WHAT STRUCTURAL ENGINEERS AND FABRICATORS NEED TO KNOW ABOUT WELD METAL *(PART I)*

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1.0 Introduction

To supply structural engineers and fabricators with the mechanical properties data needed to ensure good weldment design, manufacturers of consumables utilize standard filler metal qualification tests developed by the American Welding Society. Tensile properties are thus reported. Too frequently, engineers expect the results of these tightly controlled tests to be directly applicable to the properties of welded connections made in the shop or in the field. They are not. Both the structural engineer and the fabricator need to be aware of the ways in which many variables may affect the properties of the weld deposit.

2.0 Designing Welds

When a structural engineer is designing a welded connection, that weld will typically be a fillet weld, a full penetration butt weld, or a partial penetration weld. It is being designed for a particular strength requirement. The fillet weld strength will be proportional to the leg size, the length and the strength of the filler metal. A butt weld will be proportional to the cross-sectional area, and the strength of the filler metal. A partial penetration weld will have a strength proportional to the depth of penetration, the length, and the strength of the filler metal used. So in any of these three situations, the strength of the filler metal used is critical to the performance of the particular joint.

3.0 Properties Required

The word "strength" is used here specifically, because in some cases yield strength is more important, and sometimes tensile strength is more important. Most welded connections are designed around the tensile strength, but the yield strength is very often the controlling factor, in that permanent deformation is not desirable. The modulus of elasticity, used for designing structure stiffness, is not a structure-sensitive property, and therefore is not within the scope of this discussion.

Another strength factor that does not figure into the strength equations mentioned above is toughness, a very difficult property to use in design. Fracture mechanics is required in order to utilize the property of toughness. However, impact resistance measured by the Charpy specimen, is frequently used, and to that extent, this paper will discuss the effects of variables on toughness. Toughness properties are not required by AWS D1.1 structural code, however, unless specified in contract documents.

The structural engineer requiring the properties of yield strength and tensile strength, may go immediately to the electrode classification to try to discern these. Using an example of a typical low-hydrogen electrode, an E7018, he may look at the 70 designation, knowing that 70 stands for a minimum tensile strength of 70,000 psi, and use that for design purposes. The same strength level may not be seen in the actual weld joint selected by the engineer. To understand why, it is necessary first to review filler metal specifications and qualification tests.

4.0 Filler Metal Specifications

Mechanical properties requirements spelled out in the AWS classification include specific yield, tensile strength and elongation properties. Charpy values for toughness may or may not be specified. Certain chemical properties are specified, indicating key alloy levels.

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Finally, there may be welding performance criteria such as the percentage of moisture in the coatings of low-hydrogen electrodes. A look at a typical certification demonstrates that electrodes exceed the minimums that are specified. However, note that the Appendix to the filler metal specification includes restrictions on the use of this information, as follows:

"Weld metal properties may vary widely, according to size of the electrode and amperage used, size of the beads in the weld, plate thickness, joint geometry, preheat and interpass temperatures, surface condition, base metal composition, dilution, etc". The test plate was never designed to duplicate the actual welding properties. It would be impossible to duplicate all of the properties that may be encountered. The purpose is for classification or qualification of a particular product to a specific filler metal type. It does permit comparisons within the specification. That is, one E7018 electrode can be compared to another. But technically, an E7018 electrode cannot be compared to a deposit of submerged arc, for example, because there are differences between the tests.

5.0 Test Controls

In relying on test results, the engineer again will do well to heed the Appendix to the filler metal specification:

"Properties of production welds may vary accordingly, depending on the particular welding conditions. Weld metal properties may not duplicate, or even closely approach, the values listed and prescribed for test welds." These tests were actually designed to minimize variations in results due to testing from one manufacturer to another, from one year to another, and from one product to another.

