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Desirable Combinations of Electrode and Flux for Submerged Arc Welding of Low Carbon Steel

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Abstract

The major purpose of this study was to provide information about desirable combinations of welding electrode and appropriate fluxes for submerged arc welding of low carbon steel. Other purposes were to:

1. Test a variety of combinations of available submerged arc welding electrodes and fluxes in welding low carbon steel.

a. Prepare specimens for tensile tests.

b. Conduct tensile tests.

c. Calculate tensile strength, yield point, break point, percent of elongation, and percent reduction of area.

2. Determine the most desirable combinations of electrode and flux for companies presently using or planning to use submerged arc welding for low carbon steel applications, in an effort to save time and expense.

3. Provide a comparison of electrode/flux combinations recommended by manufacturers.

DESIRABLE COMBINATIONS OF ELECTRODE AND FLUX FOR SUBMERGED ARC WELDING OF LOW CARBON STEEL

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by

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Approved by:

Dr. Patrick W. Miller, Graduate Faculty Member — Date 7/27/82

Dr. Douglas T. Pine, Graduate Faculty Member — Date 7/27/82

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CHAPTER I

Introduction to the Study

Since 1936, when a fused, high-silicon-oxide flux made its commercial debut, submerged arc welding (SAW) has been makings its way into the American welding industry (Weymueller, 1979). Because of its ability to quickly join thick metals, SAW gained popularity during World War II in welding fighting ships and combat tanks. The use of submerged arc welding went through a slowdown period after the War, but is now making a resurgence. One reason for this growth is that no eye protection is required because the arc is completely covered. Another reason is the small amount of fumes and smoke emitted, allowing it easily to conform to Occupational Safety and Health Administration (OSHA) regulations. The flux layer also protects the weld from atmospheric contamination and can supply fluxing agents as well as alloy additions (Weymueller, 1979).

The major markets for SAW today are for pressure vessels, bridges, and pipelines. Other industries using submerged arc welding include railroad, earthmoving, shipbuilding, machinery, electrical, ordnance, nuclear power, automotive, and aviation (AWS Welding Handbook, 1969). Many of these markets (e.g., pipelines and storage tanks) should grow due to their increased use within energy-related fields.

Submerged arc welding requires the welding engineer to choose two materials--the welding electrode and flux (Uttrachi, 1978). Properties of a submerged arc weld reflect its composition, determined by base metal, electrode, flux, and welding conditions.

Most users of submerged arc welding supplies base their purchasing decisions on data supplied by the different manufacturers. The American Welding Society (AWS) requires that each manufacturer supply these data in general AWS classifications pertaining to the usage. The most common data supplied pertain to yield strength, tensile strength, and percent of elongation.

Each manufacturer recommends its own electrode/flux combination, and claims superiority over the others. Because of the limited information available, the user must base much of the purchasing decision on the representative and electrode/flux data provided by the manufacturer.

Investigation of a local Waterloo, Iowa manufacturer revealed differences in the quality and appearance of submerged arc welds with low carbon steel. This local manufacturer produces large revolving drums made in several sections for hauling concrete. The various internal parts are welded in place with more conventional welding methods. The sections are then welded together, first from the inside with a conventional welder and then are mounted between revolving centers and the outside seams are welded by the submerged arc process. After using this process for a period of time, the drum manufacturer noted weld inconsistencies, inferior weld quality, and a basic dissatisfaction with the electrode/flux combination being used. Representatives from various electrode/flux manufacturers were consulted. After recommendations and a trial-and-error experimental period, a desirable combination was chosen.

The experience of the drum manufacturer suggested a need for independent research on this topic. Furthermore, a review of related literature revealed no independent research regarding this specific aspect of submerged arc welding.

Therefore, this investigator has selected a variety of commonly available submerged arc welding electrodes and fluxes, and has conducted tensile tests on all-weld material. Five different combinations of electrode and flux were tested.

Statement of the Problem

The problem addressed in this study concerned the lack of information available on the application of submerged arc welding electrode and flux. The various manufacturers recommend their own electrode and flux, and claim superiority.

This study was an attempt to answer the following specific questions:

1. Which combination(s) of low carbon steel electrode and flux possesses the highest tensile strength?

2. Which combination(s) of low carbon steel electrode and flux possesses the highest yield strength?

3. Which combination(s) of low carbon steel electrode and flux possesses the highest breaking strength?

4. Which combination(s) of low carbon steel electrode and flux possesses the most favorable percent of elongation?

5. Which combination(s) of low carbon steel electrode and flux possesses the most favorable percent reduction of area?

Purposes of the Study

The major purpose of this study was to provide information about desirable combinations of welding electrode and appropriate fluxes for submerged arc welding of low carbon steel. Other purposes were to:

1. Test a variety of combinations of available submerged arc welding electrodes and fluxes in welding low carbon steel.

   a. Prepare specimens for tensile tests.

   b. Conduct tensile tests.

   c. Calculate tensile strength, yield point, break point, percent of elongation, and percent reduction of area.

