Selecting Submerged Arc Fluxes for Carbon and Low Alloy Steels

Requires a consideration of mechanical properties and performance characteristics wherein new guidelines for performance selection are introduced

By G. G. Wittstock

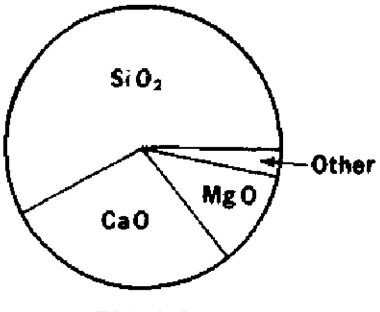
The submerged arc welding process has long been recognized for its versatility and excellent economics. It operates well at low or high currents, using single or multiple electrodes on plate from thin gage to unlimited thickness. The real key to this performance versatility is the flux itself—it blankets the arc, eliminates flash, spatter and smoke, controls arc stability, governs bead shape, and influences weld chemistry.

Submerged arc welding fluxes are granular, fusible mineral compounds in various proportions manufactured by several different methods. All of them share certain restrictions in design to assure operability, but differ widely in composition, offering many unique performance features. Proper flux selection is paramount for optimum performance, yet the user is confronted with a bewildering number of flux/electrode combinations from which to choose. Flux/electrode classifications based on American Welding Society Specifications can be useful, but are necessarily limited in scope. Advice from the consumables manufacturers helps but, in the end, the user must satisfy himself that the materials selected are the best for his application. This is done on test plates simulating the application conditions whenever possible, but even this has cost and time limitations. Improvement of our knowledge of flux characteristics can significantly reduce the number of flux/electrode combinations as candidates for a given application.

Prior to actual testing, candidate materials which are likely to meet the requirements of the application must be selected, considering the influence of both the electrode and the flux. Understanding some principal features to consider in flux selection will streamline materials evaluation, provide safeguards and alert existing users to potential savings through materials optimization.

Historical Background

Submerged arc welding was first commercialized in 1936 with a fused, high SiO_2-CaO-MgO flux composition as shown in Fig. 1. This flux is ideally suited for high current applications and was initially applied in shipbuilding and heavy tank construction using 1000—2000 A with 1/4 in. (6.4 mm) and 3 8 in. (9.5 mm) diameter electrodes. This composition still finds substantial use, but the need for improved weld ductility in multipass welds led to the development of fluxes which transfer less silicon into the weld. Fluxes containing Al_2O_3 and MnO were introduced to accomplish this and offer other performance features.



FLUX A

Fig. 1—Basic flux composition representative of first commercial submerged arc flux.

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In 1946, the bonded or agglomerated fluxes were produced commercially. Bonded fluxes are dry mixed powders bonded together with a binder such as sodium silicate, differing from prefused fluxes where all ingredients are melted in an electric furnace. The lower temperatures required for bonding permit the addition of metallic deoxidizers and alloying ingredients which can radically change the character of a flux system. The composition shown in Fig. 2 represents one of the earliest bonded fluxes. This same system is widely used today in both bonded and fused forms; the performance characteristics and application areas differ significantly for the two forms.

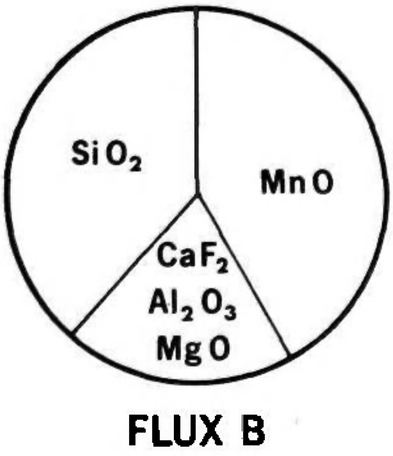


Fig. 2—A general purpose flux composition produced in both bonded and fused forms.

Fused fluxes are characterized by their extremely good chemical homogeneity and nonhygroscopic nature. Fines may be removed without changing the composition of the flux. Changes to the slag/metal consumption ratio will not appreciably affect deposit strength levels. On the other hand, bonded fluxes can be made to exhibit higher degrees of rust and scale tolerance through deoxidizer additions such as metallic manganese and silicon. The combination of fine ingredients mechanically bonded into larger particles provides good performance over a wide range of applications with one mesh size. Some restrictions in use are necessary to avoid unintentional or non-uniform alloying of the weld metal.

For the past 30 years there has been extensive development of both bonded and fused systems. Originally, these two lines of development were based on proprietary considerations; however, today it is recognized that both bonded and fused have unique characteristics and advantages in the wide variety of welding applications. Of course, there are overlaps in application suitability making proper flux selection sometimes arbitrary, but they allow the knowledgeable user to "fine-tune" his job for productivity and economy.

