Welding Education

What Structural Engineers and Fabricators Need to Know About Weld Metal *(Concluding Part)*

Duane K. Miller
Welding Engineer The Lincoln Electric Company
Cleveland, Ohio

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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.

Please refer to Volume V, No. 3 of The Welding Innovation Quarterly for Part 1 of this paper, (see IWJ April, 1989 issue) in which the author discussed : Designing Weld; Properties Required; Filler Metal Specifications; Test Controls; The Effects of Deviations and Chemical Effects.

2.0 Alloy Effects on Mechanical Properties

Plate chemistry and the amount of plate that ends up in the admixture may change the deposit analysis from that of filler metal qualification deposits. This may in turn result in different mechanical properties. The effects of individual elements will be considered next. Alloys may be singularly introduced into the admixture and their significance evaluated on a weight percent basis. Those individual trends will be considered. However, combinations of elements may produce a synergetic effect; the potentially complicated reactions of synergetic elements are beyond the scope of this paper.

In small percentages, those elements in the "most significant" column greatly increase the strength of an alloy. While still "significant," those elements listed to the left of carbon, vanadium and columbium, contribute to the strength factor in proportionally lesser degrees (see Figure 9). While nickel will contribute to the strength of the admixture, a much greater weight percentage of nickel will be required to provide the same degree of strength as a fractional percentage of, for instance, vanadium. Whereas A36 plate, used for qualification of many products, typically does not include vanadium and columbium, plate bearing these elements and welds having a high degree of admixture, and in this case, much alloy pickup (in that the vanadium and columbium are in the base material and not in the welding material) will be high-strength.

Alloys affecting toughness properties may be similarly evaluated (see Figure 10). Generally, higher strength means lower toughness. To predict toughness, alloys can be categorized in three groups. Vanadium, carbon and columbium typically lower the impact energy. Copper, silicon, chromium, and molybdenum have very little effect either way. Nickel and manganese increase the impact energy. Nickel is a key ingredient for gaining better impact properties without significantly increasing the strength of the metal.

3.0 Procedural Effects on Chemistry

Procedural changes may produce significant chemical deviations. One of those deviations is typical of the submerged arc process. Submerged arc deposit chemistry is dependent, among other things, on the effect of the flux. If an active flux is used, manganese and silicon levels in the deposit will be dependent on the arc voltage used. As previously noted, 28 volts is the voltage used for welding submerged arc filler metal qualification test plates. If a

ALLOY EFFECTS —STRENGTH—			
SIGNIFICANT ———	———	———►	MOST SIGNIFICANT
Nickel	Chromium Silicon Manganese	Molybdenum Copper	Carbon Vanadium Columbium

Fig. 9

ALLOY EFFECTS —TOUGHNESS—		
DECREASES	INACTIVE (LITTLE EFFECT)	IMPROVES
Vanadium Carbon Columbium	Copper Silicon Chromium Molybdenum	Nickel Manganese

Fig. 10

higher voltage is used, the level of manganese may be either increased, or decreased. Voltage is a variable that is not considered in the qualification plates. Acknowledging this, the Wall neutrality number, frequently designated as "W", has been developed. Since literally thousands of test plates have been run at 28 volts, this was used as one voltage for comparison. An identical test is run at 36 volts, an 8 volt difference. The absolute difference in the weight percent of silicon, is added to the absolute difference in the weight percent of manganese. Those figures, added together and multiplied by 100, equal the Wall neutrality number.

The American Welding Society has selected a Wall number of 40 or less, and defined that to designate a neutral flux. If the Wall number is greater than 40, it is considered to be an active flux. If the Wall number is less than 40, the effect of voltage is considered insignificant. If the changes are greater than 40, the structural engineer should be aware of the fact that the silicon and manganese contents of the weld may be increased, thereby increasing the weld strength. While silicon will have little effect on the weld deposit in terms of toughness, manganese tends to improve it slightly.