2. Determine the most desirable combinations of electrode and flux for companies presently using or planning to use submerged arc welding for low carbon steel applications, in an effort to save time and expense.

3. Provide a comparison of electrode/flux combinations recommended by manufacturers.

Assumptions

1. The welding apparatus used by the researcher produced a consistent, high quality weldment, comparable to that done by the various manufacturers according to specifications.

2. The particular electrode/flux combinations chosen by the investigator from the AWS classification for low carbon steel, were representative of available electrode/flux combinations.

3. SAW users have experienced problems with electrode/flux combinations similar to those of the local manufacturer interviewed.

Limitations of the Study

This study was limited by the following:

1. The background and experience of the researcher in submerged arc welding was limited to the review of literature and work done on this research project.

2. Cost and time factors limited the researcher to a small number of electrode/flux combinations.

3. The amount of Linde electrode donated to complete the weld samples was sufficient only to complete one set of test specimens.

4. The submerged arc welding apparatus available to the researcher limited the amount of welding that could be done.

5. The tensile testing machine available to the researcher was not as sophisticated as other industrial test equipment.

Delimitations of the Study

This study was delimited by the following:

1. The low carbon steel electrodes and fluxes, and combinations thereof, chosen and tested in this study.

    a. Electrodes

        1. Hobart HB-10

        2. Lincoln L-60

        3. Linde L-80

b. Fluxes

1. Hobart 100

2. Lincolnweld 780

2. Single electrode welding applications.

3. Flat welding applications.

4. Clean, dry base material applications.

5. Welding machine settings for 5/64" diameter electrodes.

Definition of Terms

Submerged arc welding (SAW) is an arc welding process wherein coalescence is produced by heating with an arc or arcs between a base metal electrode or electrodes, and the work. The arc is shielded by a blanket of granular, fusible material on the work (AWS Welding Handbook, 1969).

Submerged arc welding flux is a granular, fusible material which surrounds and completely covers the welding area, providing a blanket to keep out impurities and to keep in heat, causing a deep weld penetration (AWS Welding Handbook, 1969).

Submerged arc welding electrode is usually a spool of wire ranging in size from 1/16" to 1/4" which is automatically fed into the weld area, allowing long periods of time between electrode changing.

Welding consistency apparatus is a piece of equipment that was developed by the investigator from a radiagraph machine normally used for oxy-acetylene welding. This piece of equipment was mounted on a track to control the speed needed for weld consistency (see Figure 1).

