ARC WELDING TECHNOLOGY

A Correspondence Course

LESSON III
COVERED ELECTRODES FOR WELDING MILD STEELS

An Introduction to Mild Steel Covered Electrodes

ESAB Welding &
Cutting Products

TABLE OF CONTENTS
LESSON III
COVERED ELECTRODES FOR WELDING MILD STEELS

TABLE OF CONTENTS
LESSON III - Con't

COVERED ELECTRODES FOR WELDING MILD STEELS

3.1 DEVELOPMENT OF COVERED ELECTRODES

During the 1890's, arc welding was accomplished with bare metal electrodes. The welds produced were porous and brittle because the molten weld puddle absorbed large quantities of oxygen and nitrogen from the atmosphere. Operators noticed that a rusty rod produced a better weld than a shiny clean rod. Observations also showed that an improved weld could be made by wrapping the rod in newspaper or by welding adjacent to a pine board placed close to and parallel with the weld being made. In these cases, some degree of shielding the arc from the atmosphere was being accomplished. These early observations led to the development of the coated electrode.

3.1.0.1 Around 1920, the A.O. Smith Corporation developed an electrode spirally wrapped with paper, soaked in sodium silicate, and then baked. This was the first of the cellulosic type electrodes. It produced an effective gas shield in the area and greatly improved the ductility of the weld metal.

3.1.0.2 Because of the method used to manufacture these paper covered electrodes, it was difficult to effectively add other ingredients to the coating. In 1924, the A.O. Smith Corporation began work on coatings that could be extruded over the core wire. This method allowed the addition of other flux ingredients to further improve or modify the weld metal and by 1927, these electrodes were being produced commercially.

3.1.0.3 Since 1927, many improvements have been made and many different types of electrodes have been developed and produced. Through variations in the formulations of the covering and the amount of covering on the mild steel core wire, many different classifications of electrodes are produced today.

3.2 Manufacturing Covered Electrodes

Mild steel covered electrodes, also commonly called coated electrodes, consist of only two major elements; the core wire or rod and the flux covering. The core wire is usually low carbon steel. It must contain only small amounts of aluminum and copper, and the sulfur and phosphorus levels must be kept <u>very</u> low since they can cause undesirable brittleness in the weld metal. The raw material for the core wire is hot-rolled rod (commonly called "hot rod"). It is received in large coils, cleaned, drawn down to the proper electrode diameter, straightened, and cut to the proper electrode length.

3.2.0.1 The coating ingredients, from which there are literally hundreds to choose, are carefully weighed, blended in a dry state, wet mixed, and compacted into a large cylinder that fits into the extrusion press. The coating is extruded over the cut core wires which are fed through the extrusion press at a rapid rate. The coating material is removed from the end of the electrode that is clamped into the electrode holder to assure electrical contact, and also from the welding end of the electrode to assure easy arc initiation.

3.2.0.2 The electrodes are then stamped with the type number for easy identification before entering the ovens, where they go through a controlled bake cycle to insure the proper moisture content before packaging.

3.2.0.3 Of the many quality control checks made during the manufacturing process, one of the most important is the procedure that insures that the coating thickness is uniform. In shielded metal arc welding, the coating crater, or the cup-like formation of the coating, that extends beyond the melting core wire, performs the function of concentrating and directing the arc. See Figure 1.

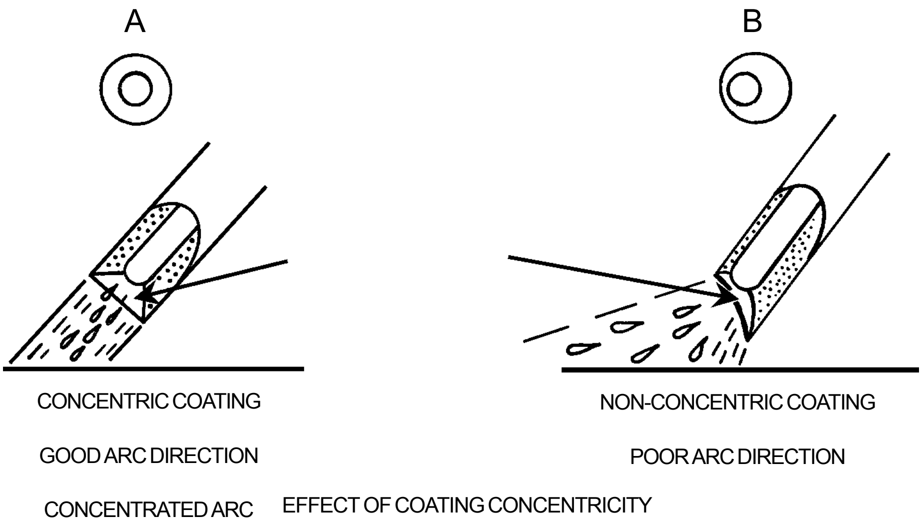


FIGURE 1

3.2.0.4 Concentration and direction of the arc stream is attained by having a coating crater, somewhat similar to the nozzle on a water hoze, directing the flow of weld metal. When the coating is not concentric to the core wire, it can cause the condition shown at B in Figure 1. The poor arc direction causes inconsistent weld beads, poor shielding, and lack of penetration. The electrode burns off unevenly, leaving a projection on the side where the coating is the heaviest. This condition is often referred to as *"fingernailing."*

3.2.1 Functions of Electrode Coatings - The ingredients that are commonly used in coatings can be classified physically in a broad manner as liquids and solids. The liquids are generally sodium silicate or potassium silicate. The solids are powdered or granulated materials that may be found free in nature, and need only concentration and grinding to the proper particle size. Other solid materials used are produced as a result of chemical reactions, such as alloys or other complex synthetic compounds.

3.2.1.1 The particle size of the solid material is an important factor. Particle size may be as coarse as fine sand, or as minute as sub-sieve size.

3.2.1.2 The physical structure of the coating ingredients may be classified as crystalline, fibrous or amorphous (non-crystalline). Crystalline materials such as rutile, quartz and mica are commonly used. Rutile is the naturally occurring form of the mineral titanium dioxide and is widely used in electrode coatings. Fibrous materials such as wood fibers, and non-crystalline materials such as glasses and other organic compounds are also common coating ingredients.

