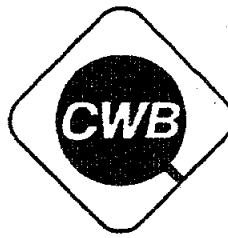


Electrodes and Consumables

PART OF THE CWB CERTIFICATE PROGRAMS



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ELECTRODES AND CONSUMABLES FOR WELDING

The purpose of this module is to acquaint the student with the major types of electrodes and consumables available and their characteristics. Completion of this module should provide the student with a knowledge of:

1. The major electrodes covered in various CSA and AWS standards.
2. The main groupings of electrodes.
3. The function of electrode coatings.
4. Materials used in coatings.
5. Requirements of various standards.
6. Operating characteristics of electrodes.
7. Solid and flux cored wires for welding.
8. Submerged arc wires and fluxes.
9. Alloy and stainless steel electrodes.
10. Other consumables for welding.

In most types of welding operations, additional "*filler metal*" is added to the joint to complete the weld. In consumable electrode electric arc welding, this comes from the melting of the electrode itself which may be a rod, or a "stick electrode" or a continuously fed wire. In non-consumable electrode welding, or gas welding, the filler metal is added as a separate rod.

Apart from providing filler metal, the electrode may also introduce other materials such as fluxes which affect the welding operation. Electrodes can therefore be complex, a wide range of operating characteristics and weld metal properties may be achieved with different electrodes. As a result of this, many specifications have been written by the American Welding Society, the Canadian Standards Association and organizations in other countries for a wide range of filler materials. The most important of these will be discussed in the module.

Covered Electrodes

Covered electrodes for shielded metal arc welding are the most widely used type of electrode. They comprise a core wire, or rod, which is coated with a layer of flux and other ingredients which provide the specific operating characteristics and properties. Covered electrodes have had a long history of development starting from the original bare electrodes, progressing to the lightly dipped electrodes having a thin layer of lime, to the asbestos wrapped electrodes, and finally to the modern electrode with a relatively thick complex coating.

The main features of the covered electrode are shown in Fig.1. The heat of the arc melts both the core wire and the coating, the latter, in some electrodes, melting at a slower rate, thus forming a collar around the arc and allowing the electrode to be dragged on the work piece. The molten slag separates from the molten metal and solidifies as a hard layer on the weld. It flakes off, or is chipped off, after welding. The weld metal is protected from contamination from the air by gases from the flux, and by the molten slag in contact with the metal.

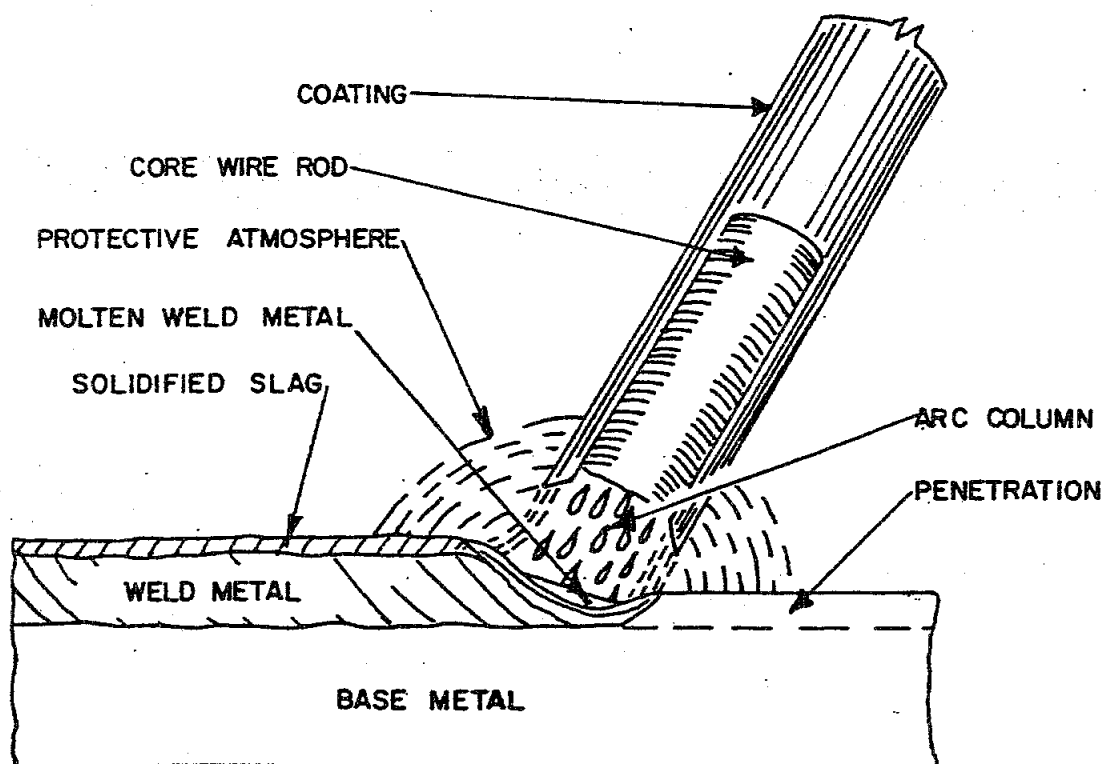


Fig. 1 – Covered Electrode

Core Wire

In most covered electrodes, the core wire is made from rimmed steel. Electrodes having a variety of properties are obtained by alloying from the coating rather than changing the core wire. When rimmed steel is made, a crust of pure iron forms on the outside and the carbon and impurities segregate to the centre. A typical analysis of rimmed steel is given in Table 1. A wire drawn down from a rimmed steel ingot will have a cross section as shown in Figure 2. A core wire made from rimmed steel would have the following features:

- The pure iron outside has better conductivity and the current passes more easily in the exterior part of the rod.
- Rimmed steel overheats less than killed steel.
- The centre of the rod melts faster than the outside giving improved metal transfer and finer droplets.

Typical Analysis of Rimmed Steel	
Carbon	0.10%
Manganese	0.50%
Sulphur	0.02%
Phosphorus	0.02%

Table 1

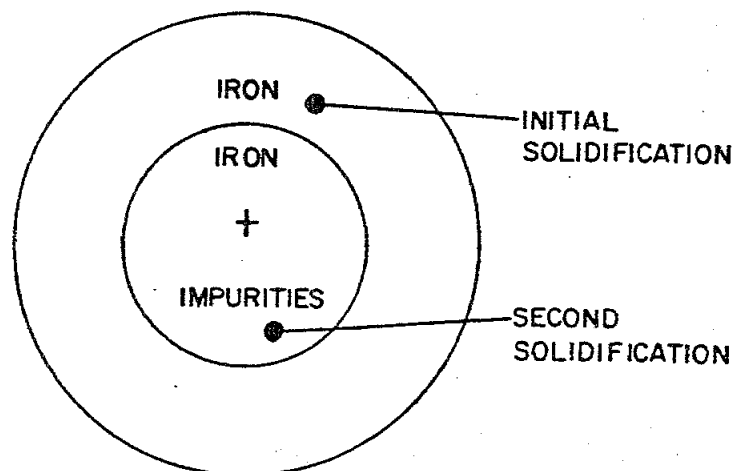


Fig. 2 — Electrode Core Wire

Manufacture of Electrodes

The various steps in the manufacture of coated electrodes are shown in the block diagram in Fig. 3. The coating is applied by an extrusion process whereby a paste of the coating mixture is squeezed around the core wire to form a concentric covering. A simplified diagram of the extrusion process is shown in Fig. 4. Electrodes are usually produced in standard lengths, the most popular being 14" and 18", and diameters from 3/32" to 1/4" although other sizes are available. The diameter refers to the *core wire*, not the overall electrode diameter.

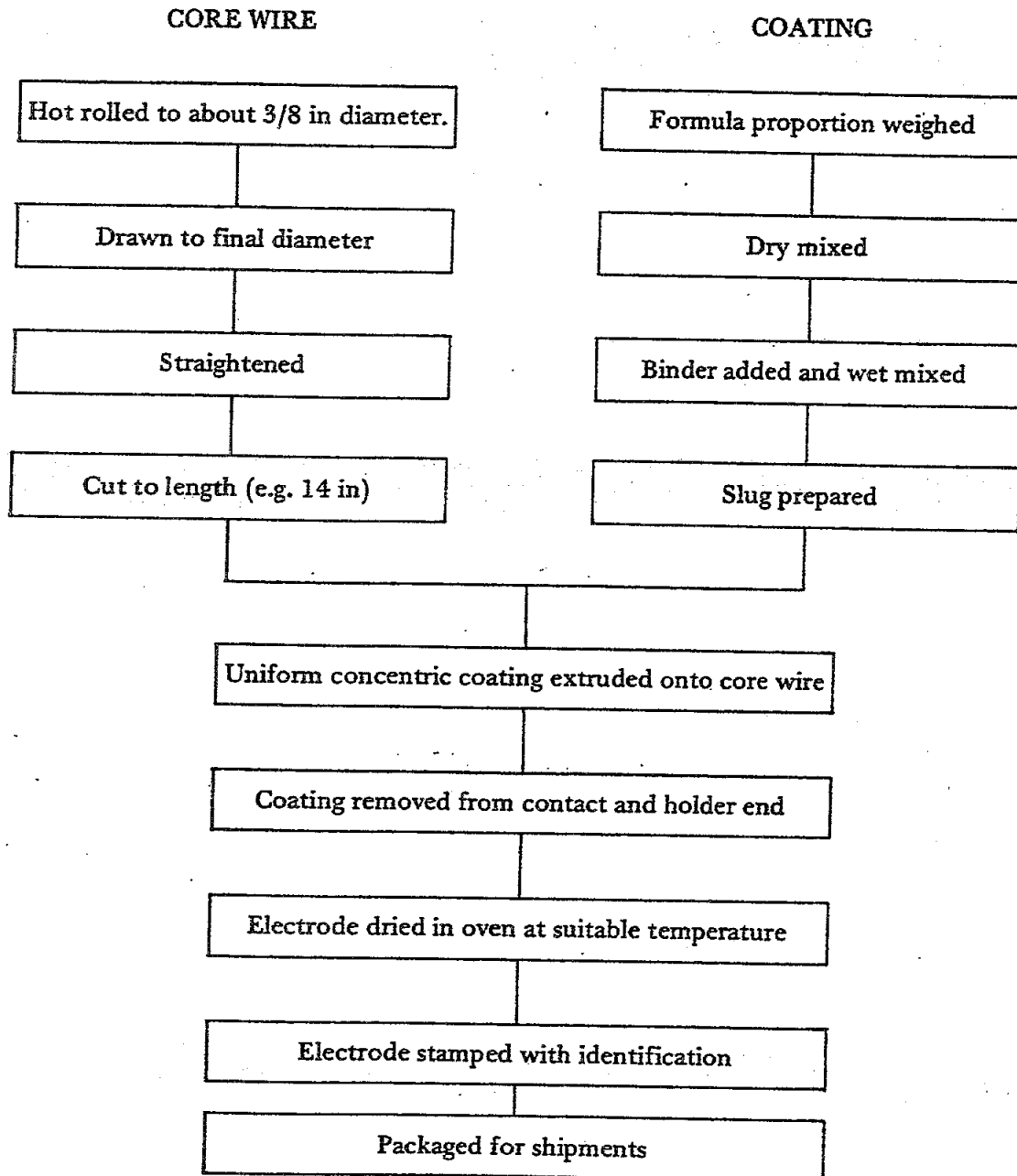


Fig. 3 — Steps in The Manufacture of Covered Electrodes

Electrodes and Consumables for Welding

The thickness of the coating depends on the type of electrode.

Lightly coated electrodes have about 10 to 20 percent electrode weight in the coating.

Medium coated electrodes comprise about 20 to 35 percent electrode weight in the coating and iron powder is usually an important constituent of the coating.

Heavily coated electrodes may have up to 55 percent electrode weight in the coating and have a high iron powder content. This contributes to a high deposition rate and these are popular electrodes for production welding in the flat position.

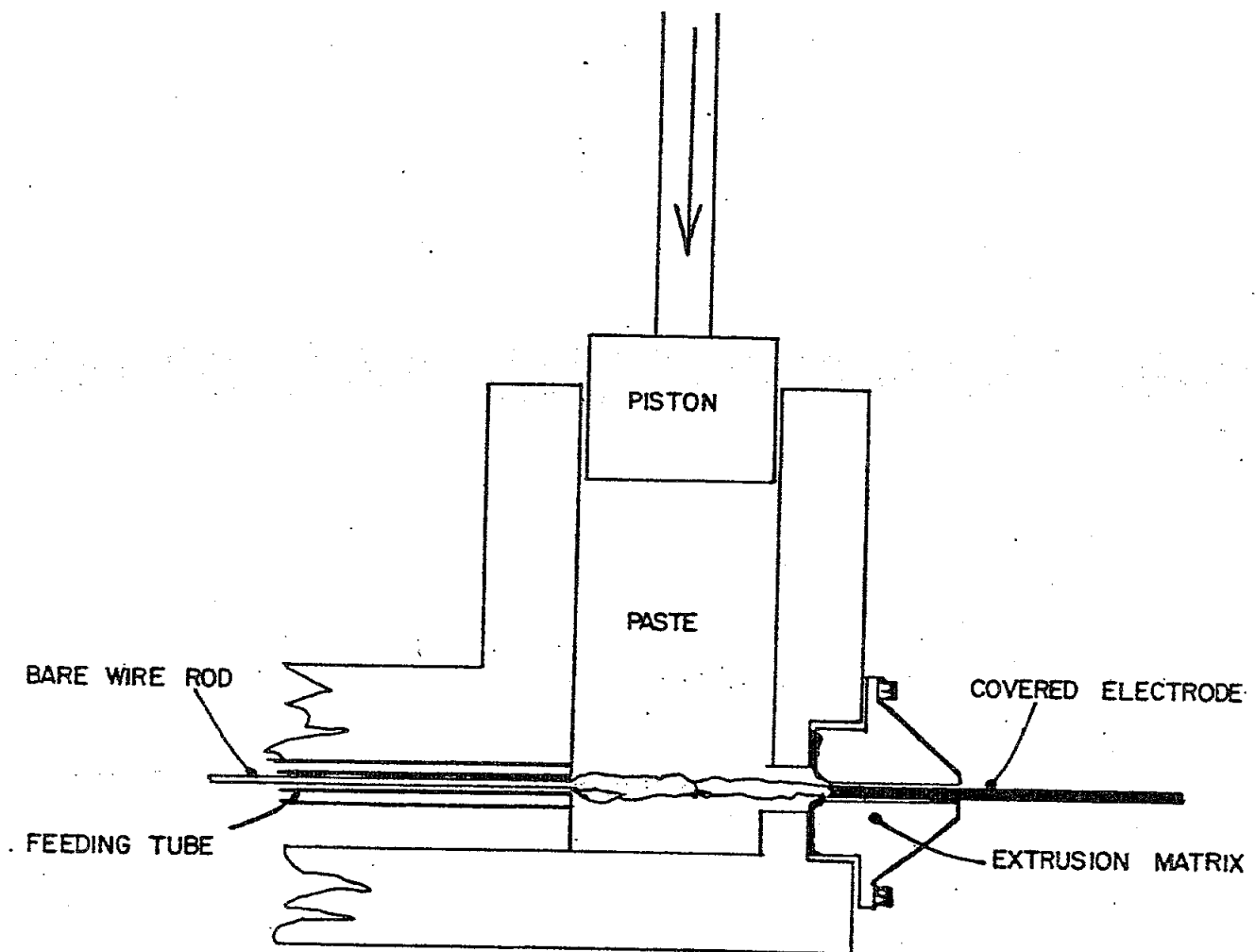


Fig. 4 — Extrusion of Electrodes

* Functions of Electrode Coatings KNOW THIS SECTION

The coating on the electrode may perform a wide variety of functions depending on the composition. The major function is the protection of the molten metal from contamination by the air through the formation of shielding gases and a molten slag. Several other functions may be important depending on the type of electrode and application. Among the more important functions, the coating can:

- Protect the molten metal by gas and slag formation.
- Act as a binder for chemical products and minerals.
- Influence the arc characteristics such as striking, ionization, stability, arc force, side arcing.
- Influence bead shape.
- Aid slag removal.
- Influence operation of electrode such as fluidity, ability to weld out of position, electrical polarity etc.
- Influence the penetration.
- Add alloying elements to the weld metal.
- Increase deposition rate.
- Control chemical and mechanical properties of the weld metal.
- Control the hydrogen introduced into the weld metal.
- Influence the ease of manufacture such as extrudability.

Functions of the Slag

The chief function of the molten slag that is formed from the flux coating is to protect the liquid weld metal from contamination from the air. It does this, both by forming a physical shield or barrier, and also by reacting chemically to reduce the gas content of the weld metal. The main functions of the slag may be summarized as follows:

- To protect the weld metal from contamination.
- To aid in the removal of oxygen and other impurities from the weld metal.
- To control the bead shape and smoothness.

Specific Materials in Electrode Coatings

Having seen the functions of electrode coatings, it is of interest to examine the functions of specific ingredients. The materials used include various organic materials, minerals, chemical compounds, clays and ferroalloys. Among the more important materials used are the following.

Cellulose	This is a product of wood pulp, or reprocessed paper, which disintegrates in the arc to form carbon dioxide and hydrogen which provide a protective gas shield to the weld metal. The penetration characteristics of the electrode are also increased.
Calcium Carbonate	Calcium carbonate (found as limestone, calcite or marble) is an important ingredient in low hydrogen electrodes. It breaks down in the arc to produce carbon dioxide which shields the weld metal and lowers the hydrogen content of the arc atmosphere. The resulting slag helps to maintain low oxygen levels in the weld metal, giving sound deposits with good properties.
Fluorspar	Fluorspar (or fluorite) is the natural form of calcium fluoride and is used to control the fluidity of the slag and allow gases to escape. It is widely used in low hydrogen electrodes where it also helps to maintain a low gas content in the weld metal.
Rutile	Minerals containing titanium dioxide such as rutile and ilmenite help to make the arc stable and form a fluid, quick freezing slag. This results in a fine, smooth finish to the weld.
Potassium Compounds	A number of different potassium compounds such as potassium feldspar and potassium titanate may be used in electrode coatings. Potassium aids in ionization and therefore helps to stabilize the arc and facilitate reignition. It is often used in electrodes intended to operate on alternating current.
Ferroalloys	Where additional alloys or deoxidizing agents are required, these are often added in the form of ferroalloys. The common additions are ferromanganese and ferrosilicon, both of which act in weld metal deoxidation and can control the strength of the weld deposit.
Sodium Silicate	Also known as water glass, this is a liquid binder which is used to hold the flux components together when baked.
Iron Oxide	Iron oxide in the form of ores, such as magnetite and hematite, is included in some electrode coatings principally as a slag former.
Iron Powder	In some electrode coatings, iron powder may be added, sometimes to 50% or more. The main purpose is to increase the deposition rate of the electrode since the iron powder melts and adds to the weld metal. It may also influence the bead appearance and the formation of the cup at the electrode tip that allows a "drag" technique to be used.

Coating Constituents	FUNCTIONS	
	Primary	Secondary
Cellulose	Gaseous Protection	Arc Force
Calcium Carbonate	Gaseous Protection	Fluxing Agent
Fluorspar	Slag Formation	Fluxing Agent
Dolomite	Gaseous Protection	Fluxing Agent
Rutile (Titanium Dioxide)	Slag Formation	Arc Stabilization
Potassium Titanate	Arc Stabilization	Slag Formation
Feldspar	Slag Formation	Arc Stabilization
Mica	Extrusion Aid	Arc Stabilization
Clay	Extrusion Aid	Slag Formation
Silica	Slag Formation	—
Asbestos	Slag Formation	Extrusion Aid
Manganese Oxide	Slag Formation	Alloying
Iron Oxide	Slag Formation	—
Iron Powder	Increases Deposition Rate	"Drag" Technique
Ferrosilicon	Deoxidation	Alloying
Ferromanganese	Alloying	Deoxidation
Sodium Silicate	Binder	Fluxing Agent
Potassium Silicate	Arc Stabilization	Binder

Summary of Main Functions of Electrode Coating Constituents

Table 2

Electrodes and Consumables for Welding

A summary of the functions of specific ingredients is shown in Table 2. Most coatings would employ about six to twelve different ingredients with one or two of them dominating. This allows an electrode to be characterized by the principal ingredients in the coating, e.g. cellulose type or rutile type.

