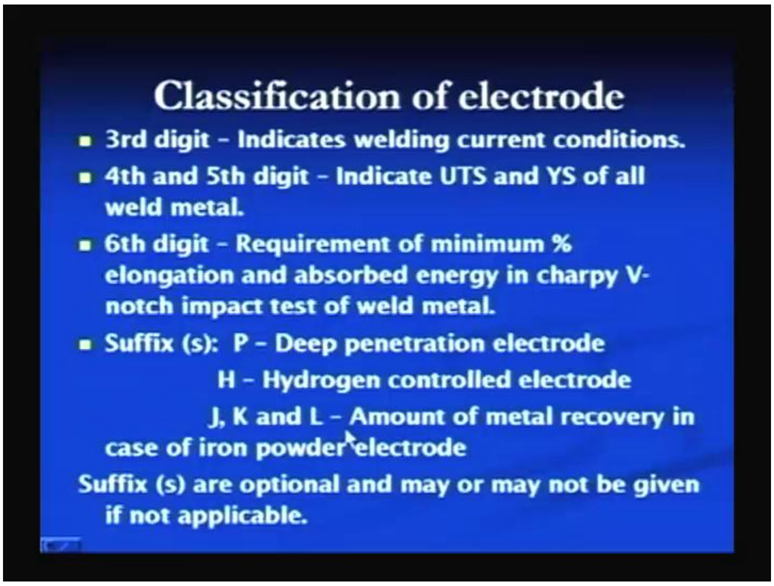
(Refer Slide Time: 39:58)



Structurally steel classification as per the Indian standard is like this. This standard is the Indian standard IS 815 was given in 1974. And as per this standard, this standard uses the letters and digits both to classify these steel electrodes. And there are the six numbers or digits and two letters. The first letter is this and the last is the letter, and the other six digits are used for complete classification of the steel electrodes. The first letter P is a prefix. It can be either E or R which indicates that the solid extruded electrode; for solid extruded electrodes E letter is used.

And for reinforced extruded electrodes R letter is used in place of P. P indicates prefix; it can be either E or R according to the way by which it has been manufactured. And the first digit this one indicates the type of coating which has been used. The second digit indicates the welding position in which electrode can be used, second digit.

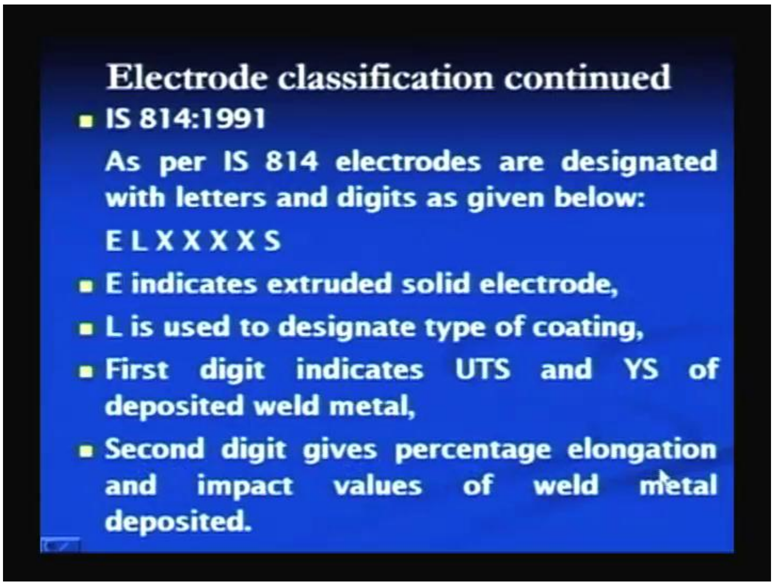
(Refer Slide Time: 41:32)



And third digit indicates the welding current conditions which are to be used, and for that particular electrode fourth and fifth digit indicates the ultimate tensile strength and yield strength of all weld metal specimen. And the sixth digit indicates the requirement of the minimum percentage elongation and the energy absorbed in charpy V notch impact test of the weld metal. So, it indicates the toughness and the percentage elongation of the weldment.