3.2.1.3 The functions of the coating on covered electrodes are as follows:

a) **Shielding of the Weld Metal** - The most important function of a coating is to shield the weld metal from the oxygen and nitrogen of the air as it is being transferred across the arc, and while it is in the molten state. This shielding is necessary to ensure the weld metal will be sound, free of gas pockets, and have the right strength and ductility. At the high temperatures of the arc, nitrogen and oxygen combine readily with iron to form iron nitrides and iron oxides that, if present in the weld metal above certain minimum amounts, will cause brittleness and porosity. Nitrogen is the primary concern since it is difficult to control its effect once it has entered the deposit. Oxygen can be counteracted by the use of suitable deoxidizers. In order to avoid contamination from the air, the stream of molten metal must be protected or shielded by gases that exclude the surrounding atmosphere from the arc and the molten weld metal. This is accomplished by using gas-forming materials in the coating that break down during the welding operation and produce the gaseous shield.

b) **Stabilization of the Arc** - A stabilized arc is one that starts easily, burns smoothly even at low amperages, and can be maintained using either a long or a short arc length.

c) **Alloying Additions to Weld Metal** - A variety of elements such as chromium, nickel, molybdenum, vanadium and copper can be added to the weld metal by including them in the coating composition. It is often necessary to add alloys to the coating to balance the expected loss of alloys of the core wire during the welding operation, due to volatization and chemical reaction. Mild steel electrodes require small amounts of carbon, manganese and silicon in the deposit to give sound welds of the desired strength level. A portion of the carbon and manganese is derived from the core wire, but it is necessary to supplement it with ferromanganese and in some cases ferrosilicon additions in the coating.

d) **Concentration of the Arc Stream** - Concentration or direction of the arc stream is attained by having a coating crater form at the tip of the electrodes as discussed earlier. Use of the proper binders assures a good hard coating that will maintain a crater and give added penetration and better direction to the arc stream.

e) **Furnish Slag for Fluxing** - The function of the slag is (1) to provide additional protection against atmospheric contamination, (2) to act as a cleaner and absorb impurities that are floated off and trapped by the slag, (3) to slow the cooling rate of the molten metal to allow the escape of gases. The slag also controls the contour, uniformity and general appearance of the weld. This is particularly true in fillet welds.

f) **Characteristics for Welding Position** - It is the addition of certain ingredients, primarily titanium compounds, in the coating that makes it possible to weld out-of-position , vertically, and overhead. Slag characteristics, primarily surface tension and freezing point, determine to a large degree the ability of an electrode to be used for out-of-position work.

g) **Control of Weld Metal Soundness** - Porosity or gas pockets in weld metal can be controlled to a large extent by the coating composition. It is the balance of certain ingredients in the coating that have a marked effect on the presence of gas pockets in the weld metal. The proper balance of these is critical to the soundness that can be produced. Ferromanganese is probably the most common ingredient used to attain the correctly balanced formula.

h) **Specific Mechanical Properties to the Weld Metal** - Specific mechanical properties can be incorporated into the weld metal by means of the coating. High impact values at low temperature, high ductility, and increases in yield and tensile properties can be attained by alloy additions to the coating.

i) **Insulation of the Core Wire** - The coating acts as an insulator so that the core wire will not short-circuit when welding in deep grooves or narrow openings; coatings also serve as a protection to the operator when changing electrodes.

3.2.2 Classification of Coating Ingredients - Coating materials can be classified into the following 6 major groups:

a) **Alloying Elements** - Alloying elements such as molybdenum, chromium, nickel, manganese and others impart specific mechanical properties to the weld metal.

b) **Binders** - Soluble silicates such as sodium and potassium silicates, are used in the electrode coating as binders. Functions of binders are to form a plastic mass of coating material capable of being extruded and baked. The final baked coating should be hard so that it will maintain a crater and have sufficient strength so that it will not spall, crack or chip. Binders are also used to make coating non-flammable and avoid premature decomposition.

c) **Gas Formers** - Common gas forming materials used are the carbohydrates, hydrates, and carbonates. Examples would be cellulose (such as wood flock), the carbonates of calcium and magnesium, and chemically combined water as is found in clay and mica. These materials evolve carbon dioxide (CO_2), carbon monoxide (CO), and water vapor (H_2O) at the high temperature of the welding arc. Free moisture is another gas-forming ingredient that is found particularly in cellulosic type electrodes and is a part of the formulation in amounts of 2%-3%. It has a marked influence on the arc and is a necessary ingredient in the E6010 type electrode.

d) **Arc Stabilizers** - Air is not sufficiently conductive to maintain a stable arc, so it becomes necessary to add coating ingredients that will provide a conductive path for the flow of current. This is particularly true when welding with alternating current. Stabilizing materials are titanium compounds, potassium compounds, and calcium compounds.

e) **Fluxes and Slag Formers** - These ingredients are used primarily to give body to the slag and impart such properties as slag viscosity, surface tension, and melting point. Silica and magnetite are materials of this type.

f) **Plasticizers** - Coatings are often very granular or sandy, and in order to successfully extrude these coatings, it is necessary to add lubricating materials, plasticizers, to make the coating flow smoothly under pressure. Sodium and potassium carbonates are often used.

3.2.2.1 The chart in Figure 2 shows typical coating constituents and their functions for two types of mild steel electrodes. Note that the moisture content in the cellulosic E6010 is much higher than in the low hydrogen E7018 type. The moisture in the E6010 coating is necessary to produce the driving arc characteristic and is not harmful when welding the lower strength steels. Hydrogen can cause problems when welding the higher strength steels and will be discussed in detail in Lesson IV.

Class	Composition		Function	Shielding
E6010	Cellulose ($C_6H_{10}O_5$)	35%	Gas Former	40% H_2
	Rutile (TiO2)	15%	Slag Former - Arc Stabilizer	40% $CO + CO_2$
	Ferromanganese	5%	Deoxidizer - Alloying	20% H_2O
	Talc	15%	Slag Former	
	Sodium Silicate	25%	Binder - Fluxing Agent	
	Moisture	5%		
E7018	Calcium Carbonate	30%	Gas Former - Fluxing Agent	
	Fluorspar (CaF_2)	20%	Slag Former - Fluxing Agent	
	Ferromanganese	5%	Deoxidizer - Alloying	80% CO
	Potassium Silicate	15%	Binder - Arc Stabilizer	20% CO_2
	Iron Powder	30%	Deposition Stabilizer	
	Moisture	0.1%		

COMPOSITION AND FUNCTION OF ELECTRODE COATING CONSTITUENTS

FIGURE 2

3.3 AWS SPECIFICATION A5.1-91

This American Welding Society (AWS) specification has been developed over the years by a filler metals committee, composed of members who represent electrode producers, such as ESAB, users from the welding industry, and independent members from colleges, universities and independent laboratories. This balanced membership is required to prevent prejudice from entering into the specifications.