Classification of Electrodes

The large number of electrodes available, and the wide range of operating characteristics and properties than can be achieved, has led standards organizations and societies in many countries to issue standards and specifications for welding electrodes. In the U. S. A., specifications are issued by the American Welding Society (AWS), and in Canada by the Canadian Standards Association (CSA). The Canadian standards are similar, but not necessarily the same as the AWS specifications. Other U.S. organizations such as the American Society of Mechanical Engineers (ASME) adopt the AWS system. The AWS system is in Imperial units, whereas the CSA Standards, originally in Imperial units, are being replaced by standards in SI (metric) units. There is a two year period after the publication of the SI version during which time both standards are in force. Following this, the SI version supersedes the Imperial version.

WELDING PROCESS	FILLER METAL	CSA STANDARD CURRENT (METRIC)	AWS SPECIFICATION
Shielded metal arc welding (SMAW)	Covered electrode	W48.1 (W48.1-M)	A5.1
Gas metal-arc welding (GMAW)	Solid wire electrode (on spools, etc.)	W48.4 (W48.4-M)	A5.18
Gas tungsten arc welding (GTAW)	Solid wire rod (usually in cut lengths)	W48.4 (W48.4-M)	A5.18
Flux-cored arc welding (FCAW)	Flux-cored wire electrode (on coils, etc.)	W48.5 (W48.5-M)	A5.20
Submerged arc welding (SAW)	Solid wire electrode (on coils, etc.)	W48.6 (W48.6-M)	A5.17

Specifications and Standards for Mild Steel Electrodes

Table 3

A complete list of the available AWS and CSA specifications for electrodes is contained at the end of this module. The most widely used are those for mild steel, and the relevant standards are summarized in Table 3.

The AWS and CSA classification systems are established according to *weld deposit strength, type of coating, position of welding, and type of current*. The standards describe the various tests that have to be carried out and list the requirements that must be met. An electrode may only be designated under one classification. Each classification has a code number and this number must be imprinted on each electrode near the grip end so that it is properly identified. Proper identification is of great importance since the use of an incorrect electrode could be extremely dangerous.

*AWS and CSA Classification System for Covered Electrodes

KNOW THIS.

The symbol used to designate the classification of the electrode comprises the letter E (denoting a covered electrode) followed by four digits (or five digits in the SI version).

The first two digits (three in higher-strength classes) denote the minimum tensile strength of the deposited weld metal in the as-welded condition in units of ksi (i.e., thousands of pounds per square inch). In the SI version, the first three digits denote minimum tensile strength in megapascals. For example, the symbol E7018 indicates that the electrode has a minimum tensile strength of 70 ksi or 70,000 psi (pounds per square inch). In the SI version (metric) the symbol E48018 indicates an electrode with a minimum tensile strength of 480 megapascals.

The minimum specified tensile strength is dependent on the elongation measured in the tensile test. For an E7018, the minimum specified tensile strength is 70 ksi if the elongation is 24% or more. If the elongation is 22% (the minimum specified) the minimum specified tensile strength is 72 ksi.

The third digit (i.e., the one following the strength group), gives information on the welding positions in which the electrode may be satisfactorily operated.

- | |
|---|
| 0 = all positions (W48.1-M only) |
| 1 = all positions, except vertical down |
| 2 = flat and horizontal fillets |
| 3 = flat only |
| 4 = flat and vertical down only |

Electrodes and Consumables for Welding

The welding positions are given the following abbreviations:

- F = flat position
- H = horizontal
- V = vertical (vertical up progression)
- OH = overhead
- VD = vertical (vertical down)

The final digit signifies the type of coating on the electrode and the type of electrical current that the electrode is designed for, as follows:

- 0 = cellulose, DC
- 1 = cellulose, AC or DC
- 2 = rutile (titania), AC or DC
- 3 = rutile (titania), AC or DC
- 4 = rutile (titania) + iron, AC or DC
- 5 = basic, DC
- 6 = basic, AC or DC
- 7 = iron oxide + iron powder, AC or DC
- 8 = basic + iron, AC or DC

Table 4 summarizes the meaning of the symbols for covered electrodes. As an example consider the symbol:—

E7018

This indicates an electrode with a minimum tensile strength (as-deposited weld metal) of 70,000 psi or 70 ksi. It is designed for welding in all positions, except vertical down, and has a basic coating with iron powder added. It can be used with AC or DC.

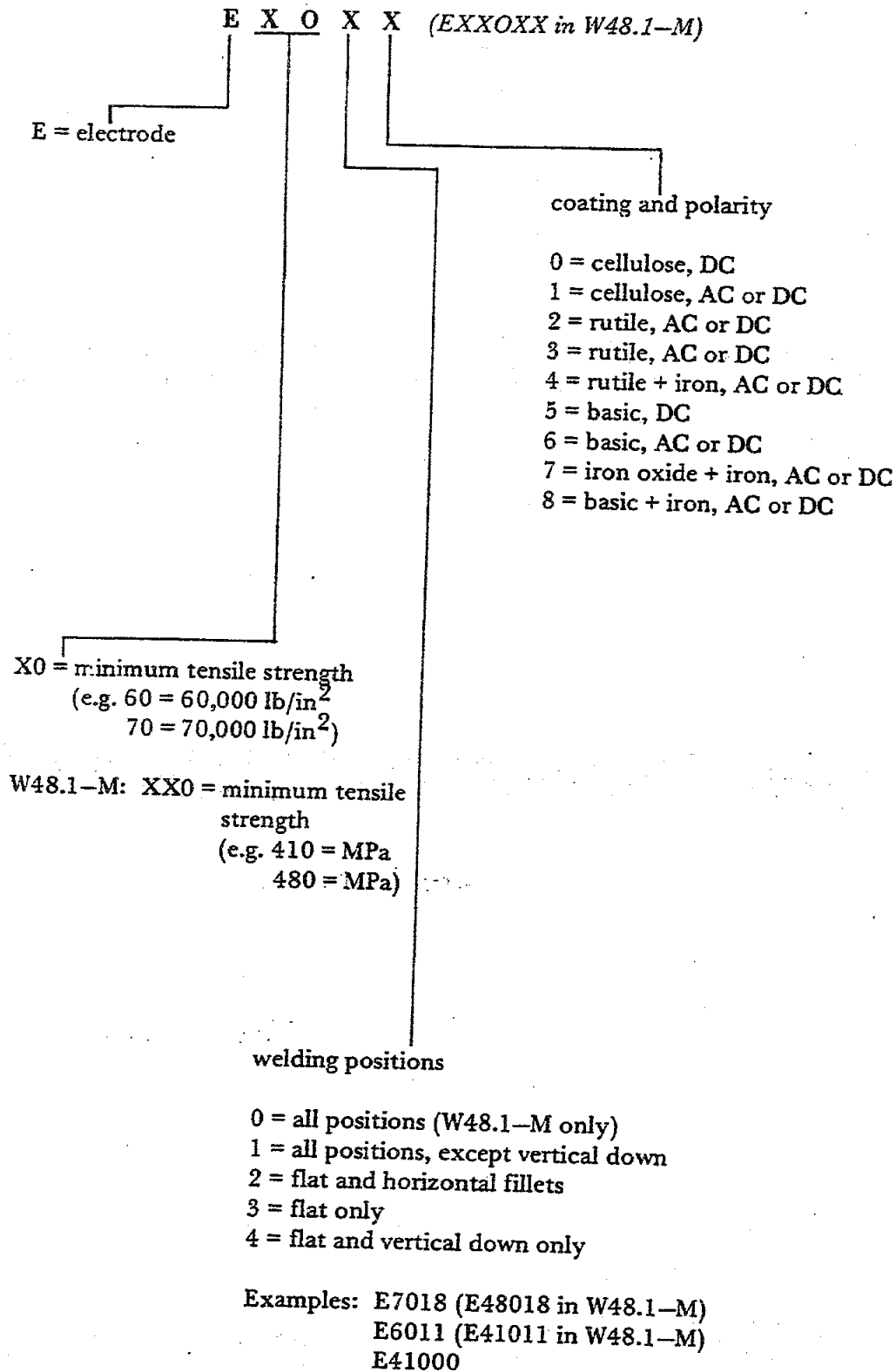
As another example, consider the following electrode which is included in W48.1—M (the standard in SI units):—

E41000

This designates an electrode with a minimum tensile strength of 410 megapascals (MPa) for a minimum elongation of 24%. It can be used in all positions, including vertical down, and has a cellulose coating. It is not designed for AC welding.

The complete list of mild steel electrodes classified under the AWS and CSA systems are shown in Table 5. Table 6 summarizes the chemical requirements and Table 7 the mechanical property requirements.

Fundamentals of Welding Technology



Meaning of Symbols for Covered Electrodes
Table 4

Electrodes and Consumables for Welding

CLASSIFICATION			Type of Coating	Welding Positions	Current ⁽¹⁾
W48.1	A5.1	W48.1-M			
—		E41000	Cellulose, sodium	F, VU, VD, O, H	dc
—		E48000	Cellulose, sodium	F, VU, VD, O, H	dc
E6010		E41010	Cellulose, sodium	F, VU, O, H	dc
E7010 ⁽²⁾		E48010	Cellulose, sodium	F, VU, O, H	dc
E6011		E41011	Cellulose, potassium	F, VU, O, H	ac or dc
E7011 ⁽²⁾		E48011	Cellulose, potassium	F, VU, O, H	ac or dc
E6012		E41012	Titania, sodium	F, VU, O, H	ac or dc
E7012 ⁽²⁾		E48012	Titania, sodium	F, VU, O, H	ac or dc
E6013		E41013	Titania, potassium	F, VU, O, H	ac or dc
E7013 ⁽²⁾		E48013	Titania potassium	F, VU, O, H	ac or dc
E7014		E48014	Titania, iron powder	F, VU, O, H	ac or dc,
E7015		E48015	Basic, sodium	F, VU, O, H	dc
E7016		E48016	Basic, potassium	F, VU, O, H	ac or dc
E7018		E48018	Basic, iron powder	F, VU, O, H	ac or dc
E6022 ⁽³⁾		E41022	Titania, iron powder	F, H-F	ac or dc
—		E48022	Titania, iron powder	F, H-F	ac or dc
E7024		E48024	Titania, high iron powder	F, H-F	ac or dc
E6027		E41027	Iron oxide, high iron powder	F, H-F	ac or dc
E7027		E48027	Iron oxide, high iron powder	F, H-F	ac or dc
E7028		E48028	Basic, high iron powder	F, H-F	ac or dc
E7048		E48048	Basic, iron powder	F, VD	ac or dc

Abbreviations:

- F = Flat
- VU = Vertical: Progression upwards
- VD = Vertical: Progression downwards
- O = Overhead
- H = Horizontal
- H-F = Horizontal (Fillet welds only)
- ac = alternating current
- dc = direct current

Notes:

- (1) The specific code should be consulted regarding correct polarity, positional limitations for dc and positions in which tests must be undertaken.
- (2) These appear in CSA W48.1 but appear in AWS A5.5 (low alloy steel electrodes) as E7010A1 etc.
- (3) AWS A5.1-1978 only

AWS A5.1-78, CSA W48.1-M Covered Electrode Classifications
Table 5

CLASSIFICATION		CHEMICAL COMPOSITION – MAXIMUM PERCENT						
W48.1 A5.1	W48.1–M	C	Mn	Si	Ni	Cr	Mo	V
——— E7010 E7011 E7015 E7016 E7028 E7048	E48000 E48010 E48011 E48015 E48016 E48028 E48048	0.15	1.25 ⁽¹⁾	0.90	0.30 ⁽¹⁾	0.20 ⁽¹⁾	0.30 ⁽¹⁾	0.08 ⁽¹⁾
E7018 E7027	E48018 E48027	0.12	1.60 ⁽²⁾	0.75	0.30 ⁽²⁾	0.20 ⁽²⁾	0.30 ⁽²⁾	0.08 ⁽²⁾
——— E6010 E6011 E6012 E6013 E6022 ⁽³⁾ E6027 E7012 E7013 E7014 ——— E7024	E41000 E41010 E41011 E41012 E41013 E41022 E41027 E48012 E48013 E48014 E48022 E48024	NO CHEMICAL REQUIREMENTS						

Notes:

- (1) The total of all these elements shall not exceed 1.50 per cent.
 (2) The total of all these elements shall not exceed 1.75 per cent.
 (3) AWS A5.1 only

AWS A5.1–78, CSA W48.1 and W48.1–M
 Chemical Requirements (Deposited Metal)

Table 6

Electrodes and Consumables for Welding

Electrode Classification		Tensile Strength ⁽¹⁾		Yield Strength (min) ⁽¹⁾		Elongation in 2 in. (50 mm)	Charpy Impact Requirements	
W48.1 A5.1	W48.1-M	ksi	MPa	ksi	MPa	(minimum %)	ft. lb. @ °F	J @ °C
— E6010 E6011	E41000 E41010 E41011	62 min.	430 min.	50	340	22	20 @ -20	27 @ -30
E6012 E6013 —	E41012 E41013 E41022	62 min. ⁽³⁾	430 min. ⁽³⁾	50 ⁽³⁾	340 ⁽³⁾	17	NONE	
E6027	E41027	62 min.	430 min.	50	340	25	20 @ -20	27 @ -30
— E7010 E7011 E7015 E7016 E7018 E7048	E48000 E48010 E48011 E48015 E48016 E48018 E48048	72-92 ⁽²⁾	500-650 ⁽²⁾	60	410	22	20 @ -20	27 @ -30
E7012 E7013 E7014 — E7024	E48012 E48013 E48014 E48022 E48024	72 min.	500 min.	60	410	17	NONE	
E7027	E48027	72-92 ⁽²⁾	500 min.	60	410	25	20 @ -20	27 @ -30
E7028	E48028	72-92 ⁽²⁾	500-650 ⁽²⁾	60	410	22	20 @ 0	27 @ -20

Notes:

- (1) For each increase of one percentage point in elongation over the minimum, the tensile strength or yield strength, or both, may decrease 1000 psi (10 MPa) to a minimum value 2000 psi (20 MPa) below that listed.

For example, the minimum tensile strength of an E6010 showing 22% elongation is 62 ksi, but the minimum for an E6010 showing greater than 24% elongation is 60 ksi.

Similarly an E48000 showing greater than 24% elongation has a minimum required tensile strength of 480 MPa.

- (2) AWS A5.1-78 does not have a maximum on tensile strength.

- (3) AWS A5.1-78 requires 67 ksi (460 MPa) and 55 ksi (380 MPa), for tensile and yield strength respectively, for E6012 and E6013 electrodes.

It should be noted that all similarly numbered electrodes in each series have the same operating characteristics. Their only difference would be in the mechanical and/or physical properties of the weld deposit. For example, an E6010 would have the same type of coating and operate in the same way as an E8010.

Generally speaking, the electrodes in the E80 and E100 series are restricted to either a cellulose or basic coating, and the higher tensile rods in the E110 and E120 classes are virtually all basic types. This is mainly because basic coatings, by nature lend themselves to the transfer of alloys to the deposited metal, far better than any other type.

AWS A5.1-78, CSA W48.1 and W48.1-M Mechanical Property Requirements
Table 7

Characteristics of Covered Electrodes

In this section, the characteristics of individual electrodes will be described in more detail. Covered electrodes can be divided roughly into four classes depending on the type of flux covering and the dominant component of the flux as shown in Table 8.

System	ELECTRODE TYPE	
	A5.1 & W48.1	W48.1-M
Cellulosic	EXX10 EXX11	EXX000 EXX010 EXX011
Rutile	EXX12 EXX13 EXX14 ⁽¹⁾ EXX24 ⁽¹⁾	EXX012 EXX013 EXX014 ⁽¹⁾ EXX022 ⁽¹⁾ EXX024 ⁽¹⁾
Iron Oxide	EXX20 EXX22 ⁽²⁾ EXX27 ⁽¹⁾	EXX027 ⁽¹⁾
Basic	EXX15 EXX16 EXX18 ⁽¹⁾ EXX28 ⁽¹⁾ EXX38 ^{(1) (3)} EXX46 ⁽³⁾ EXX48 ⁽¹⁾	EXX015 EXX016 EXX018 ⁽¹⁾ EXX028 ⁽¹⁾ EXX048 ⁽¹⁾
Notes: (1) Contains iron powder (2) AWS A5.1-78 only (3) CSA W48.1-1976 only <i>The more important of these electrodes are described in detail.</i>		

Four Classes of Covered Electrodes

Table 8

E6010 and E7010 — (Cellulosic)

Electrodes of this type are used on *DC current, electrode positive* (reverse polarity) only.

The flux coating is high in cellulose and is usually white or grey in appearance. High cellulosic content is designed to produce large volumes of gases such as *carbon dioxide, carbon monoxide* and *hydrogen* which effectively protect the molten metal passing across the arc.

The combination of coating constituents causes considerable liberation of heat in the base metal (negative pole) with resultant deep penetration. Care must be taken to ensure that the operational procedure is correct because the deeply penetrating arc can give rise to undercutting with careless handling of the rod.

Because of its high organic content, the slag volume is low and in many cases it does not cover the weld deposit completely. The slag is fast-freezing and for this reason it is ideal for welding in the vertical and overhead positions. Being porous, light and friable, it is easily removed but its effect on bead formation is only slight and the bead is comparatively rough.

With the core wire melting before the coating, a cup (frequently up to 1/16" deep) is formed at the end of the rod and this enables the operator to hold the rod very close to the work without it sticking. Holding the electrode close gives added protection against oxidation and decreases the spatter loss. Any increase in arc length or excessive current causes high spatter loss in this type.

The soundness of metal deposited is of very high order. Porosity is usually negligible and the ductility is high, usually ranging from 22 to 30 percent. Until the development of the basic type electrode, the EXX10 produced the soundest and most ductile deposit in the vertical and overhead positions. This electrode has long been considered to have a high degree of tolerance for detrimental factors, such as poor storage and faulty manipulation.

Because of its good quality metal and deep penetration, the E6010 is favoured for much work where a high standard is required. Welding of pipelines and much storage tank work is carried out with this electrode. It is particularly good for the joining of square groove butt joints where 100 percent penetration is required and for welding galvanized material. Although of high penetrating characteristics, it may be usefully employed where fit-up varies. Also, because of its penetrating properties, it is often used to ensure deep fusion and high quality in the first and most critical run, while other electrodes are employed for subsequent runs.

The electrodes are made in all of the standard diameters, 3/32" to 5/16" and generally in 14 inch lengths only, although some larger sizes are made in 18 inch lengths. Deterioration of the coating due to heating of the core wire may occur during welding. Cellulose decomposes at temperatures as low as 180°F, and it is unwise to use high current densities with this type. Moisture also plays an important part in the coating, and care should be taken to prevent either absorption or loss of moisture through unfavourable storage conditions. Excess moisture results in arc instability and increases spatter loss, while excessively low moisture reduces penetration and causes pinholes and blistered craters.

E6011 and E7011

With the advent of alternating current welding came the demand for an electrode having all the good qualities of the EXX10 electrode and yet capable of being used on the AC transformer.

Combining these requirements is almost an impossibility because ingredients which aid one characteristic oppose another. However, electrodes which meet code requirements have been developed by making a slight compromise, mainly in the matter of depth of penetration.

The cellulosic content is usually lower and easily ionized materials, such as potassium feldspar, are added to increase arc stability at low open circuit voltage and low welding currents. Spatter with the EXX11 electrode is generally finer and readily removed. When used on AC the arc can be recognized as being somewhat noisier than an EXX10 on DCEP.

The electrodes are used on work similar to that indicated for EXX10 and, as stated above, the characteristics are very close to this type. Usually, ductility, tensile strength and yield strength are higher than those obtained with EXX10 electrodes.

E6012 and E7012 - (Rutile)

Commonly known as the general purpose rod, almost every welder will have used this type. Usually tan or light brown in colour, it is made in all diameters up to 5/16" and in lengths varying from 9" to 18", depending on the diameter. Originally developed for use on direct current electrode negative, most rods can be satisfactorily operated on AC and DC.

Rutile is the main coating constituent with clays, silica, feldspar, etc. being added to aid extrusion, arc stability and slag characteristics. The cellulose content is quite low, protection for the molten metal being afforded by the shield of molten slag.

The slag is usually rather heavy, bluish black in colour and very fast freezing, making the electrode easy to use in all positions. It is fairly easy to remove, although it tends to cling to the upper edge of horizontal fillet welds, and is a little harder to remove when deposited in a downhand fillet. These slag characteristics produce single pass fillets which are slightly convex, the edges of the bead being sharply defined. The bead is smooth and bright with fine ripples and ends in a shallow dense crater.