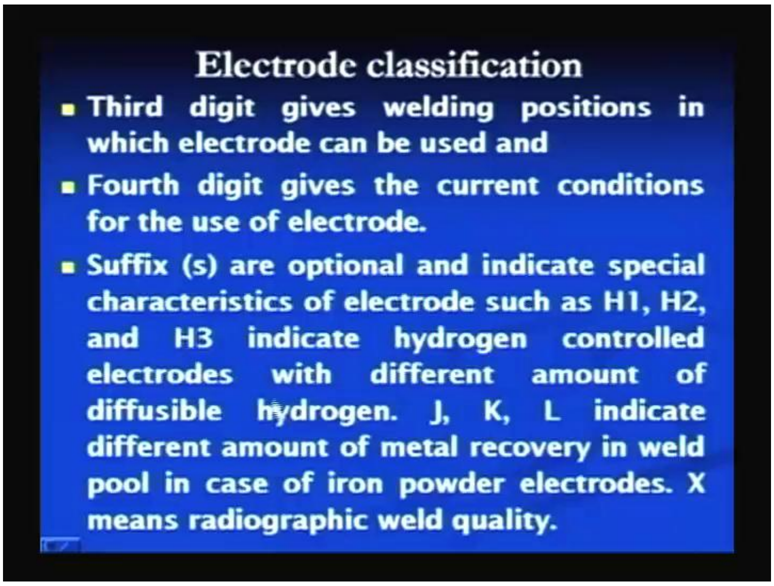
And the last letter which is suffix S can be either P H J K or L. P is used for deep penetration electrodes, H is used for the Hydrogen controlled electrodes, J K and L according to the amount of the metal recovery in case of the iron powder electrodes. So, the different J K and L letters can be used. Suffix is the optional one; it may be used or may not be used in a given electrode specification.

(Refer Slide Time: 42:47)



Another electrode steel electrode classification was given in 1991, and it is IS 814, 1991. According to this classification or as for this IS 814 electrode classification, it also uses the letters and digits, but the letters are there as E L and then four digits, and the last is again letter. So, the four digits and the three letters are used in this classification. E indicates the extruded solid electrode; L is used to designate the type of coating. The first digit indicates the ultimate tensile strength and yield strength of the deposited weld metal. And the second digit gives the percentage elongation and impact values of the weld metal deposited.

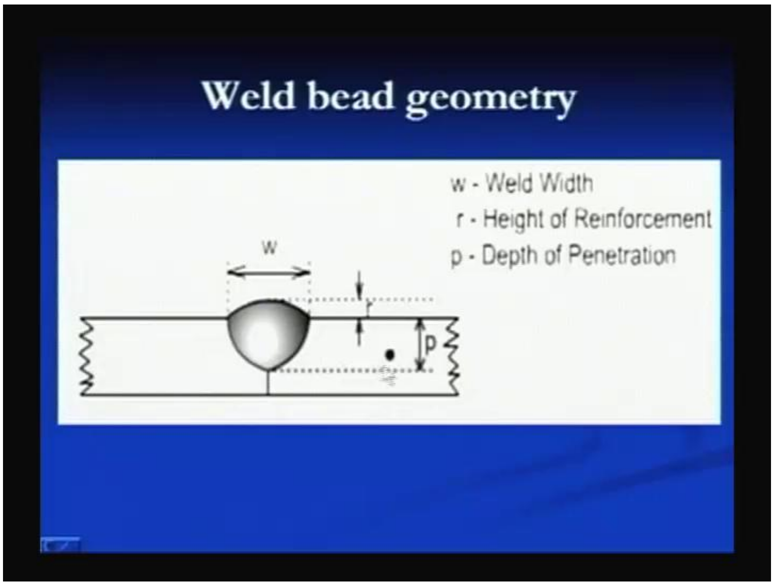
(Refer Slide Time: 43:42)



And third digit gives the welding conditions in which electrode can be used, and the fourth digit gives the current conditions which give the current conditions for use of the electrode. And a suffix S or the last letter is optional and indicates the special characteristics of the electrode such as H 1, H 2, H 3 as per which indicates the hydrogen controlled electrodes for the different amount of the diffusible hydrogen. Depending upon the kind of the hydrogen percentage, that will be permissible with the different electrodes that are indicated in terms of the H 1, H 2 or H 3.