3.3.0.1 Individual Mild Steel electrodes are classified by the manufacturer according to the above specification on the basis of the mechanical properties (also called physical properties) of the weld metal, the type of covering, the welding position of the electrode, and the type of current (AC or DC). The classification system is designed to give certain information about the electrode and the weld metal produced from it. The significance of the AWS designations are shown in tabular form in Figure 3.

3.3.0.2 These classifications, with the AWS Specification A5.1-91, are assigned by the manufacturer of the electrodes according to the results of his own tests. The American Welding Society does not approve or disapprove electrodes.

3.3.0.3 The American Society of Mechanical Engineers (ASME) uses the AWS Electrode Specifications word for word by adding the letters SF before the specification number. Thus, AWS Specification A5.1-91 becomes ASME Specification SFA5.1. The classification and requirements are the same.

MILD STEEL COVERED ELECTRODES

EXAMPLE: E 60 1 0
(1) (2) (3) (4)

1. E — Stands for electrode.
2. Two digits indicate tensile strength x 1000 PSI.
3. Third digit refers to welding position.

EXX1X	All position (flat, horizontal, vertical, overhead).
EXX2X	Horizontal and flat only.
EXX3X	Flat position only.
EXX4X	Flat, overhead, horizontal, vertical down.

4. Last digit indicates usability of the electrode, i.e. type of current and the type of covering. In some cases, both the third and fourth digits are significant.

Classification	Current	Arc	Penetration	Covering & Slag	Iron Powder
EXX10	DCEP	Digging	Deep	Cellulose - sodium	0- 10%
EXXX1	AC or DCEP	Digging	Deep	Cellulose - potassium	0
EXXX2	AC or DCEN	Medium	Medium	Titania - sodium	0-10%
EXXX3	AC or DCEN or DCEP	Soft	Light	Titania - potassium	0- 10%
EXXX4	AC or DCEN or DCEP	Soft	Light	Titania - iron powder	25-40%
EXXX5	DCEP	Medium	Medium	Low hyd. - sodium	0
EXXX6	AC or DCEP	Medium	Medium	Low hyd. - potassium	0
EXXX8	AC or DCEP	Medium	Medium	Low hyd. - iron powder	25-40%
EXX20	AC or DCEN	Medium	Medium	Iron oxide - sodium	0
EXX22	AC or DCEN or DCEP	Medium	Medium	Iron oxide - sodium	0
EXX24	AC or DCEN or DCEP	Soft	Light	Titania - iron powder	50%
EXX27	AC or DCEN or DCEP	Medium	Medium	Iron oxide- iron powder	50%
EXX28	AC or DCEP	Medium	Medium	Low hyd. - iron powder	50%
EXX48	AC or DCEP	Medium	Medium	Low hyd. - iron powder	25-40%

DCEP — Direct Current Electrode Positive
DCEN — Direct Current Electrode Negative

Note: Iron powder percentage based on weight of the covering.

ELECTRODE CLASSIFICATION

FIGURE 3

<u>3.3.1</u> **<u>Chemical Composition of Weld Metal (AWS A5.1-91)</u>** - Chemical requirements are as follows:

a) Classifications E6010, E6011, E6012, E6013, E6020, E6022 and E6027 have no requirements.

b) Classification E7018 and E7027 must have no more than 1.60% Manganese, 0.75% Silicon, 0.30% Nickel, 0.20% Chromium, 0.30% Molybdenum, and 0.08% Vanadium.

c) Classifications E7014, E7015, E7016, E7024, E7028 and E7048 must have no more than 1.25% Manganese, 0.90% Silicon, 0.30% Nickel, 0.20% Chromium, 0.30% Molybdenum, and 0.08% Vanadium.

<u>3.3.2</u> **<u>Mechanical Properties (AWS A5.1-91)</u>** - Physical tests are performed on all specimens in the *"as-welded"* condition. This means that the weldment or weld metal is not subjected to any type of heat treatment. Tensile test specimens for all electrode classifications other than the low hydrogen types (E7015, E7016, E7018, E7028 and E7048) are aged at 200°F to 220°F for forty-eight (48) hours prior to being subjected to the tensile test. This is not considered heat treatment. It simply accelerates the diffusion of hydrogen from the weld metal welded with the cellulosic or titania type of electrodes.

3.3.2.1 **Classifications E6010, E6011 and E6027** weld metals are required to have more than 62,000 psi tensile strength, 50,000 psi yield strength, 22% elongation in two inch gauge, and 20 ft-lb at -20°F Charpy V-notch impact.

3.3.2.2 **Classification E6020** weld metals are required to have more than 62,000 psi tensile strength, 50,000 psi yield strength, 22% elongation in two inch gauge, and no Charpy V-notch impact requirements.

3.3.2.3 **Classifications E6012 and E6013** weld metals are required to have more than 67,000 psi tensile strength, 55,000 psi yield strength, 17% elongation in two inch gauge, and no Charpy V-notch impact requirements.

3.3.2.4 **Classification E6022** weld metals are required to have more than 67,000 psi tensile strength, no requirement for yield strength and no Charpy V-notch requirements.

3.3.2.5 **Classifications E7014 and E7024** weld metals are required to have more than 72,000 psi tensile strength, 60,000 psi yield strength, 17% elongation in two inch gauge, and no Charpy V-notch impact requirements.

3.3.2.6 **Classifications E7015, E7016, E7018, D7027 and E7048** are required to have more than 72,000 psi tensile strength, 60,000 psi yield strength, 22% elongation in two inch gauge, and 20 ft-lb at -20°F Charpy V-notch impacts.

3.3.2.7 **Classification E7028** is required to have more than 72,000 psi tensile strength, 60,000 psi yield strength, 22% elongation in two inch gauge, and 20 ft-lb at 0°F Charpy V-notch impacts.