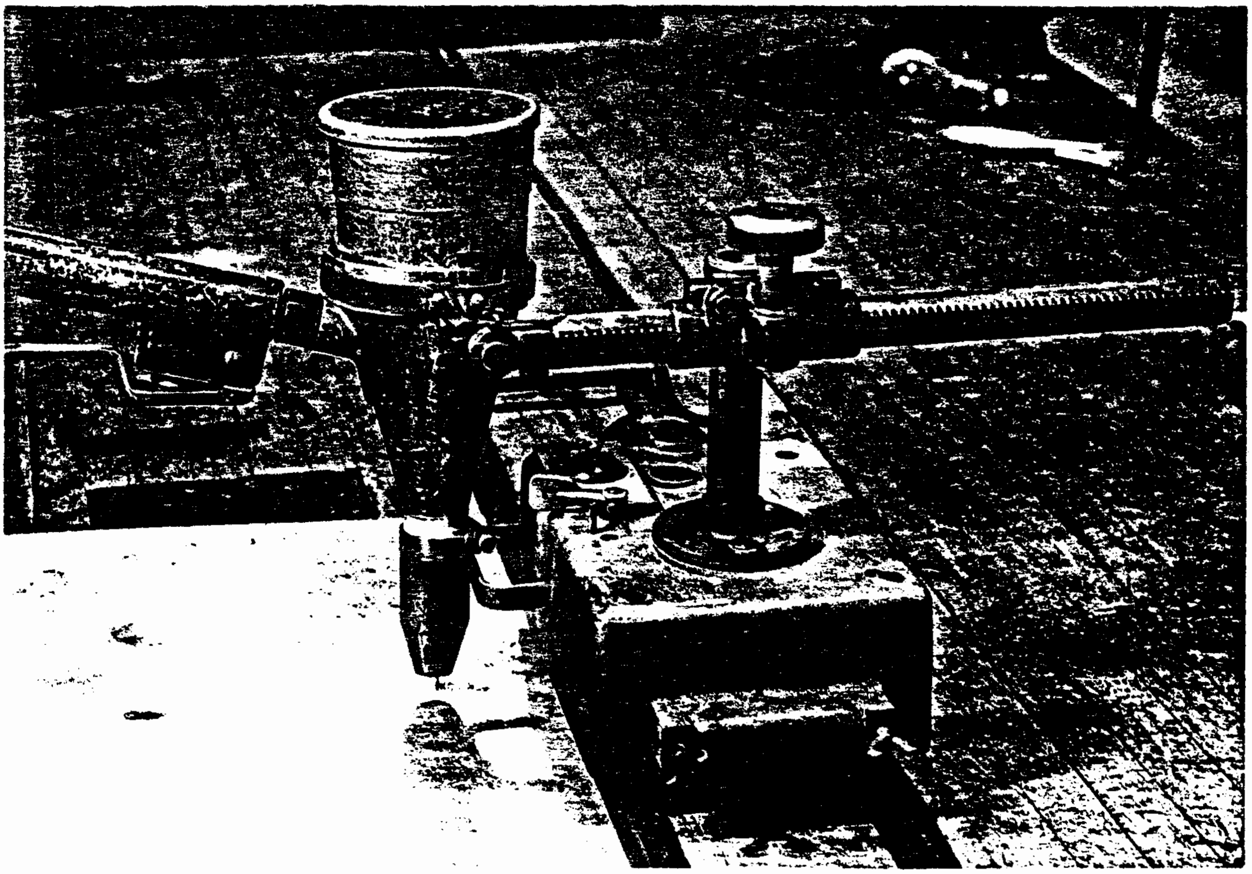

Figure 1. Investigator-Designed Welding Apparatus

CHAPTER II

Review of Related Literature

Background

When using submerged arc welding, the arc is completely shielded by a blanket of granular, fusible flux on the work. The electrode is not in contact with the workpiece; the current is carried across the gap through the molten, fluid flux. Welding electrode is fed automatically into the molten weld puddle and flux shield (Crooks & Schmid, 1979). The layer of flux protects the weld from atmospheric contamination and supplies fluxing agents as well as alloy additions.

Submerged arc welding is often selected for welding pressure vessels because the high current levels allow rapid welding, making for high deposition rates (Crooks & Schmid, 1979). Because SAW has the ability to join thick material, it gained popularity during World War II in welding fighting ships and combat tanks (Weymueller, 1979). The uses of SAW went through a slowdown period after that, but it is currently making an upsurge (Weymueller, 1979).

Electrode and Flux

Submerged arc welding requires the welding engineer to choose two materials: welding electrode (wire) and welding flux (Uttrachi, 1978). Because the electrode and flux combine to form the weld metal, the properties of the finished weldment vary according to the electrode/flux combination (Crooks & Schmid, 1979). Consequently, the engineer should know how these mechanical properties change so the proper electrode and flux can be selected (Crooks & Schmid, 1979). Properties of a submerged arc weld reflect its composition, determined by base metal, electrode, flux, and welding conditions (Uttrachi, 1978).

Helpful information regarding SAW electrode/flux combinations can be found in American Welding Society (AWS) Specification for Bare Low Alloy Steel Electrodes and Fluxes for Submerged Arc Welding (AWS 5.17, 1977). The major suppliers offer several electrode/flux combinations to meet the diverse needs of users (Weymueller, 1979). Though the fabricator of low alloy steels has many SAW electrodes and fluxes, the fundamental problem is what electrode/flux combination will do the job at the lowest cost (Prestowity & Thomas, 1978).

Fluxes are manufactured in two ways: fusing and bonding. Fused fluxes are made by melting the ingredients, letting them solidify, and then crushing. Bonded fluxes are made by mixing dry ingredients, then bonding them together with a low melting point compound (Uttrachi, 1978).

Fluxes are also classified as active or inactive, depending on the amount of manganese and silicon that transfers from the flux to the weld material (Uttrachi, 1978). More manganese and silicon flow into the metal as voltage rises. Active fluxes should be limited on multipass butt weld plates to a maximum thickness of one inch due to increased chances of cracking (Uttrachi, 1978).

The AWS categorizes flux by an "F" followed by a two-digit number. The first digit, given in pounds per square inch (psi) times 10,000, represents tensile strength. The second digit indicates the flux's required impact strength. See Table 1 for impact strength requirements. Therefore, a flux with AWS number "F-60" requires tensile strength of 60,000 pounds per square inch, and has no required impact strength.

Table 1

Impact Strength Requirements

Second Digit AWS Number	Impact Strength Requirement
0	No requirement
1	20 ft. lb. @ 0° F
2	20 ft. lb. @ -20° F
3	20 ft. lb. @ -40° F
4	20 ft. lb. @ -60° F

Following is an example of how the electrode "EL12" is described by AWS (AWS 5.17, 1977).

E--designates electrode

L--indicates manganese content

L (low), .30-.60%

M (medium), .60-1.25%

H (high), 1.25-2.25%

12--nominal carbon content (.12 percent in this case)

Welding and Testing

All types of welded structures, regardless of their end use, are expected to serve some function. The most important criterion for judging the weldment is whether or not it performs the functions required for its intended service (Mechanical Testing, 1981). Therefore, a service performance test would be ideal. However, due to cost and time factors, this generally is not possible. Consequently, independent lab testing provides the next best alternative (Mechanical Testing, 1981).

Steel products usually call for welds with compatible weld metal properties such as tensile strength, yield strength, elongation, bend ductility, and notch toughness (Prestowity & Thomas, 1978). Test results can be reported in many ways, but may include ultimate strength, yield strength, stress/strain curves, modulas of elasticity, elongation, reduction of area, and fracture characteristics (Mechanical Testing, 1981). These tests provide numerical values which can be compared or analyzed and used for the design of welded structures. Testing of weldments will always be a necessary part of determining the suitability of welds in connection with design and fabrication of a welded product (Mechanical Testing, 1981).