So, as per the hydrogen controlled possible with the particular kind of electrodes, these are indicated by H 1, H 2 or H 3. The other letters like J K and L can be used to indicate the different amount of the metal recovery in weld pool in case of the iron powder electrodes and X letter can be used to show the radiographic weld quality.

(Refer Slide Time: 45:01)

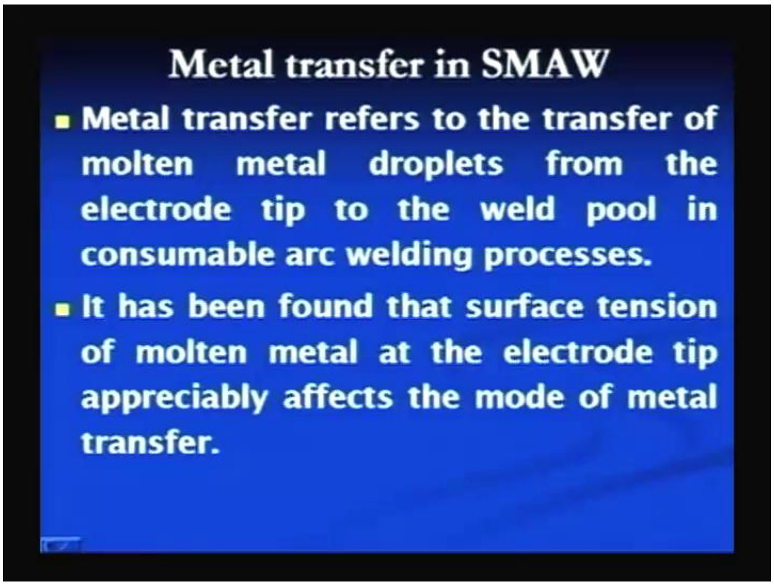


The weld bead geometry which is produced by depositing the weld metal is characterized by using the number of parameters, and these parameters are particularly weld bead width the height of the reinforcement and the depth of penetration. The width of the weld or weld bead width is indicated by this W, and the distance from this point to this point indicates the weld bead width. And the height which is above the base metal level, height of the weld bead above the base metal level is described as height of reinforcement.

So, height of the weld bead above the base metal level is this one. So, here this distance is termed as the height of the reinforcement or reinforcement, and the depth up to which base metal is melted during the welding from the surface is termed as depth of penetration. And these three parameters are normally used to characterize the weld bead geometry.

During the welding by shielded metal arc welding process, the consumable electrode is used, and the electrode melts continuously during the welding to fill the groove between the plates to be welded. And when molten metal melts at the tip of the electrode, it gets transferred gracefully one by one. And how this transfer takes place, what are the different forces acting in the arc zone, and which affects the way by which metal transfer can take place? That will be discussed here in metal transfer. The way by which metal transfer takes place in the shielded metal arc welding process and the different modes related to the metal transfer in shielded metal arc welding process.