<u>3.3.3 Individual Electrode Characteristics</u>

a) **E6010** electrodes were originally developed to provide improved welding operation and weld metal. The coating is mostly wood pulp or flour modified with mineral silicates, deoxidizers, and sodium silicate. The amount of coating on the electrode is low, about 10-12% by weight. Because the wood pulp burns away during welding, the slag is minimal and is usually easily removed. The arc has deep penetration and with proper manipulation of the arc, good welds can be deposited in all positions. Most of the ships built in the United States during World War II were welded with this classification of electrode. Special formulations of this classification are used to weld line pipe joints in the vertical-down position. Reasonably sound welds can be deposited in open root butt joints (see Appendix A - Glossary) with this electrode.

b) **E6011** electrodes are similar to E6010 except that sufficient potassium compounds have been added to the coating to stabilize the arc stream and allow the electrode to be used on alternating current. Penetration is slightly less than that of the E6010 type.

c) **E6012** electrodes have several common names. In Europe, they are called rutile (see Glossary) electrodes. Many welders call them cold rods. The coating contains large percentages of the mineral rutile (titanium dioxide), i.e., the titania referred to in the classification. The arc has low penetration, and with proper manipulation wide gaps can be bridged. Although the specification calls for operation on either AC or DC, the arc is smoother and spatter level lower when direct current is used.

d) **E6013** electrodes also contain a large percentage of titanium dioxide in their coating. They are designed to have a low penetrating arc allowing thin sheet metal to be welded without burn-through. The coating contains sufficient potassium compounds to stabilize the arc sufficiently for welding with alternating current.

e) **E7014** electrodes are related to 6013 electrodes except that iron powder has been added and a heavier coating is applied to the core wire. This results in higher deposition rates with the E7014 electrode than with the E6013.

f) **E7015** electrodes were the first of the low hydrogen electrodes. They were developed in the 1940's to weld hardenable steels such as armor plate. All of the previously discussed electrodes have appreciable amounts of hydrogen in their coatings in the form of water or chemically combined hydrogen in chemical compounds. When hardenable steel is welded with any of those electrodes containing considerable hydrogen, *"underbead cracking"* commonly occurs. These cracks appear in the base metal usually just below, and parallel to, the weld bead. Limestone and other ingredients that are low in moisture are used in the coating, eliminating this hydrogen induced cracking. The coating is a low hydrogen, sodium type that limits these electrodes to be used only with direct current, reverse polarity. E7015 electrodes are not generally available today having been replaced by the E7016 and E7018 type.

g) **E7016** electrodes are very similar to the E7015 type except that the use of potassium in the coating allows these electrodes to be used with alternating current as well as direct current, reverse polarity.

h) **E7018** electrodes are the more modern version of the low hydrogen electrode. The addition of considerable amounts of iron powder to the covering results in a smoother arc with less spatter. This modern balance of covering ingredients results in a great improvement in arc stability, arc direction and ease of handling in all welding positions.

i) **E6020** electrodes have a coating that consists mainly of iron oxide, manganese compounds and silica. They have a spray-type arc and produce a heavy slag that provides protection of the molten weld metal. The molten weld metal is very fluid, limiting the use to flat or horizontal fillet welds.

j) **E6022** electrodes are for high speed, high current single pass welding of sheet metal. They are not generally available today.

k) **E7024** electrodes have a coating similar to the E6012 and E6013 types, but have a very heavy coating that contains 50% iron powder by weight. Run at relatively higher currents, the deposition rate is high. Welds are limited to the flat and horizontal fillet positions. Penetration is relatively low. AC or DC, either polarity may be used.

m) **E6027** electrodes are also a high iron powder type, the coating consisting of 50% iron powder by weight. Current may be AC or DC, either polarity. The penetration is medium and the weld beads are slightly concave with good side wall fusion. As with all high iron powder electrodes, deposition rate is high.

n) **E7028** electrodes are much like the E7018 electrodes except that the coating is heavier and contains 50% iron powder by weight. Unlike the E7018 electrode, they are suitable for flat and horizontal fillet welding only. Deposition rate is very high.

o) **E7048** electrodes are much like the E7018 electrodes except they are designed for exceptionally good vertical-down welding.

3.4 SELECTING THE PROPER MILD STEEL COVERED ELECTRODE

Many factors must be considered when selecting the proper electrode for a given application. Some items to be considered are:

a) **Type of Base Metal** - Welding mild steels or low carbon steels (carbon content below 0.30%) with mild steel coated electrodes presents no problems as far as tensile strength is concerned since the tensile strength of the weld metal usually exceeds the tensile strength of the base metal. However, chemistry of the base metal is important. Welds made on free machining steels that have a relatively high sulfur content, will be porous unless welded with a low hydrogen type electrode such as E7018. Sometimes off analysis steels or mild steels of doubtful analysis are encountered. In this case, one of the low hydrogen types would be the best choice.

b) **Position of the Weld** - Weld position will determine whether an all-position electrode or a flat and horizontal type electrode should be used. Higher welding currents, and therefore, higher deposition rates are possible when welding flat or horizontally. Whenever possible, the work should be positioned both for ease of welding and to attain the highest welding speed.

c) **Available Equipment** - Electrode choice will depend on whether AC or DC welding machines are available. If both currents are available, consider these general facts.

1. For deepest penetration, use DC reverse polarity (Electrode Positive).
2. For lower penetration and higher deposition rate, use DC straight polarity (Electrode Negative).
3. For freedom of arc blow, use AC.

d) **Plate Thickness** - When welding sheet metal, low penetration electrodes should be chosen. Heavier plate may demand an electrode with deep penetration. Very heavy plate may require a deep penetrating electrode for the initial or root pass, and a higher deposition type for succeeding passes.

e) **Fit-Up** - Some electrodes are more suitable than others for bridging gaps between the members to be welded. This is termed "poor fit-up" and some electrode manufacturers produce electrodes that are specially formulated for this purpose.

f) **Welding Costs** - The major factors that affect welding costs are labor and overhead, deposition rate, efficiency of the electrode being used and the cost of the electrodes. The cost of electrical power is also a factor to a lesser degree. By far, the largest factor is labor and overhead.

g) **Welder Appeal**- Welder appeal is definitely important, although this factor must not be allowed to subordinate other more significant criteria.

3.4.1 Typical Electrode Use by Welding Classification

3.4.1.1 The E6010 and E6011 classification electrodes would most likely be used for welding a mild steel joint in the vertical position with an open root. If there are only AC power sources available, the choice between these two must be the E6011 type. Many times arc blow is encountered when welding with direct current. The use of E6011 electrodes on alternating current eliminates the arc blow.

3.4.1.2 The E6012 classification electrodes are largely used today in repair and welding of less critical structures. Carbon steels with some rust present can be welded with this type of electrode. It can be used to bridge or weld across wide gaps. The use of this electrode, however, has diminished greatly in the past few years. Before the advent of the low hydrogen electrodes and other welding processes, the E6012 electrode made up 60% of the total production of electrodes. Today, it represents about 6% of the total production in the United States.