Most recently, fluxes have been developed to provide improved notch toughness in varied applications to meet the needs of industry. Better control of oxygen, phosphorus, and sulphur is a contributing factor in achieving superior weld metal brittle fracture resistance (Refs. 1, 2, 3). Other evidence suggests that the distribution of microconstituents, the overall microstructure of the bead, and the effects of precipitation hardening mechanisms are equally important (Refs. 4, 5). The compositions of two widely used high impact fluxes are shown in Fig. 3. It is important to note the contrast between formulations and manufacturing technique, yet their similarity in purpose.

Flux C is based on the silica-lime system with over 80% of this fused composition made up of these two components. On the other hand, flux D contains six major constituents, with far less silica and lime. Both fluxes provide similar deposit composition control and are used to optimize deposit toughness.

Flux Behaviour

Fluxes perform many key roles in addition to providing atmospheric protection for the molten metal and influencing the mechanical properties of the weld deposit. Their actions in controlling arc stability, bead shape, puddle fluidity, rust and scale tolerance, peeling characteristics, and welding speed capabilities give the submerged arc welding process its inherent application flexibility. The complex interactions of the oxide, fluoride, and metallic ingredients in a flux give each its own personality.

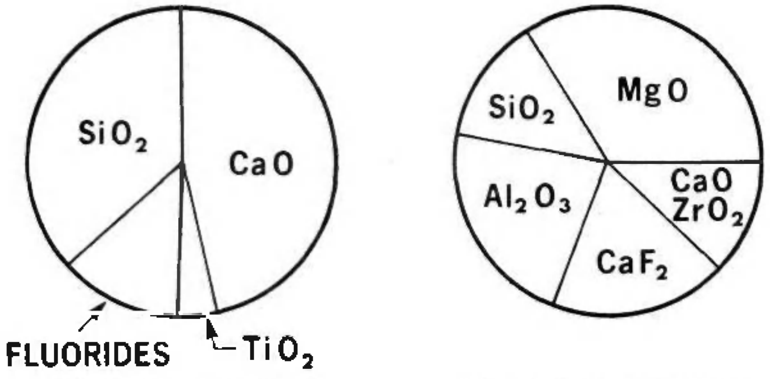
Optimization of these performance features to fulfill specific industry needs has resulted in the development of a large variety of compositions. For certain welding applications, fluxes have been tailored to meet specific weld objectives. It is unfortunate, as with many welding material areas, that one flux cannot perform optimally for all applications. Compromises must be made under many circumstances to either capitalize on a particular welding performance feature such as high welding speed or accept a more general purpose flux suitable for a variety of applications.

Flux Chemistry

Considerable effort has been expended in attempts to relate flux composition to welding characteristics to aid in flux development and correct application. While meaningful relationships can sometimes be demonstrated, no broadly applicable expressions have been developed to quantitatively relate composition and flux behaviour. The basicity index, for example, has long been expounded as a key to submerged arc weld properties, perhaps drawing analogy from electrode coating experiences and steel making practices. It is defined in concept as the weight percent (wt-%) of basic components divided by the weight percent (wt-%) of acidic components (Ref. 6).

Proponents of basic slag systems point out that a higher basicity index encourages a more favourable distribution of harmful elements between the slag and the molten weld metal. However, complications in applying this principle severely limit its usefulness (Refs. 2, 7, 8). There are many published indexes leading to conflicting results. Also, many other factors influencing weld metal mechanicals must be taken into account.

Standardizing fluxes by their chemistry is not practical for many reasons. Many constituents, for example have more than one function, and more than one constituent may contribute to the same function. The degree of interaction is not easily predictable. Examining the fluxes available in this country reveals that several fluxes designed for different applications have nearly identical basic chemical compositions; the differences are in less than 10% of the composition. Other fluxes with radically different compositions have similar purposes—Figs. 2 and 3. Relating every welding application to a particular flux composition is simply not possible.



FUSED FLUX C **BONDED FLUX D**

Fig. 3—Two commercial flux compositions for high impact, multipass welding.

Slag/Metal Interactions

Understanding certain slag/metal interactions can assist in the correct application of the various electrodes and fluxes. Of primary interest are the reactions involving manganese and silicon. Pickup of these elements in the weld deposit by reduction of metal oxides or from the free metal additions influences mechanical properties and can lead to excessive hardness or cracking, if uncontrolled.

The importance of understanding the influence of the flux on deposit properties was underscored by the American Petroleum Institute's study of cracking in wet sulfide vessel service (Ref. 9). Figures 4 and 5 illustrate the effects of flux type and voltage on deposit manganese and silicon levels in three-layer pads. The deposit chemistry changes were greater with certain bonded fluxes because the metals in these fluxes were transferred to the weld pool. Higher voltages melt more flux per pound of electrode deposited (unlike covered electrodes where the slag/metal ratio is fixed), increasing the quantity of metal available to the weld pool. Figure 6 relates increasing weld pad hardness to higher levels of manganese and silicon in the third layer. This study also noted that even a more "neutral" fused flux caused test failures when an improper electrode chemistry was used.