Penetration is decidedly lower than either E6010 or E6011, but this factor enables it to be used on joints where "fit-up" is poor and deep-penetrating rods would tend to burn through. For this reason it is good for the welding of sheets and light-gauge material. Undercutting is rare.

It is used to advantage for welding low-alloy steels and those of relatively high carbon since the admixture with the parent metal, or what is called 'pickup', is low due to little penetration. Consequently, the effect of carbon or other hardening alloys is reduced. The lower heat input of this rod reduces distortion to a minimum.

The electrode is quite easy to handle in any position, has a fairly high burning speed combined with low spatter loss and is very economical. A cup is rarely formed in the rutile type and there is a slight tendency to sticking if the arc is held too short. Decomposition of the coating (away from the arc) during welding is rare even at high current densities.

Unfortunately the mechanical properties of the weld metal are the poorest displayed by any coated electrode. Porosity is quite common, particularly in the root of fillet welds, and codes require an elongation of only 17 percent in 2 inches although this is often substantially exceeded. These mechanical properties and the lack of deep penetration prevent it being used with confidence on weldments and structures where fatigue stresses are anticipated. It is excellent for building up mild steel shafts, fabrication of sheet metal, machinery, tacking, general repair work, etc.

At one time it accounted for a large percentage of electrodes used, but heavily covered electrodes, with their higher deposition rates and excellent mechanical properties, have replaced it to a great extent.

E6013 and E7013 -- (Rutile)

Use of this type of electrode has steadily increased with the use of AC welding. The coating is similar but usually thicker than that on the E6012 rod and may be tan or brown in colour, often with a reddish hue. Because of the relatively high cellulosic content of this rod, rutile is present in larger proportions in order to produce steady operation when the current is in the reverse polarity phase of the alternating cycle. Ionization of the arc atmosphere, to facilitate easy striking and maintenance of the arc under all conditions, is achieved by additions of potassium-bearing compounds such as potassium titanate and potassium feldspar.

The rod can be held very close to the work, spatter loss is very low and the metal flows smoothly across the arc in any position.

The slag produced is slightly heavier and slower freezing than the E6012 type, but it is still satisfactory for all-position welding. Slag removal is almost perfect, in many cases peeling itself from the weld deposit. Beads are flat, shiny and evenly rippled, having straight, clearly defined edges.

In depth of penetration, most mechanical properties and uses, this type is almost identical with the E6012 electrode. Ductility is somewhat improved by the higher cellulose content, although most codes require a minimum of only 17 percent as for E6012. High current densities are not recommended because of coating decomposition. Root porosity in fillet welds made with this type of electrode is virtually eliminated, and it is well suited for single-pass welding. Weld metal is usually freer of slag-oxide inclusions than E6012 and E7012 and slag removal is somewhat better for the small sizes, 1/16", 3/32" and 5/64".

E7014 -- (Rutile)

This electrode is essentially of the E6012 and E6013 type with the addition of approximately 30 percent iron powder. The amount of coating and the percentage of iron powder in the coating are usually less than those of an E7024 electrode. E7014 is not quite as fast as E7024 in the flat position, but is faster than E6013. Slag removal is usually better, arc characteristics are smoother, and less sticking occurs with the small sizes than with similar sizes of E6013. The bead appearance is improved and the deposition rate is higher than E6013, but it is not as high as obtained with an E7024 electrode. The amount and character of the slag permits the E7014 electrode to be used in all position welding and it is therefore more versatile than the E7024 electrode.

The E7014 electrode is suitable for welding mild and low alloy steels. Penetration is approximately the same as E6012, which is advantageous when welding over gaps due to poor fit-up. Currents are higher than for E6012 and E6013 deposition.

E7024 -- (Rutile)

The E7024 classification electrode has a covering with fluxing ingredients similar to E6012 and E6013, together with a high percentage of iron powder. As a rule, the coverings on E7024 electrodes are very heavy, usually amounting to about 50 percent of the covered electrode weight. The core wire is identical to that used in types E6010 or E6012.

Due to the thick covering and deep arc cup produced, the E7024 electrodes are used more extensively with the covering in contact with the parts being welded, i.e., with a "drag" technique. This consists of keeping the electrode covering in contact with the workpiece (both legs of fillet welds) at all times, which makes for exceptionally easy handling. However, sometimes an open arc technique is preferable in groove welding.

The E7024 electrode is well suited for fillet welds in mild steel. The welds are slightly convex in profile, with a very smooth surface and extremely fine ripples approaching the appearance of machine-made welds. The electrode is characterized by a smooth quiet arc, very low spatter, low penetration and can be used at high lineal speed.

This electrode operates with AC or DC, either polarity. The E7024 electrode, although most generally used on mild steel, also produces satisfactory welds on many low-alloy, medium and high-carbon steels.

Originally it was possible, because of the conductive nature of the coating on this type of electrode, to strike the arc through the coating in practically all cases when the electrode was hot and in some cases when the electrode was cold. Further developments now provide an electrode where the coating is insulated, both hot and cold, but where the restriking characteristic has been retained.

E6020 and E7020 – (Iron Oxide)

The E6020 electrode is limited by the volume and nature of its slag for use in two positions only, horizontal fillet and flat. The rod operates well on direct or alternating current, straight polarity being preferred on DC because it produces a flatter bead contour.

Generally referred to as mineral coated, this rod has a heavy coating usually black or red in colour, depending on which iron oxide predominates in the coating. Although it is manufactured in all the standard diameters, by far the greatest proportion consumed is in the 3/16", 1/4" and 5/16" diameters. These three sizes are nearly always produced in 18 inch lengths.

The heavy coating, composed mainly of iron oxides, manganese oxides and siliceous materials, provides a mechanical shield of molten slag to guard against oxidation in the arc. Ferromanganese is used as the main deoxidant and sodium silicate is used as a binder.

When solid, the slag is usually shiny black and extremely porous. This porosity makes it very friable and easily removable. Its fluid nature and wetting power influences the freezing weld metal by forming a concave bead, whose edges are ideally flared into the plate.

In depositing horizontal fillets at high amperages there is a tendency to undercut the vertical plate, but this can be overcome by holding the rod at an angle of 60° to the horizontal plate.

Penetration with this class is good and can be increased by the use of high amperages. The coating will withstand exceptionally high temperatures without deterioration.

The weld metal has excellent mechanical properties with elongation in 2 inches being in the region of 30%. Porosity is negligible and most joints fabricated with E6020 are perfect under X-ray examination.

Before the advent of the iron powder electrode, EXX20 was in wide use for heavy weldments such as machine bases, centre sills on railway cars, pressure vessels etc. However, the increased deposition rate of the iron powder electrodes, together with the high quality obtainable has resulted in a steady decrease in the relative importance of this type. The EXX020 classification does not appear now in CSA W48.1-M.

E6027 and E7027 (Iron Oxide)

The EXX27 classification has a covering similar to that found in E6020 electrodes together with a high percentage of iron powder. The coverings, as with E7024, are very heavy, amounting to approximately 50 percent of the total electrode weight. A deep arc cup is formed and the "drag" technique is usually used with the open arc technique sometimes used in groove welding.

The EXX27 electrode is designed to produce satisfactory fillet or groove welds in the flat position with AC or DC, either polarity, and will produce flat or slightly concave horizontal fillet welds with either AC or DC electrode negative.

This electrode has a spray type of metal transfer and deposits at high speeds. Penetration is medium and spatter loss is very low. The covering on this type produces a heavy slag, honeycombed on the under side, which covers the weld deposit and is quite friable and easy to remove, particularly in deep groove joints. Consequently, because of the wash-in of the weld metal combined with the ease of slag removal, X-ray quality welds are readily made in deep groove joints in very heavy sections.

Welds produced with the EXX27 electrode have a flat, to slightly concave profile with a smooth, fine, even ripple and with a good metal wash up the sides of the joint. The weld metal possesses excellent radiographic quality. Current ranges for the various diameters are high since a considerable portion of the electrical energy passing through the electrode is used to melt the covering and the iron powder contained therein.

The EXX27 electrode has had wide usage in the pressure vessel and structural field but, as with other electrodes, there has been a tendency for it to be replaced by the low-hydrogen, iron-powder types such as the E7028.

E7015 and E7016

The recognition that the presence of hydrogen in the weld metal was a prime cause of cracking led to the development, about 30 years ago, of electrodes that produced low, controlled levels of weld metal hydrogen. This allowed carbon and alloy steels to be welded without cracking, often without the need of preheating, reduced problems in welding sulphur bearing steels and produced weld metals of improved toughness. Traditionally, these electrodes have been known as 'low hydrogen' electrodes, but now they are formally referred to as 'basic'. The term 'basic' refers to the chemical character of the coating which has a high content of lime or calcium carbonate. The breakdown of this coating produces carbon dioxide gas which minimizes the amount of hydrogen in the arc atmosphere. Ingredients such as cellulose that can produce hydrogen are not used in the coating mix.

Basic electrodes require different handling from other types in that the arc is somewhat hesitant. Higher current densities are required for suitable operation, and whipping techniques are not recommended. Penetration is medium and there is little tendency to undercutting.

In the vertical position, the slag is rather fluid and heavy, and the maximum diameter rod recommended for this position is 5/32 inch. A smooth, evenly rippled bead is produced in all positions, spatter loss is low but the slag is not very easily removed. A deep arc cup is formed allowing a 'drag technique' to be used.

E7015 is designed for DC electrode positive welding, whereas the E7016 contains potassium compounds promoting ionization and allowing AC to be used.

E7018 - (Basic)

Although still used, the E7015 and E7016 have been largely superseded by the E7018 type. This is a basic type with iron powder and its higher deposition rate and ease of handling make it the preferred electrode for many applications.

The coating of this electrode is slightly thicker than that of the E7015 and E7016 type. The iron powder in the coating usually amounts to between 25 and 40 percent of the coating weight.

It can be used with DC electrode positive and AC but the highest speeds are obtained with DC. It is designed for the same applications as the E7015 and E7016 electrodes. In common with all basic electrodes a short arc should be maintained at all times.

In addition to its use for mild steel, the E7018 electrode is well suited for fillet welds in high-strength, high-carbon or alloy steels. The fillet welds made in the horizontal and flat position are slightly convex in profile, with a smooth or finely rippled surface. The electrode is characterized by a smooth quiet arc, very low spatter, low penetration and can be used at high lineal speeds.

E7028 - (Basic)

The E7028 electrode is in many respects very much like the E7018. The E7028 differs from the E7018 in the following respects:

1. The E7018 is an all-position electrode, where the E7028 is suitable for horizontal fillet and flat position welding only.
2. The coating of the E7028 electrode is much thicker than that of E7018; the coating of E7028 electrodes representing approximately 50 percent of the weight of the electrode. The iron powder content of the E7028 coating is higher than that of the E7018. As a consequence, in horizontal fillet and flat position welding, the E7028 gives a higher deposition rate than the E7018 for any given size of electrode. The iron powder content of the E7028 coating represents about 50 percent of the weight of the coating, compared to 25-40 percent for E7018.
3. The E7028 has a spray type of transfer; the E7018 transfer is globular.
4. The ratio of the weight of the weld metal to the weight of the core wire consumed is about 1.05 minimum for the E7018 and about 1.30 minimum for the E7028.
5. The weld metal toughness of the E7018 is usually better than that of the E7028.

Summary of Electrode Characteristics

The characteristics of the various electrodes described in detail in the preceding sections are summarized in Tables 9, 10 and 11. Following W48.1-M, the S.I. (metric) designation is used but the tables apply equally well to the equivalent electrodes using Imperial units. For example the comments for EXX018 electrodes apply to W48.1-M electrodes such as E48018, and also to A5.1 and W48.1 electrodes such as E7018.

Fundamentals of Welding Technology

CLASSES	INGREDIENTS
EXX027	iron oxide, silica, manganese oxide, feldspar, clay, mica, asbestos, carbonates, sodium silicate, ferromanganese, ferrosilicon,
EXX000, EXX010, EXX011	cellulose, asbestos, rutile, carbonates, silicates
EXX012, EXX013	rutile, feldspar, clay, cellulose, silicates, ferromanganese
EXX014, EXX024	rutile, iron powder, feldspar, carbonates, cellulose, ferromanganese, silicates
EXX018, EXX028, EXX048 EXX015*, EXX016*	fluorspar, carbonates, iron powder*, ferromanganese, ferrosilicon, silicates

* EXX015 and EXX016 do not contain iron powder

Principal Ingredients in Electrode Coatings
Table 9

0-10%	10-20%	20-40%	40-60%
EXX000	EXX048	EXX014	EXX022
EXX010		EXX018	EXX024
EXX011			EXX027
EXX012			EXX028
EXX013			
EXX015			
EXX016			

Iron Powder Content of Coatings
Table 10

Fundamentals of Welding Technology

Classification	Deposition	Penetration	Soundness	Ductility
EXX000	4	10	6	6
EXX010	4	10	6	6
EXX011	4	9	6	7
EXX012	5	6	3	4
EXX013	5	5	5	5
EXX014	6	6	7	6
EXX015	4	7	9	10
EXX016	4	7	10	10
EXX018	6	7	9	10
EXX024	10	4	8	5
EXX027	10	8	9	10
EXX028	8	7	9	10
EXX048	5	7	9	9

Note: The figures are not measured quantities but are used to give an approximate indication of performance on a scale of 1 to 10. The actual electrode performance will depend on many factors such as welding conditions and skill of the welder.

Performance Comparison of Electrodes (10 Maximum)
Table 11

✕ An Example of Electrode Selection

In order to select an electrode, the job for which it is being chosen must be carefully considered, and at least five or six of the most essential characteristics listed.

As an example of such consideration, take the fabrication of a heavy excavator frame or base of 0.25 to 0.30% carbon plate.

Although perhaps unusual in a shop where such work is performed, it can be assumed that no positioning equipment is installed and therefore an all-position electrode must be used. Also, only AC is available.

From the nature of the job and anticipated service it can also be assumed that:

1. The frame will be subject to fatigue and alternating stresses and therefore sound weld metal of high impact and ductility values will be highly desirable.
2. Since the plate is fairly high in carbon, an electrode low in sensitivity and of low or medium penetration would be best.
3. Good fit-up may be anticipated.
4. A straight-to-concave fillet contour will be best for fatigue performance.
5. Good bead appearance is of course desirable but not really important.
6. Low electrode cost is to be desired but is relatively insignificant in a job of such importance and high overall costs.

Since an electrode high in impact value is desirable, this would lead the selector to E7018, 7016, 7014 or 6011. Minor cost factors would favour both E6012 and E6013 about equally. Both would have a smoother bead than E6011 and between the two, E6013 would have the better finish and contour.

However, in a job of this nature, weld qualities of impact, ductility and soundness must be given preference and the choice will fall on type E7016 or E7018.

Principles of Electrodes Selection

It will perhaps be found helpful, in electrode selection, to keep the following principles in mind:

1. If a deep groove is to be filled or a heavy fillet weld made, these would, wherever possible, be arranged for downhand or horizontal position. Economy would dictate the use of an iron powder electrode with its high deposition rate would lead to the choice of E6027, 7024 or 7028. Design requirements would rule as to whether or not the E70 series was needed and questions of preheat and type of steel would determine if it were necessary or desirable to have low hydrogen weld metal, with the choice then pointing to E7028.
2. If high production on light-gauge metal is sought, an electrode which can carry high currents and move at fast speeds while still retaining satisfactory bead size and shape would give the best answer. This would be an application for E6012. In the automotive industry this electrode is being used for lap welds at 60 inches per minute welded with as much as 48 inches of joint with one electrode.
3. Vertical and overhead welding and horizontal butt welding require that the metal stay in position by solidifying rapidly. All the XXIX electrodes are designed for this, with E6010 the first choice unless low-hydrogen weld metal is called for, when E7016 or E7018 would be chosen.
4. When the steel is high in sulphur, carbon or phosphorus, or is thick enough to cause rapid quenching, or is of low-alloy composition, the best assurance of crack-free welds will come from the use of low-hydrogen electrodes. These would be E7016, 7018 or 7028 if there were no necessity to match the plate composition. Otherwise, one of the compatible low-alloy electrodes would be the choice.



Detrimental Action of Moisture and Hydrogen from Electrode Coatings

Moisture is a component of all electrode coatings just as much as any of the chemicals and should be maintained within certain desirable limits as with other ingredients. This is not easy since some coatings absorb moisture in varying degrees, depending on the atmospheric conditions. If a coating takes up excessive moisture, it can be dried, but here again some electrodes fail to function properly if they are too dry.

The coating of an excessively damp electrode will have a tendency to 'pop' or explode. Often a swelling will be observed just above the arc in operation. Also, if the electrode is short circuited, permitting the welding current to pass through it for a short period, moisture may be driven off as a vapour. This should be done only as a test for moisture and not as a means of drying.

Moisture will have a tendency to produce porosity in the weld, but more important, it can break down into hydrogen gas and this can be seriously detrimental to a weld, and lead to cracking in or near the weld. These cracks are originally microscopic but may well develop and result in failure. See Figure 5.

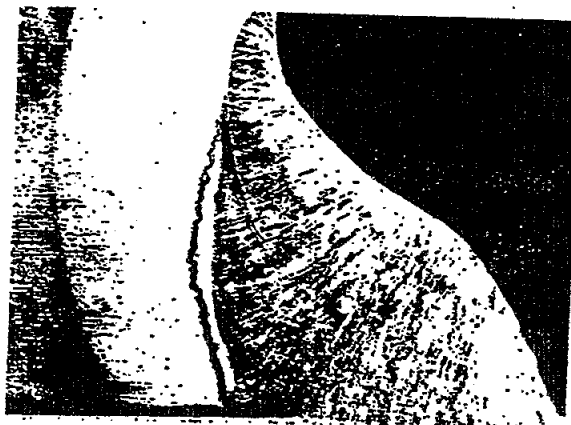


Fig. 5 — An Example of Cracking in the Weld due to Hydrogen

It is for this reason that low hydrogen electrodes are used and for the same reason it is of the utmost importance that the coatings of low hydrogen electrodes be kept dry.

Considerable research has been undertaken on the effects of hydrogen which can be partly explained as follows.

Hydrogen from the electrode coating is absorbed by the molten metal during the welding process. The solubility of hydrogen in iron diminishes with decreasing temperature and at the solidification point it even drops abruptly. Thus the absorbed hydrogen will be partly released during the cooling process. The thicker the metal from which the gas is to be released and the lower the temperature, the longer the diffusion process will take. Hence, if the metal to be welded is very thick, a large quantity of hydrogen will be retained, in the first place owing to the long distance it has to travel to the surface in the diffusion process and in the second place by the rapid cooling caused by the thickness of metal. This retention of hydrogen encourages cracking both in the weld metal and heat affected zone of the parent metal.

Welding with conventional types of electrodes with non-basic coatings may be expected to lead to the absorption of relatively large amounts of hydrogen and its entrapment as above. Figure 6 shows the phenomenon called "fisheyes" on the surface of the fracture after test bars welded with such electrodes have been broken.

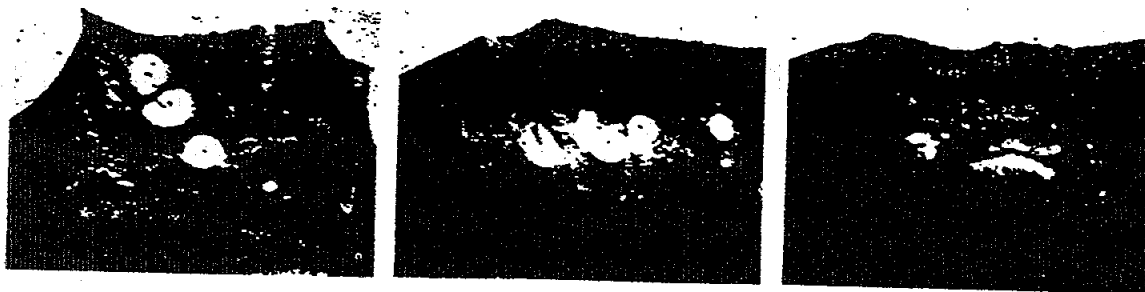


Fig. 6 — These fisheyes are normally associated with inclusions or voids where hydrogen collects and are generally considered evidence of the presence of gaseous hydrogen.