3.4.1.3 The E6013 classification of covered mild steel electrodes was originally designed to have low arc penetration and flat smooth weld beads. These features allowed the electrode to weld sheet metal. Today, many 6013 electrodes are used instead of 6012 electrodes because of the smoother arc, less spatter and more uniform weld bead surface.

3.4.1.4 The E7014 classification of covered mild steel electrodes, as indicated earlier, have iron powder added to the coating formulation of the E6013 electrodes. This addition allows the electrode to be welded at higher currents, resulting in higher deposition rates and deposition efficiencies. Applications for the E7014 are similar to those of the E6013 electrodes.

3.4.1.5 The E7016 covered mild steel electrodes are, as indicated earlier, low hydrogen with a basic slag system. This combination of attributes allows the electrode to be used to weld some of the higher carbon steels and some low alloy steels. This electrode has diminished in usage because of its lower deposition rate and lower deposition efficiency than the more modern E7018 electrode.

3.4.1.6 The E7018 classification is the low hydrogen iron powder electrode. The appreciable amount of iron powder in the coating and the somewhat heavier amount of coating on the core wire allow the electrodes to be used at higher currents than those used with the

E7016. The smooth arc and easy welding with the E7018 electrode make it a welder's favorite. The relatively high welding currents and the addition of the iron powder melting into the weld metal result in higher deposition rates and higher deposition efficiencies. The E7018 covered mild steel electrode deposits the highest quality weld metal available from manual arc welding. The only major disadvantage of the E7018 is the need to be kept dry. Electrodes that have picked up moisture by exposure to the atmosphere or other sources deposit porous weld metal. Also E7018 electrodes cannot be used to weld the root pass in an open butt joint without excess porosity. When E7018 electrodes are to be used in butt welds, the root should be closed by a backing bar, ceramic back-up tape, or consumable insert. If a backing bar is used, it must be removed after the joint is welded by the gas metal arc or the gas tungsten arc process and successive passes applied with E7018 for a high quality weld metal deposit.

3.4.1.7 The E7024 classification of covered mild steel electrodes is the result of heavy additions of iron powder to the E6012 formulation and large increases in the amount of coating on the core wire. About 50% of the coating is iron powder. Very high deposition rates and deposition efficiencies result from this combination of more coating and iron powder. The electrode is limited to welding horizontal fillets and flat positions. The quality of the weld metal is not as high as that from E7018 electrodes since the ductility of E7024 weld metal is lower.

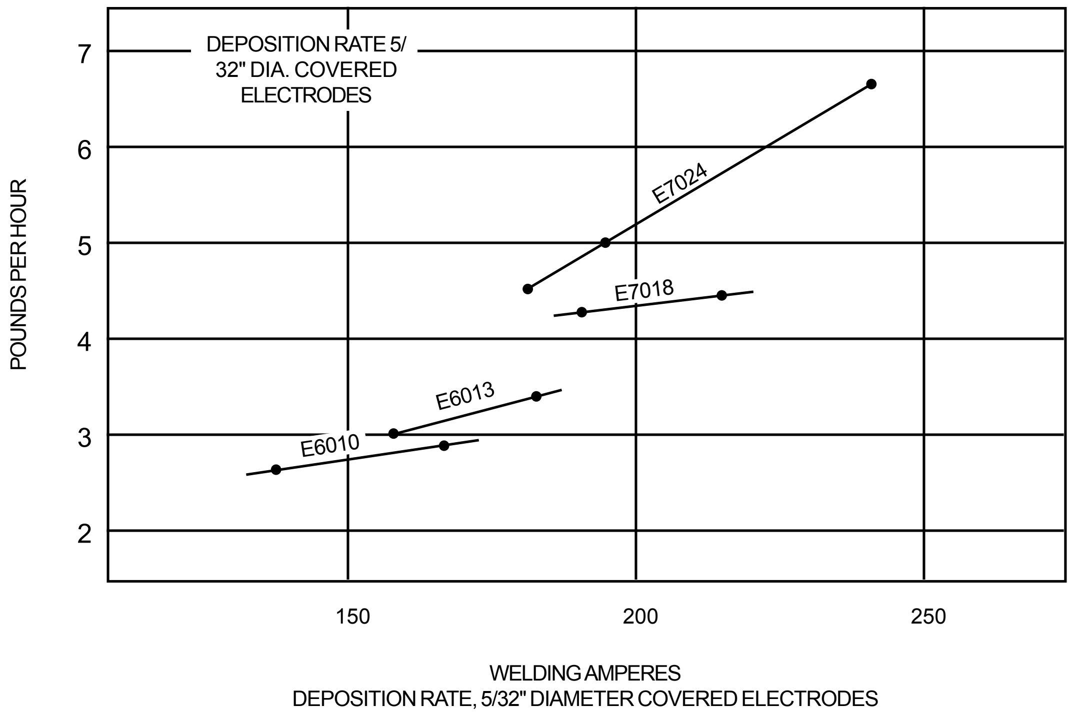


FIGURE 4

<u>3.4.2</u> **<u>Electrode Deposition</u>** - The <u>deposition rate</u> of a given electrode influences the total cost of depositing weld metal substantially. The deposition rate is the weight of weld metal deposited in a unit of time. Deposition rate increases as the welding current increases within the limits of a given electrode. As can be seen in Figure 4, a 5/32" diameter E7024 electrode can deposit weld metal more than twice as fast as a 5/32" diameter E6010 electrode. It is apparent that a substantial saving in labor and overhead can be achieved if one of the higher deposition electrodes can be used.

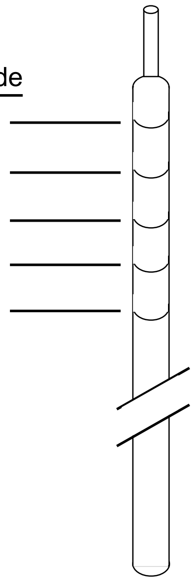
3.4.2.1 The <u>deposition efficiency</u> of a given electrode also has an effect on welding costs. The deposition efficiency is the weight of the weld metal deposited compared to the weight of the electrode consumed, expressed as a percentage.