An in-depth look at one test, for a low-hydrogen stick electrode, will help to clarify the purpose of the tests. That products, a shielded metal arc welding electrode, is covered in AWS A5.1. The mechanical properties are those with which structural engineers are most concerned. The first step is to find out what tests are required by the specification. Table # 8 in that specification indicates that for an E7018 electrode, 3/32 in diameter and 1/8 in, diameter electrodes do not require mechanical testing. For the 5/32 in. diameter electrode, however, an all-weldmetal tension test is required, with the plate to be welded in the flat position. Out of the same plate, impact specimens are to be taken, and also a fillet weld test is to be performed in the vertical and overhead position to ensure weld soundness.

The 3/16 in. diameter electrode has the same requirements for mechanical testing as does the 5/32 in. diameter. However, the fillet weld is to be made in the horizontal position, as opposed to the vertical and overhead position of the 5/32 in. A 7/32 in. diameter electrode does not require any mechanical tests.

The 5/32 in. electrode can be subjected to a closer look, since it does require mechanical testing. The next step is that the particular test plate to be used must be made of one of the three grades of steel listed: A285 Grade C; A36; or A283 Grade D. Typically, A36 is used. The plate is to be configured as per Figure 1.

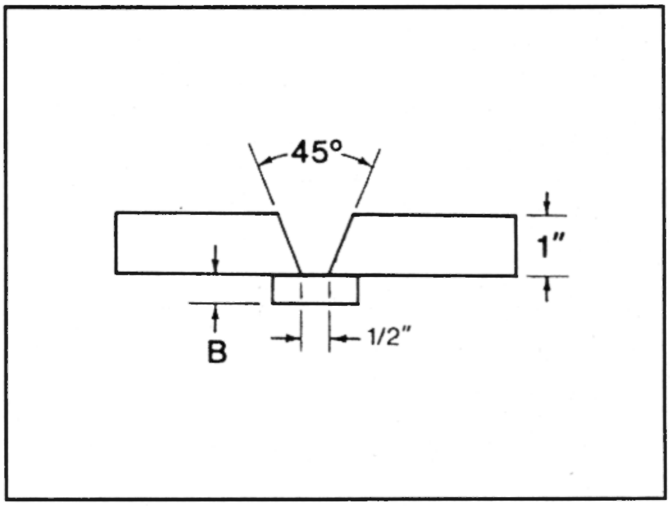

Fig 1. Preparation of the test assembly

That is, a 45 degree included angle, with a one-half inch root opening, a plate thickness dependent on the electrode size, typically a 3/4 in. for a 5/32 in. electrode, and a backing bar appropriate to the size of electrode being used. The plate is to be pre-heated to 225 degrees F, plus or minus 25 degrees. Interpass temperature is to be maintained at 225 to 350 degrees F. The amperage is suggested to be run between 150 and 220 amps. The welding sequences is specified. The first layer is to be made with a full weave, with one layer for the entire half-inch of the root opening. The second and all subsequent layers are to be welded with two passes per layer. A total of 7 to 9 layers could be used to make this weld specimen. Dictating the amperage and welding sequence restricts the travel speed. Note that the test plate will always be multiple pass, with a minimum of 13 relatively small beads.

The specimen is to be tested per ASTM specifications. The test specimens are to be removed from the plate configuration, as shown in Figures 2 and 3.