Techniques to develop quantitative information relating the fluxes' influence on deposit mechanical properties to the welding parameters have not been standardized. "Neutral" fluxes can be defined qualitatively, as those fluxes whose deposit strength is not significantly altered by the amount of flux fused. The welding voltage controls the amount of flux fused. Similarly, "active" fluxes, which should be restricted to single or limited multipass welding, can be defined as those fluxes which significantly increase weld metal strength with increasing flux consumption which occurs at higher welding voltage levels.

Using so-called "neutral" fluxes is not to be construed as equivalent to an inert atmosphere. All of the fluxes, for example, described by Kubli and Sharav (Ref. 2) can be considered "neutral" based on their influence on weld strength. Deposit toughness at —50 F (—46 C), however, varied from less than 15 ft-lb (20 J) to 90 ft-lb (122 J) with the same electrode, but different fluxes—Fig. 7. The separation of phosphorus and sulphur impurities from the metal to the slag, improved weld cleanliness, and reduction in microinclusions were believed to be the primary mechanisms explaining the improved impact properties.

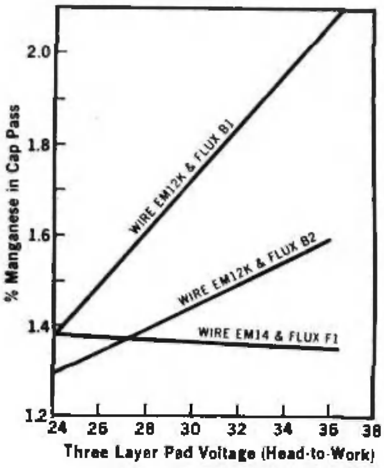


Fig. 4—Manganese content vs. voltage for three-layer pads (Ref. 9).

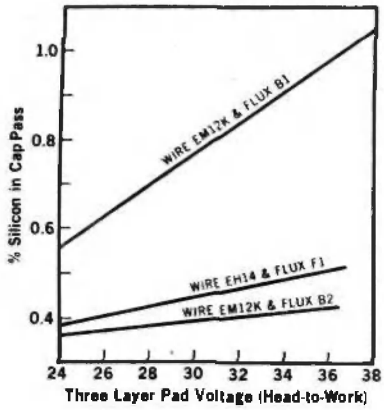


Fig. 5—Silicon content vs. voltage for three-layer pads (Ref. 9).

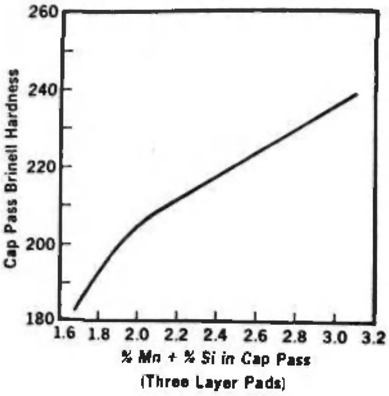


Fig. 6—Cap pass hardness vs. composition for three-layer pads (Ref. 9).

Figure 8 illustrates the difference in weld metal inclusion contents between four "neutral" fluxes with flux F giving the cleanest weld deposits and a three-fold increase in toughness over flux A at 0 F (—18 C).

Influence of the Electrode

Submerged arc electrodes are selected primarily for their influence on the mechanical properties and/or the required weld metal composition. Carbon and manganese are the most common alloying elements, with additions of Si, Mo, Ni, Cr, Cu, and others used to raise weld metal strength and control low or high temperature mechanical properties. Manganese and silicon additions also assist in eliminating CO porosity.

Most of the commonly used carbon and low alloy steel electrode compositions are defined in submerged arc electrode specifications such as AWS A5.17-69, "Bare Mild Steel Electrodes and Fluxes for Submerged Arc Welding" and AWS A5.23-76 "Specification for Bare Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding". Table 1 shows some typical electrode classifications under these specifications.

Significantly, in these specifications electrodes are not related to weld deposit mechanical properties without the association of a flux—this is recognition of the role the flux plays in controlling mechanical prop-

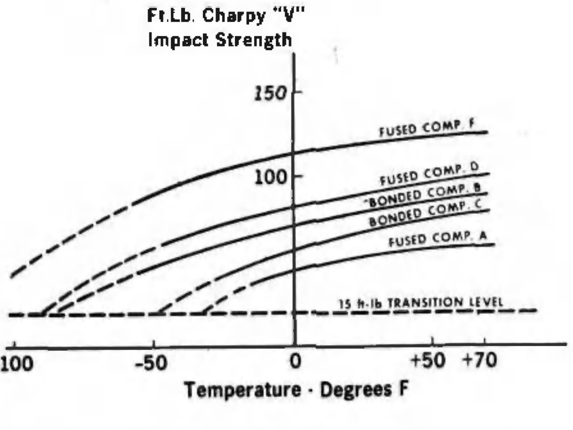


Fig. 7—Weld metal impact curves for multipass welds in the stress-relieved condition (Ref. 2).