Class	Average Efficiency*
E6010	63.8%
E6011	68.5%
E6012	66.9%
E6013	66.8%
E7014	64.6%
E7016	62.8%
E7018	69.5%
E6020	65.2%
E7024	66.8%
E7027	68.6%

* Includes 2" Stub Loss

Stub Loss **

Stub Length	5/32" 6010 % Deposit	% Loss 14" Electrode
2"	63.8%	36.2%
3"	58.5%	41.5%
4"	53.2%	46.8%
5"	47.9%	52.1%
6"	42.6%	57.4%



** E6010 is 71.57% efficient.
Loss due to slag, spatter, and smoke

$$\text{EFFICIENCY} = \frac{\text{Weight of Weld Metal}}{\text{Weight of Electrode Used}}$$

ELECTRODE EFFICIENCY AND STUB LOSS

FIGURE 5

3.4.2.2 When welding with coated electrodes, some of the electrode weight is lost as slag, spatter, fumes, gases, and stubs. If an electrode is 65% efficient, it means that for every 100 pounds of electrodes consumed, 65 pounds of weld metal will be produced. Stub loss, the part of the electrode that is thrown away, is not considered in the deposition efficiency, since the stub length will vary with the operator or the application. Figure 5 illustrates how stub loss affects efficiency. An 6010 electrode has an actual average efficiency of 71.5% before the allowance for stub loss. A 2" stub results in the efficiency dropping to 63.8%. If 6" stubs are thrown away, 100 pounds of electrodes will produce only 42.6 pounds of weld metal. Methods of calculating total weld costs will be covered in a subsequent lesson.

3.5 ACID AND BASIC SLAG SYSTEMS

The type of slag produced from covered electrodes has a definite effect on the quality of the weld metal. The E6010, 6011, 6012, 6013, 7014, 7024 and other cellulosic and rutile electrodes, produce slags that are predominantly silicon dioxide (sand) and have an acidic behavior. Acid slag systems do no refining of the weld metal. In contrast, the slag from the E7016, E7018 and other low hydrogen electrodes is made up mostly of lime and fluorspar,two items that are basic in chemical behavior. Basic slags do some refining of the weld metal, resulting in lower nonmetallic inclusion content.

3.6 ADVANTAGES AND DISADVANTAGES OF MILD STEEL COVERED ELECTRODES

Of all the welding done in the United States, approximately half of it is done with covered electrodes via the shielded metal arc welding (SMAW) process. Every imaginable shape and structure made of medium or low carbon steel has been welded with mild steel covered electrodes. The welding advantages of this process are several. It is the simplest welding process available. All that is needed is a constant current power source, two electrical leads and the electrode. It is the most flexible welding process in that it can be used in any position on almost any thickness of carbon steel in any location. The disadvantages are that the covered mild steel welding has lower deposition rates than other processes, thus making it less efficient. Also, the use of covered mild steel electrodes requires more welder training than the semi-automatic and automatic welding processes.

3.7 ESAB SUREWELD MILD STEEL COATED ELECTRODES FEATURES AND DATA

3.7.1 SUREWELD 10P (AWS E6010) - This is an all-position cellulosic (wood flour) electrode that is especially suited for pipe welding but also functions as an excellent general purpose 6010 wire. As a pipe welding electrode, it produces the consistent, deep penetration required to maintain a proper keyhole when welding in open root pipe joints. Recommended for API grades A25, A, B, and X42 grade pipe and for general structural, ship, barge, and storage tank fabrication.

Typical mechanical properties are:

Yield Strength - 67,100 psi

Tensile Strength - 79,800 psi

Elongation (2" Gauge) - 29%

Charpy V-Notch Impact Resistance - 27 ft-lbs @ 0°F
22 ft-lbs @ -20°F

The typical chemical composition of the weld metal is:

Carbon	0.12%	Phosphorus	0.009%
Manganese	0.28%	Sulfur	0.017%
Silicon	0.18%		

DEPOSITION RATE DATA: SUREWELD 10P*

Electrode Diameter	Amperage	Efficiency, %	Deposition (Lbs/Hr.)
3/32"	70	72.0%	1.5
	100	65.0%	1.7
1/8"	100	76.34	2.12
	130	68.81	2.31
5/32"	140	73.57	2.8
	170	64.14	2.93
3/16"	160	74.9	3.3
	190	69.7	3.52

*Note: Efficiencies do not include stub loss

3.7.2 SUREWELD 710P (AWS E7010-P1) - An all-position cellulosic electrode especially suited for welding high strength pipe. It produces the consistent, deep penetration required to maintain a proper keyhole when vertical-down welding in open root pipe joints. X-ray quality welds can be produced using flat, horizontal, overhead, vertical-up, and vertical-down procedures. Recommended for X46, X52, and X56 grade pipe, it may also be used for welding root passes in higher grade pipe in some circumstances.

Typical mechanical properties are:

Yield Strength - 69,800 psi

Tensile Strength - 81,200 psi

Elongation (2" Gauge) - 22%

Charpy V-Notch Impact Resistance - 29 ft-lbs @ -20°F
26 ft-lbs @ -50°F

The typical chemical composition of the weld metal is:

Carbon	0.10%	Sulfur	0.016%
Manganese	0.31%	Nickel	0.53%
Silicon	0.18%	Molybdenum	0.24%
Phosphorus	0.008%		

DEPOSITION RATE DATA: SUREWELD 710P*

Electrode Diameter	Amperage	Efficiency, %	Deposition (Lbs/Hr.)
3/32"	70	72.0%	1.5
	100	65.0%	1.7
1/8"	100	76.34	2.12
	130	68.81	2.31
5/32"	140	73.57	2.8
	170	64.14	2.93
3/16"	160	74.9	3.3
	190	69.7	3.52

*Note: Efficiencies do not include stub loss

3.7.3 SUREWELD 810P (AWS E8010-P1) - An all-position cellulosic electrode especially suited for welding high strength pipe. It produces the consistent, deep penetration required to maintain a proper keyhole when vertical-down welding in open root pipe joints. X-ray quality welds can be produced using flat, horizontal, overhead, vertical-up, and vertical-down procedures. Recommended for X60, X65, and X70 grade pipe.

