Key Concepts in Welding Engineering

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Selecting Filler Metals: Matching Strength Criteria

Introduction

This column is the first of a series that will address topics related to filler metal selection. The focus will be on the concerns of design engineers, beginning with filler metal strength. The strength of weld metal vs. base metals may be defined as matching, overmatching or undermatching. This column will address "matching" filler metal.

What is "Matching" Strength?

What is "matching strength" filler metal? The *AWS A3.0 Standard Welding Terms and Definitions* does not contain such a term, although it has been used for years. "Matching strength," on the surface, would seem to imply that the filler metal will deposit weld metal of the exact strength as (or "matching") the base metal. Codes have tables with lists of matching filler metals, such as the *AWS D1.1 Structural Welding Code – Steel*, Table 3.1, as do various filler metal suppliers. A careful review of AWS D1.1, Table 3.1, shows that the matching electrodes do not deposit welds with exactly the same strength as the base metal, and in reality, this is not what is meant by "matching."

In Table 3.1, A36 and A570 Gr. 50 are both listed in the Group I category. "Matching" filler metal is shown as both E60 and E70 electrode and flux/electrode classifications. A36 and A570 Gr. 50 have different minimum specified yield and tensile strengths, as do E60 and E70 filler metals. Obviously, matching cannot be as simple as "matching" the base metal strength (see Table 1).

While AWS D1.1 calls the preceding combinations "matching," clearly the minimum specified weld metal properties are not the same as the minimum specified base metal properties. The matching combinations for AWS D1.1, Table 3.1, Group III materials provide some additional insight, where the minimum specified filler metal properties are more closely matched to the base metal, and the tensile strength values are very similar (see Table 2).

All of the preceding examples are considered "matching," although the degree of match is different. The common element is that the minimum specified tensile strength of the filler metal is always the same as or greater than the minimum specified tensile

Matching tensile strengths often do not result in matching yield strengths

Table 1. Filler/Base Metal Strength Comparison in AWS D1.1, Table 3.1, Group I.

Base Metal AWS D1.1, Table 3.1, Group I			"Matching" Filler Metal			
			E60, Fy = 48 ksi (330 MPa) Fu = 60 ksi (415 MPa)		**E70**, Fy = 58 ksi (400 MPa) Fu = 70 ksi (480 MPa)	
	Yield, ksi (MPa)	Tensile, ksi (MPa)	Yield	Tensile	Yield	Tensile
A36	36 min. (250)	58-80 (400-550)	Weld is 12 ksi (80 MPa) greater	Weld is between 2 ksi (15 MPa) greater to 20 ksi (135 MPa) less	Weld is 22 ksi (150 MPa) greater	Weld is between 12 ksi (80 MPa) greater to 10 ksi (70 MPa) less
A572 Gr. 50	50 min. (345)	65 min. (450)	Weld is 2 ksi (15 MPa) less	Weld is 5 ksi (35 MPa) less	Weld is 8 ksi (55 MPa) greater	Weld is 5 ksi (30 MPa) greater

Table 2. Filler/Base Metal Strength Comparison in AWS D1.1, Table 3.1, Group III.

Base Metal AWS D1.1, Table 3.1, Group III			"Matching" Filler Metal E80, Fy = 68 ksi (470 MPa) Fu = 80 ksi (550 MPa)	
	Yield, ksi (MPa)	Tensile, ksi (MPa)	Yield Strength	Tensile Strength
A572 Gr. 65	65 min. (450)	80 min. (550)	Weld is 3 ksi (20 MPa) greater	Weld is equivalent
A913 Gr. 60	60 min. (415)	75 min. (520)	Weld is 8 ksi (55 MPa) greater	Weld is 5 ksi (30 MPa) greater

strength of the base metal. The comparison is of the "minimum specified properties," not the actual properties of the delivered steel, or of the deposited weld metal. Since these are minimum properties, actual deposited welds on the actual steel will routinely exceed those values.