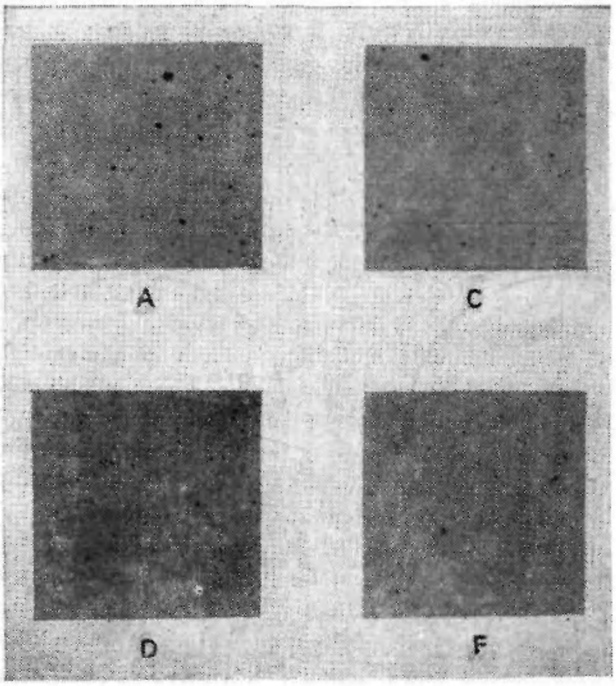


Fig. 8—Unetched weld metal comparing deposits made with four different fluxes (reduced 52% on reproduction).

Table 1—Some Typical Submerged Arc Electrode Classifications

Specification	Classification	Electrode composition, %						
		C	Mn	P	S	Si	Mo	Ni
ASW A5. 17-69	EL12	0.07/ 0.15	0.35/ 0.60	0.030	0.035	0.05		
	EM12K	0.07/ 0.15	0.85/ 1.25	0.030	0.035	0.15/ 0.35		
	EH14	0.10/ 0.18	1.75/ 2.25	0.03	0.035	0.05		
ASW A5.23-75	EA2	0.07/ 0.15	1.00/ 1.30	0.025	0.035	0.05	0.45/ 0.65	
	EA3	0.10/ 0.18	1.70/ 2.40	0.025	0.035	0.05	0.40/ 0.65	
	EF2	0.10/ 0.17	1.70/ 2.40	0.020	0.020	0.10	0.40/ 0.65	0.40/ 0.75
	EM2	0.10	1.25/ 1.80	0.010	0.010	0.20/ 0.60	0.25/ 0.55	1.40/ 2.10

Table 2—Characterization of Applications for Various Submerged Arc Welding Electrode Groups

Major elements	Electrode classification examples	Characteristics and uses
C-Mn	All AWS A5. 17	General purpose, low cost, suitable for structural steels and many vessel and ship applications. Exmple: ASTM A515, A516, A36, A287, and A441
C-Mn-Mo	AWS A5.23 Classes A1-A3	Similar to above, but Mo addition retards strength reductions from stress relieving. Example: A533, A537, A516
Mn-Mo-Ni	AWS A5.23 Classes 1Ni, 3Ni EF1-EF3	High weld strength and/or toughness with selected fluxes, Example: A302, A537
All Other	AWS A5.23 EF4, EF5 EM1-EM4 EW	Special high strength steels, A517, A543 A387 Corrosion resistant steels, A588

erties. A summary of electrode alloy types and application areas is shown in Table 2. In the first three groups, the manganese content varies up to 2 percent and the silicon content up to 0.7 percent to provide flexibility in meeting varying requirements for strength and toughness, welding performance, and deoxidation to assure soundness. Of course, the influence of the flux and base plate must also be considered since the molten flux, electrode and base metal interact to determine weld metal composition and properties.

Published literature defines many suitable flux/electrode combinations. Alternative marriages of combinations not listed require careful consideration of these interactions (and testing) to determine compatibility.

Electrode and Flux Selection

In selecting submerged arc materials, our primary intent is to get the job done within specifications at the lowest cost. This is no different than the criteria established when using any other welding process; the difference lies in the importance of selecting both an electrode and a flux that perform well together. With covered electrodes, the slag system is selected for you. In gas metal arc welding, the effects of shielding gas are well defined and are basically independent of the electrode composition. In submerged arc welding, however, the specific effects of different electrodes and fluxes are sometimes confused and flux interchangeability is not well understood.

Materials selection must consider primarily *two* key functional factors: (1) fulfilling the mechanical property requirements, and (2) satisfying the performance features desired, i.e. usability—maximum travel speed, rust and scale tolerance, current capability, slag peeling, stability with multi-electrodes or fillet weld performance.