Published tests provide guidelines for fabricators, but the final test should be done using test procedures which match procedures for the job. These qualification tests are best suited for predicting production weld metal performance with a given electrode/flux combination. Weld sequence, energy input, the composition and thickness of the base metal, the post weld heat treatment, and other fabrication factors can also affect weld properties; hence, the choice of electrode/flux combinations (Prestowity & Thomas, 1978).

According to the American Welding Society (AWS Welding Handbook, 1969) the welding variables for submerged arc welding are:

1. Welding current,
2. Welding voltage,
3. Welding speed,
4. Electrode size,

5. Electrode stickout,
6. Type of flux and electrode, and
7. Width and depth of the layer of flux.

The fabricator can reduce the number of combinations to be tested by first referring to the literature produced by manufacturers or independent studies (Prestowity & Thomas, 1978). The performance criteria to be met should also be determined. Then the electrode/flux combinations which seem most likely to give the best overall results in meeting all requirements should also be tested.

Welds of uniformly high quality require homogeneous base materials free from rust, scale, moisture, and other surface impurities. Special welding techniques are necessary when these conditions are less than desirable (AWS Welding Handbook, 1969).

In single pass welds, a considerable amount of base metal is fused compared to the amount of filler metal. The base metal may greatly influence the chemical and mechanical properties of the deposit (AWS Welding Handbook, 1969). Therefore, to test weld metal only, it is necessary to perform multiple pass welds.

The most common test on welded material is a tensile test made with an indicating pull gage. This is the best indicator of mechanical reliability and strength, and can form the basis of statistical methods of process quality control (AWS Welding Handbook, 1969). Results of tensile and impact tests are determined completely by all-weld metal (Crooks & Schmid, 1979).

For all-weld applications, the joint must be assembled and held securely to limit displacement caused by heat (AWS Welding Handbook, 1969). Tacking, clamping, jigging, or a combination of these methods is required. Most submerged arc welds are made with the electrode in the normal position; that is, straight up and down, or vertical (AWS Welding Handbook, 1969).

Table 2 shows the generally accepted current ranges for various sizes of mild steel electrodes (AWS Welding Handbook, 1969).

Table 2

Accepted Current Ranges

Electrode Diameter, Inches	Current Range, Amperes
1/16	150-400
5/64	200-500
3/32	250-600
1/8	300-800
5/32	400-900
3/16	500-1200
7/32	600-1300
1/4	700-1400

The AWS Handbook specifies welding parameters and specifications for the preparation of test specimens. The round specimens in the .500 and .350 inch diameter are generally used for tensile tests. Those specimens are prepared by first preparing the weld material as shown in Figure 2.

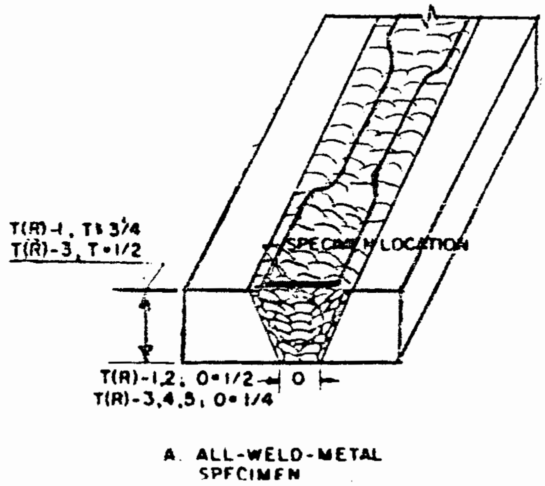

Figure 2. Preparation of All-Weld Metal Specimen. (Dimensions in Figure 2 refer to Tables 3 and 4.)

The welding is done and the specimen is machined to the specifications given by AWS or ASTM (American Society for Testing Materials) for tensile specimens (AWS D14.477, ASTM A370). See Tables 3 and 4 for test specimen specifications.

Table 3

Dimensions of Specimen, (in.)

Specimen	D	G	C	B	L,min	A,min	F,min	Approx. area sq. in.
T(R)-1	0.500 ± 0.010	2.000 ± 0.005	2-1/4	3/4	5	1	3/8	1/5
T(R)-2	0.350 ± 0.007	1.400 ± 0.005	1-3/4	1/2	3-1/2	5/8	0.25	1/10
T(R)-3	0.250 ± 0.005	1.000 ± 0.005	1-1/4	3/8	3	5/8	0.18	1/20
T(R)-4	0.160 ± 0.003	0.640 ± 0.005	3/4	5/16	2	1/2	0.15	1/50
T(R)-5	0.113 ± 0.002	0.450 ± 0.005	5/8	1/4	1-5/8	3/8	0.09	1/100

