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IDENTIFICATION AND SELECTION OF FLUX COATED WELDING ELECTRODE FOR TECHNOLOGICAL TRANSFORMATION

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ABSTRACT

There are many different types of welding electrodes used in arc welding process. The choice of these welding electrodes depends on many parameters; one of them is the welding process (SMAW, GMAW, GTAW….). Electrode is either consumable or non-consumable, flux coated or bare rod/wire.
The intent of this paper is to help the personnel involved in governing welding activities in Manufacturing and Oil/Gas industry with the identification and selection of the right electrodes to use in the shielded metal arc welding (SMAW) process and also selection of a correct welding electrode improves the live span and integrity of a welded joint. Arc welding electrodes are identified using the American Welding Society (A.W.S) Standard, ISO 2560 Standard or Indian specification and numbering system and are made in sizes from $^{1}/_{16}$" (1.6mm) to $^{5}/_{16}$" (7.9mm). An example would be a welding rod identified as $^{1}/_{8}$" (3.2mm) E6011 electrode. The electrode is $^{1}/_{8}$" (3.2mm) in diameter The "E" stands for arc welding electrode. Next will be either a 4 or 5 digit number stamped on the electrode. The first two numbers of a 4 digit number and the first 3 digits of a 5 digit number indicate the minimum tensile strength (in thousands of pounds per square inch) of the weld that the rod will produce, stress relieved.

INTRODUCTION:

Arc Welding is act of joining two or more metals together by means of heat generated as a result of the electric current passing through the metals involved. In arc welding, electrodes are used to conduct electric current through a work-piece with discharge of intense light and heat to melt both the electrode and work piece together. Depending upon the process the electrode is either consumable or non-consumable. When electrode gets melted and becomes part of the weld puddle as in the case of gas metal arc welding (GMAW) or Manual metal arc welding (MMA), the electrode is known as consumable electrode whereas electrodes that do not melt under the heat of arc welding is non-consumable electrodes. For a direct current system the weld rod or stick may be a cathode for a filling type weld or an anode for other welding processes. For an alternating current arc welder the welding electrode would not be considered an anode or cathode. Carbon & tungsten electrodes are non-consumable.

ARC WELDING PROCESSES:

Shielded metal arc welding: One of the most common types of arc welding is shielded metal arc welding (SMAW), which is also known as manual metal arc welding (MMAW) or stick welding. An electric current is used to strike an arc between the base metal and a consumable electrode rod or stick. The electrode is made of a material that is compatible with the base metal being welded and is coated with a flux that gives off vapours which serve as a shielding gas and providing a layer of slag, both of which protect the weld pool from atmospheric contamination. The process is very versatile, requiring little operator training and inexpensive equipment. Furthermore, the process is generally limited to welding ferrous materials, though distinct electrodes have made possible the welding of cast iron, nickel, aluminium, copper and other metals. The versatility of the method makes it popular in a number of applications including repair work and construction. [1,2,5]

Gas metal arc welding (GMAW); Commonly called MIG (metal Inert-Gas), is a semi-automatic or automatic welding process with a continuously feed consumable solid wire which serves as both electrode and filler metal, along with an inert or semi-inert shielding gas flowing around the wire to protect the molten pool from contamination. Constant voltage (CV), Direct Current (DC) power source is most commonly used, but Constant Current (CC) and alternating current (AC) are used as well. With continuously fed filler wire electrodes, the process offers relatively high welding speeds. Originally developed for welding aluminium and other non-ferrous materials in the 1940s, GMAW was soon economically applied to steels. Today, GMAW is commonly used in industries such as the automobile industry for its quality, versatility and speed. Because of the need to maintain a stable shroud of shielding gas around the weld site, it can be problematic to use the GMAW process in areas of high air movement such as outdoors. However the more complicated equipment reduces convenience and versatility in comparison to the SMAW process. [1,2,5]

Flux-cored arc welding (FCAW): is similar to GMAW welding as far as operation and equipment are concerned. FCAW wire is actually a fine metal tube filled with powdered flux materials. An externally supplied shielding gas is sometimes used, but often the flux itself is relied upon to generate the necessary protection from the atmosphere. The process is widely used in construction because of its high welding speed and portability. [6]

Submerged arc welding (SAW) is a high-productivity welding process in which the arc is struck beneath a covering layer of granular flux. This increases arc quality, since contaminants around the atmosphere are blocked by the flux. The slag that forms on the weld generally comes off by itself and, combined with the use of a continuous wire feed, the weld deposition rate is high. Working conditions are much improved over other arc welding processes since the flux hides the arc and no smoke is produced. The process is commonly used in industry, especially for large products. As the arc is not visible, it is typically automated. SAW is only possible in the 1F (flat fillet), 2F (horizontal fillet), and 1G (flat groove) positions. [6]

Gas tungsten arc welding (GTAW), or Tungsten Inert Gas (TIG) welding, is a welding process that uses a non-consumable electrode made of tungsten, an inert or mixture of inert gases and a separate filler material. This welding process is more useful for welding thin materials, this method is characterized by a stable arc and high quality welds, but it requires significant operator skill and can only be accomplished at relatively low speeds. It can be used on nearly all weldable metals, though it is most often applied to stainless steel and light metals. It is often used when quality welds are extremely important, such as in bicycle, aircraft and naval applications. [3]

WELDING ELECTRODES:

There are basically two types of welding electrodes that are used normally during welding operation. These are consumable and non-consumable electrode.