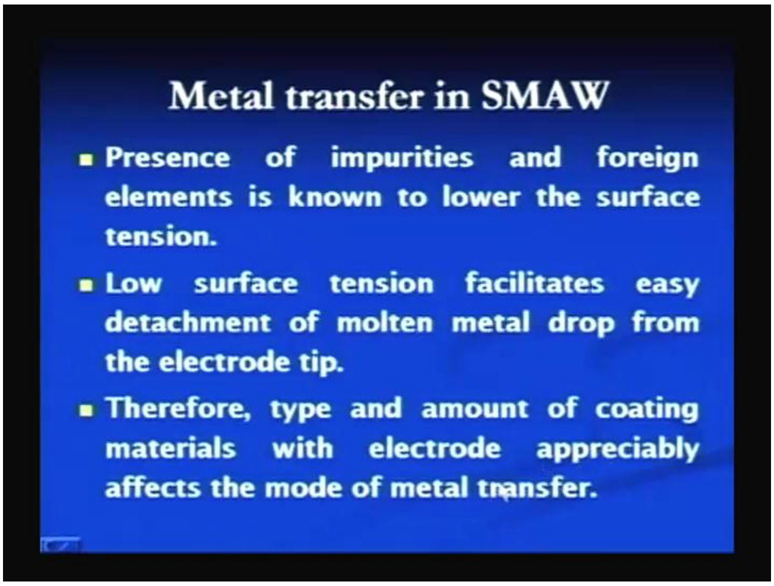
(Refer Slide Time: 47:09)



Metal transfer refers to the transfer of the molten metal droplets from the electrode tip to the weld pool in consumable arc welding processes. And it has been found that surface tension of the molten metal at the tip of the electrode appreciably affects the mode of metal transfer. Normally surface tension is the force that hinders the detachment of the droplet. If the surface tension is high, the transfer of the molten metal droplet hanging at the tip of the electrode is hindered. It tends to remain attached with the tip of the electrode. So, if the surface tension is high, the transfer becomes difficult.

And the pool tends to grow continuously until unless other forces dominate the molten metal droplet to get transferred from the tip of the electrode to the weld pool. So, the surface tension of the molten metal at the electrode tip plays significant role in its transfer to the weld pool.

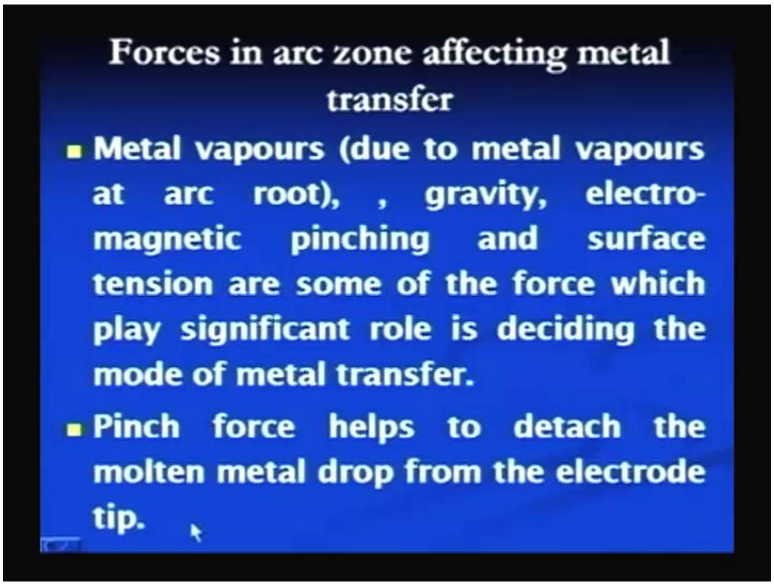
(Refer Slide Time: 48:13)



The presence of the impurities and the foreign elements in the molten metal droplet plays a significant role in the surface tension in effecting its surface tension. The temperature of the molten metal and the presence of impurities, these two things significantly affect the surface tension force. If the impurities and the foreign elements are present in the molten metal, these will lower the surface tension forces and will facilitate the transfer easily. The low surface tension facilitates easy detachment of the molten metal droplet form the tip of the electrode.

And therefore, the type and amount of the coating material with the electrode appreciably affects the molten metal transfer. In the coating material, certain elements are present which makes the molten metal droplet of greater impurity. And the more foreign elements are present in the molten metal droplet, then they will lower the surface tension, and that will facilitate the easy transfer of the molten metal. So, other aspects related to the molten metal transfer we will see in next slide.