Table 4

Dimensions of Specimen, (mm)

								sq. mm
T(R)-1	12.7 ± 0.25	50.8 ± 0.13	57.1	19.1	127.0	25.4	9.5	129
T(R)-2	8.9 ± 0.18	35.6 ± 0.13	44.5	12.7	188.9	15.9	6.4	65
T(R)-3	6.4 ± 0.13	25.4 ± 0.13	31.8	9.5	76.2	15.9	4.6	32
T(R)-4	4.1 ± 0.08	16.3 ± 0.13	19.1	7.9	50.8	12.7	3.8	13
T(R)-5	2.9 ± 0.05	11.4 ± 0.13	15.9	6.4	41.3	9.5	2.3	6.5

CHAPTER III

Major Methodological Procedures

Welding Material

Visitations and telephone calls were made to local electrode/flux suppliers and to manufacturers using the submerged arc welding process in an attempt to acquire electrode and flux through donations or limited purchase sales. Through these means, three different electrodes and two fluxes were obtained for this study.

All electrodes were classified by the American Welding Society (AWS) as mild steel electrodes, classification EL12 (AWS 5.23, 1980). Compatible fluxes were then matched with the various electrodes.

A total of five electrode/flux combinations were tested. In two cases, the manufacturer's own electrode/flux combination was tested. The remaining three cases represented mixtures of one manufacturer's electrode with another manufacturer's flux.

See Table 5 for the manufacturer's name, electrode number, and chemical makeup of each electrode. The flux manufacturer and flux number are shown in Table 6. The fluxes' chemical compositions were not available from the manufacturers.

Table 5

Chemical Analysis of Electrodes

		CHEMICAL ANALYSIS					
Electrode letter	Manufacturer	C	Mn	P	S	Si	Manufacturer no.
A	Hobart	.09	.50	.020	.025	.01	HB-10
B	Lincoln	.10	.52	.025	.030	.01	L-60
C	Linde	.10	.55	.030	.035	Trace	L-80

Table 6

Types of Fluxes Used

Flux letter	Manufacturer	Manufacturer no.
A	Hobart	H-100
B	Lincoln	Lincolnweld 780

Other welding parameters, within the acceptable ranges (given by the AWS), included 300 amps, current; 29 volts; 100 inches per minute (IPM), wire feed; 15 IPM, travel speed; and one-half inch, distance from workpiece. These parameters were held constant throughout the welding procedures (see Appendix A).

Welding Apparatus

A Hobart submerged arc welding attachment unit, model number GAF-500, designed for semi-automatic submerged arc welding, was used in this study. This unit was connected to a Hobart wire feeder, model number AGH-27, and a Hobart model number RC-500 welding machine power unit. The electrode used was 5/64" in diameter.

Current, voltage, and electrode feed were held constant with the GAF-500 welding machine. However, because of the handheld gun, it was necessary to develop an apparatus to allow for consistent travel speed and nozzle height. This investigator developed and tested such an apparatus. A variable speed carriage mechanism mounted on a track and normally used for oxy-acetylene cutting was adapted for use with the submerged arc welding unit. The electrode nozzle and flux hopper were mounted on the traveling carriage, allowing it to be held stationary and adjusted to the desired height and travel speed. A photograph of the investigator-designed welding apparatus is shown in Figure 1.

Weld Specimens

Weld specimens were carefully welded and prepared according to AWS specification D14.4-77 (Table 3) for a .350" diameter test specimen. Basically, this involved preparing 3/4" mild steel plates which formed a 20° included angle. The two plates were placed ½ inch apart with a copper backing, and clamped to a worktable. Welds were then applied, one at a time, until the cavity was filled with weld metal (see Figure 2). Pieces were cleaned between welds with a wire brush to prevent contamination of the weld. After all welding was completed, the plates were allowed to cool at room temperature.

Sufficient welding was done with each electrode/flux combination to allow performance of three tensile tests. This reduced the possibility of one test causing erroneous results. A record sheet was kept on each electrode/flux combination, and each piece was carefully marked to avoid confusion of specimens (see Appendix A).

After all welding was completed, specimens were carefully prepared in UNI's production laboratory. First, weld specimens were cut out with an oxy-acetylene cutting torch. Round test specimens with a reduced section of .350 inch diameter were prepared on the engine lathe. Specifications are shown in Table 3 (AWS D14.4-77 or ASTM E8-66). See Figure 2 for specimen location.

Testing of Specimens

Tensile tests were performed in UNI's materials testing laboratory. Before testing actually began, several sample specimens were made and tested to familiarize the researcher with the testing apparatus.

The 1.400 inch gage length was marked on each test specimen. The diameter was measured and the area was calculated. After each test, distance between gage marks was again measured to determine elongation. The cross-sectional area was also measured to determine reduction of area.

A dial indicator was attached to each test specimen to allow detection of rapid increases in length or stress. The rapid increase in stress in conjunction with a sudden decrease in strain allowed for detection of the yield point (ASTM 5.4.1.1, 1968). Ultimate load and breaking load were also recorded for further calculations. These record sheets are shown in Appendix A.

Due to the limitations of the tensile testing machine used, direct comparisons to the strengths published by the manufacturers were not possible. However, direct comparisons were possible within the confines of this study. The relative strength of one electrode/ flux combination was compared with another.