Storage of Arc Welding Electrodes

To obtain the best possible results from arc welding electrodes, it is essential that they should be stored in suitably dry conditions. This is particularly so in the case of low hydrogen electrodes, which are more hygroscopic than other types, i.e. they readily pick up moisture.

Electrodes are manufactured so that the proper level of moisture, consistent with the covering type and the electrode strength classification, is in the coverings. These electrodes are then normally packaged in a container which has been designed to provide the degree of protection appropriate to the type of covering involved.

Under proper storage conditions (normal room temperatures, 50 percent maximum relative humidity or holding ovens) the electrodes can be maintained for many months. However, if the original containers are damaged, improperly stored, or for any reason the electrodes are exposed to high moisture conditions, the coverings of the electrodes may absorb excessive moisture.

If there is a possibility that the electrodes may have picked up excessive moisture, they can be restored by rebaking as indicated in Table 12. Such rebaking may well be required when low hydrogen electrodes, purchased in non-hermetically sealed packages, may have been exposed to the moist air.

The low hydrogen (E7015 and E7016) and low hydrogen-iron powder (E7018 and E7028) electrodes are the most critical types for moisture absorption. When a container is opened, only sufficient electrodes for use in a four hour period should be removed and the remainder returned to the storage oven. These types of inorganic covered electrodes are designed and developed to contain the very minimum of moisture in their coverings and as such should be handled with the utmost care. This care should be extended particularly to field welding where the danger of moisture absorption is greatly increased.

E6010 and E6011 electrodes should not be rebaked because the coverings for these types are designed to have moisture levels of 3 to 7 percent and excessive drying may substantially affect their operation.

Filler Metal	Storage Temperature		Rebaking Temperature	
	°C	°F	°C	°F
cellulosic electrodes	25-40	75-100	NOT RECOMMENDED	
basic electrodes	100-150	200-300	350-425	650-800
other electrodes	25-40	75-100	120-150	250-300
flux-cored wires	20-150	70-300	NOT RECOMMENDED	
solid wires	20-40	70-100	NOT REQUIRED	
submerged arc flux	100-150	200-300	400-450	750-850

Storage and Rebaking of Filler Metals (After opening package)

Table 12



Fig. 7 — Electrode Storage Ovens stacked for space saving



Fig. 8 — Portable Electrode Storage Oven serving on site

When a package of basic electrodes is opened, the electrode should be placed in a holding oven heated to 100-150°C. A typical holding oven is shown in Fig. 7. An oven holding basic electrodes should not contain anything else, or even any of other type of electrode. When removed from the oven, basic electrodes must be used within a certain period of time (4 hours for mild steel electrodes). If this is exceeded, the electrodes should be rebaked at a higher temperature and this usually requires a different type of oven. Electrodes that have become wet should be discarded.

Store rooms for electrodes should have a controlled humidity of less than 50% (relative humidity) by using a dehumidifier and sealing the room. Smaller quantities of electrodes may be stored in unheated containers that use silica gel or other material to maintain a dry atmosphere. Small portable containers will also be effective in keeping electrodes dry (Fig. 8).

Low Alloy Steel Arc Welding Electrodes

All the electrodes described in the preceding sections produce, essentially, mild steel weld deposits (although the manganese and silicon content may vary between electrode types). Weld material of higher strength, however, may be obtained by using low alloy electrodes where additional alloying comes from components of the flux. Electrodes of this type are covered by specifications AWS A5.5-69 and CSA W48.3-1976. There are differences between the American and Canadian standards, although the types of electrodes included are the same. A major difference between these standards, and those for mild steel electrodes, is that the low alloy steel electrodes are usually tested in the stress-relieved condition to determine mechanical properties. Increased strength may be obtained by a variety of alloy elements and the chemical composition of the deposited metal of similarly classified electrodes may not necessarily be the same. If specified properties, such as corrosion resistance or high temperature strength, are required, care must be exercised in choosing electrodes not only on the basis of their strength but also on the chemical composition.

When making the weld deposit for the purpose of testing the electrodes to the appropriate standard, the preheat, interpass temperature, and stress relief time and temperature are specified. These may be different for the various classifications. It is important to note that these temperatures (particularly those of preheat) may not necessarily be the same as those used on the job for the same electrode. Tables 13 and 14 summarize the types of low alloy steel electrodes covered in the AWS and CSA standards.

CSA Standard W48.3 Type of Covering	CSA & AWS Classification	AWS Type of Covering	Capable of Producing Satisfactory Welds in Positions Shown	Type of Current
E70 Series-Minimum Tensile Strength of Deposited Metal in Stress-Relieved Condition, 70,000 psi				
High cellulose, sodium	E7010-X	High cellulose sodium	F, V, OH, H	dc reverse polarity
High cellulose, potassium	E7011-X	High cellulose potassium	F, V, OH, H	ac or dc reverse polarity
Basic, sodium	E7015-X	Low hydrogen sodium	F, V, OH, H	dc reverse polarity
Basic, iron powder	E7018-X	Iron powder, low hydrogen	F, V, OH, H	ac or dc reverse polarity
Iron powder	E7020-X	High iron oxide	H-Fillets	ac or dc straight polarity
Iron oxide, high iron powder	E7027-X	Iron powder, iron oxide	F	ac or dc either polarity
E80 Series-Minimum Tensile Strength of Deposited Metal, 80,000 psi				
High cellulose, sodium	E8010-X	High cellulose sodium	F, V, OH, H	dc reverse polarity
High cellulose, potassium	E8011-X	High cellulose potassium	F, V, OH, H	ac or dc reverse polarity
High titania, potassium	E8013-X	High titania potassium	F, V, OH, H	ac or dc either polarity
Basic, sodium	E8015-X	Low hydrogen sodium	F, V, OH, H	dc reverse polarity
Basic, potassium	E8016-X	Low hydrogen potassium	F, V, OH, H	ac or dc reverse polarity
Basic, iron powder	E8018-X	Iron powder, low hydrogen	F, V, OH, H	ac or dc reverse polarity
E90 Series-Minimum Tensile Strength of Deposited Metal, 90,000 psi				
High cellulose, sodium	E9010-X	High cellulose sodium	F, V, OH, H	dc reverse polarity
High cellulose, potassium	E9011-X	High cellulose potassium	F, V, OH, H	ac or dc reverse polarity
High titania, potassium	E9013-X	High titania potassium	F, V, OH, H	ac or dc either polarity
Basic, sodium	E9015-X	Low hydrogen sodium	F, V, OH, H	dc reverse polarity
Basic, potassium	E9016-X	Low hydrogen potassium	F, V, OH, H	ac or dc reverse polarity
Basic, iron powder	E9018-X	Iron powder, low hydrogen	F, V, OH, H	ac or dc reverse polarity
E100 Series-Minimum Tensile Strength of Deposited Metal, 100,000 psi				
High cellulose, sodium	E10010-X	High cellulose sodium	F, V, OH, H	dc reverse polarity
High cellulose, potassium	E10011-X	High cellulose potassium	F, V, OH, H	ac or dc reverse polarity
High titania, potassium	E10013-X	High titania potassium	F, V, OH, H	ac or dc either polarity
Basic, sodium	E10015-X	Low hydrogen sodium	F, V, OH, H	dc reverse polarity
Basic, potassium	E10016-X	Low hydrogen potassium	F, V, OH, H	ac or dc reverse polarity
Basic, iron powder	E10018-X	Iron powder, low hydrogen	F, V, OH, H	ac or dc reverse polarity
E110 Series-Minimum Tensile Strength of Deposited Metal, 110,000 psi				
Basic, sodium	E11015-X	Low hydrogen sodium	F, V, OH, H	dc reverse polarity
Basic, potassium	E11016-X	Low hydrogen potassium	F, V, OH, H	ac or dc reverse polarity
Basic, iron powder	E11018-X	Iron powder, low hydrogen	F, V, OH, H	ac or dc reverse polarity
E120 Series-Minimum Tensile Strength of Deposited Metal, 120,000 psi				
Basic, sodium	E12015-X	Low hydrogen sodium	F, V, OH, H	dc reverse polarity
Basic, potassium	E12016-X	Low hydrogen potassium	F, V, OH, H	ac or dc reverse polarity
Basic, iron powder	E12018-X	Iron powder, low hydrogen	F, V, OH, H	ac or dc reverse polarity

Table 13 — Low Alloy Steel Arc Welding Electrodes

Fundamentals of Welding Technology

CSA AWS-ASTM Classification ¹	CHEMICAL COMPOSITION, PERCENT ⁴ (MAX)								
	C	Mn	P	S	Si	Ni	Cr	Mo	V
Carbon-Molybdenum Steel Electrodes									
E7010-A1 } E7011-A1 } E7015-A1 } E7016-A1 } E7018-A1 } E7020-A1 } E7027-A1 }	0.12	0.60 } 0.60 } 0.90 } 0.90 } 0.90 } 0.60 } 1.00 }	0.03	0.04	0.40 } 0.40 } 0.60 } 0.60 } 0.80 } 0.40 } 0.40 }			0.40-0.65	
Chromium-Molybdenum Steel Electrodes									
E8016-B1 } E8018-B1 }	0.12	0.90	0.03	0.04	0.60 } 0.80 }		0.40-0.65	0.40-0.65	
E8015-B2L } E8016-B2 } E8018-B2 }	0.05 0.12	0.90	0.03	0.04	1.00 } 0.60 } 0.80 }		1.00-1.50 1.00-1.50	0.40-0.65	
E9015-B3L } E9015-B3 } E9016-B3 } E9018-B3 }	0.05 0.12	0.90	0.03	0.04	1.00 } 0.60 } 0.60 } 0.80 }		2.00-2.50 2.00-2.50	0.90-1.20	
E8015-B4L } E8016-B5 }	0.05 0.07-0.15	0.90 0.4-0.7	0.03 0.03	0.04 0.04	1.00 0.3-0.6		1.75-2.25 0.4-0.6	0.40-0.65 1.00-1.25	0.05 min
Nickel Steel Electrodes									
E8016-C1 } E8018-C1 }	0.12	1.20	0.03	0.04	0.60 } 0.80 }	2.00-2.75			
E8016-C2 } E8018-C2 }	0.12	1.20	0.03	0.04	0.60 } 0.80 }	3.00-3.75			
E8016-C3 ² } E8018-C3 ² }	0.12	0.40-1.10	0.03	0.03	0.80	0.80-1.10	0.15	0.35	0.05
Manganese-Molybdenum Steel Electrodes									
E9015-D1 } E9018-D1 }	0.12	1.25-1.75	0.03	0.04	0.60 } 0.80 }			0.25-0.45	
E10015-D2 } E10016-D2 } E10018-D2 }	0.15	1.65-2.00	0.03	0.04	0.60 } 0.60 } 0.80 }			0.25-0.45	
All Other Low-Alloy Steel Electrodes ⁵									
EXX10-G } EXX11-G } EXX13-G } EXX15-G } EXX16-G } EXX18-G } EXX20-G }		1.00 min ³			0.80 min ³	0.50 min ³	0.30 min ³	0.20 min ³	0.10 min ³
E9018-M ² } E10018-M ² } E11018-M ² } E12018-M ² }	0.10 0.10 0.10 0.10	0.60-1.25 0.75-1.70 1.30-1.80 1.30-2.25	0.03 0.03 0.03 0.03	0.03 0.03 0.03 0.03	0.80 0.60 0.60 0.60	1.40-1.80 1.40-2.10 1.25-2.50 1.75-2.25	0.15 0.35 0.40 0.30-1.50	0.35 0.25-0.50 0.30-0.55 0.30-0.55	0.05 0.05 0.05 0.05

Table 14 — Chemical Requirements

See "Notes to Table 14" following page.

Electrodes and Consumables for Welding

Notes to Table 14

- 1 *The suffixes A1, B3, C2, etc. designate the chemical composition of the electrode classification.*
- 2 *These classifications are intended to conform to classifications covered by US military specifications for similar compositions.*
- 3 *In order to meet the alloy requirements of the G group, the weld deposit must have the minimum, of only one of the specified elements as indicated.*
- 4 *For determining the chemical composition, DC, straight polarity only, may be used where DC, both polarities, is specified.*
- 5 *The letters "XX" used in the classification designations in this table stand for the various strength levels (70, 80, 90, 110 and 120) of electrodes.*

The chemical requirements with respect to CSA Standard W48.3—1976 are similar to AWS A5.5—69 except that the following three electrodes have been added to the table.

- E8018-B2L The chemistry is identical to that of electrode E8018-B2 except that the carbon is now reduced to 0.05%. The L means low carbon, Normally the carbon is set at a maximum of 0.12%C.
- E9018-B3L This is similar to E9018-BL except that carbon content is set at 0.05%.
- E8016-B5 This is a completely new addition. This electrode having the following chemistry; 0.07-0.15% C; 0.40-0.70% Mn; 0.03% max. P; 0.04% S; 0.30-0.60% Si; 0.40-0.60% Cr; 1.00-1.25% Mo and 0.05% min. V.

For the test welds used in certifying low alloy electrodes, the preheat and interpass temperature is specified. With the exception of the following electrodes the mechanical properties are obtained from welds which have been stress relieved:

- E8016-C3
- E8018-C3
- E9018-M
- E10018-M
- E11018-M
- E12018-M

These electrodes contain vanadium and have a tendency to become embrittled when held at temperatures of about 1,000°F (540°C).

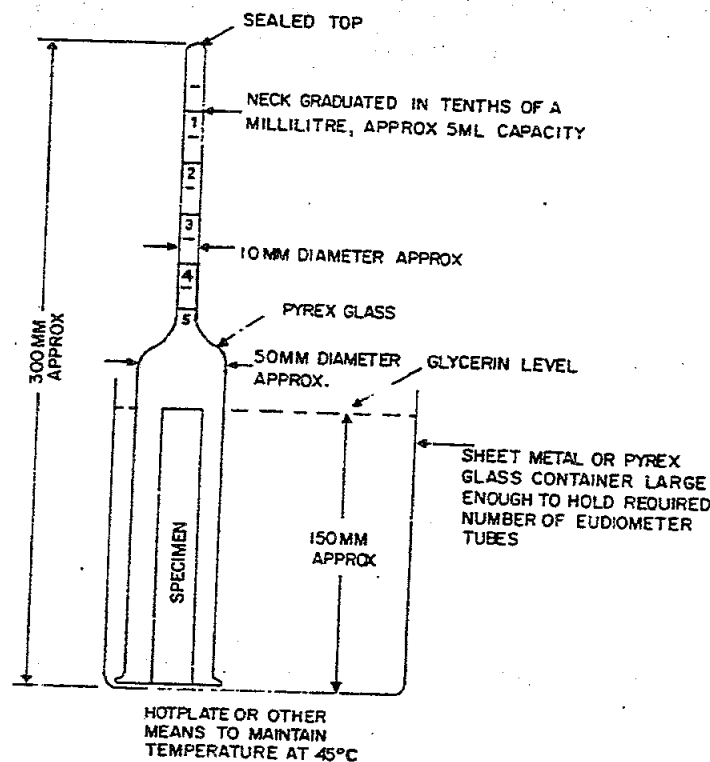
Moisture and Hydrogen Tests

It was pointed out that electrodes with a basic coating are designed to provide a weld deposit with a low content of hydrogen. If the moisture level of these electrodes is too high, they will not be capable of producing low hydrogen deposits. The term 'low hydrogen' is relative since it is not possible to eliminate the hydrogen completely, and different countries have adopted different levels and test methods to define 'low hydrogen'.

In the AWS specifications for low alloy steel electrodes, a moisture test is required. The weight of moisture as a percentage of the weight of the electrode must not exceed a specified value. Special apparatus is required to conduct the moisture test which involves heating some of the flux to drive off the moisture which is removed by a gas, collected, and measured.

In the CSA standards, basic electrodes (low alloy and mild steel) are required to undergo a hydrogen test. Fig. 9 shows a diagram of the apparatus used. A weld bead is deposited on a small plate and then cooled rapidly in water. It is then placed immediately in a tube under glycerine and the hydrogen allowed to bubble off. The amount of hydrogen collected is measured and hydrogen content of the weld metal is calculated.

Other countries employ a similar method but use mercury for the confining liquid. The mercury method is covered by an ISO standard 3690-1977 (E). The two methods can lead to different results since, with glycerine, a foam of very tiny bubbles can form which does not float up. The measured hydrogen may therefore be less than the total amount evolved from the specimen. It is most important, therefore, when testing to a standard that the specified method be followed. Typically, the glycerine method may show values 60–70% of those determined by the mercury method.



Apparatus for Determining Diffusible Hydrogen in Weld Metal (from CSA W48.7-M1977)
Fig. 9

Electrodes and Consumables for Welding

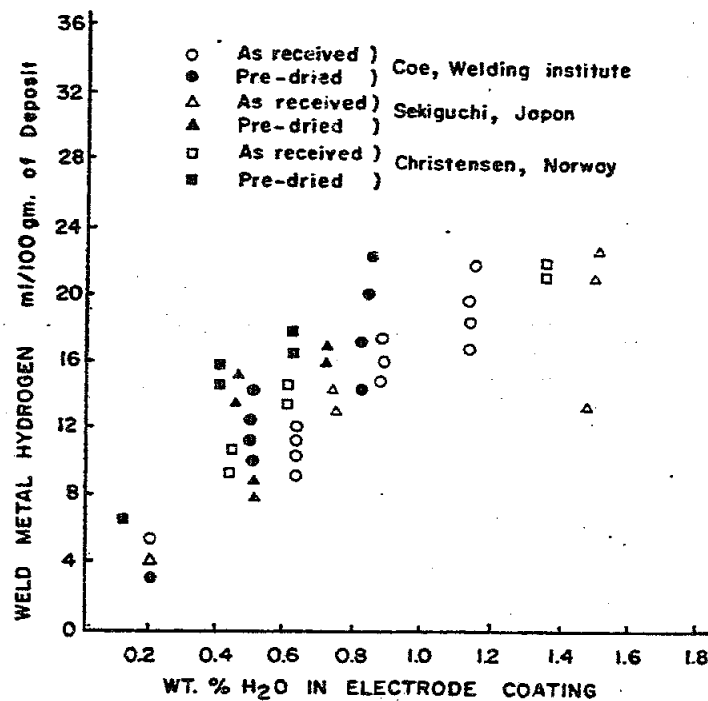


Fig. 10 — Relation Between Moisture in Electrode Coatings and Weld Metal Hydrogen Content (Mercury Method)

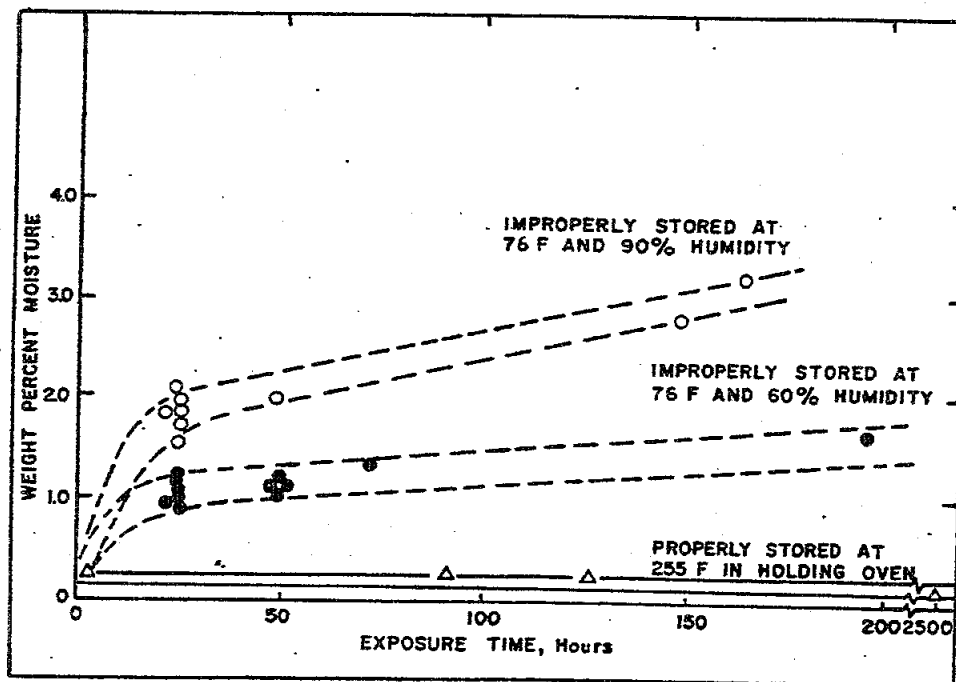


Fig. 11 — Effect of Exposure Time of Electrodes in Humid Atmosphere on Subsequent Hydrogen Content

The approximate relation between the moisture content and the hydrogen level (measured by the mercury method) is shown in Fig. 10, and the effect of exposure of an electrode to a humid atmosphere on the resulting weld metal hydrogen content is shown in Fig. 11. It is therefore obvious why it is important to keep electrodes dry and to rebake them if they have been exposed to the air too long.