(Refer Slide Time: 49:38)

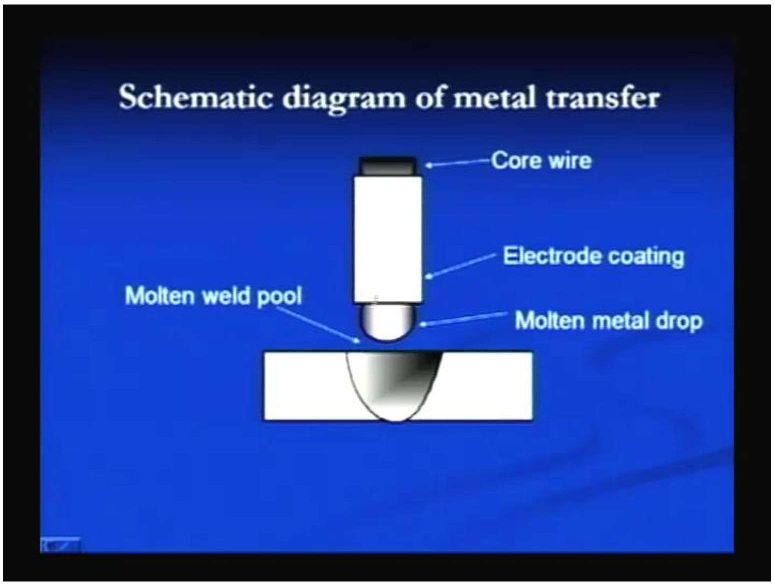


The different forces which act in the arc region which affect the transfer of the molten metal from the electrode tip are like metal vapors which are generated due to the evaporation of the molten metal in the weld pool because of high temperature. So, the metal vapors will be moving upward direction and will be hindering the detachment of the droplet. And the gravity is another force, because gravitational force will always be acting on the molten metal droplet which is hanging at the tip of the electrode.

So, gravitational force will help to detach the droplet from the electrode tip in normal positions, but in upward positions in overhead welding conditions, the gravitational force hinders the detachment of the droplet form the electrode tip. Electromagnetic pinch force is another major force which affects the metal transfer, because it helps to pinch the molten metal droplet at the tip of electrode and helps in its detachment easily. Surface tension is another force which affects the metal transfer appreciably; this is what I have just discussed.

So, the gravitational force, electrode pinch force and surface tension force are the main forces that affect the mode of the metal transfer. The pinch force helps to detach the molten metal droplet from the electrode tip, and thereby facilitates its transfer from the electrode tip to the weld pool.

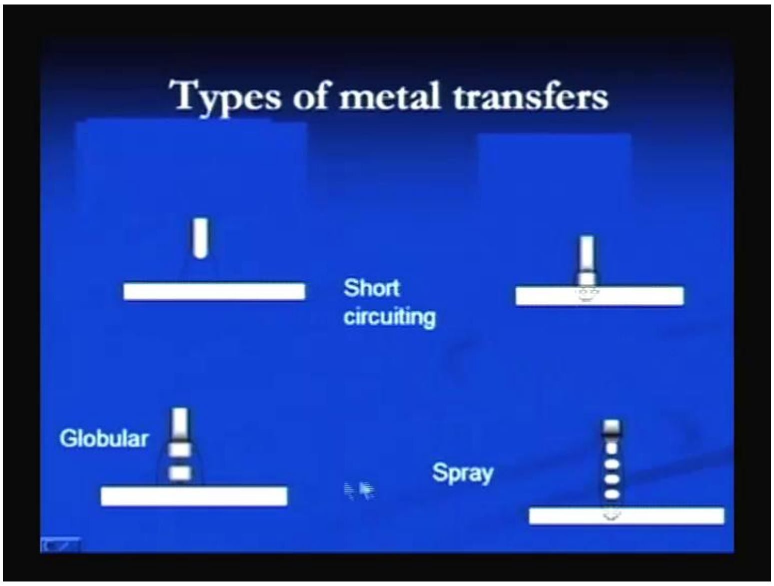
(Refer Slide Time: 51:26)



We can see schematically how metal transfer takes place and how droplet is formed at the tip of the electrode, say, this is the covering and this is the core wire. Core wire will be melting, and the droplet will be hanging at the tip of the electrode, and here say this is the weld pool. So, the different forces will be acting on the droplet hanging at the tip of the electrode like gravitational force will be acting in the downward direction. And the pinch force will be acting tangentially on the molten metal droplet and will be tending to reduce the cross section of the droplet near the electrode tip.