CHAPTER IV

Analyses

Data from the tensile tests were used to calculate yield strength, ultimate tensile strength, breaking strength, percent of elongation, and percent of reduction of area. American Society of Testing Materials (ASTM) gives specifications for calculating these tests (ASTM, A370). The following formulae were used in analyzing the test results.

$$\text{Yield Strength} = \frac{\text{Yield Load}}{\text{Original Area}}$$

$$\text{Tensile Strength} = \frac{\text{Ultimate Load}}{\text{Original Area}}$$

$$\text{Breaking Strength} = \frac{\text{Breaking Load}}{\text{Original Area}}$$

$$\text{Percent of Elongation} = \frac{\text{Distance between gage marks after break-G.L.}}{\text{G. L. (gage length)}} \times 100$$

$$\text{Percent of Reduction} = \frac{\text{Original Area-Final Area}}{\text{Original Area}}$$

When all data were analyzed, the three tests for each electrode/flux combination were averaged. See Tables 7-11 for a series of matrices showing each electrode/flux combination and the test results. Thus, selecting the most desirable combination of each property was facilitated. By examining these tables, a direct comparison of electrodes, fluxes, and combinations of the two can be made by the reader.

Table 7

Yield Strength

	Electrode A Hobart	Electrode B Lincoln	Electrode C Linde
Flux A Hobart	49,407 psi	41,905 psi	48,171 psi
Flux B Lincoln	46,416 psi	43,326 psi	
Mean	47,911 psi	42,615 psi	48,171 psi

Table 8

Tensile Strength

	Electrode A Hobart	Electrode B Lincoln	Electrode C Linde
Flux A Hobart	62,908 psi	57,026 psi	61,585 psi
Flux B Lincoln	59,869 psi	57,883 psi	
Mean	61,298 psi	57,454 psi	61,585 psi

Table 9

Breaking Strength

	Electrode A Hobart	Electrode B Lincoln	Electrode C Linde
Flux A Hobart	49,697 psi	43,780 psi	44,057 psi
Flux B Lincoln	44,980 psi	42,900 psi	
Mean	47,338 psi	43,340 psi	44,057 psi

Table 10

Percent of Elongation

	Electrode A Hobart	Electrode B Lincoln	Electrode C Linde
Flux A Hobart	32%	35%	36%
Flux B Lincoln	34%	37%	
Mean	33%	36%	36%

Table 11

Percent Reduction of Area

	Electrode A Hobart	Electrode B Lincoln	Electrode C Linde
Flux A Hobart	71%	71%	75%
Flux B Lincoln	74%	73%	
Mean	73%	72%	75%

CHAPTER V

Findings, Discussion, and Recommendations

Findings

The welding materials used in this study were considerably lower in strength than the information from the manufacturers indicated. This researcher attributes these differences to one of two reasons. The first possibility is that the information published by the manufacturers is incorrect. The second, and perhaps more likely, is that the tensile testing machine used for this study was inaccurate. Regardless of this discrepancy, the tests performed within this study were consistent. Therefore, the results allow direct mechanical property comparisons for the electrode/flux combinations used in this study.

Hobart flux used in combination with Hobart electrode was stronger in all categories than Lincoln flux used in combination with Hobart electrode (see Tables 7, 8, and 9, Column 1). Yield strength was 6% higher; tensile strength was 5% higher; and breaking strength was 9% higher. Other differences in fluxes tested were less than 5%; no pattern was established for higher or lower strengths between fluxes.

The most noticeable differences concerned the various electrodes tested (Tables 7-11). The Hobart electrode had an average of 11% more yield strength, 6% more tensile strength, and 8% more breaking strength than the Lincoln electrode. In addition, the Linde electrode had an average of 11% more yield strength and 7% more tensile strength than Lincoln electrode.

See Tables 7, 8, and 9 for a direct comparison between Lincoln's and Hobart's flux/electrode combinations. The Hobart combination resulted in a 12% greater yield strength, 8% greater tensile strength, and 14% greater breaking strength than the Lincoln combination.

Overall, the highest yield strength, tensile strength, and breaking strength were from a combination of Hobart electrode and Hobart flux. Hobart and Linde electrodes had very similar strength characteristics, and both were stronger than the Lincoln electrode.

Percent of elongation and percent reduction in area were very close for all of the combinations tested (see Tables 10 and 11). A direct comparison shows all combinations to be within 4% of each other in elongation and within 3% in reduction of area.

Discussion

The importance of the results of this study depends on the individual user's application and requirements. Purchasing decisions would probably be based on characteristics such as ultimate strength, yield strength, elongation, or reduction of area, depending on the requirements or primary concerns. Another important concern would be the availability of a particular product in the user's area. Service and variation in costs, also, influence such a selection. The purchaser should consider the factors mentioned above before purchasing electrode and flux for SAW.

This research permits a direct comparison of some of the more widely used electrodes and fluxes. However, before combinations are chosen, one should carefully consider the limitations of this study.