Present AWS flux/electrode classification standards can be helpful since they define mechanical properties obtained (strength and toughness), but even these have limitations AWS A5.17-69 and A5.23-76 consider only undiluted welds, deposited under very specific conditions, 550 A, 28 V, 16 ipm (406 mm/min.) 58 KJ/in., (2.3 MJ/m).

The AWS test assembly used for defining flux classifications with particular electrodes is illustrated in Fig. 9. This assembly requires a number of small passes (usually 14 to 16) which minimizes dilution to obtain weld metal most representative of the flux/electrode combination tested. It does not resemble most production welds and is not intended to define mechanical property ranges attainable in production. The American Bureau of Shipping and Lloyd's specify standards for weld metal testing in specific, diluted two pass welds, but these results are very dependent on the base metal. None of these specifications test quantitatively many of the flux performance features which influence usability and application economics.

To obtain the additional information vital to materials selection, it is necessary to consult the manufacturer's literature describing the different flux types and flux classification data; it is also necessary to consider past usability experiences and utltimately evaluate possible flux/electrode combinations duplicating job conditions as closely as possible.

The first priority is to define in detail the specific application requirements. This summary must include the mechanical property requirements, exact postweld heat treatment, plate condition, thickness and composition. The number of weld passes, acceptable travel speed, number of electrodes, and required current are also key considerations.

If a fabrication code governs the welding to be performed, many of these requirements will be defined. Application conditions can usually be established using basic submerged arc welding handbooks. The selection of pass sequence will depend on several factors including the desired mechanical properties, available equipment, joint fitup and required economy. Some consideration must be given to the degree of specialization desirable, considering overall plant efficiency and possible costs from handling a variety of specific fluxes, compared to fewer general purpose compositions.

Meeting Mechanical Property Requirements

Usually the first consideration when selecting electrodes and fluxes is to determine that they will meet the required mechanical properties. This can be easy when the application closely matches the conditions used for AWS flux classification, but is usually complicated by the effects of dilution, bead size and heat treatments.

When meeting the requirements of a fabrication code, minimum filler metal requirements are usually well defined. Consider the AWS "Structural Welding Code" D1. 1-75. Here Table 4.12.2 matches specific base metal types to applicable AWS filler metal classes. Suitability of flux/electrode combinations can then be established by consulting published records of conformance to AWS standards or by running classification tests. Procedure qualification tests will define suitability for a specific application.

The ASME Boiler and Pressure Vessel Code is also very specific in defining filler metal requirements Section III, Nuclear, for example, requires that "tests shall be conducted ... for each combination of heat of bare electrodes and lot of submerged arc flux" NB-2420. (Class 1 components).

When mechanical property requirements for welding are not well-defined, the base metal properties are often used as guidelines. Weld metal strength and toughness minimums for essentially undiluted submerged arc welds are specified by classification data from either AWS A5.17 or A5.23. When an application differs from the standard classification multipass weld test by such factors as weld bead size. dilution, plate thickness or heat treatment, their effects on mechanical properties must be included for proper selection.

As a general rule, as bead size is increased beyond the 58 KJ/in. (2.3 MJ/m) size used for AWS testing, weld toughness and strength will decline from the published values. When high currents are employed, increasing weld dilution in the base metal by over 20%, weld toughness will again likely decline from the published data. Since weld size and cooling rate as measured by heat input ($V \times I \times 60 \div$travel speed) have a major effect on weld mechanical properties, welding speed or the use of multiple electrodes need not be considered separately.

Meeting minimum tensile properties in a diluted weld is generally assured by selecting materials meeting corresponding strength levels achieved in the multipass