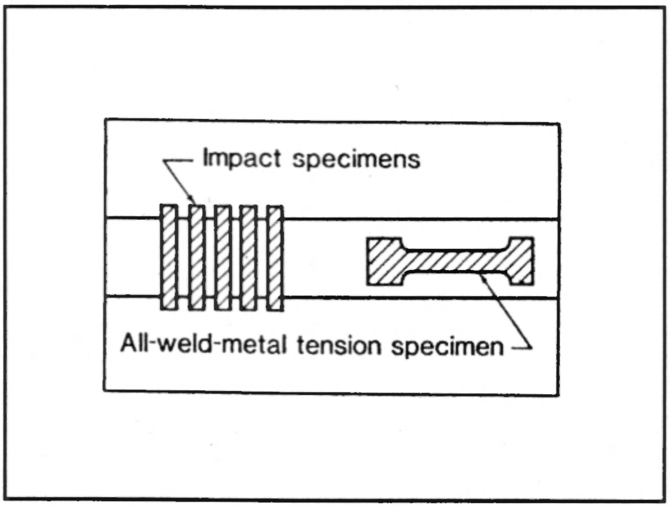

Fig 2. Location of test specimens in test plate

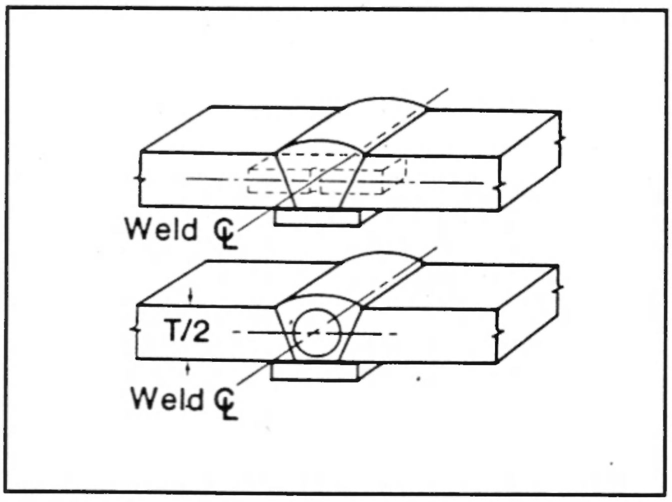

Fig 3. Location of test specimens in allweldmetal deposit.

The machining of the test plate, the accuracy of the test instruments, etc, are all covered in the ASTM specifications. For the E7018 electrode, the all-weld-metal tensile strength must be a minimum of 72,000 psi. Yield must be 60,000 psi minimum. Elongation must be 22 per cent minimum. The impact energy must be a minimum of 20 ft. lbs. at minus 20 degrees F. In addition, there are chemical and performance tests that are not discussed here, but if all these other criteria are met, it may be classified as an E7018 SMAW stick electrode.

Other consumables may be tested in a different form. For instance, consider the E6010 electrode, which is still within the A5.1 specification. In this case, the specimen can be aged at 200 to 220 degrees F for 48 hours, plus or minus two hours. This permits any hydrogen to escape from the weld metal. This test is not designed to hide the fact that hydrogen may be present in the weld metal: its purpose is rather to present a very consistent way of comparing products that may have hydrogen in the weld metal. If for example, the weld specimens are not tested for two to four weeks after welding, most of the hydrogen has escaped from the sample. This is an accelerated way of letting the hydrogen escape, in order to ensure the consistency of test results.

A different filler metal specification, A5.20. for flux cored arc welding, shows that the ambient or starting temperature for the test plate is room temperature, vs. the low hydrogen test under 5.1, which called for an initial temperature of 225 degrees F. Here, the initial temperature is specified as 70 degrees F. In addition, flux-cored arc welding may utilize externally supplied shielding gas. When required, the controlling gas is t be carbon dioxide.

A consideration of specification 5.17 for submerged arc welding demonstrates that the procedure is tightly controlled for testing. The 5/32 in. diameter electrode should be used at 550 amps and 28 volts. There can also be post-weld heat treatment, or stress relieving, of submerged arc welds and other products as well. The stress relief temperature is 1150 degrees F., plus or minus 25 degrees, and the weld should be stress relieved for one hour.

6.0 The Effects of Deviations

These test configurations and controls may or may not represent the actual welding conditions. Indeed, in the majority of situations, there will be deviations. Such deviations as amperage, weld bead placement, plate thickness, and so forth, have already been noted. These can be classified, however, into two broad categories: chemical and thermal changes.

7.0 Chemical Effects

Chemical changes are due to two key influences: first, the plate chemistry, and secondly, the amount of admixture. Three terms may need definition here: admixture, dilution and pickup.

Figure 4 helps to illustrate admixture. As the illustration shows, this weld is joining plate A to plate B. A backing strip labeled C is included. The joint is to be filled with a filler metal labeled D. The arc force and energy of the electrode will melt some of plate A, some of plate B and some of plate C. The final composition of the weld metal will be A,B,C, and D. This conglomeration of material is called "admixture."