The review of related literature provides useful information concerning the selection of electrodes and fluxes for SAW. The references may also provide assistance in choosing welding parameters, conducting various tests, and deciding on submerged arc welding usage.

The individual user should utilize the research information gained from this study as well as the manufacturers' and AWS suggestions. After a careful study of recommendations and other local circumstances, such as service, the most desirable electrode/flux combination should be selected. The user should then test that combination on a particular welding application to be certain that satisfactory results occur. If problems appear, it will be possible to make changes before going into full scale production.

Recommendations for Further Study

The following recommendations are divided into two categories. The first section is designed for the researcher attempting to duplicate this research effort or a related problem area. The second section suggests recommendations for the practitioner in the field using SAW.

Recommendations for the Researcher:

1. How do other electrodes within the AWS classification EL12 compare to the ones tested in this study?

2. How do electrodes in other AWS classifications, containing low alloy or stainless steel, compare to each other?

3. How do other properties such as impact strength, and the microstructure of the weld compare for the various electrode/flux combinations?

4. Will variations in current or voltage levels change the properties of the weld material? What effects do the high and low ends of the current ranges have on the weld material? What is the most desirable voltage to use at each current level?

5. Do various heat treatments have an effect on the weld properties (e.g., microstructure, impact strength, yield point, tensile strength)?

6. Does active or alloying flux have an effect on weld properties?

7. Does wire feed speed or carriage travel speed have an effect on weld properties? Is there a desirable relationship between wire feed, carriage travel speed, deposition rate of weld material, and amount of weld penetration?

8. What would be the effect of testing submerged arc welding electrode/flux combinations under other conditions (e.g., extreme temperatures, exposure to moisture, and vibration)?

Recommendations for Practitioners:

1. Would the results of future investigations differ from those in this study if performed with a piece of industrial welding equipment designed with automatic carriage travel, height adjustments, and lateral adjustments?

2. Would the results of future investigations differ from those in this study if performed with a more sophisticated tensile testing machine?

3. How does welding done on the job compare with laboratory tests of weld material? How does it compare with job specifications?

APPENDIX A

Welding Procedure Sheets

Welding procedure no. 1

Electrode: A   Electrode classification(AWS): EL12   Manufacturer: Hobart

Electrode size: 5/64"   Manufacturer no.: HB-10

Flux: A   Manufacturer: Hobart   Manufacturer no.: H-100

Welding parameters

Amperage: 300 amps, DC reverse polarity (electrode positive)   Voltage: 29 volts

Electrode feed rate: 100 IPM   Carriage travel speed: 15 IPM   Travel angle: 90°

Test data

Coupon number	Yield load	Ultimate load	Breaking load	Gage length	Gage distance after break	Dia. before break	Area before break	Dia. at break	Area at break
1	4200 lbs.	5220 lbs.	4520 lbs.	1.400 in.	1.726 in.	.320 in.	.084 in^2	.191 in.	.029 in^2
2	4300 lbs.	5680 lbs.	4450 lbs.	1.400 in.	1.898 in.	.344 in.	.093 in^2	.183 in.	.026 in^2
3	5100 lbs.	6280 lbs.	5000 lbs.	1.400 in.	1.792 in.	.352 in.	.097 in^2	.193 in.	.029 in^2

Calculated data

Coupon number	Yield strength	Tensile strength	Breaking strength	% elongation	% reduction of area
~~1~~	~~50,000 psi~~	~~62,143 psi~~	~~53,810 psi~~	~~23%~~	~~65%~~
2	46,237 psi	61,075 psi	47,849 psi	36%	72%
3	52,577 psi	64,742 psi	51,546 psi	28%	70%
Mean	49,407 psi	62,908 psi	49,697 psi	32%	71%

Specimen #1 had a void

Welding procedure no. 2

Electrode: A   Electrode classification(AWS): EL12   Manufacturer: Hobart

Electrode size: 5/64"   Manufacturer no.: HB-10

Flux: B   Manufacturer: Lincoln   Manufacturer no.: Lincolnweld 780

Welding parameters

Amperage: 300 amps, DC reverse polarity (electrode positive)   Voltage: 29 volts

Electrode feed rate: 100 IPM   Carriage travel speed: 15 IPM   Travel angle: 90°

Test data

Coupon number	Yield load	Ultimate load	Breaking load	Gage length	Gage distance after break	Dia. before break	Area before break	Dia. at break	Area at break
1	4450 lbs.	5700 lbs.	4300 lbs.	1.400 in.	1.874 in.	.351 in.	.097 $in.^2$	.184 in.	.027 $in.^2$
2	4580 lbs.	5800 lbs.	4400 lbs.	1.400 in.	1.882 in.	.344 in.	.093 $in.^2$	.174 in.	.024 $in.^2$
3	4280 lbs.	5620 lbs.	4200 lbs.	1.400 in.	1.880 in.	.352 in.	.097 $in.^2$	.171 in.	.023 $in.^2$