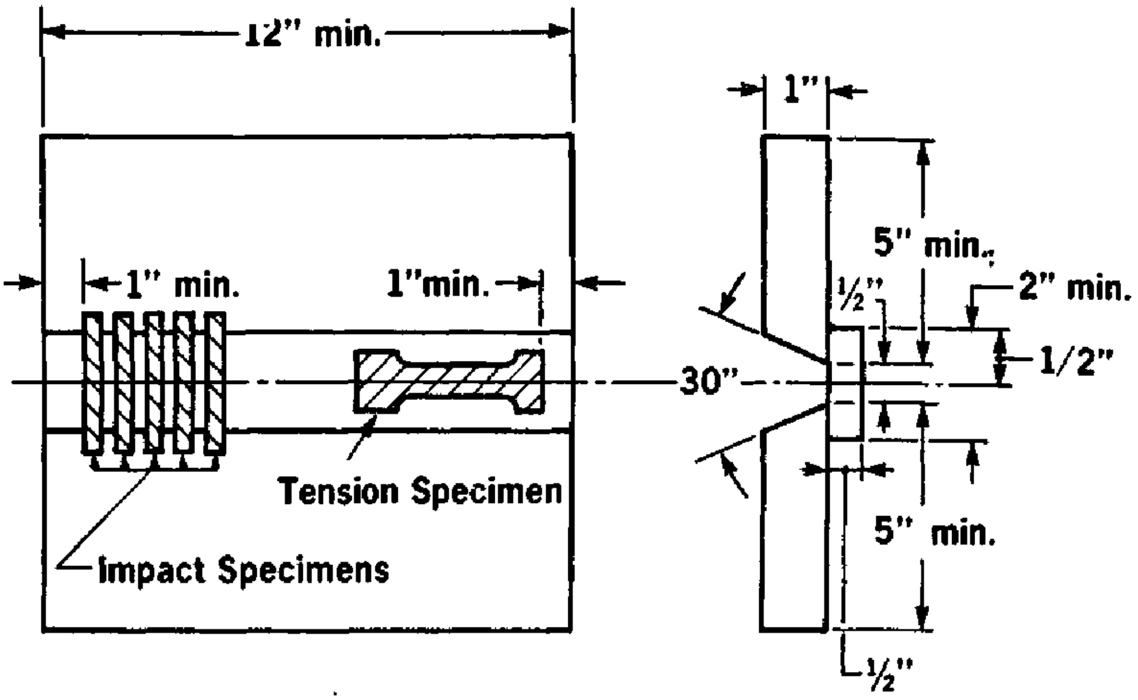


Fig. 9—Details of AWS flux classification test assembly.

classification weld. Carbon or other alloy pickup from the base metal may increase weld strength, usually with a corresponding reduction in weld toughness.

When weld toughness is a prime consideration, multipass welds generally offer the best weld metal and heat-affected zone properties. Toughness data from AWS classification tests often represent the highest toughness obtainable with a particular flux/electrode combination. Therefore, applications requiring toughness to be achieved with larger or fewer weld bads may benefit by selecting a flux/electrode combination meeting a higher toughness classification level. For example, if 20 ft-lb at—20 F (27 J at—29 C) is required in a three or four pass butt weld in 1 in. (25 mm) thick plate, it may be necessary to use a combination classified as meeting 20 ft-lb at—40 F (27 J at—40 C) in the standard multipass test.

Past experience and manufacturers' recommendations should be consulted as well for guidance. Ultimately, it will be necessary to assess the material performance using the welding condition in service or in a procedure qualification test made in advance.

Meeting Performance Needs

Final electrode and flux selection is usally made by studying the economics to be gained using specialized fluxes. Most fluxes can be categorized into one or two of the following groups according to their performance features:

1. General purpose active flux (butt, fillet, multipass) for applications requiring the best performance over rust and mill scale. Especially useful for fillet welding and thin plate butt welding with appropriate good slag peeling. usually restricted to approximately 1-in (25 mm) thick plate to limit excessive weld tensile strength.
2. Similar to 1, however. less rust tolerance. These less active fluxes allow multipass welds to be made in plate up to approximately 2 in. (50 mm) thick with satisfactory weld tensile control.
3. General purpose flux (butt, fillet, multipass) for applications on relatively clean steel or moderate scale condition.
4. High current flux capable of welding at 1500 amps on a single electrode.
5. High current multipower flux capable of welding at over 1200 amps per electrode with weld speeds in excess of 80 ipm (2 m/min.) travel. Primarily used for two pass line pipe welding or similar applications.
6. Gage welding flux for welding speeds in excess of 120 ipm (3 m/min.) travel with a single electrode.
7. Neutral flux for multipass welding of clean material. Deposit strength is not significantly altered by the amount of flux fused.

Very often, application requirements alone dictate the use of specific fluxes. In a structural shop, for example, rust and scale tolerance may be paramount and satisfactory fluxes may well be limited to either group 1 or 2. In a vessel shop, on the other hand, if optimum toughness is a prerequisite, selection may be limited to fluxes from group 7.

If work volume dictates increased output,and capital costs for material handling and fixtures can be justified, high speed fluxes such as defined in categories 5 and 6 might be useful to evaluate.

If good plate fit-up can be achieved and toughness is not critical, high current, two pass butt welds can be considered to replace multipass welding. Fluxes in categories 4 and 5 should then be considered for evaluation.

Identifying specific fluxes to particular groups is done by studying flux descriptions. Past experience is also a good guide, so good in fact that one must guard against overlooking possibilities in new materials. Since job requirements can be categorized within the flux performance groups shown, candidate fluxes can be selected from the appropriate group.

Final evaluations are useful not only to measure specific flux/electrode mechanical properties, soundness, etc. on your job, but also to establish costs considering flux consumption, ease of flux handling and slag peeling. Other specific needs can also be evaluated by studying flux descriptions or through final evaluation assessing, for example, higher speed welding capabilities, the ability of a flux to deal with positional welding or small rounds, joint fit-up tolerance and so forth.

Welding Applications

The following applications demonstrate some of the principal features of electrode and flux selection discussed. They were chosen to illustrate the variety of requirements encountered in the welding industry, and the extreme range of usefulness of the submerged arc welding process.

Structural

Structural shops make extensive use of fillet welding since little or no joint preparation is necessary. The bridge girder application shown in Fig. 10 employs two separate submerged arc systems, operating independently on opposite sides of the 1/2 in. (13 mm) thick A441 bridge girder stiffener.