Continuous Wires for Welding

Continuous wires are used in the gas metal arc, submerged arc, electroslog and electrogas welding process and when cut into rod, are used in the gas tungsten arc process. In contrast to covered electrodes which are made from rimmed steel, continuous wires are usually made from steel containing some alloy elements. The general sequence for the manufacture of wires is shown in Fig. 12.

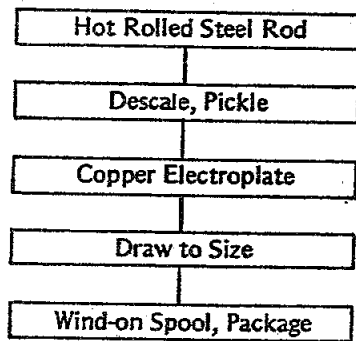


Fig. 12 — Sequence in the Manufacture of Wires for Welding

Many wires have a thin coating of copper electroplated on them which aids in the drawing operation. It may also assist with current pick-up in the welding nozzle and prevent rusting of the wire when stored.

Continuous wires are available in a wide range of sizes and can be supplied in coils, on spools or large drums, and pay-off-packs. The sizes of wires, and the dimensions and weights of spools etc., are specified in relevant specifications or standards.

Cast and Helix

An important aspect of coiled wires is the unrestrained shape the wire takes up after it comes off the coil. This can have an important effect on the welding operation, affecting arc wander or a misplaced weld bead. The *cast* is the diameter that a single loop of wire assumes when a length is cut from the coil and placed unrestrained on a flat surface. It will be larger than the diameter of the coil, and the minimum value is specified in some standards. The *helix* refers to the spacing between two loops when unrestrained. It is defined in the standards by the maximum distance from any joint on the wire to the flat surface when a single unrestrained loop is placed on the surface. The helix for all coils larger than 4 inch spools should not exceed 1 inch (25 mm). Fig. 13 illustrates the meaning of cast and helix.

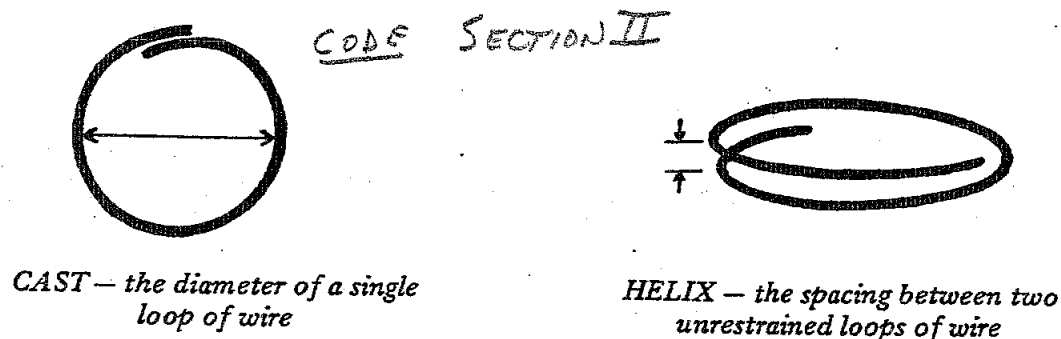


Fig. 13

Tensile Strength

Wires for gas shielded arc welding are usually stronger than mild steel wires because of the effect of cold drawing and the presence of alloy elements. This higher strength is a useful property, and makes the wire easier to feed through the guns and conduits of automatic and semi-automatic equipment. The specifications for wire for gas shielded arc welding specify the minimum tensile strength that the wire should have. For small diameter wires this is 135,000 psi. It is important to note that this is the tensile strength of the wire as it comes off the coil and must not be confused with the tensile strength of the weld deposit.

Solid Mild Steel Filler Metals for Gas Shielded Arc Welding

Wires for gas shielded arc welding may be used as either an electrode (i.e., forming part of the electrical circuit) as in gas metal arc welding, or as a rod separately fed into the arc as in gas tungsten arc welding. Although called mild steel, they do contain alloy elements which are used for deoxidation. These are mainly manganese and silicon but some wires may contain additional elements such as aluminum and titanium. Deoxidation is particularly important when carbon dioxide shielding gas is used since this gas reacts with the molten steel. The amount of deoxidation required also depends on the type of steel being welded. More deoxidation is required for welding rimmed steel which has not been deoxidized than for semi-killed and killed steels. The same is true when welding steel with rust or scale on it.

AWS Specification A5.18-79 and CSA Standard W48.4-M2980 cover solid mild steel filler metals for gas shielded arc welding. CSA W48.4-1978 (in Imperial units) covers only wires for gas metal arc welding but in most respects is similar. The meaning of the symbols used for classification is explained as follows:

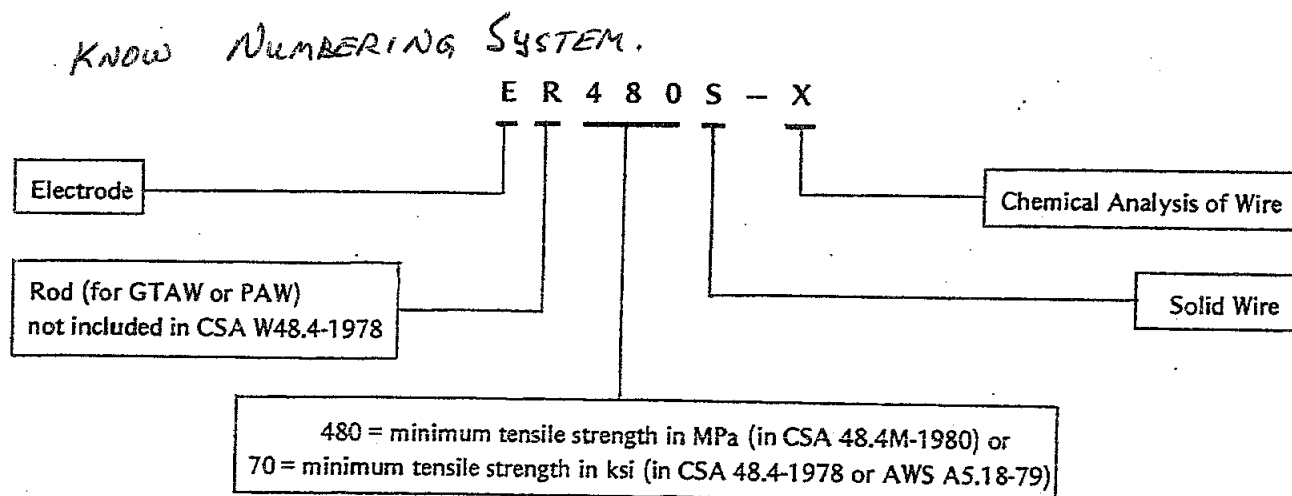


Fig. 14

Note that the welding position is not included in the classification as it is with covered electrodes. The position is actually determined by the wire diameter, shielding gas and the mode of metal transfer.

The chemical requirements for these wires are summarized in Table 15. Minor differences between the AWS and CSA Standards are to be noted, but are not significant in regard to the behaviour of the wires. The various classifications differ mainly in the level of deoxidizing elements contained in the wires. The main characteristics of the wires are as follows.

CLASSIFICATION			CHEMICAL COMPOSITION					
A5.18-79	W48.4	W48.4-M	C	Mn	Si	Ti	Zr	Al
ER70S-2	E70S-2	ER480S-2	0.07 ¹	0.90 to 1.40	0.40 to 0.70	0.05 to 0.15	0.02 to 0.12	0.05 to 0.15
ER70S-3	E70S-3	ER480S-3	0.06 to 0.15	0.90 to 1.40	0.45 to 0.70	—	—	—
ER70S-4	E70S-4	ER480S-4	0.07 to 0.15	1.00 to 1.50	0.65 to 0.85	—	—	—
ER70S-5	E70S-5	ER480S-5	0.07 to 0.19	0.90 to 1.40	0.30 to 0.60	—	—	0.50 to 0.90
ER70S-6	E70S-6	ER480S-6	0.07 to 0.15	1.40 to 1.85	0.80 to 1.15	—	—	—
ER70S-7	E70S-7	ER480S-7	0.07 to 0.15	1.50 to 2.00 ³	0.65 to 0.85 ²	—	—	—
ER70S-G	E70S-G	ER480S-G	NO CHEMICAL REQUIREMENTS					
¹ 0.06 in CSA W48.4-1978. ² 0.50 to 0.80 in AWS A5.18-79. ³ 1.85 in CSA W48.4-1978. Notes: a) Single values are maximum. b) The maximum copper content is 0.50%, including copper present in the coating. c) The maximum phosphorus and sulphur contents are .025% and .035%, respectively.								

*AWS A5.18-79, CSA W48.4 and W48.4-M Chemical Requirements for Wires
Table 15*

Electrodes and Consumables for Welding

E70S-2 (or ER480S-2)

This is a triple deoxidized steel electrode which is capable of making sound welds in rimmed and semi-killed steels even when some rusty conditions exist. Shielding gases permitted are carbon dioxide, argon and oxygen (1-5% O_2) and argon- CO_2 mixtures.

E70S-3

These are primarily single pass welds but in the case of semi-killed and killed steels they are satisfactory for multi-pass operation. Sometimes they can also be used with multi-pass applications in the case of rimmed steels.

The carbon dioxide shielding gas will result in greater loss of alloying elements than in the case of argon-oxygen (1-5% O_2) applications. This may result in some loss of tensile strength, especially if high heat inputs are used in test pieces involved.

E70S-4

These electrodes have slightly more alloying elements than E70S-3 and consequently can be expected to provide slightly higher tensile strength than an E70S-3, if used under identical situations.

The Standard permits the use of argon-oxygen and argon- CO_2 mixtures even though this electrode is primarily for use with CO_2 shielding gas.

E70S-5

These electrodes contain aluminum as a deoxidizer in addition to the elements contained in those we have previously listed.

It can be used with CO_2 shielding gas to deposit such weld metal in situations where the base metal is rusty or dirty. However, they are not recommended to be used for short circuiting transfer because of the aluminum content.

The weld deposit is not required to demonstrate impact properties.

E70S-6

These have more alloying and deoxidant material than the electrodes with lower suffixes (E70S-3 to E70S-5 inclusive). This will permit the use of higher current and will result in sound weld deposits, even in the case of rimmed steels when using CO_2 shielding gas.

The increased alloy content, which can be anticipated if argon-oxygen (1-5%) or argon-carbon dioxide shielding gas mixtures are used, should be given due consideration. The soundness of the weld deposit will naturally depend upon the amount of parent metal surface contaminants which are present.

E70S-7

These have a substantially higher manganese content than the E70S-J wires. The increased alloy content will provide slightly better weld appearance and welding characteristics allowing higher welding speeds.

These filler metals are recommended for use with argon-oxygen shielding gas mixtures, but they are usable with argon- CO_2 and CO_2 shielding gases.

E70S-G

These electrodes do not have to meet specific chemical bend or impact requirements but they are required to meet tensile and radiographic requirements. The current and polarity which is to be used is not specified in the Standard.

Welding Conditions and Shielding Gases

The conditions under which the qualification test weld is performed are shown in Table 16. Except for E70S-G (ER480S-G) which is not specified, all wires are operated with DC electrode positive and with carbon dioxide shielding gas.

CLASSIFICATION		CURRENT AND POLARITY	SHIELDING GASES	
W48.4	W48.4-M		Test Gas	Other Gases Qualified
E70S-2	ER480S-2	dcep	CO ₂	*Ar-O ₂ -CO ₂
E70S-3	ER480S-3	dcep	CO ₂	
E70S-4	ER480S-4	dcep	CO ₂	
E70S-5	ER480S-5	dcep	CO ₂	None
E70S-6	ER480S-6	dcep	CO ₂	*Ar-O ₂ -CO ₂
E70S-7	ER480S-7	dcep	CO ₂	
E70S-G	ER480S-G	not specified	not specified	None
*Restrictions: 1. O₂—1 to 5% when present 2. H_e may replace A_r up to 5% total gas mixture				

CSA Standards W48.4 & W48.4-M Welding Conditions & Shielding Gases
Table 16

Electrodes and Consumables for Welding

Mechanical Properties of As-Welded Deposits

In the American specifications the tensile strength is not subject to a maximum limit as is required in the CSA Standard. However, the other mechanical properties with respect to tensile strength, yield strength and elongation are the same for all types of these electrodes.

The Canadian requirements are as follows:-

Tensile Strength	Minimum Yield Strength	Elongation
72 ksi to 92 ksi (500 MPa)	60 ksi (420 MPa)	22% minimum

As in the case of covered electrodes a decrease of minimum tensile strength (to 70 ksi, 480 MPa) and yield (to 58 ksi, 390 MPa) is allowed for tests showing an elongation greater than 24%.

Impact Properties

The impact properties are similar in both the American and the Canadian Standards.

Minimum Impact Properties

E70S-2 } E70S-6 } E70S-7 }	20 ft-lbs at -20°F or 27J at -29°C
----------------------------------	------------------------------------

E70S-3	20 ft-lbs at 0°F or 27J at -18°C
--------	----------------------------------

E70S-4 } E70S-5 }	not required
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E70S-G	A5.18 — As agreed between supplier and purchaser W48.4 & W48.4M — not required.
--------	--

Flux Cored Wires

The *flux cored arc welding* process employs wires comprising an outer metal sheath with a core containing fluxing and alloying components. Some wires are designed to be used with a shielding gas (usually carbon dioxide) in a manner similar to gas metal arc welding, whereas others can be used without any additional external shielding gas. Certain cored wires (composite wires) can also be used with the submerged arc process, and these will be discussed in a later section.

The sequence of manufacture of flux cored wires is summarized in Fig. 15 and the fabrication method is illustrated in Fig. 16. A steel strip is passed through a set of rolls which form it into a V shape. The flux is poured in and the V closed up to make a tubular wire which is then drawn down to final size. Sometimes the wire receives a baking treatment during manufacture depending on the type of wire and flux formulation. The type of closure may vary and examples of various cross-sections are illustrated in Fig. 17.

Cored wires are not copper coated because there is a seam along the wire. Seamless wires, however, have been made by drawing down seamless tubes filled with flux, and these can be copper coated. The manufacture of flux cored wires from strip has many advantages over solid wires since a wide range of electrode compositions can be made by changing the flux. The metal sheath, however, would be the same mild steel. In operation the flux cored wires are usually easier to handle than solid wires, and have a high deposition rate. Some wires contain iron powder in the core which increases the deposition rate.

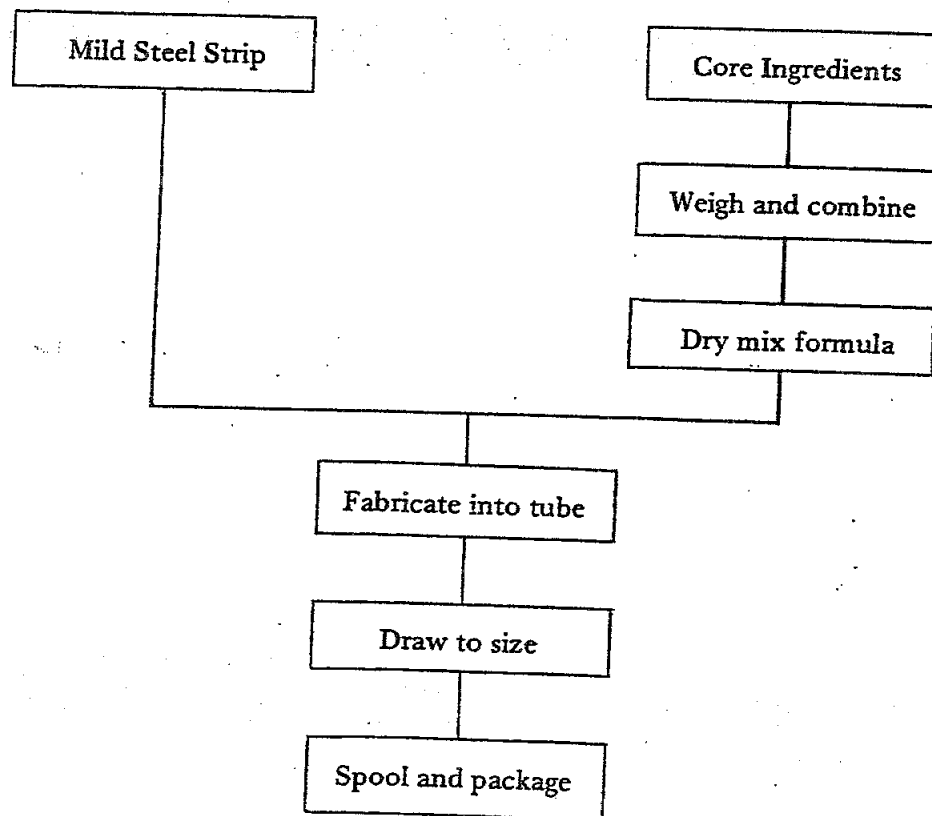


Fig. 15 — Sequence of Manufacture of Flux Cored Wires

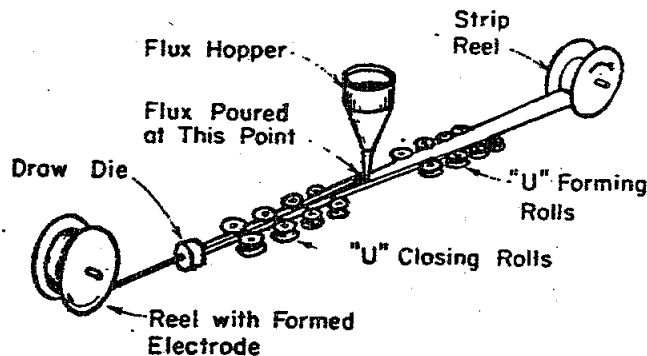


Fig. 16 — Simplified Schematic of the Manufacture of Flux Cored Wires.

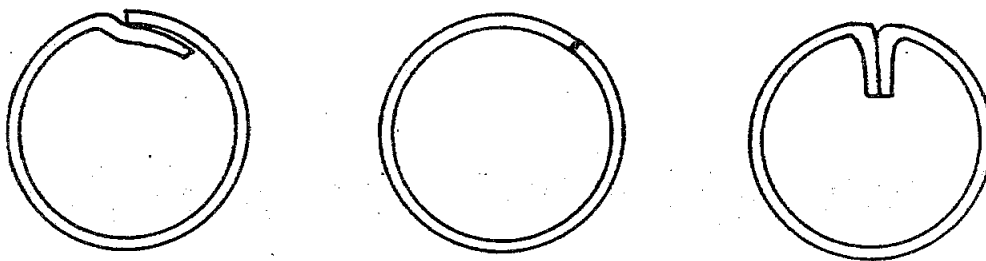


Fig. 17 — Typical Cross-Section of Flux Cored Wires

Cored wires are available in a range of diameters from $\frac{1}{8}$ inch (3.2 mm) down to 0.045 inch (1.1 mm) with the $\frac{3}{32}$ inch (2.4 mm) being the most widely used. The availability of the very small diameter has increased the use of flux cored wires in positional welding involving vertical and overhead welds.

Types of Flux Cored Wires

As with covered electrodes, the operating characteristics and the resulting weld metal properties depend largely on the flux and other ingredients used. The two main classes of wires are those intended for use with an external gas shield (usually carbon dioxide), and those designed for use without an external gas shield (self-shielding types). The latter types can be very complex and contain elements for deoxidation and denitrifying, in addition to ingredients that control the operating characteristics.

In the gas shielded class, most of the available wires can be classed in one of three groups:

- High rutile type (titania)
- Lime-rutile (titania)
- High lime (basic type)

The fluxes affect the electrode characteristics in a manner similar to covered electrodes with the rutile cored wires producing a slag like that from a rutile covered electrode.

The basic cored wires are more difficult to handle in the same way that a basic covered electrode is more difficult than a rutile electrode.