Typical mechanical properties are:

Yield Strength - 72,700 psi

Tensile Strength - 88,300 psi

Elongation (2" Gauge) - 24%

Charpy V-Notch Impact Resistance - 31 ft-lbs @ -20°F
25 ft-lbs @ -50°F

The typical chemical composition of the weld metal is:

Carbon	0.10%	Sulfur	0.014%
Manganese	0.48%	Nickel	0.98%
Silicon	0.24%	Molybdenum	0.11%
Phosphorus	0.008%		

DEPOSITION RATE DATA: SUREWELD 810P*

Electrode Diameter	Amperage	Efficiency, %	Deposition (Lbs/Hr.)
3/32"	70	72.0%	1.5
	100	65.0%	1.7
1/8"	100	76.34	2.12
	130	68.81	2.31
5/32"	140	73.57	2.8
	170	64.14	2.93
3/16"	160	74.9	3.3
	190	69.7	3.52

*Note: Efficiencies do not include stub loss

3.7.4 SUREWELD SW14 (AWS E6011) - This is also a cellulosic all-position electrode that has the arc stabilized to weld with alternating current. It produces an easily controlled forceful arc with a deep penetration and high quality weld metal that meets specification requirements for soundness. Typical applications include welding of bridges and buildings, piping, ships, pressure vessels and tanks.

Typical mechanical properties of the weld metal are:

Yield Point - 66,800 psi

Tensile Strength - 76,100 psi

Elongation (2" Gauge) - 22%

Reduction of Area - 56%

Charpy V-Notch Impact Resistance - 31 ft-lbs @ -20°F

The typical chemical composition of the weld metal is:

Carbon	0.10%	Phosphorus	0.012%
Manganese	0.36%	Sulfur	0.016%
Silicon	0.15%		

DEPOSITION RATE DATA: SW14*

Electrode Diameter	Amperage	Efficiency, %	Deposition (Lbs/Hr.)
1/8"	120	70.7	2.3
5/32"	150	77.0	3.7
3/16"	180	73.4	4.1
7/32"	210	74.2	5.0
1/4"	250	71.9	5.0

*Note: Efficiencies do not include stub loss

3.7.5 SUREWELD SW612 (AWS E6012) - This is a multiple purpose rutile electrode that is useful for poor fitup welding. It deposits convex weld beads that have great resistance to cracking. It withstands the high amperage of production welding without coating breakdown. The weld deposit has excellent mechanical properties for the classification. The SW612 electrode is used to weld truck bodies, trailers, tanks, farm machinery and auto parts.

Typical mechanical properties are:

Yield Point - 62,300 psi

Tensile Strength - 69,400 psi

Elongation (2" Gauge) - 21%

Reduction of Area - 54%

The typical chemical composition of the weld metal is:

Carbon	0.05%	Phosphorus	0.008%
Manganese	0.31%	Sulfur	0.016%
Silicon	0.12%		

DEPOSITION RATE DATA: SW612*

Electrode Diameter	Amperage	Efficiency, %	Deposition (Lbs/Hr.)
1/8"	130	81.8	2.9
5/32"	165	78.8	3.2
	200	69.0	3.4
3/16"	220	77.0	4.0
	250	74.5	4.2
7/32"	320	69.8	5.6
1/4"	320	70.0	5.6
	360	67.7	6.6
	380	66.0	7.1

*Note: Efficiencies do not include stub loss

<u>3.7.6</u> **<u>SUREWELD SW15 (AWS E6013)</u>** - This is a fine high production electrode that can weld thicknesses from light gauge sheet to heavy plate. High welding currents and travel speeds can be used without undercut. The slag is self-cleaning. SW15 may be used to weld metal fixtures, road equipment, farm machinery, building structures, storage tanks, and iron work.

Typical mechanical properties of the weld metal are:

Yield Point - 63,000 psi

Tensile Strength - 71,000 psi

Elongation (2" Gauge) - 24%

Reduction of Area - 49%

The typical chemical composition of the weld metal is:

Carbon	0.06%	Phosphorus	0.012%
Manganese	0.32%	Sulfur	0.013%
Silicon	0.23%		

<u>DEPOSITION RATE DATA:</u> SW15*

Electrode Diameter	Amperage	Efficiency, %	Deposition (Lbs/Hr.)
5/32"	140	75.6	2.60
	160	74.1	3.02
	180	71.2	3.48
3/16"	180	73.9	3.20
	200	71.1	3.80
	220	72.9	4.09
7/32"	250	71.3	5.30
	270	73.0	5.70
	290	72.7	6.08
1/4"	290	75.0	6.20
	310	73.5	6.50
	330	72.1	7.10

*Note: Efficiencies do not include stub loss

<u>3.7.7</u> **<u>6013LV (AWS E6013)</u>** - The arc characteristics, weld metal properties and intended applications are similar to SW-15 (E6013) electrodes. This electrode is intended for use on AC power sources where there is less than 50 open circuit volts. These lower open circuit voltage machines make the arc initiation and restrike difficult with a conventional E6013 electrode. The 6013LV is a suitable replacement for SW-15.

<u>3.7.8</u> **<u>SUREWELD SW15-IP (AWS E7014)</u>** - This electrode has iron powder added to the coating, permiting use of higher welding currents. The deposition rate is increased by the use of higher welding currents while the iron powder content of the covering increases the deposition efficiency. Both of these increases make the welding operation more efficient. The high currents and high welding speeds can be used without undercut. The slag removal is easy and complete. Typical applications include construction equipment, metal fixtures, automotive parts, barges and farm machinery.

Typical mechanical properties of SW15-IP weld metal are:

Yield Point - 61,000 psi

Tensile Strength - 71,300 psi

Elongation (2" Gauge) - 28%

The typical chemical composition of the weld metal is:

Carbon	0.04%	Phosphorus	0.015%
Manganese	0.31%	Sulfur	0.019%
Silicon	0.14%		

<u>DEPOSITION RATE DATA:</u> SW15-IP*

Electrode Diameter	Amperage	Efficiency, %	Deposition (Lbs/Hr.)
1/8"	120	63.9	2.45
	150	61.1	3.10
5/32"	160	71.9	3.04
	200	67.0	3.69
3/16"	230	70.9	4.50
	270	73.2	5.50
7/32"	290	67.2	5.82
	330	70.3	7.12
1/4"	350	68.7	7.08
	400	69.9	8.70

*Note: Efficiencies do not include stub loss

<u>3.7.9</u> **<u>SUREWELD 70LA-2 (AWS E7016)</u>** - This low hydrogen electrode has a special lime covering that allows the electrode to deposit trouble-free welds on difficult to weld steels, such as high carbon, low alloy, sulfur bearing free machining, and cold rolled steels. It is usable with high amperages with corresponding high deposition rates making it more economical than conventional electrodes on heavy work. The electrodes must be kept dry, and welding should be performed using as short an arc as possible.