Calculated data

Coupon number	Yield strength	Tensile strength	Breaking strength	% elongation	% reduction of area
1	45,876 psi	58,763 psi	44,330 psi	34%	72%
2	49,247 psi	62,366 psi	47,312 psi	34%	74%
3	44,124 psi	57,938 psi	43,299 psi	34%	76%
Mean	46,416 psi	59,689 psi	44,980 psi	34%	74%

Welding procedure no. 3

Electrode: B Electrode classification (AWS): EL12 Manufacturer: Lincoln

Electrode size: 5/64" Manufacturer no.: L-60

Flux: A Manufacturer: Hobart Manufacturer no.: H-100

Welding parameters

Amperage: 300 amps, DC reverse polarity (electrode positive) Voltage: 29 volts

Electrode feed rate: 100 IPM Carriage travel speed: 15 IPM Travel angle: 90°

Test data

Coupon number	Yield load	Ultimate load	Breaking load	Gage length	Gage distance after break	Dia. before break	Area before break	Dia. at break	Area at break
1	4000 lbs.	5470 lbs.	4000 lbs.	1.400 in.	1.898 in.	.351 in.	.097 $in.^2$	.173 in.	.024 $in.^2$
2	3980 lbs.	5470 lbs.	4250 lbs.	1.400 in.	1.912 in.	.350 in.	.096 $in.^2$	.181 in.	.026 $in.^2$
3	4130 lbs.	5540 lbs.	4400 lbs.	1.400 in.	1.867 in.	.349 in.	.096 $in.^2$	.204 in.	.033 $in.^2$

Calculated data

Coupon number	Yield strength	Tensile strength	Breaking strength	% elongation	% reduction of area
1	41,237 psi	56,392 psi	41,237 psi	36%	75%
2	41,458 psi	56,979 psi	44,271 psi	37%	73%
3	43,021 psi	57,708 psi	45,833 psi	33%	66%
Mean	41,905 psi	57,026 psi	43,780 psi	35%	71%

Welding procedure no. 4

Electrode: B　　Electrode classification (AWS): EL12　　Manufacturer: Lincoln

Electrode size: 5/64"　　Manufacturer no.: L-60

Flux: B　　Manufacturer: Lincoln　　Manufacturer no.: Lincolnweld 780

Welding parameters

Amperage: 300 amps, DC reverse polarity (electrode positive)　　Voltage: 29 volts

Electrode feed rate: 100 IPM　　Carriage travel speed: 15 IPM　　Travel angle: 90°

Test data

Coupon number	Yield load	Ultimate load	Breaking load	Gage length	Gage distance after break	Dia. before break	Area before break	Dia. at break	Area at break
1	4090 lbs.	5420 lbs.	4020 lbs.	1.400 in.	1.920 in.	.345 in.	.093 $in.^2$	.177 in.	.025 $in.^2$
2	4070 lbs.	5420 lbs.	3980 lbs.	1.400 in.	1.922 in.	.347 in.	.095 $in.^2$	.170 in.	.023 $in.^2$
3	4100 lbs.	5540 lbs.	4140 lbs.	1.400 in.	1.926 in.	.348 in.	.095 $in.^2$	.174 in.	.024 $in.^2$

Calculated data

Coupon number	Yield strength	Tensile strength	Breaking strength	% elongation	% reduction of area
1	43,978 psi	58,280 psi	43,226 psi	37%	73%
2	42,842 psi	57,053 psi	41,895 psi	37%	76%
3	43,158 psi	58,316 psi	43,579 psi	38%	75%
Mean	43,326 psi	57,883 psi	42,900 psi	37%	75%

Welding procedure no. 5

Electrode: C Electrode classification (AWS): EL12 Manufacturer: Linde

Electrode size: 5/64" Manufacturer no.: Linde 80

Flux: A Manufacturer: Hobart Manufacturer no.: H-100

Welding parameters

Amperage: 300 amps, DC reverse polarity (electrode positive) Voltage: 29 volts

Electrode feed rate: 100 IPM Carriage travel speed: 15 IPM Travel angle: 90°

Test data

Coupon number	Yield load	Ultimate load	Breaking load	Gage length	Gage distance after break	Dia. before break	Area before break	Dia. at break	Area at break
1	4680 lbs.	6020 lbs.	4800 lbs.	1.400 in.	1.819 in.	.353 in.	.098 in^2	.234 in.	.043 in^2
2	4640 lbs.	5910 lbs.	4200 lbs.	1.400 in.	1.892 in.	.356 in.	.099 in^2	.175 in.	.024 in^2
3	4700 lbs.	6030 lbs.	4340 lbs.	1.400 in.	1.921 in.	.347 in.	.095 in^2	.174 in.	.024 in^2

Calculated data

Coupon number	Yield strength	Tensile strength	Breaking strength	% elongation	% reduction of area
~~1~~	~~47,755 psi~~	~~61,428 psi~~	~~48,980 psi~~	~~30%~~	~~56%~~
2	46,869 psi	59,697 psi	42,424 psi	35%	76%
3	49,474 psi	63,474 psi	45,684 psi	37%	75%
Mean	48,171 psi	61,585 psi	44,057 psi	36%	75%

Specimen #1 had a void

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