The flux has an important effect on the properties of the deposited weld metal, particularly the toughness. Welds made with a covering of a basic slag will pick up less oxygen and have better fracture resistance than welds made under a rutile slag. Basic cored electrodes, therefore, show better toughness than rutile cored wires, although the latter have adequate toughness for most applications and are far more widely used.

Specifications and Standards for Flux Cored Wires

Mild steel flux cored wires are covered by specification AWS A5.20-79 and by CSA W48.5-1970. The latter standard is currently under revision (1981) and a metric version (S.I. units) W48.5M will be published. The meaning of the symbols is explained in Table 17. Certain differences should be noted in the classification system:

- The system for denoting minimum tensile strength. The AWS symbol uses only one digit to indicate this.
- The system for denoting welding position. The AWS use the SECOND digit whereas CSA W48.5M uses the FOURTH digit. CSA W48.5-1970 does not indicate welding position.
- The CSA Standards have a requirement for maximum weld metal hydrogen.

Chemical Requirements

The requirements for the chemical composition of the deposited weld metal are shown in Table 18 for CSA W48.5 and Table 19 for AWS A5.20-79 and CSA W48.5M. The newer standards have simplified the requirements considerably, and it should be noted that, although classified as mild steel electrodes, the weld metal may be allowed to contain some alloy elements. These are added to the wires to control the performance characteristics, weld metal toughness and, in the self-shielded wires, oxygen and nitrogen removal.

Mechanical Properties

The requirements for the mechanical properties of the deposited weld metal (in the as-welded condition) are summarized in Tables 19 and 20. The various classes of wire differ mainly in their requirements for toughness as measured by the Charpy V notch impact test. As with covered electrodes, the minimum tensile and yield strength depends on the elongation. For each increase of one percentage point in elongation over the minimum, the minimum required yield strength (or tensile or both) may decrease 1 ksi (10 MPa in W48.5M) for a maximum reduction of 2 ksi (20 MPa in W48.5M).

Electrodes and Consumables for Welding

CSA W48.5-1970

Electrode _____ E X X T - X - C H

Minimum tensile strength }
 60 = 60 ksi
 70 = 70 ksi

Tubular wire _____

Slag system, current, polarity, shielding gas _____

Controlled hydrogen _____

CSA W48.5M*

Electrode _____ E X X O X T - X - C H

Minimum tensile strength }
 410 = 410 MPa
 480 = 480 MPa

Welding positions:
 1 = all positions
 2 = flat & horizontal fillets }

Tubular wire _____

Slag system, current, polarity, shielding gas _____

Controlled hydrogen _____

AWS A5.20-79

Electrode _____ E X X T - X

Minimum tensile strength }
 6 = 60 ksi
 7 = 70 ksi

Welding Positions:
 0 = horizontal and flat
 1 = all positions }

Tubular wire _____

Slag system, current, polarity, shielding gas _____

* This is a committee document not yet published and could be subject to change.

Meaning of Symbols for Flux Cored Wires
 Table 17

CSA STANDARD W48.5

Classification	CHEMICAL COMPOSITION (%)						
	Mn	Si	Ni	Cr	Mo	V	Al
E60T-7	1.50	0.90	0.50	0.20*	0.30*	0.08*	1.8
E60T-8	1.50	0.90	0.50	0.20*	0.30*	0.08*	1.0
E70T-1	1.75	0.90	0.30*	0.20*	0.30*	0.08*	—
E70T-2	NO CHEMICAL REQUIREMENTS						
E70T-3	NO CHEMICAL REQUIREMENTS						
E70T-4	1.50	0.90	0.50	0.20*	0.30*	0.08*	1.8
E70T-5	1.50		0.30*	0.20*	0.30*	0.08*	—
E70T-6	1.50	0.90	0.80	0.20*	0.30*	0.08*	—
E70T-9	1.75	0.90	0.30*	0.20*	0.30*	0.08*	—
E70T-G	NO CHEMICAL REQUIREMENTS						
E70T-G1	NO CHEMICAL REQUIREMENTS						
E70T-G2	NO CHEMICAL REQUIREMENTS						

* The amount of these elements shall be reported if added intentionally

Chemical Requirements (Deposited Weld Metal)

Table 18

CSA STANDARD W48.5-M

Classification		Chemical Composition, wt. percent ^d								
AWS	CSA	Mn	Si	P	S	Ni	Cr	Mo	V	Al
EXXT-1 EXXT-4 EXXT-5 EXXT-6 EXXT-7 EXXT-8 EXXT-11 EXXT-G	EXXXXT-1 EXXXXT-4 EXXXXT-6 EXXXXT-7 EXXXXT-8 EXXXXT-9 EXXXXT-11 EXXXXT-G	1.75	0.90	0.04	0.03	0.50 ^a	0.20 ^a	0.30 ^a	0.08 ^a	1.8 ^b
EXXT-GS EXXT-2 EXXT-3 EXXT-10	EXXXXT-GS EXXXXT-2 EXXXXT-3 EXXXXT-10	No Chemical Requirements ^c								

^a The amount of these elements shall be reported if added intentionally.^b For self shielded electrodes only.^c Maximum chemistries of undiluted weld metal are not meaningful, since these classifications are intended for single pass welding with resultant high dilution.^d Single values are maximum percentages.

Chemical Requirements (Deposited Weld Metal)

Table 19

Fundamentals of Welding Technology

	Minimum Tensile Strength	Minimum Yield Strength	Minimum Elongation in 2 in (50 mm)
CSA W48.5	ksi	ksi	per cent
E60T-7	67	55	22
E60T-8	62	50	22
E70T-X	72	60	22
E70T-2 & 3	72	— not required —	
AWS A5.20-79			
E6XT-X	62	50	22
E6XT-GS	62	— not required —	
E7XT-X	72	60	22
E7XT-2, 3, 10 & GS	72	— not required —	
CSA W48.5M	MPa	MPa	per cent
E410XT-X	430	340	22
E480XT-X	500	410	22
E480XT-2, 3, 10, GS	500	— not required —	

Summary of Tensile Requirements for Mild Steel Flux Cored Wires
Table 20

	CHARPY V-NOTCH IMPACT TEST	
	Temperature for 20 ft lbs	Temperature for 27 joules
CSA W48.5		
EXXT-1, 6, 8 EXXT-5, 9 EXXT-2, 3, 4, 7, G	0°F -20°F not required	
AWS 5.20-79		
EXXT-1 EXXT-5, 6, 8 EXXT-2, 3, 4, 7, 10, 11, G, GS	0°F -20°F not required	
CSA W48.5M		
EXXXXT-1, 6, 8 EXXXXT-9 EXXXXT-2, 3, 4, 7, 10, G, GS		-20°C -30°C not required

Summary of Impact Requirements for Mild Steel Flux Cored Wires
Table 21

Description of the Various Electrode Classifications

T-1 Electrode Classification

Electrodes of this classification usually have a rutile base slag and are designed to be used with CO_2 shielding gas for single and multiple pass welding in the flat position, and for horizontal fillets. Some electrodes in this classification require that joints be relatively clean and free of oil, excessive oxide and scale, in order that welds of radiographic quality can be obtained. A quiet arc, high deposition rate, low spatter loss, flat-to-slightly convex bead configuration, and easily controllable and removable slag, are characteristics of these electrodes. Weld deposits made with these electrodes have good impact properties. Argon- CO_2 mixtures can be used to improve the usability, but increasing amounts of argon may increase manganese and silicon in the deposit.

T-2 Electrode Classification

Electrodes of this classification are used with CO_2 shielding gas and are designed primarily for single pass welding in the flat position and for horizontal fillets. Multiple pass welds with some E70T-2 electrodes require an appreciable amount of admixture of the base and filler metals.

Both the tensile strength and the manganese content of the weld metal are likely to be high in multi-pass applications. However, when making two single passes (one on each side of the groove weld) it may be considered as a single pass application because of the weld metal dilution.

The higher deoxidation level will permit satisfactory welding over scale or on rimmed steels.

These electrodes can be used for welding material which has heavier mill scale, rust, or other foreign materials on its surface, than can be tolerated by some electrodes of the E70T-1 classification, and still produce welds of radiographic quality. The arc characteristics and deposition rates are similar to those of the E70T-1 electrodes.

T-3 Electrode Classification

Electrodes of this classification are used without externally applied gas shielding and are intended primarily for depositing *single pass*, high speed welds in the flat and horizontal positions on light plate and gauge thickness base metals. They should not be used on material thicker than 3/16" or for multiple pass applications.

T-4 Electrode Classification

Electrodes of this classification are used without externally applied gas shielding, and may be used for single and multiple pass applications in the flat and horizontal positions. Due to low penetration and other properties, the weld deposits have a low sensitivity to cracking. The low penetration allows them to be used on poor fit-up joints.

T-5 Electrode Classification

This classification covers electrodes primarily designed for flat fillet or groove welds with an externally applied shielding gas, such as carbon dioxide or argon- CO_2 mixtures.

These electrodes have a lime-fluoride (basic) core producing a thin slag which may not completely cover the weld deposit. They have a globular transfer, low penetration and provide a slightly convex bead configuration.

The basic flux provides reduced weld metal oxygen content and gives improved impact properties. The wires are generally more difficult to handle than the rutile cored wires.

T-6 Electrode Classification

Electrodes of this classification are designed for use without an externally applied shielding gas. They can be used for single or multiple pass applications and are designed to give good low temperature impact values.

In general they are used with DC electrode positive and they have a spray type of transfer.

T-7 Electrode Classification

Electrodes of this classification are used without externally applied gas shielding, and may be used for single and multiple pass applications in all positions. The weld deposits have a low sensitivity to cracking, and the slag system is designed to desulphurize the weld metal. They are used with the electrode negative.

T-8 Electrode Classification

Electrodes of this classification are used without externally applied gas shielding, and may be used for single and multiple pass applications in the flat and horizontal positions. Due to low penetration and to other properties, the weld deposits have a low sensitivity to cracking. The weld deposits have good notch toughness properties. Differences between the requirements of AWS and CSA standards should be noted.

T-9 Electrode Classification

This classification covers electrodes primarily designed for flat fillet or groove welds with externally applied CO₂ shielding gas. Horizontal fillet welds can be satisfactorily made, but at lower deposition rates than that obtainable in flat groove welds. The E70T-9 electrodes can be used in single pass applications with minimum surface preparation, as described for the E70T-2 electrodes, as well as for multiple pass work. These electrodes have a globular transfer, low penetration, slightly convex bead configuration, and a thin, easily removable slag. Weld deposits have improved impact properties and meet the same requirements as the T-5 classification. Most T-9 wires have a rutile core. This classification is not included in the American Standard.

T-10 Electrode Classification

These wires are intended for self shielding operation, electrode negative, and permit high speed welding.

They can be used for single pass applications and for welding in flat and horizontal positions.

T-11 Electrode Classification

These electrodes can be used on straight polarity (electrode negative) with a smooth type of spray arc transfer condition. They can be used for either single or multiple pass welding for every position.

T-G Electrode Classification

This is a general classification to include those composite electrodes not included in the preceding classes. The electrode supplier should be consulted for the characteristics and intended use of these electrodes. They may be used with or without gas shielding and may be used for multiple pass work or may be limited to single pass applications. The E70T-G weld metals need not meet chemical, radiographic, bend test, or impact requirements; however, they are required to meet tension test requirements (obtained from either an all-weld-metal tension or transverse tension test specimen), and all other requirements of the Standard.

T-G1 Electrode Classification

This classification includes electrodes which would normally be classified as E70T-G, but do deposit welds that in addition will meet radiographic test requirements, as well as impact requirements of 20 foot pounds at 0°F. This is not included in A5.20-79.

T-G2 Electrode Classification

This classification is similar to E70T-G1 except that the electrodes will satisfy impact requirements of 20 pounds at -20°F. This classification is not included in A5.20-79.

T-GS Electrode Classification

This is a general classification similar to T-G, but covering electrodes designed for single pass applications.

A summary of the applications, shielding gas and welding current is given in Table 22. Although the type of flux used in the core is not a requirement of the standards, most wires meeting a certain classification would have similar principal ingredients. An exception might be where a basic cored wire is classified as a T-9 under CSA requirements to reflect the improved impact properties, although most T-9 wires would be rutile cored. A summary of the usual principal ingredients is given in Table 23.

Fundamentals of Welding Technology

Classification	Shielding Gas	Current and Polarity
T- 1 (Multiple Pass)	CO ₂	dc, electrode positive
T- 2 (Single Pass)	CO ₂	dc, electrode positive
T- 3 (Single Pass)	None	dc, electrode positive
T- 4 (Multiple Pass)	None	dc, electrode positive
T- 5 (Multiple Pass)	CO ₂	dc, electrode positive
T- 6 (Multiple Pass)	None	dc, electrode positive
T- 7 (Multiple Pass)	None	dc, electrode positive
T- 8 (Multiple Pass)	None	dc, electrode negative
T- 9 (Multiple Pass)	None	dc, electrode negative
T-10 (Single Pass)	CO ₂	dc, electrode positive
T-11 (Multiple Pass)	None	dc, electrode negative
T-G (Multiple Pass)	a	a
T-GS (Single Pass)	a	a
T-G1	a	a
T-G2	a	a

a = Not specified

Welding Conditions and Shielding Gases
Table 22

Suffix	Slag
T- 1	Rutile
T- 2	Rutile, extra metal powders
T- 3	Fluorspar, rutile, aluminum
T- 4	Fluorspar, aluminum
T- 5*	Lime, fluorides (basic)
T- 6	Fluorspar, lime, rutile, aluminum
T- 7	Fluorspar, aluminum
T- 8	Fluorspar, aluminum
T- 9†	Rutile
T-10	Fluorspar, aluminum
T-11	Fluorspar, iron powder, aluminum
T-G	Not defined
T-GS	Not defined

* not in W48.5M

† CSA only

Usual Principal Ingredients of Flux Cored Wires
Table 23

Submerged Arc Welding Consumables

WILL BE SOME ON LEVEL 3

Two separate consumables are used in the submerged arc welding system; the *wire* and the *flux*. The wire is fed from a coil, and the flux, in the form of a granular material, is fed into the welding arc zone from a hopper. Some of the flux melts to produce a slag that covers the weld pool, while the unmelted flux may be recovered and used again. A diagram of the essentials of the submerged arc process are shown in Fig. 18. Since the arc is surrounded or 'submerged' by the loose granular flux, it is not visible and this is an attractive feature of the process.

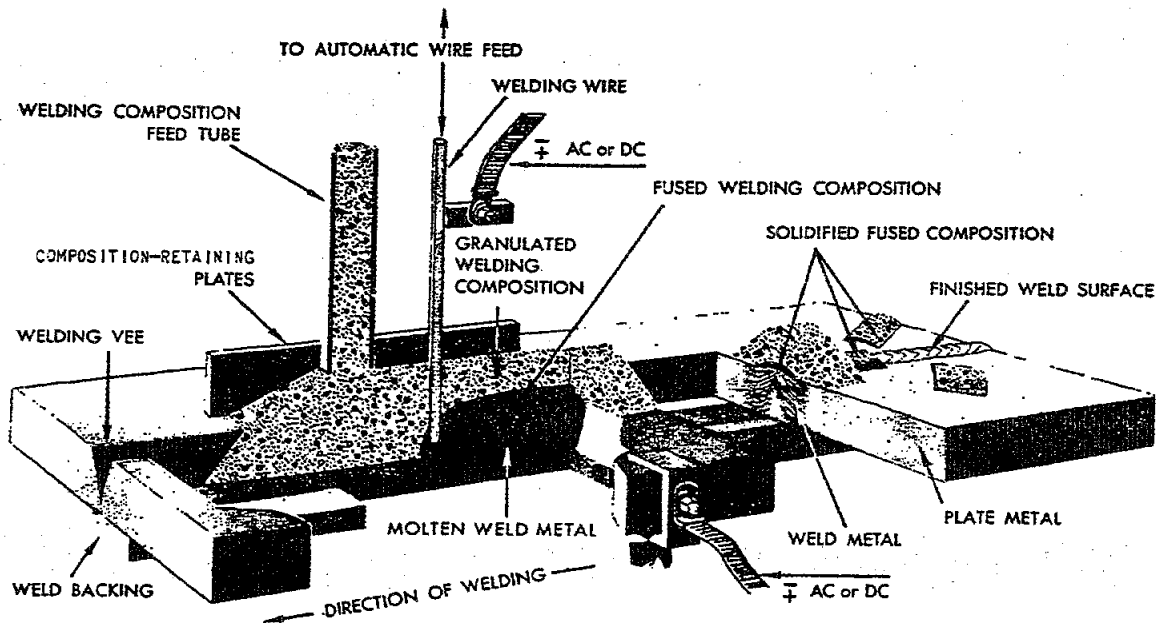


Fig. 18

Submerged Arc Wires

Wires for submerged arc welding (SAW) are made in the same way as that described for GMAW earlier, except they are generally of a larger diameter. They are not usually as 'hard' as GMAW wires (i.e. the tensile strength is not as high), since they are not drawn down to the same extent and generally have a lower level of alloy content. In most cases SAW wires are copper coated. Composite, or flux, or alloy cored wires are used for SAW, particularly for high alloys and stainless steels, but also for low alloy structural steels.

As with GMAW, the cast and helix is important in controlling the position of the tip of the wire as it emerges from the contact tip, but the specifications do not set limits as they do for GMAW wires. SAW wires are available as coils without supports, coils with supports, or in drums and pay-off packs (Fig. 19). Identification of the wire is most important and the outside of each package will have the following information:

- Classification and specification numbers
- Suppliers' name and trade designation
- Electrode size and net weight
- Lot, control, or heat number

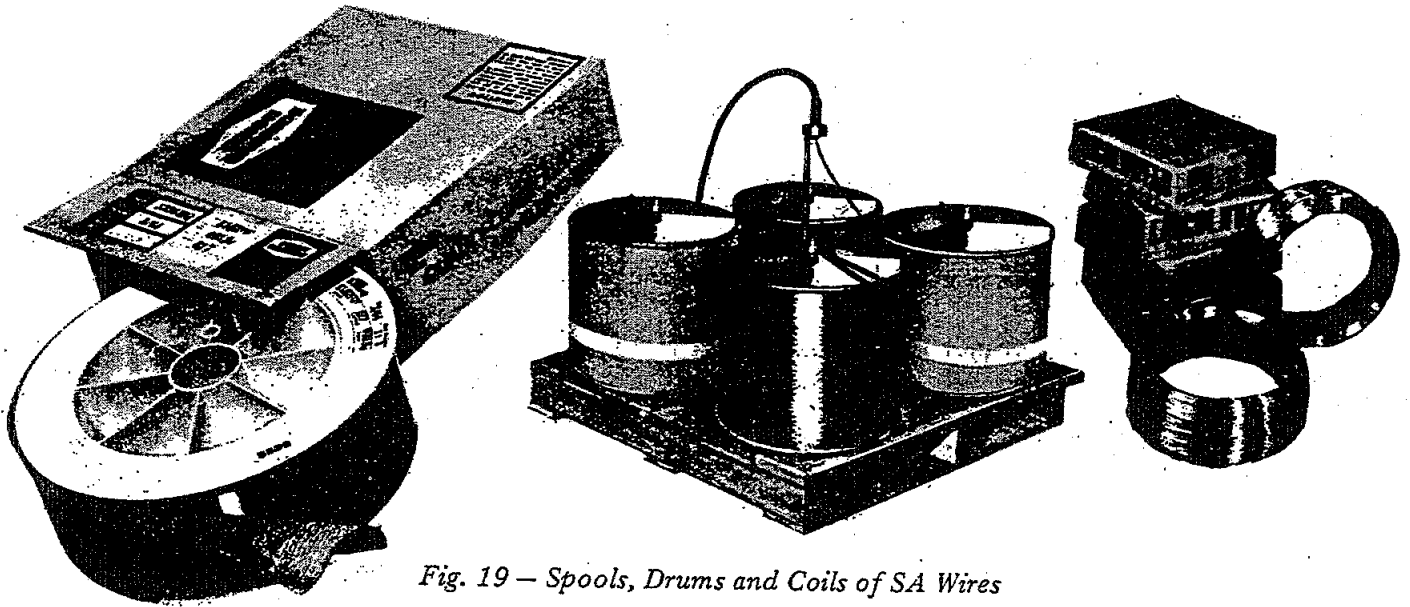


Fig. 19 — Spools, Drums and Coils of SA Wires

In addition a coil will have an identification tag attached to the coil and, if the wire is on a liner or drum, identification will be placed directly on the liner or drum.