Matching tensile strengths often do not result in matching yield strengths because the yield-to-tensile ratio for most hot rolled steels is lower than that of most as-deposited welds. Therefore, a match of both yield and tensile strength is improbable. However, for higher strength steels, the yield-to-tensile ratio typically approaches the values for welds and provides for a closer match of both the yield and tensile strengths. Table 3 shows the average yield-to-tensile ratio for all the base metals contained in Groups I and III and the corresponding matching filler metals of the AWS D1.1-98 Code, Table 3.1. The difference between the filler metal and base metal yield-to-tensile ratio is much less of the higher strength combination (Group III) than that of the mild steel combination (Group I) as shown by the percent difference (% Diff.).

Ultimately, matching compares weld and base metal properties. However, welds are not specified per se; filler metals are. Thus, tables of matching products typically are called "matching filler metals," not "matching weld metals."

Joints Requiring Matching Filler Metal

The need for matching filler metals is dependent upon joint type and loading condition. AWS D1.1, Table 2.3 "Allowable Stresses in Nontubular Connection Welds" shows that matching filler metal is required for only one combination of loading and joint type – tension loading of CJP groove welds, but is permitted for all other welds and loading conditions. Thus, a simple conclusion could be to always use matching filler metal. However, this may preclude better options such as undermatching combinations where cracking tendencies may be minimized. A common misuse of tables of matching filler metals occurs when other options are never considered. Particularly for high strength materials (>70 ksi [480 MPa] yield), undermatching filler metals may significantly reduce cracking tendencies.

Actual vs. Minimum Specified Properties

The traditional definition of "matching" compares minimum specified properties, not actual properties. For most applications, this has proven to be adequate, even though, based on actual properties of either the base metal or the weld, the weld may be the lower strength element. For example, A572 Gr. 50 with matching strength E70 filler metal may have matching, undermatching or overmatching relationships, based on actual properties.

A common misuse of tables of matching filler metals occurs when other options are never considered

In theory, specified service loads would be limited to some percentage of the minimum specified yield or ten-

Table 3. Varying yield-to-tensile ratios prevent matching both the yield and tensile strengths (data from AWS D1.1-98, Table 3.1).

Base Metals		Matching Filler Metals		
	Avg. Fy/Fu*	Weld	Fy/Fu*	% Diff
Group I (mild steel)	.62	E60	.80	22%
		E70	.83	25%
Group III (higher strength)	.80	E80	.85	6%

*Based on minimum specified values

sile strength. If this were the case, the weaker component in the system would not limit the design even at the maximum design load.

This is not necessarily the case for welded components that are expected to be loaded into the inelastic range. Examples would include components in buildings subject to inelastic (plastic) deformations in large earthquakes, and roll-over protection devices on construction equipment. Under these severe loading conditions where yielding is expected, it is preferred that such deformations be distributed throughout the base metal, and therefore, the undermatching combination shown in Table 4 may be unacceptable. Further definition of matching properties as a function of the actual materials may be necessary.

For high strength materials...undermatching filler metals may reduce cracking tendencies

It is sometimes desirable to evaluate actual, or typical, properties of base metals and filler metals. For example, an electrode classified as an E70 (such as E71T-1) may also meet E80 requirements. For an application where E80 is required, the E70 product could be used, providing there is adequate assurance that the deposited weld metal will still deliver E80 properties given variability in the production of the filler metal, as well as differences in procedures.

The yield and tensile strength properties for the base and weld metal are all determined by standard tensile test coupons, uniaxially loaded, slowly strained, smooth specimens. Under different conditions of loading, and with different geometries, these mechanical properties will vary, generally resulting in higher yield and tensile strengths and reduced ductility.

Table 4. Matching (M), Undermatching (U) and Overmatching (O) tensile strength combinations for A572 Gr. 50 with E70 filler metal.

Base Metal - A572 Gr. 50		E70 Filler Metal - Strength Levels		
		Minimum 70 ksi (480 MPa)	Medium 80 ksi (550 MPa)	High 90 ksi (620 MPa)
Strength	Min. - 65 ksi (450 MPa)	M	O	O
Strength	Med. - 80 ksi (550 MPa)	U	M	O
Strength	High - 90 ksi (620 MPa)	U	U	M

Conclusion

Matching strength is not formally defined by AWS. However, the accepted interpretation is that the filler metal tensile strength will be equal to or greater than that of the base metal. The need for matching filler metal is dependent upon the joint type and loading condition, and it is generally required for CJP groove welds in tension applications. Matching can be used for most applications, but in some cases, it may not be the most economical or conservative choice.