Figure 5 illustrates dilution. Dilution occurs when a high alloy electrode is used to weld on lower alloy plate. Thus, as the high alloy is mixed with the lower alloy, creating an admixture, the high alloy is diluted. For example, using a stainless steel electrode with high chrome and high nickel to weld on mild steel, will result in lower chrome and nickel content in the weld than in the electrode. This result is called "dilution."

Figure 6 shows alloy pickup, which is just the opposite of dilution. Here, mild steel electrode is used to weld on high alloy plate. The weld deposit will contain nickel that was never present in the mild steel filler. When the deposit contains a greater amount of alloy than the electrode, the situation is referred to as alloy "pickup."

As base plate is introduced into the admixture, the weld chemistry changes. If the plate chemistry is different than that used for filler metal qualification, the weld chemistry may be different. The significance of this will be considered later.

The extent of admixture is a function of joint geometry, the process used, and procedures. Since few people weld AWS filler metal qualification plates in production, the test plate is not typical of most production joints.

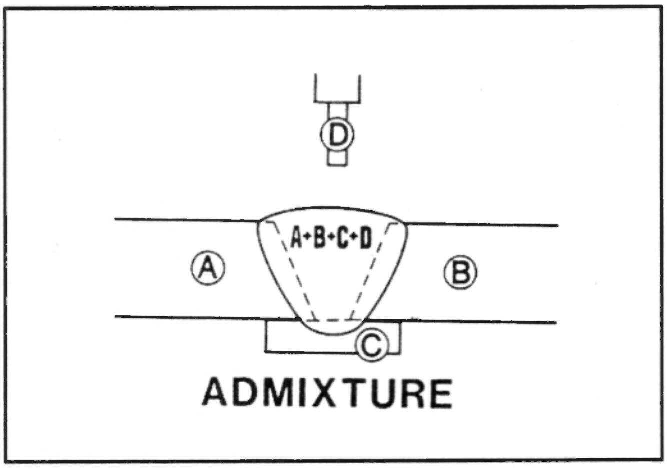

Fig. 4

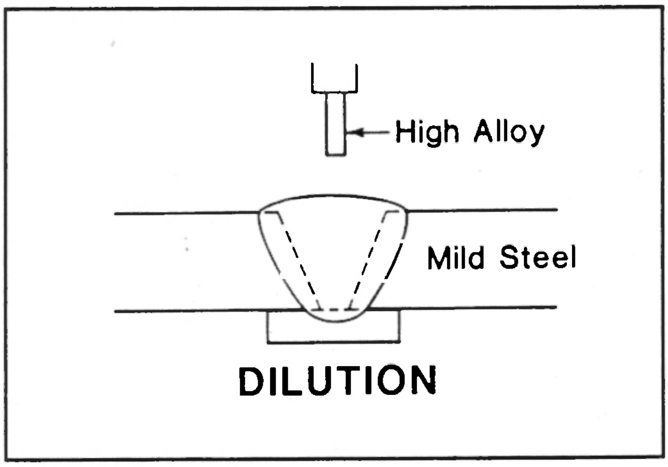

Fig. 5

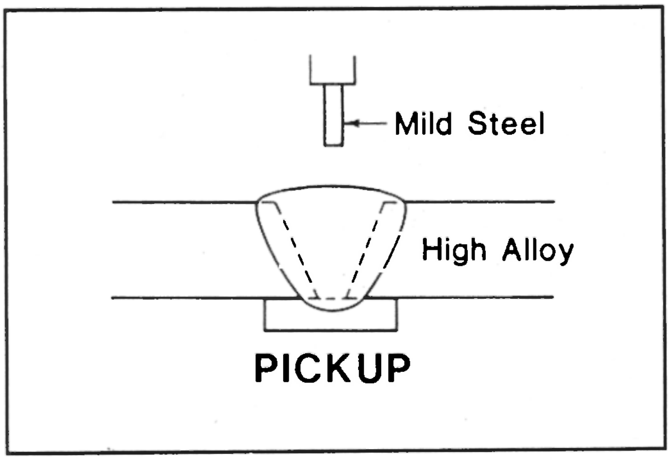

Fig. 6

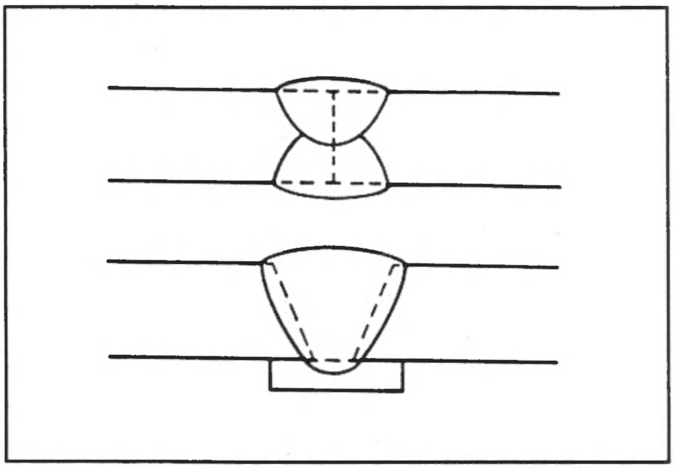

Fig. 7 Admixture in two joint configurations.

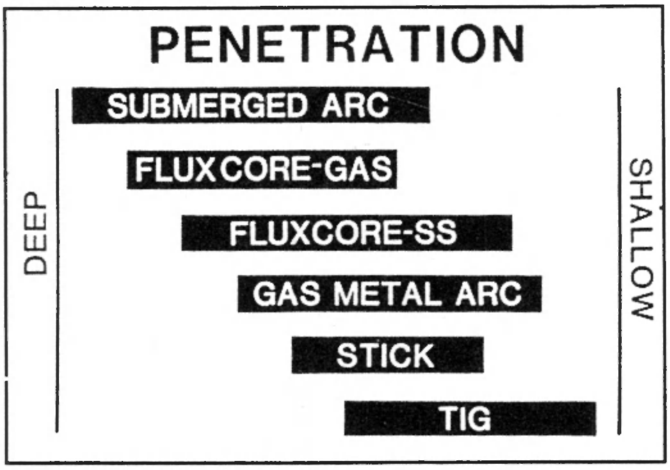

Fig. 8 Comparative penetration

Figure 7 shows two different butt joint. The plate thickness is the same in both cases. One involves a penetration weld, welding from two sides. In this example, the bottom side was welded first, then the plate was turned, the top side was welded, and full joint strength was achieved. The artwork shows that there would be tremendous influence of base material in this particular weld, as shown by the dotted lines. A high percentage of the base metal. This admixture would be composed primarily of base material.

The second butt joint in Figure7 shows a beveled joint with a back-up that comes close to approaching that of a filler metal specification. Here, minimum amounts of base material are melted. The admixture is composed primarily of the filler metal. So the joint geometry plays an important role in determining the composition of the admixture.

The process selected is very important with respect to penetration. Figure 8 delineates six major arc welding processes; the degree of penetration will vary, according to the process. The deepest penetration process, the one in which the base material has the most significant effect, is submerged arc welding or TIG welding has relatively shallow penetration, still giving adequate fusion, but the base material has a lesser effect. Between these two extremes are: the flux-cored gas process, which gives relatively deep penetration; the self shielded flux cored process, which can have a tremendous range in penetration; the gas metal arc process, which features deep penetration in the spray mode and relatively shallow penetration in the short arc mode(Note: the latter is restricted on structural applications); and the stick electrode process or shielded metal arc welding, which has a tighter range. For a given process, the extent of penetration is a function of amperage and electrode size. Travel speed, polarity and welding position affect the penetration to a lesser extent (Figure 8).

-To be continued in the next issue-

8.0 References

1. "Specification for Covered Carbon Steel Arc Welding Electrodes," Appendix, page 25, ANSI/AWS A5.1-81, October 30,1981.
2. Ibid.