Fluxes for Submerged Arc Welding

The flux performs functions essentially the same as in SMA electrodes, the main one being the protection of the molten weld metal from the atmosphere. There are several important differences, however, and these should be noted.

- SAW fluxes do not have to be designed to be extruded and, therefore, do not contain ingredients added to covered electrodes for this purpose.
- SAW fluxes must be capable of handling a wide range of current. In some cases currents over 2000 amps are used in SAW.
- SAW fluxes need not produce large quantities of gas to protect the arc as in SMAW. Organic materials, such as cellulose, are not, therefore used in SAW fluxes.

Fluxes are made from minerals comprising oxides of calcium, silicon, manganese and other elements. By careful design of the flux formulation, a wide range of properties may be obtained. The melting range of fluxes is below that of the weld metal so that molten slag can float out of the weld metal before it solidifies. Slags melt typically in the range 1100 — 1200°C. When the slag becomes solid, the shrinkage rate should exceed that of the steel so that the slag shrinks faster and peels off from the weld. A good flux will form a slag that detaches by itself, leaving a completely clean weld without the need of chipping or grinding.

Methods for Making Fluxes

There are two basic methods for making submerged arc fluxes. The first involves *fusing* the flux ingredients together then crushing to size. The second involved mixing the ingredients together with a binder, then baking. The latter process has variations depending on the baking temperature and is termed *agglomerated* or *bonded*.

Fused fluxes are made by dry mixing the ingredients and melting them together at a temperature of 1500 – 1700°C in an electric furnace in which the current passes through the flux itself (which becomes a conductor when molten). The molten flux is poured into water, or onto a chill plate, and the glassy material then crushed and sized. The advantages of this type of flux are:

- A uniform product with all particles of constant composition.
- Fused fluxes do not usually absorb moisture.

Agglomerated and Bonded fluxes are made by mixing the ingredients together with a binder, such as sodium silicate, then heated in a kiln. The particles agglomerate to form small balls which are subsequently ground to size. A temperature of 800 – 1000°C is used in the agglomeration process. Bonded fluxes are made by a similar process except that lower temperatures are used for curing.

A major advantage of this method of manufacture is that oxidizable materials such as ferro-silicon can be added to the flux, and will remain 'active' (i.e. not turn to oxide) after the baking treatment. Thus, deoxidizing elements and alloys can be included in the flux rather than the wire.

Agglomerated fluxes have a lower density than fused fluxes, and less flux is used in the welding operation. In a typical application the flux consumption for an agglomerated flux is approximately 20% less by weight than for a fused flux.

Chemical Action of Fluxes

Although the main purpose of a submerged arc flux is to protect the weld metal from the atmosphere, the flux itself may react chemically with the weld metal. The two most important consequences of this are:

- The composition of the weld metal will not necessarily be the same as that of the wire. Some elements may increase in concentration, while others decrease.
- The flux may transfer oxygen to the weld metal.

The extent to which these effects occur depends on the type of flux; those fluxes having little effect on the composition being called 'neutral' in North American practice. European terminology is somewhat different. Fluxes transferring significant amounts of oxygen to the weld metal are termed 'acidic', while those transferring small amounts are termed 'basic'.

It is most important to recognize that the flux can influence the composition because it will also influence the properties of the weld. For this reason, fluxes and wires must be selected as a combination, and the specifications treat them as such.

The elements which can change most in concentration are:

- Elements such as manganese and silicon which may be present in the flux.
- Readily oxidizable elements.

If the flux contains a large percentage of silica (SiO_2), the silicon level of the weld metal may be well above that of the wire. Similarly, the chromium content of a stainless steel deposit may be well below that of the wire, and careful selection of fluxes for stainless steel welding is necessary to minimize this chromium loss.

It was pointed out that one of the advantages of agglomerated, or bonded fluxes was that they could contain 'active' deoxidants and alloys. These are useful, for example, in a flux that is tolerant to rust and scale on the plate. The amount of these deoxidants transferred to the weld metal will depend on how much flux is melted, and this in turn depends on the arc voltage. Some fluxes, therefore, are sensitive to the welding parameters and in some cases they are only recommended for single pass welding. Fig. 20 shows the effect of arc voltage on the weld metal silicon content for two fluxes, one being an 'active' flux and the other 'neutral'. When selecting fluxes it is important to study the manufacturers' recommendations to determine if there are any limitations in application, and whether special procedures are required to obtain the best results.

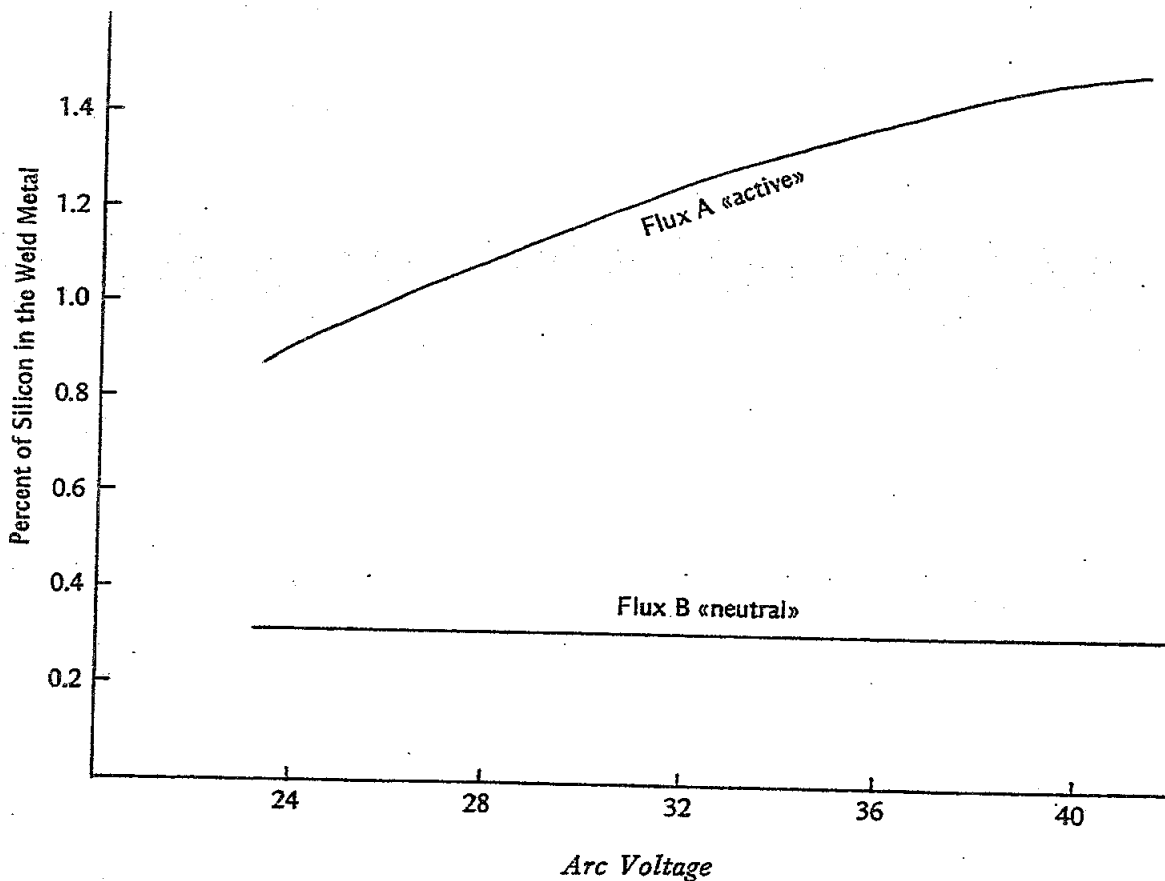


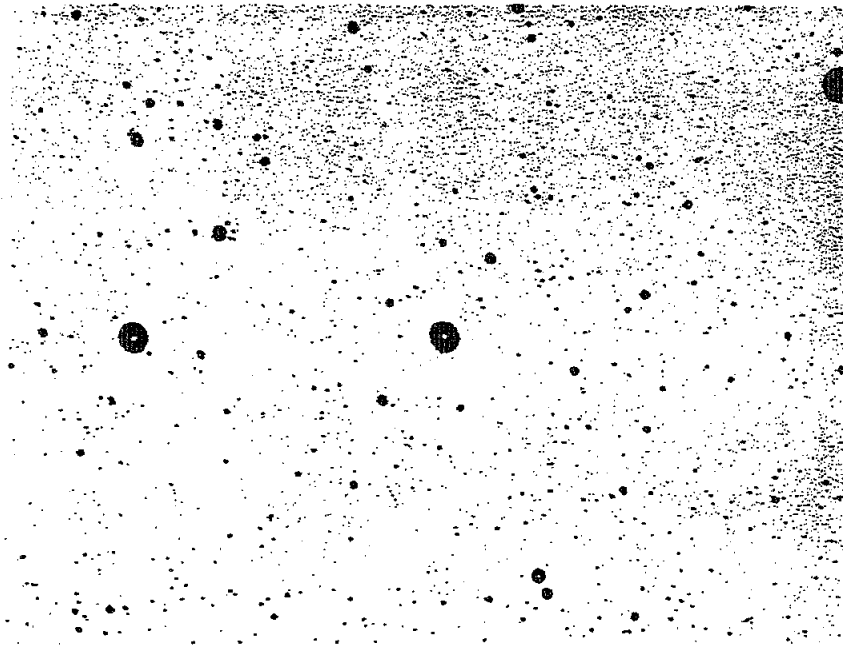
Fig. 20

Graph showing the effect of arc voltage on the amount of silicon transferred to the weld metal for two fluxes. Both fluxes are of the bonded type, but "A" contains 'active' deoxidants whereas "B" is 'neutral'.

Oxygen Transfer

The amount of oxygen transferred from the flux depends on the types of oxides contained in the flux. At the high temperatures involved in welding, some of the oxides may break down to a limited extent and transfer oxygen to the weld metal. Silica (SiO_2) is one of the least stable oxides used in fluxes, and high contents of silica tend to result in high levels of transferred oxygen. On the other hand, these components have many desirable characteristics, and the design of a flux will depend on the intended application and the desired properties.

The main reason oxygen in the weld metal is important, is because it can affect the toughness of the weld metal. When the weld metal solidifies, the oxygen forms tiny round inclusions of oxides which are dispersed throughout the weld metal. They are very small (one millionth of a meter in diameter), but they can reduce the energy required to fracture the metal. An example of weld metal inclusions is shown in Fig. 21.



Non-Metallic Inclusions in Weld Metal (Magnification X500)

Fig. 21

Where improved toughness is required, fluxes have been developed that have reduced oxygen transfer. Special care should be exercised in the selection of submerged arc consumables whenever there is a toughness requirement, bearing in mind that many other requirements may also have to be met.

Specification of Submerged Arc Welding Consumables TEST QUESTION

Two separate consumables are used in submerged arc welding; the wire and the flux. Wires can be specified in terms of the chemical composition of the wire, (as with other solid wires for gas shielded welding) but the flux is not specified separately. Instead, fluxes are specified in terms of the properties of the resulting weld metal *when used in conjunction with a specified wire*. The specification, therefore, refers to a *wire/flux combination*.

Specifications

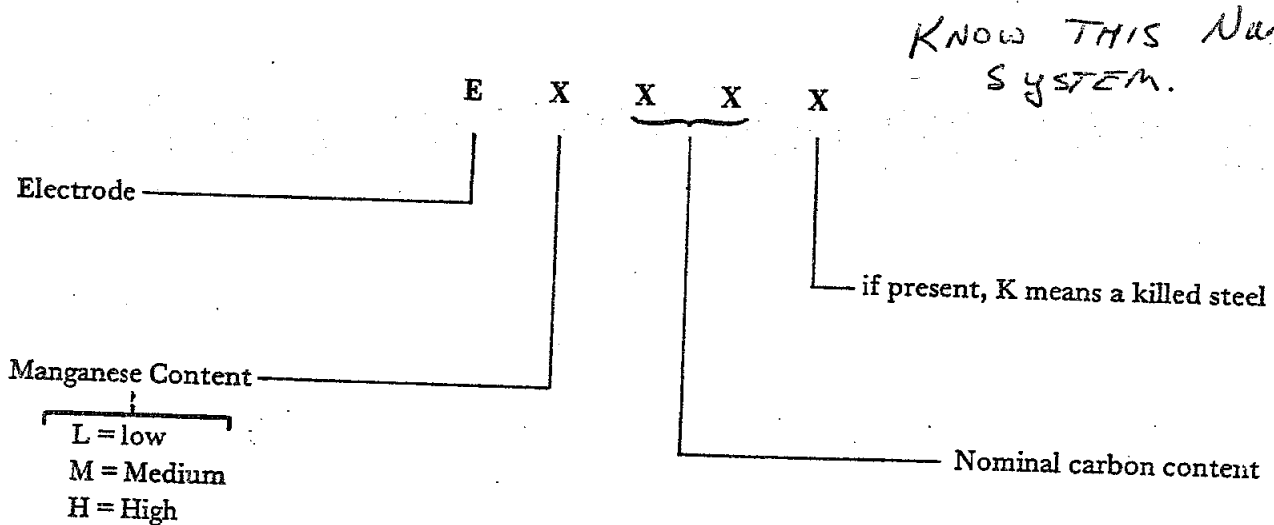
Submerged arc consumables are covered by:

AWS A5.17-76
CSA W48.6-1977
CSA W48.6-M 1980

For Bare Mild Steel Electrodes and Fluxes for SAW.

Specification for Wires

The symbol used for specifying wires for SAW describes the chemical composition in the following way:



Example:

EM12K represents a wire with medium manganese content, nominally 0.12% carbon, and is silicon killed steel.

The full chemical requirements for wires are shown in Table 24. AWS A5.17-76 and CSA W48.6-1977 are the same, but CSA W48.6-M 1980 has some slight differences although the designations are the same.

Electrodes and Consumables for Welding

	CSA W48.6-1977 & AWS A5.17-76			CSA W48.6-M 1980		
Classification	C	Mn	Si	C	Mn	Si
Low Manganese						
EL8	0.10	0.30-0.55	0.05	0.10	0.25-0.60	0.07
EL8K	0.10	0.30-0.55	0.10-0.20	0.10	0.25-0.60	0.10-0.25
EL12	0.07-0.15	0.35-0.60	0.05	0.05-0.15	0.25-0.60	0.07
Medium Manganese						
EMSK*	0.06	0.90-1.40	0.40-0.70	Not Included		
EM12	0.07-0.15	0.85-1.25	0.05	0.06-0.15	0.80-1.25	0.10
EM12K	0.07-0.15	0.85-1.25	0.15-0.35	0.05-0.15	0.80-1.25	0.10-0.35
EM13K	0.07-0.19	0.90-1.40	0.45-0.70	0.07-0.19	0.90-1.40	0.35-0.75
EM15K	0.12-0.20	0.85-1.25	0.15-0.35	0.10-0.20	0.80-1.25	0.10-0.35
High Manganese						
EH14	0.10-0.18	1.75-2.25	0.05	0.10-0.20	1.70-2.20	0.10

Notes:

* This class contains other deoxidizing elements specified.

† For all classes: maximum sulphur 0.035%; phosphorous 0.03%; copper 0.3% (including coating) and some of all other unspecified elements is 0.5%.

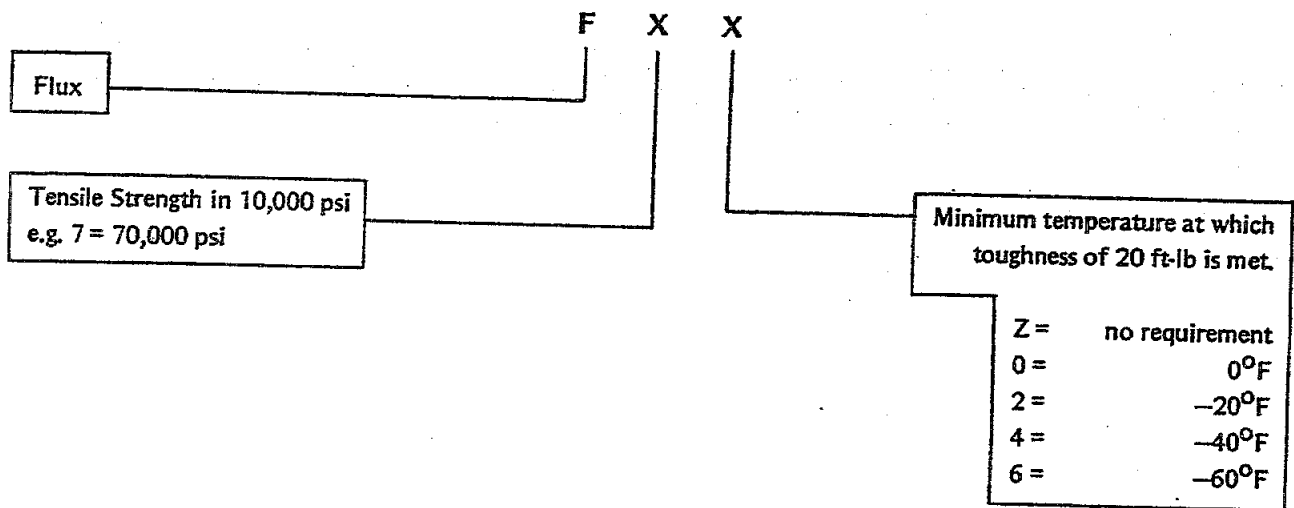
Chemical Requirements for SAW Wires †
Table 24

The suffix letter N is used to denote Nuclear grade. Grade N has restricted sulphur, phosphorus, vanadium and copper, and wires must not be copper coated.

Flux-Wire Combination

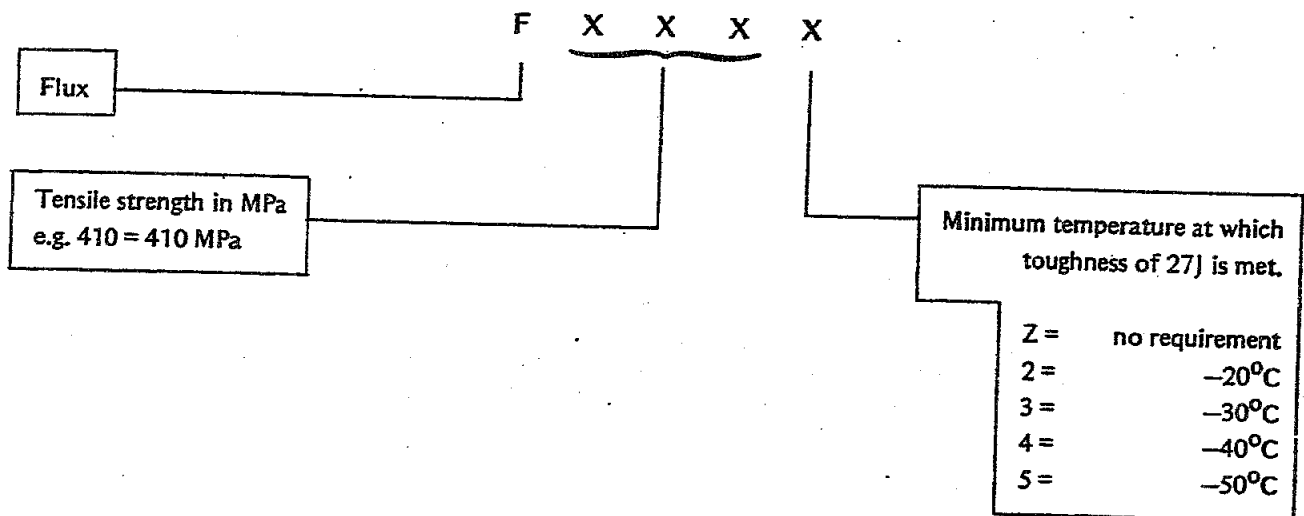
The symbol for the flux portion describes the tensile strength and impact properties.