Consumable welding electrodes: Consumable electrode tips melt when an arc produces enough heat, and molten metal droplets detach and mix with the weld pool from the base metal. Shielded metal arc welding (SMAW/MMA), gas metal arc welding (GMAW), flux cored arc welding and submerged arc welding (SAW) are all forms of arc welding that are using consumable electrodes.

Non-Consumable welding electrodes: When using non-consumable electrodes in arc welding, the electrodes do not melt. Rather, filler metal is melted into the joint from a separate rod or wire. Gas tungsten arc welding (GTAW) is a form of arc welding that utilizes non-consumable electrodes. Therefore the choice between using a consumable and a non-consumable electrode lies with the types of metal that is set up for welding. A consumable electrode can aid in the process of better elimination of impurities.

Manual Metal Arc welding process requires consumable welding electrodes (flux coated electrode). These electrodes when used the coat is burnt to create a shielding gas around the weld. This help to prevent the surrounding air from contaminating the weld. Also a consumable electrode can melt and mix with the weld creating a stronger bond. [6]

CLASSIFICATION OF COATED WELDING ELECTRODES

Coated welding electrodes are classified by their strength and standard use. The classification type states the electrode's coating composition, penetration depth, welding position and required current type. Penetration depths range includes light, medium or deep. Current types include alternating current (AC), direct current electrode positive (DCEP) and direct current electrode negative (DCEN) etc.

Electrode Classification by AWS A 5.1

The American Welding Society (AWS) numbering system can tell a welder quite a bit about a specific coated electrode including what application it works best in and how it should be used to maximize performance. With that in mind, let's take a look at the system and how it works. The prefix "**E**" designates an arc-welding electrode. The first two digits of a 4-digit number and the first three digits of 5 – digit number indicate minimum tensile strength. For example, E**60**10 is a 60ksi tensile strength electrode while E**100**18 designates a 100ksi tensile strength electrode. The next to last digit indicates welding position.

Let us use **E7018** electrode as an example:
E Indicates arc-welding electrode.
70 Indicates minimum Tensile strength
1 Indicates welding Position.
8 Indicates type of flux Coating and current.

Welding Positions

The second to the last digit is used to describe the welding position. Example E70**X**8**,** the **X** stands for the welding position. The table below shows the number representations of the welding position.

1 All position (Flat, Horizontal, Vertical (up), Overhead etc.)
2 Flat and Horizontal
3 Flat welding
4 Flat, Horizontal, Overhead, Vertical (down).

Flat Position - usually groove welds, fillet welds only if welded like a "V" Horizontal - Fillet welds, welds on walls (travel is from side to side). Vertical - welds on walls (travel is either up or down). Overhead - weld that needs to be done upside down. [6]

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Flux Coating and Current

The last digit is used to describe the flux coating. Example E701**X,** the **X** stands for the flux coating. The table below shows the number representations of the coating.
0 - Indicates High cellulose sodium (Cellulosic)
1 - Indicates High cellulose potassium
2 - Indicates High titania sodium (Rutile)
3 - Indicates High titania potassium (Rutile)
4 - Indicates Iron powder titania (Rutile)
5 - Indicates Low hydrogen sodium
6 - Indicates Low hydrogen potassium (Basic)
7 - Indicates Iron powder iron oxide
8 - Indicates Iron powder low hydrogen (Basic)

COMPOSITION OF COATING INGREDIENTS

The components 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. 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. 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 fibres and non-crystal-line materials such as glasses and other organic compounds are also common coating ingredients. Coating materials can be categorised 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. Function of binders is 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.

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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.

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.

AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)

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.

Chemical Composition of Weld Metal (AWS A5.1-91)

Chemical requirements are as follows:

a. **Classifications** E6010, E6011, E6012, E6013, E6020, E6022 andE6027 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.

Mechanical Properties (AWS A5.1-91)

Physical tests are performed on all specimens in the *"as-welded"* condition. This means that the weldments 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 at200°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.

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.

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.

Classifications E6012 and E6013 weld metals are required to have more than67,000 psi tensile strength, 55,000 psi yield strength, 17% elongation in two inch gauge, and no Charpy V-notch impact requirements.

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.

Classifications E7014 and E7024 weld metals are required to have more than72,000 psi tensile strength, 60,000 psi yield strength, 17% elongation in two inch gauge, and no Charpy V-notch impact requirements.

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.

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.

THE FUNCTIONS OF ELECTRODE COATINGS 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 andiron oxides that, if present in the weld metal above certain minimum amounts, will cause brittle-ness 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 weldmetal. 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 the min 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.

INDIVIDUAL ELECTRODE CHARACTERISTICS

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 with this electrode.

b. **E6011** electrodes are similar to E6010 except that sufficient potassium com-pounds 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 spatters 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 hardernable 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, *"under bead 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 fewer spatters. 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 of50% 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 sidewall 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 electrodes, 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.

SELECTION OF COATED WELDING ELECTRODES:

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

1. **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 relatively high sulphur 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.

2. **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 for both the ease of welding and to attain the highest welding speed.

3. **Available Equipment** - Electrode choice will depend on whether AC or DC welding machines are available. If both currents are available, consider this 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

4. **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.

5. **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.

6. **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.

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

CONCLUSIONS:

Selection of a correct welding electrode improves the live span and integrity of a welded joint. Quality in welding industry has no compromise therefore welding administrators and personnel should always consider these factors in order to produce good and sound welded structures or joints. The selection of appropriate welding electrode solely depends on the six to seven factors listed in this paper. Wrong selection of welding electrode increases the tendency of having poor and low quality welded joints.

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