And thereby will be helping to detach the droplet from the electrode tip. Surface tension force will also be acting against the detachment of the droplet. Higher the surface tension force, greater will be the tendency of the droplet to remain attached with the electrode tip. So, this is how the different forces will be acting on the molten metal droplet.

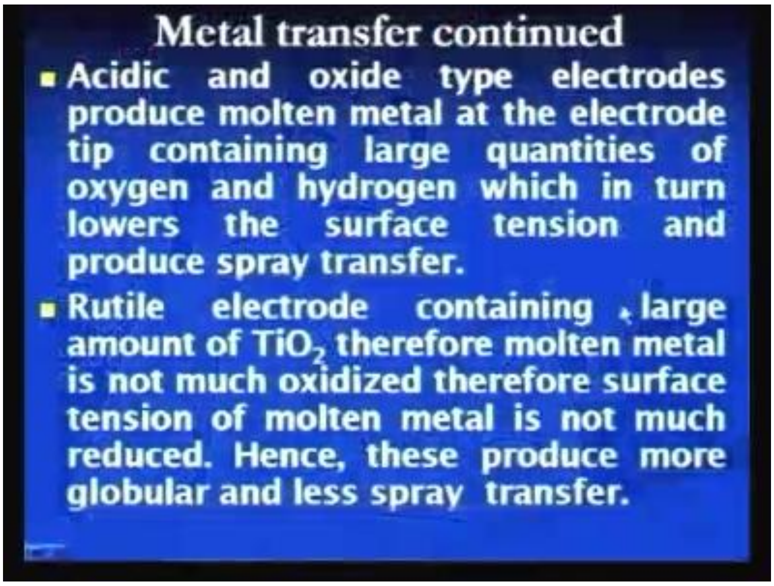
(Refer Slide Time: 52:41)



These are the three main types of the metal transfers which are noticed. In short circuiting metal transfer when the electrode is very close to the weld pool, droplet is formed, and it touches to the weld pool and by the surface tension force of the weld pool it gets transferred. This type of transfer is known as short circuiting transfer. In globular transfer when the distance between the electrode tip and the work piece is more, the droplet is formed at the tip of the electrode. It grows gradually and then by the gravitational force it is detached after sometime, but before detachment it is able to take the larger size.

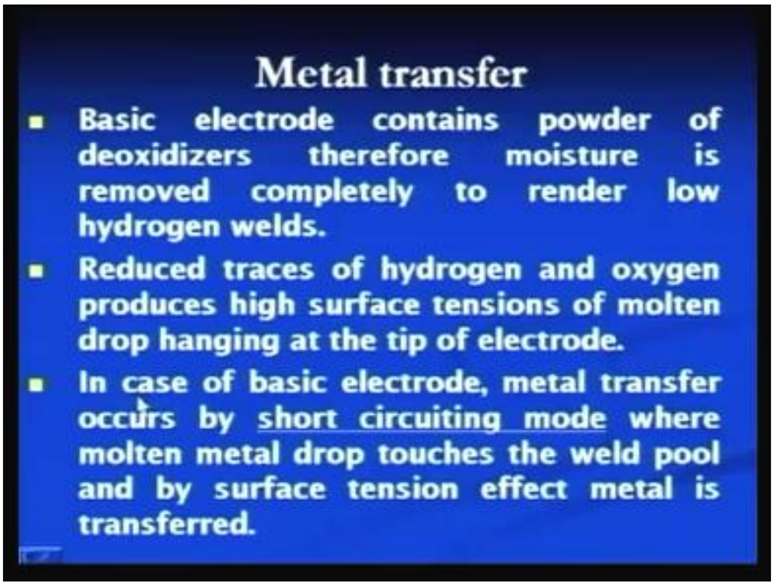
And in spray transfer when pinch force is significantly high or if the impurity is present in the molten metal are high, then the reduced surface tension and increased pinch force can lead to the detachment of the small droplets. And these droplets will be running along the axis of the electrode to produce this spray kind of transfer.