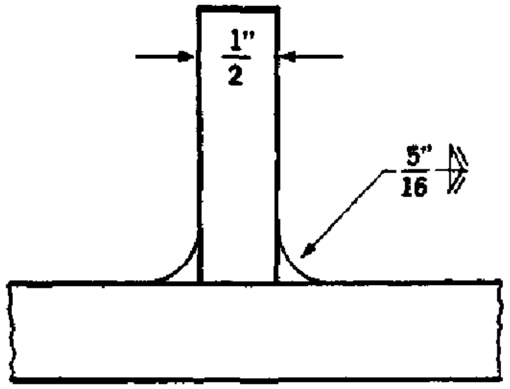


Fig. 10—Fillet welding bridge girder stiffeners: joint design

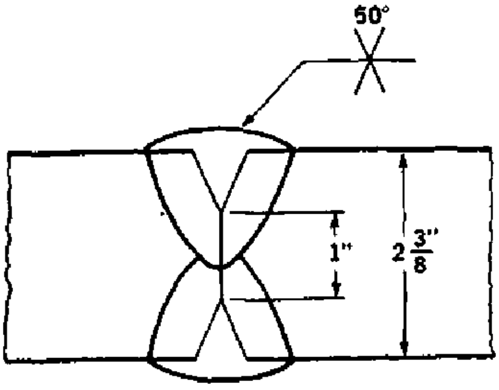


Fig. 11—High current, two-pass butt welding in 2-3/8 in. thick motor cases: joint design.

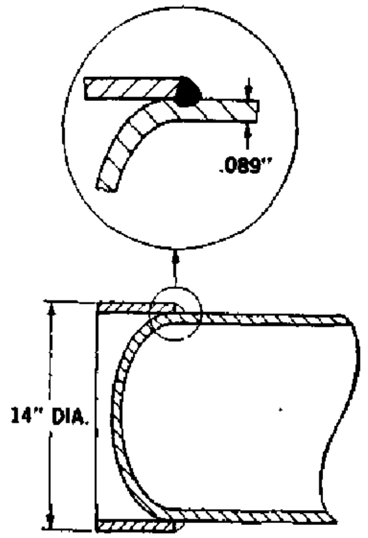


Fig. 12—Circumferential fillet welding joining the foot ring to an LPG tank: joint design.

The dominating requirements influencing electrode and flux selection were the ability to weld over rust and scale, since the hot rolled plate is not precleaned and the need to meet an AWS F72-EXXX flux classification established for this service by the Federal Highway Administration. These requirements were satisfied by selecting a flux from category 1, used with an EM12K electrode. Fluxes from this category are ideally suited because of their rust and scale tolerance and free peeling characteristics. Checking published information for the candidate fluxes revealed that tests with an EM12K electrode in accordance with AWS A5.17 met the requirements for an F72-EM12K classification.

Machinery Component

The heavy plate (2-3/8 in., 60 mm) butt welding application shown in Fig. 11 required the most economical joining method for high volume production of electrical motor cases. Weld metal mechanical property specifications required matching the 60 ksi (415 MPa) AISI 1020 base metal tensile strength.

It was established that with good joint fit-up and a 1 in. (25 mm) land, this weld could be completed in two passes, one from either side to achieve full penetration. The current levels of 1300 and 1800 A ac for the first and last pass respectively dictated selection of a flux from category 4, to handle the high currents and provide a stable arc. To offset increased deposit Si levels from slag/metal interaction, an EH14 electrode was selected to provide a high Mn/Si ratio and assure achievement of the minimum strength desired.

Gas Tank

One weld required for LPG construction is a foot ring to tank fillet weld pictured in Fig. 12. This application required the use of high welding speeds to achieve production efficiencies and a controlled viscosity slag to prevent loss of slag coverage on the small 14 in. (350 mm) diameter round. The longitudinal tank welds in the same 0.089 in. (2.3 mm) plate thickness permitted the use of still higher welding speeds, and it was desirable to select materials which could satisfy both requirements.

Fluxes from several categories could be useful, with categories 3 and 6 containing the most likely candidates. In this example, a flux from category 3 was used at 65 ipm (28 mm sec.). An EM12K electrode was selected to provide silicon deoxidation, useful at high weld metal solidification rates in reducing weld porosity. It also satisfied the need for a 70,000 psi (483 MPa) transverse tensile strength in the longitudinal seams.

Heavy Vessel

The weld being made in the lead photograph (joint design shown in Fig. 13) is a long seam on a 6 in. (152 mm) thick shell course for a commercial nuclear steam generator. The base metal is ASTM A516-70. The weld metal mechanical property requirements included a 38 ksi (260 MPa) yield strength and 70 ksi (485 MPa) ultimate strength, with 30 ft-lb (40 J) at + 10 F (—12 C).