AWS A5.17-76 & CSA W48.6-1977



EXAMPLE: F72-EM12K

CSA W48.6-M1980



EXAMPLE: F480Z-EM12K

Electrodes and Consumables for Welding

MECHANICAL PROPERTY REQUIREMENTS				
Classification W48.6/W48.6-M	Tensile Strength	Minimum Yield Strength	Elongation in 2" (50 mm) (min. per cent)	Minimum V-Notch Impact Strength
F6Z/F410Z - XXXX F60/F4102 - XXXX F62/F4103 - XXXX F64/F4104 - XXXX F66/F4105 - XXXX	62-80 ksi 430-550 MPa	50 ksi 350 MPa	22	NOT REQUIRED 20 ft. lb. @ 0°F/27 J @ -20°C 20 ft. lb. @ -20°F/27 J @ -30°C 20 ft. lb. @ -40°F/27 J @ -40°C 20 ft. lb. @ -60°F/27 J @ -50°C
F7Z/F480Z - XXXX F70/F4802 - XXXX F72/F4803 - XXXX F74/F4804 - XXXX F76/F4805 - XXXX	72-95 ksi 500-650 MPa	60 ksi 410 MPa	22	NOT REQUIRED 20 ft. lb. @ 0°F/27 J @ -20°C 20 ft. lb. @ -20°F/27 J @ -30°C 20 ft. lb. @ -40°F/27 J @ -40°C 20 ft. lb. @ -60°F/27 J @ -50°C

AWS A5.17 and CSA W48.6 & W48.6-M
Table 25

Mechanical Property requirements are summarized in Table 25. It is important to note that the mechanical tests used for classification are performed on samples taken from a multi-pass weld, 1 inch thick, made in a standard manner. In practice, however, the flux and wire being tested may not be recommended for multi-pass use. The operating characteristics, recommended applications and other conditions are not covered by the specification and, therefore, choice of a wire/flux combination for a specific job cannot usually be made on the basis of the specification alone. Attention must be paid to the manufacturers' recommendations and often additional testing and evaluation is necessary before making a choice.

Low-Alloy Steel Electrodes for SAW

Bare low-alloy steel electrodes and fluxes for SAW are covered by AWS specification A5.23-76. At present, there is no equivalent CSA standard for low alloy SA consumables. As with mild steel consumables, the electrodes are classified according to chemical composition, but wire/flux combinations are classified according to weld metal composition as well as mechanical properties. Many types of electrodes are listed in AWS A5.23-76 and these will not be discussed in detail here. Cored-type composite electrodes are allowed under the specification and are denoted by the letter "C" following the "E" for electrode. A group of letters and numbers is included to represent the weld metal composition, and this may differ from the electrode composition depending on the type of flux being tested.

Recommended Reading

Much information on welding consumables can be obtained from the manufacturer's own literature. In addition the following sources are to be recommended.

1. Modern Welding Technology, by Howard Cary, published by Prentice Hall.
2. Fluxes and Slags in Welding, by C. E. Jackson, Welding Research Council Bulletin, No. 190, December, 1973.

List of CSA Standards Covering Consumables for Welding

W48.1-1976.....	Mild Steel Covered Arc-Welding Electrodes (1a)
W48.1-M1980.....	Mild Steel Covered Arc-Welding Electrodes
W48.2-1977.....	Corrosion-Resisting Chromium and Chromium-Nickel Steel Covered Welding Electrodes
W48.2-M1980.....	Corrosion-Resisting Chromium and Chromium-Nickel Steel Covered Welding Electrodes
W48.3-1976.....	Low-Alloy Steel Arc-Welding Electrodes
W48.4-1978.....	Solid Mild Steel Electrodes for Gas Metal-Arc Welding
W48.4-M1980.....	Solid Mild Steel Filler Metals for Gas Shielded Arc Welding
W48.5-1970.....	Mild Steel Electrodes for Flux Cored Arc Welding (11a)
W48.5M.....	to be published
W48.6-1977.....	Bare Mild Steel Electrodes and Fluxes for Submerged Arc Welding
W48.6-M1980.....	Bare Mild Steel Electrodes and Fluxes for Submerged Arc Welding
W48.7-M1977.....	Diffusible Hydrogen in Mild Steel and Low-Alloy Steel Weld Metals: Test Methods

Electrodes and Consumables for Welding

List of AWS Specifications Covering Consumables for Welding

A5.0-78.....	Filler Metal Comparison Charts
A5.01-78.....	Filler Metal Procurement Guidelines
A5.1-78.....	Specification for Carbon Steel Covered Arc Welding Electrodes
A.2-69.....	Specification for Iron and Gas Welding Rods
A5.3-69.....	Specification for Aluminum and Aluminum-Alloy Arc-Welding Electrodes
A5.4-78.....	Specification for Corrosion-Resisting Chromium and Chromium-Nickel Steel Covered Electrodes
A5.5-69.....	Specification for Low-Alloy Steel Covered Arc-Welding Electrodes
A5.5Add.	1-77 1977 Addenda to A5.5 Addenda (free with purchase of basic document).
A5.6-76.....	Specification for Copper and Copper-Alloy Covered Electrodes
A5.7-77.....	Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes
A5.8-76.....	Specification for Brazing Filler Metal
A5.9-77.....	Specification for Corrosion-Resisting Chromium and Chromium-Nickel Steel Bare and Composite Metal Cored and Stranded Arc Welding Electrodes and Welding Rods
A5.10-69.....	Specification for Aluminum and Aluminum-Alloy Welding Rods and Bare Electrodes
A5.11-76.....	Specification for Nickel and Nickel Alloy Covered Welding Electrodes
A5.12-69.....	Specification for Tungsten Arc-Welding Electrodes
A5.13-70.....	Specification for Surfacing Welding Rods and Electrodes
A5.14-76.....	Specification for Nickel and Nickel Alloy Bare Welding Rods and Electrodes
A5.15-69.....	Specification for Welding Rods and Covered Electrodes for Welding Cast Iron
A5.16-70.....	Specification for Titanium and Titanium Alloy Bare Welding Rods and Electrodes
A5.17-76.....	Specification for Bare Carbon Steel Electrodes and Fluxes for Submerged Arc Welding
A5.18-79.....	Specification for Carbon Steel Filler Metals for Gas Shielded Arc Welding
A5.19-69.....	Specification for Magnesium-Alloy Welding Rods and Bare Electrodes
A5.20-79.....	Specification for Carbon Steel Electrodes for Flux Cored Arc Welding
A5.21-70.....	Specification for Composite Surfacing Welding Rods Electrodes

Fundamentals of Welding Technology

- A5.22-74.....Specification for Flux-Cored Corrosion-Resisting
Chromium and Chromium-Nickel Steel Electrodes
- A5.23-76.....Specification for Bare Low-Alloy Steel Electrodes and
Fluxes for Submerged Arc Welding
- A5.23-Add.1-761976 Addenda to A5.23 Addenda (free with purchase of
basic document).
- A5.24-79.....Specification for Zirconium and Zirconium Alloy Bare
Welding Rods and Electrodes
- A5.25-78.....Specification for Consumables Used for Electroslag
Welding of Carbon and High Strength Low Alloy Steels
- A5.26-78.....Specification for Consumables Used for Electrogas Welding
of Carbon and High Strength Low Alloy Steels
- A5.27-78.....Specification for Copper and Copper Alloy Gas Welding
Rods
- A5.28-79.....Specification for Low-Alloy Steel Filler Metals for Gas
Shielded Arc Welding
- A5.30-79.....Specification for Consumable Inserts

GUIDES AND EXERCISES

MODULE 6

ELECTRODES AND CONSUMABLES

FOR WELDING

ELECTRODES AND CONSUMABLES FOR WELDING

MODULE 6

Guides & Exercises

To obtain maximum benefit from this module we suggest that you follow this guide and complete the exercises as indicated. It is important that you work through the text methodically, studying each section thoroughly before moving on. The exercises are designed to give you an indication of whether you have learned the material and can move on or whether you need to go back and study the section again.

Do the exercises honestly. They will not help you unless you take them seriously. If you get a question wrong go back through the text until you understand where you have gone wrong and know the correct answer.

The length of time required to complete the module will vary from student to student. Find your own pace. Do not rush. Remember you are trying to teach yourself something, not win a race.

Some people like to underline sections when they read a text. We suggest that you use caution if you do this. What you think is important first time you read it may be different after reading it three times. We suggest you read a section three times thoroughly before highlighting anything.

The last exercise is designed to give you an indication of whether you are ready to take the WIC closed-book exams. The exercise questions are of a similar standard to the official exams. Do not take the exam until you feel you are ready and you may wish to study several Modules before taking the exams on each. The details of the examination procedures are on a separate sheet.

If you have any difficulties with this Module do not hesitate to ask for help. You may find you learn more by attending some of the seminars and you should also contact your local WIC Chapter to see if they can be of assistance. Remember, if you fail the examination you can always try again later.

MODULE 6

Guide 1

Carefully read pages 1 to 10 and answer the following questions:

1. When welding with covered electrodes, how is the weld metal protected from contamination from the air?
2. Which of the following features would be attributable to a core wire made from rimmed steel?
 - a) Rimmed steel overheats less than killed steel
 - b) The outside of the rod melts faster than the inside
 - c) The pure iron outside has better conductivity and the current passes more easily in the exterior part of the rod
3. In a medium coated electrode what percentage of the weight is coating?
4. What are the three main functions of the slag?

Check your answers for accuracy. If any of your answers are wrong re-study the guide subject matter until you understand it.

MODULE 6

Guide 2

Carefully read pages 11 to 20 and answer the following questions:

1. Considering the meaning of symbols for covered electrodes, what symbols would be assigned to an electrode 70,000 psi or 70 ksi designed to weld in all positions, except vertical down, has a basic coating with iron powder added, which can be used with AC or DC?
2. Covered electrodes can be divided roughly into four classes depending on the type of flux covering and the dominant component of the flux. What are the four classes?
3. From the following list of electrodes select those which are classed as rutile:

E6010	E7014
E7010	E7024
E7018	E6013
E6027	E7027
4. The 6020 electrode is limited by the volume and nature of its slag for use in two positions only. What are these positions?

Check your answers for accuracy. If any of your answers are wrong re-study the guide subject matter until you understand it.

MODULE 6

Guide 3

Carefully read pages 21 to 30 and answer the following questions:

1. What is the percentage range of iron powder content in the coating of E7014 and E7018?
2. When welding vertical, overhead, and horizontal groove welds what would be the first choice of electrode (in this case low-hydrogen weld metal is not called for)?
3. The moisture in electrode coatings will have a tendency to produce two problems in the weld. What are they?
4. When a package of basic electrodes is opened, the electrode should be placed in a holding oven. What temperature range should the oven be heated to?

Check your answers for accuracy. If any of your answers are wrong re-study the guide subject matter until you understand it.

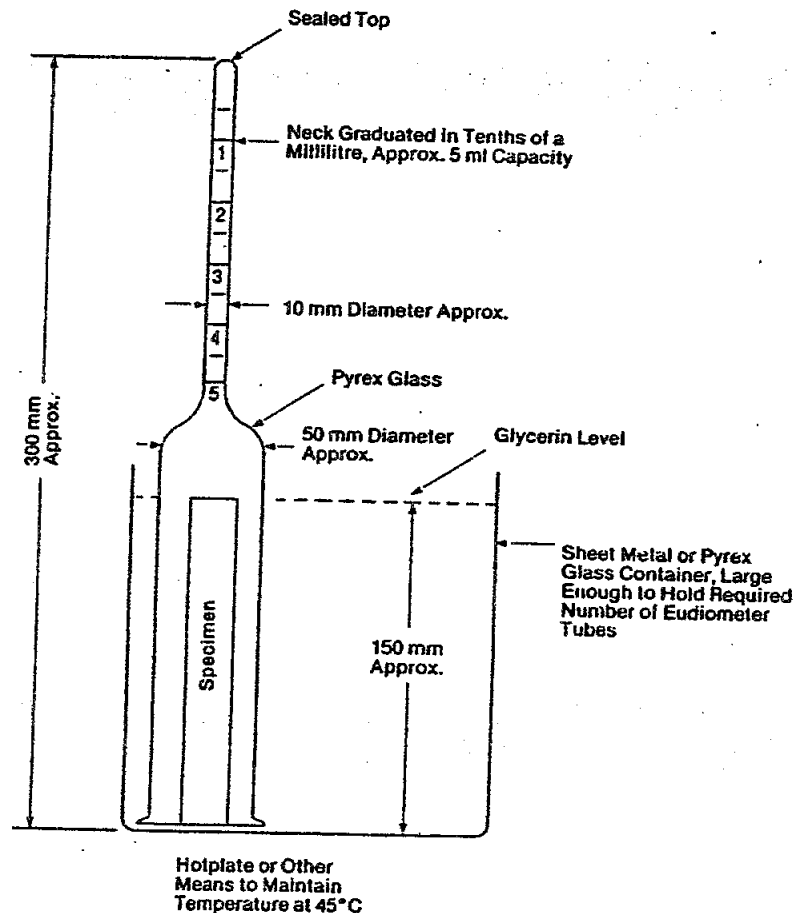
MODULE 6

Guide 4

Carefully read pages 31 to 40 and answer the following questions:

1. Electrodes such as E10018-M, E11018-M and E12018-M contain vanadium and have a tendency to become embrittled when held at temperatures of about: (select one answer only)

(a) 1300°F	(705°C)
(b) 2100°F	(1150°C)
(c) 1000°F	(540°C)
(d) 800°F	(427°C)
(e) 1800°F	(983°C)
2. In the CSA standards, basic electrodes (low alloy and mild steel) are required to undergo a specific test. The illustration shows a diagram of the equipment used in the test. What is the test?



MODULE 6 - Guide 4 (cont.)

3. Why are wires for gas shielded arc welding usually stronger than mild steel wires?

4. What is the reason that most flux cored wires are not copper coated?

Check your answers for accuracy. If any of your answers are wrong re-study the guide subject matter until you understand it.

MODULE 6

Guide 5

Carefully read pages 41 to 50 and answer the following questions:

1. Flux cored wires in the gas shielded class can be classed in one of three groups. From the following select the three groups:
 - a) High rutile type
 - b) Low rutile type
 - c) Lime rutile type
 - d) High lime type
 - e) Low lime type
 - f) Low iron type

2. To what electrode classification does the following description pertain?

"Electrodes of this classification are used without externally applied gas shielding and are intended primarily for depositing single pass, high speed welds in the flat and horizontal position on light plate and gauge thickness base metals. They should not be used on material thicker than 3/16" or for multiple pass applications."

3. T-G2 electrode classification. What are the impact requirements which these electrodes will meet?

Check your answers for accuracy. If any of your answers are wrong re-study the guide subject matter until you understand it.

MODULE 6

Guide 6

Carefully read pages 51 to 62 and answer the following questions:

1. What are the two separate consumables used in the submerged arc welding system?
2. In the manufacture of fused fluxes what is the temperature at which they are melted?
 - a) 1500° - 1700°C
 - b) 15,000° - 17,000°C
 - c) 500° - 700°C
 - d) 1800° - 2400°C
3. What is the main reason that oxygen transfer to the weld metal is important?
4. The following symbols represent a submerged arc welding wire—EM12K. What does the K signify?

Check your answers for accuracy. If any of your answers are wrong re-study the guide subject matter until you understand it.

MODULE 6

ANSWERS

Guide 1

1. By gases from the flux and by the molten slag in contact with the metal
2. (a) and (c)
3. 20% - 35%
4.
 - To protect the weld metal from contamination
 - To aid in the removal of oxygen and other impurities from the weld metal
 - To control the bead shape and smoothness

Guide 2

1. E7018
2. Cellulosic, Rutile, Iron Oxide, Basic
3. E6013 E7014 E7024
4. Horizontal Fillet and Flat

Guide 3

1. 20% - 40%
2. E6010
3. Porosity, hydrogen gas
4. 100 - 150°C

Guide 4

1. (c) 1000°F (540°C)
2. Hydrogen test
3. Because of the effect of cold drawing and the presence of alloying elements
4. Because there is a seam along the wire

MODULE 6

ANSWERS continued

Guide 5

1. (a) (c) (d)
2. T3
3. 20 ft pounds at -20°F

Guide 6

1. Wire and flux
2. (a)
3. Because it can affect the toughness of the weld metal
4. Killed steel

MODULE 6

TEST

This test is designed to determine whether you are ready to attempt the formal examination.

Complete the ANSWER SHEET and compare the results with the TEST KEY. If you have a pass mark less than 70% you are advised to re-study the material.

1. A submerged arc wire contains 0.12% carbon, medium manganese content and is made of killed steel. Which of the following designations would be correct?
 - (a) E L 12 K
 - (b) E H 14 K
 - (c) E L 12
 - (d) E L 8 K
 - (e) E M 12 K

2. The thickness of coating on an electrode depends on the type of electrode. Heavily coated electrodes may have up to.....electrode weight in the coating:
 - (a) 35 per cent
 - (b) 80 per cent
 - (c) 55 per cent
 - (d) 75 per cent
 - (e) 65 per cent

3. Which of the following steels are generally used for the core wire of a mild steel covered electrode?
 - (a) rimmed.
 - (b) killed
 - (c) semi-killed
 - (d) none of the above
 - (e) all of the above

4. The main function of slag is:
 - (a) to protect the weld metal from contamination
 - (b) to aid the removal of oxygen and other impurities from the weld metal
 - (c) control the carbon content of the deposited weld metal
 - (d) to control the bead shape and smoothness
 - (e) answer (a) (b) and (d)

MODULE 6

TEST continued

5. Where there is a possibility that certain classifications of electrodes have picked up excessive moisture, they can be restored by rebaking; 6010 and 6011 Electrodes should not be rebaked because the coverings for these types are designed to have moisture levels of.....and excessive drying may substantially affect their operation:
- (a) 1 to 3 per cent
 - (b) 3 to 7 per cent
 - (c) 7 to 10 per cent
 - (d) 8 to 11 per cent
 - (e) 4 to 8 per cent
6. The various classes of wire differ mainly in their requirements for toughness as measured by:
- a) charpy V notch impact test
 - (b) Vickers hardness test
 - (c) drop weight test
 - (d) tensile test
 - (e) charpy U notch impact test
7. In considering E48018 electrodes, (W48.1-7) the "18" describes which of the following combinations?
- (a) all positions, except vertical down and rutile and iron
 - (b) flat and vertical down and basic and iron
 - (c) all positions, except vertical down and basic and iron
 - (d) all positions, except vertical down and basic
 - (e) all positions and cellulose

MODULE 6

TEST continued

8. When a package of basic electrodes is opened, which of the following should be ensured?
- (a) storage is irrelevant
 - (b) electrode should be baked
 - (c) none of the above
 - (d) electrodes should be stored in a controlled oven, providing no other electrodes are present, at 200°F - 300°F and controlled upon removal from the oven
 - (e) all of the above
9. In considering submerged arc flux designations under AWS A5.17 and CSA W48.6, indicate the correct description for F74 flux designation.
- (a) F = Flux 74 = 70,000 psi tensile, 20 ft lbs at -40°F
 - (b) F = Flux 74 = 74,000 psi tensile at -40°F
 - (c) F = Flux 74 = 70,000 psi tensile, 40 ft lbs at 0°F
 - (d) all of the above
 - (e) none of the above
10. Which of the following solid wire designations meet min. impact properties of 20 ft lbs at -20°F or 27 J at -29°C?
- (a) E70S2 - E70S6 - E70S7
 - (b) E70S4 - E70S5
 - (c) E70S3 - E70S4
 - (d) E70SG - E70SG1
 - (e) none of the above

Canadian Welding Bureau Answer Sheet - Module 6

Complete the "Answer Sheet" and compare the results with the "Test Key". If you have a pass mark less than 70%, you are advised to re-study the material.

Please circle only ONE letter corresponding to the answer you think is most correct.

QUESTION	ANSWERS				
1	a	b	c	d	e
2	a	b	c	d	e
3	a	b	c	d	e
4	a	b	c	d	e
5	a	b	c	d	e
6	a	b	c	d	e
7	a	b	c	d	e
8	a	b	c	d	e
9	a	b	c	d	e
10	a	b	c	d	e

The answer key below is provided for your use in the event that you wish to retest yourself.

QUESTION	ANSWERS				
1	a	b	c	d	e
2	a	b	c	d	e
3	a	b	c	d	e
4	a	b	c	d	e
5	a	b	c	d	e
6	a	b	c	d	e
7	a	b	c	d	e
8	a	b	c	d	e
9	a	b	c	d	e
10	a	b	c	d	e

Canadian Welding Bureau
Test Key - Module 6

Compare your answer sheet to this key.

QUESTION	ANSWERS				
1	a	b	c	d	(e)
2	a	b	(c)	d	e
3	(a)	b	c	d	e
4	a	b	c	d	(e)
5	a	(b)	c	d	e
6	(a)	b	c	d	e
7	a	b	(c)	d	e
8	a	b	c	(d)	e
9	(a)	b	c	d	e
10	(a)	b	c	d	e