Typical mechanical properties of the weld metal are:

Yield Point - 69,500 psi

Tensile Strength - 79,000 psi

Elongation (2" Gauge) - 28%

Reduction of Area - 75%

The typical chemical composition of the weld metal is:

Carbon	0.07%
Manganese	0.09%
Silicon	0.50%

<u>DEPOSITION RATE DATA:</u> 70LA-2*

Electrode Diameter	Amperage	Efficiency, %	Deposition (Lbs/Hr.)
5/32"	140	70.5	3.01
	160	69.1	3.24
	190	66.0	3.61
3/16"	175	71.0	3.79
	200	71.0	4.23
	225	70.0	4.40
	250	65.8	4.77
1/4"	250	74.5	5.93
	275	74.1	6.42
	300	73.2	6.78
	350	71.5	7.58

*Note: Efficiencies do not include stub loss

<u>3.7.10 ATOM ARC 7018 (AWS E7018)</u> - This electrode was the original iron powder low hydrogen electrode in the United States and continues to be the standard of comparison against all others. Outstanding economy and mechanical properties are achieved when Atom Arc 7018 electrodes are used to weld carbon steels, high sulfur steels, enameling steels, and low alloy high tensile steels in all thicknesses. In addition, Atom Arc 7018 electrodes today are manufactured with a moisture resistant coating. Preheat levels may be reduced when welding many hardenable steels with Atom Arc 7018 electrodes.

Applications for Atom Arc 7018 electrodes include practically every structure that is welded today. It has been especially useful in welding large oil storage tanks, nuclear plant parts, and in many critical weldments that require the highest possible quality and reliability.

Typical mechanical properties of Atom Arc 7018 weld metal are:

Yield Point - 68,000 psi

Tensile Strength - 78,000 psi

Elongation (2" Gauge) - 30%

Reduction of Area - 75.5%

Charpy V-Notch Impact Resistance - 125 ft-lbs @ 72°F
70 ft-lbs @ -20°F

The typical chemical composition of Atom Arc 7018 weld metal is:

Carbon	0.045%	Phosphorus	0.015%
Manganese	1.10%	Sulfur	0.014%
Silicon	0.4%		

<u>DEPOSITION RATE DATA:</u> Atom Arc 7018*

Electrode Diameter	Amperage	Efficiency, %	Deposition (Lbs/Hr.)
1/8"	120	71.6	2.58
	140	70.9	2.74
	160	68.1	2.99
5/32"	140	75.0	3.11
	170	73.5	3.78
	200	73.0	4.31

3/16"	200	76.4	4.85
	250	74.6	5.36
	300	70.3	5.61
7/32"	250	75.0	6.5
	300	74.0	7.2
	350	73.0	7.4
1/4"	300	78.0	7.72
	350	77.0	8.67
	400	74.0	9.04

*Note: Efficiencies do not include stub loss

3.7.11 ATOM ARC 7018AC (AWS E7018) - This iron powder low hydrogen electrode was specifically designed for optimum performance on AC power sources. This electrode features easier arc starting, improved restrike, and smoother metal transfer than a standard E7018 electrode on AC. Typically, this electrode is used as a tacking electrode.

3.7.12 SUREWELD 7024 (AWS E7024) Conforms to 7024-1 - The Sureweld 7024 electrode is approved by the American Bureau of Shipping. It is a high speed electrode using heavy concentrations of iron powder in the coating. Used with high welding currents, it produces high deposition rates in horizontal fillet and flat welding positions. The electrode has excellent operator appeal and produces equal leg 45° fillets that eliminate overwelding. The welds have excellent appearance and a self-cleaning slag. The 7024 electrode is ideal for making high speed horizontal fillets and lap welds on mild steel and some low alloy steels in weldments such as earth moving and construction equipment, truck bodies, ships, barges and railcars.

Typical mechanical properties of 7024 weld metal are:

Yield Point - 71,000 psi

Tensile Strength - 81,000 psi

Elongation (2" Gauge) - 26%

Reduction of Area - 63%

Charpy V-Notch Impact Value - 25 ft-lbs @ 0°F

The typical chemical composition of 7024 weld metal is:

Carbon	0.06%	Phosphorus	0.010%
Manganese	0.80%	Sulfur	0.018%
Silicon	0.27%		

DEPOSITION RATE DATA: 7024*

Electrode Diameter	Amperage	Efficiency, %	Deposition (Lbs/Hr.)
1/8"	140	69	3.57
	180	66	5.1
5/32"	180	67	4.48
	200	70	5.23
	240	67	6.67
3/16"	250	69	7.34
	290	68	9.15
7/32"	320	69	9.43
1/4"	400	70	12.58

*Note: Efficiencies do not include stub loss

APPENDIX A

LESSON III - GLOSSARY OF TERMS

Electrode Core Wire - The steel wire about which the coating is applied. The electrode size is determined by the diameter of the core wire.

Electrode Coating - The mixture of chemicals, minerals and metallic alloys applied to the core wire. The coating controls the welding current, the welding position, and provides a shielding atmosphere, deoxidizers to clean the weld metal, and the welding slag that absorbs impurities from the weld metal. It also helps shape the weld bead and becomes an insulating blanket over the weld bead.

Mild Steel - An alloy of mostly iron with low content of alloying elements such as carbon and manganese.

Low Alloy Steel - An alloy of iron with alloy additions, usually in the range of 1½ to 5%.

Hardenable Steel - An alloy of iron that is subject to hardening when rapidly cooled.

Deposition Rate - The weight of weld metal deposited compared to the time of welding. It is usually expressed in pounds per hour.

Deposition Efficiency - The relationship of the electrode used to the amount of the weld metal deposited, expressed in percent, i.e.;

DE = Weight of Weld Metal ÷ Weight of Electrode Used

Arc Blow - Welding with direct current may set up a magnetic field in the steel plate being welded. This magnetic field causes the arc to flutter and blow, creating difficulty in controlling the arc.

Cellulose - A chemical of carbon, hydrogen and oxygen. As used in mild steel electrode coatings, it consists of wood pulp or flour.

Rutile - The natural form of the mineral titanium dioxide (TiO_2).

Titania - The synthetic form of titanium dioxide (TiO_2). In this text the terms rutile and titania have the same significance.

Root Pass - The initial weld bead deposited in a multi-pass weld requiring high weld integrity.

Root Opening - The intentional gap between members to be joined to assure 100% penetration in groove type welds.