(Refer Slide Time: 53:51)



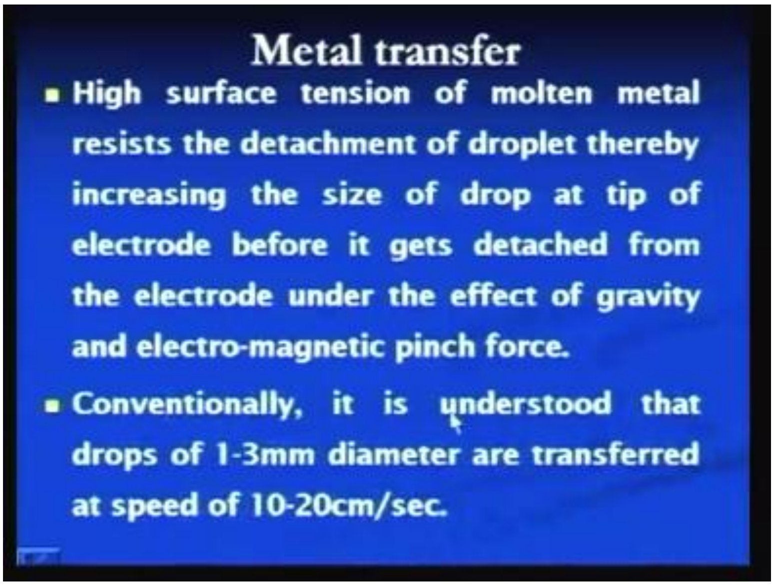
The acidic and oxide type electrodes produce the molten metal at the electrode tip containing the large quantities of oxygen and hydrogen which in turn lowers the surface tension. So, in these two types of the electrodes the oxygen and the hydrogen contents are more in the molten metal hanging at the tip of the electrode which in turn lowers the surface tension, and thereby, it helps to produce the spray kind of transfer, because lower surface tension droplets are not able to take the larger size. Rutile electrodes containing the large amount of TiO2, therefore, the molten metal is not much oxidized. And therefore, surface tension of the molten metal is not much reduced. Hence, this type of the electrodes produced more globular and the less spray transfer.

(Refer Slide Time: 54:47)



The basic electrodes contain the powder of deoxidizers; therefore, moisture is removed completely from the molten metal, or the hydrogen content is also reduced from the weld metals significantly. Therefore, reduced traces of hydrogen and oxygen from the molten metal results in high surface tension of the molten metal hanging at the tip of the electrode, and therefore, in case of the basic electrodes metal transfer takes place by the short circuiting mode where molten metal drop touches the weld pool and by surface tension effect it is transferred to the weld pool.

(Refer Slide Time: 55:36)



High surface tension of the molten metal resist the detachment of the droplet, and thereby increase the size of size of the droplet at the tip of the electrode before it gets detached from the electrode under the gravitational force and electromagnetic pinch force. And conventionally, it is understood that the drops of 1 to 3 mm diameter are transferred at the speed of 10 to 20 centimeter per second. So, this was the second lecture on the shielded metal arc welding process, and now I will summarize the lecture on the shielded metal arc welding process as a whole.

We have seen that that what are the different power sources to be used with the shielded metal arc welding process. And what is the importance of the welding parameter selection, what are the different electrode coating materials used in the shielded metal arc welding processes electrodes, and what are the different functions performed by the coating materials, how the molten material is transferred during the welding from the electrode tip to the weld pool. And understanding on all these aspects will help to increase the better utilization of the shielded metal arc welding process as a whole to produce the sound weld joint.

Thank you.