When CO_2 gas is used in flux-cored welding, alloys may oxidize, and not appear in the weld deposit. When inert gases are used for shielding, less alloy is oxidized. The deposit has a higher alloy content, meaning that the strength levels typically go up, and the impact energy typically goesdown. In fact, a 5,000 to 10,000 psi increase in tensile strength is very common. Impact properties may drop by as much as 50 percent with the use of inert gas shielding.

Some testing specifications utilize the aging process to eliminate hydrogen from the weld. The structural engineer should be aware that the weld metal may contain hydrogen, even though the tested results do not show this. The time before loading may become a critical variable that should be addressed.

4.0 Thermal Effects

The second major change in welding test plates vs. "real-life" welding takes place in the area of thermal effects. In general, with carbon steel materials, the faster the material is cooled, the lower the impact properties will be. What are the significant thermal differences between filler metal qualification plates and "real-life" welds ? First, preheat may or may not be present in the test plate, and it may or may not be required on the job site. If preheat is not used in either case, the first weld passes cool at a very rapid rate, increasing the strength.

Secondly, the heat input may be different. The list of variables covered by tests includes such things as electrode size, voltage, amperage, stick-out, polarity, process, travel speed and position of welding. All of these address the heat input factor. Heat input is proportional to the voltage (E), amperage (I), divided by the travel speed, times the efficiency.

The voltage and amperage are dictated by the welding procedure, as is the travel speed. The efficiency has to do

with the process. Submerged arc causes most of the heat of the arc to be put into the base material. Other processes may involve a tremendous amount of radiation, smoke, spatter, and other sources for the energy to escape, other than entering the plate. Many heat input equations do not even consider the effect of efficiency, however.

The higher the amperage, for instance, the more heat will be put into the joint. That pressumes that the same travel speed is being used. However, if travel speed increases, high deposition or high amperage welding procedures are not necessarily high heat input procedures. A case in point: if the weld nugget size is kept the same, the heat input is very often a constant.

Another factor to be considered is the interpass temperature that is maintained. In terms of welding on steel that is less than 80,000 psi tensile strength, the heat input has a limited effect. On higher tensile strength steels, heat input is more critical. In general, higher heat input will produce lower tensile strength, but better impact properties. Next, the cooling rate must be considered.

A fast cooling rate typically gives higher strength weld metal and lower impact properties. The cooling rate is dependent upon the heat input, the thickness of the part, the geometry of the part, and any preheat, or the ambient temperature, of the plate, Figure 11 illustrates heat conduction in three directions on thick plate, which produces a rapid cooling rate. Conversely, Figure 12 illustrates the slower cooling rate associated with thin plate, where heat is transferred in only two directions.

Post-weld heat treatments also require consideration. Multiple pass welding involves a thermal effect on previous beads. This thermal effect or annealing of welds, as several beads are made, significantly improves impact properties. For this reason, multiple passes are highly desirable if the goal is to achieve the ultimate in impact properties.

Stress relief typically caused the tensile strength to drop 5,000 psi, and the yield strength to drop 10,000 psi. The stress relief procedure used for AWS specimens is 1,100 degrees F for one hour. Longer term stress relief or different temperatures will affect those results. Normalizing, or thermal treatment at temperatures approaching 1,600 or 1,700 degrees F, will have a very significant effect, typically lowering yield and tensile properties.

All of these thermal effects can reinforce each other. For example, a weld may be made with an interpass temperature of 300 degrees F. If strees-relieved at 1,150 degrees F for one hour, a given set of results will be obtained. The same plate, with the same welding procedure, could be welded at 200 degrees F interpass temperature, stress-relieved at 1,150 degrees F for eight hours vs. one hour, and the same yield and tensile would be obtained from both welds.