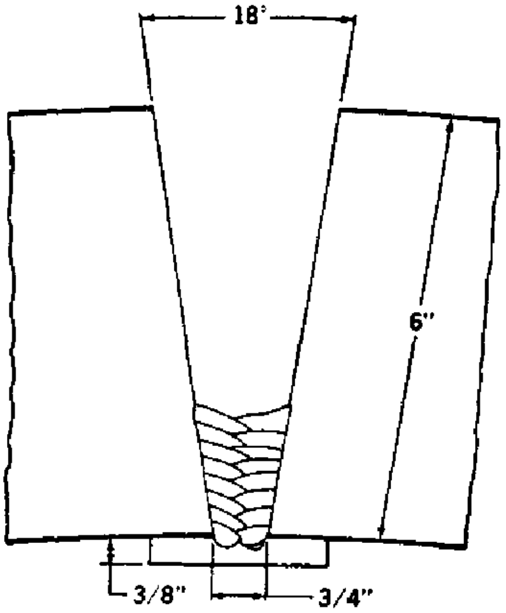


Fig. 13—Joint design for multipass welding a 6 in. thick shell course for a nuclear steam generator.

A flux from category 7 was chosen for use with an AWS A5.23 EA3 electrode after consultation with wire and flux manufacturers. Fluxes from category 7 (neutral multipass fluxes) avoid cracking in heavy, restrained welds by suitably limiting weld metal silicon and manganese content. The EA3 low alloy electrode which contains 2% Mn and 1/2% Mo was necessary to meet minimum strength levels after a 24 h 1150 F (620 C) postweld heat treatment. A procedure qualification test was required to assure that all weld metal specifications were satisfied.

Summary

In submerged arc welding, both the electrode and the flux influence process performance and provide characteristic application flexibility. Selection of welding materials must consider flux/electrode and base metal interaction, following usability guidelines and classification data outlined by the manufacturers. One of the first considerations when selecting materials is to determine that they will meet the mechanical properties desired. Key points to remember are:

1. Mechanical properties are influenced by many factors including: electrode and flux, base metal dilution, bead size, cooling and postweld heat treatments. For critical applicatons, only

duplication of job conditions satisfactorily takes all these factors into account.

2. Data from standard AWS multipass welds are useful for comparing fluxes using identically classified electrodes and for estimating mechanical properties. Identically classified fluxes may not be interchangeable.
3. Always consult the literature of manufacturers to be sure the flux/electrode combination is compatible and establish if any limitations are necessary when using a particular flux.

In addition to satisfying mechanical properties, the welding materials must provide certain minimum performance standards. Most fluxes can be categorized into one or sometimes two of seven specific performance groups. These groups identify fluxes which are "best" for:

1. General purpose, high rust and scale tolerance, 1 in. (25 mm) maximum plate thickness.
2. General purpose, moderate rust and scale tolerance, 2 in (50 mm) maximum plate thickness.
3. General purpose relatively clean plate.
4. High current stability, single electrode.
5. High current, high speed multielectrodes, one and two pass welds.
6. Gage welding, and
7. Multipass welding, unlimited thicknesses.

By categorizing existing fluxes and job requirements into these performance groups, applicable fluxes can be selected which offer either the ultimate in specialization or the best compromise for a variety of applications. Flux/electrode suitability for a specific application and cost estimates should be measured by closely duplicating job conditions whenever possible.

Figure 14 outlines the steps normally taken when selecting materials prior to production. In many cases, the mechanical property requirements receive more attention than the performance needs, partly due to the availability of quantitative mechanical property data, and partly because of the qualification requirements of fabrication codes.

Proper consideration of performance needs is essential, nevertheless, to realize optimum application of process capabilities—rust tolerance, speed, current handling capacity etc. The introduction of flux performance categories should prevent users from advancing down to procedure qualification or production before first noticing performance difficulties.

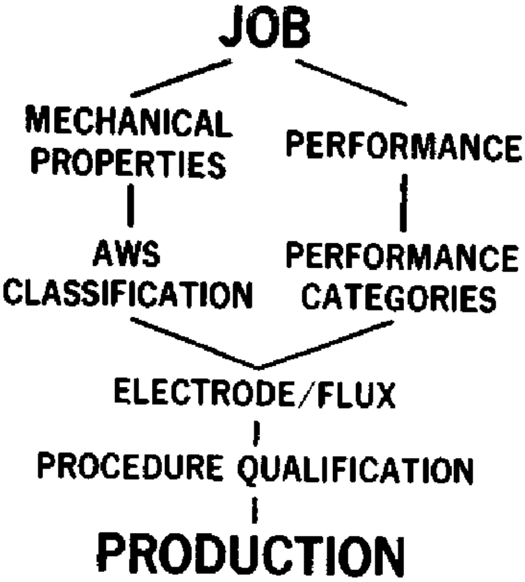


Fig. 14—Steps necessary for submerged arc materials selection process.

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