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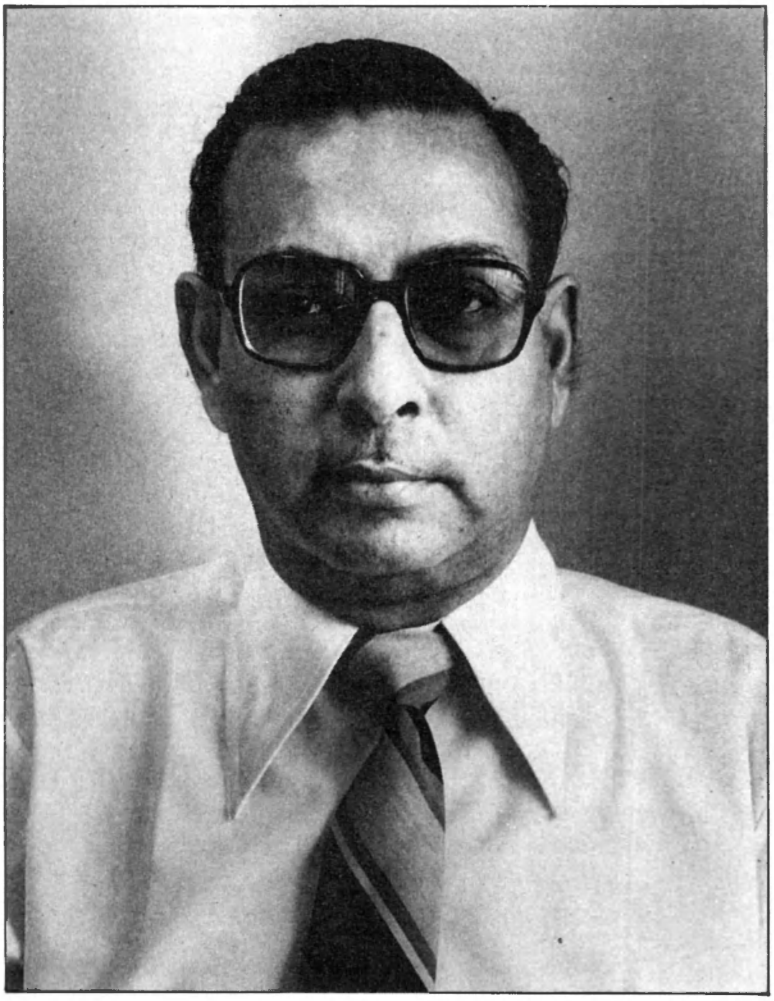
OBITUARY



Late N. Mukerjea, our immediate past Hony. General Secretary, expired on 8th December 1988 at the age of 60 years, in Calcutta, after a short illness.

In 1949, N. Mukerjea started his career, graduating with First Class in Chemistry from Presidency College, Calcutta, with I.O.L. in sales. Gradually over the years he rose to the position of Zonal Sales Manager- Welding and became specialised in the field of welding, having served I.O.L. for more than 38 years. He had a wide knowledge of welding product, applications, market, sales techniques and National and International trends in this field.

He became a Member of our Institute in the year 1969 and took keen interest in the activities of the Institute in the Branches wherever he was posted. He was selected as Hony. General Secretary of the Institute in July 1977 and served this Institute continuously for a period of eight years in that capacity with dignity and remarkable efficiency. He took keen interest in promoting the professional status of the Institute's Members, opened many new Branches of the Institute in various parts of India and helped to open a permanent place for the Headquarters at 3A, Loudon Street, Calcutta-700 017. He also paved the way of making ground work for the preparation of AME-IIW Examination for the Institute.

N. Mukerjea retired from the services of I.O.L. in March 1986 and then served with General Electrodes & Equipment Ltd., Bombay as Chief Executive-Marketing till his last day.

Besides his love for welding activities and the Indian Institute of Welding, he was a proficient vocal singer and ardent lover of Tagore's songs.

He was a happy and contented family man and is survived by his wife, children and host of relatives and friends all over India.