5.0 Controlling Weld Quality

Engineers have specified, and fabricators have successfully made, welds for many years without knowledge of the differences between actual welding conditions and filler metal qualification tests. This success is due, in part, to industry controls which address these differences. The filler metal manufacturer designs an electrode, tests it in a qualification plate, and certifies it to a given classification. The fabricator takes that particular electrode and runs a procedure qualification test. The test utilizes the particular shop practice, duplicating the details of procedure, joint design and steel grade. He then tests the weld metal, typically with a tensile test, and will run an impact test if required. The AWS D1.1 Structural Welding Code does not require the properties of this test to meet those of the filler metal classification. Rather, it is required that the properties exceed those of the base material. For example, if A572 Grade 50 steel with a tensile strength of 65,000 psi is used, and welded with E7018 electrode, the procedure qualification test does not require meeting the 72,000 psi of the filler metal test. Instead, only the 65,000 psi of the steel must be met.

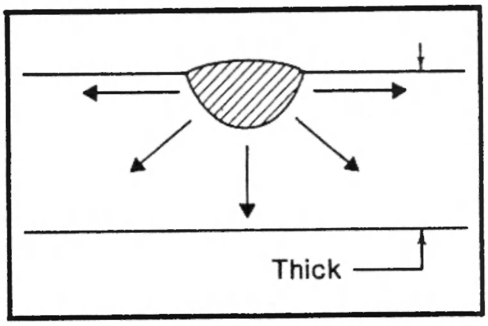

Fig. 11

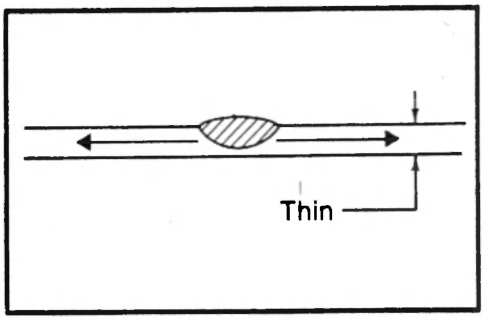

Fig. 12

6.0 In Conclusion

The information presented herein will be useful in predicting trends and making the initial selection of a filler metal. If the engineer knows, for example, that he is welding on higher carbon material with a process that will have a great deal of penetration, and the admixture will have a higher carbon content than the filler metal - due to pickup - then he may be able to predict in advance that he will have little difficulty in achieving the required strength. However, if impact properties are required, he will know that increased strength decreases toughness. Perhaps a filler metal with greater impact properties should be selected.

To Summarize

- Filler metal test plates have tight controls, and do not necessarily represent actual working conditions.
- There are predictable trends, based on chemistry and thermal effects.
- The industry codes requiring qualification test plates define and bring together all of these conditions so that engineers and fabricators can be confident that they are exceeding the base metal properties. Knowledge of these variables permits more intelligent selection of a starting point, relieving the engineer or fabricator from running interminable tests before selecting an appropriate filler metal.

Teach a Computer to Learn !

"It has been said that a person doesn't really understand something until he teaches it to someone else. Actually a person doesn't really understand something until he can teach it to a computer i.e express it as an algorithm....The attempt to formalise things as algorithms leads to a much deeper understanding than if we try to understand things in the traditional way".

Donalt Knuth
"Computer Science and Mathematics",
American Scientist, Vol 61, 1975.

Innovations and Education

"I reiterated the crux of my talk, that innovation and education would indeed exert a positive impact on the fortunes of steel industry. The Steel Service Centre chose to diversity and provide more services to the customers while constantly improving quality. Business has flourished, demand has grown to create material shortage, and the future was bright. Successful companies in the welding industry followed the same approach....Perhaps, the most important marketing innovation took place when manufacturers trained thousands of distributor sales people. The synergic effect of this new cadre of competent professionals working in concert with direct technical representation, has really benefitted the many fledging organisations that make up today's welding customers.

In summary, let's continue to educate, innovate and motivate in order to stimulate our economic growth."

Richard S. Sabo.
Executive Director & Secretary The James F. Lincoln Arc Welding Foundation, Cleveland, OHIO.
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