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Essential vs. Nonessential Variables

CWIs must review the applicable welding standard to determine which welding parameters are defined as essential, nonessential, and supplementary essential variables

This article is the second in a series aimed at helping you understand the concept of Welding Procedure Specifications (WPSs), how to write them, and how to use them. This article defines the differences between essential and nonessential variables. Article three will cover qualifying a WPS by testing, and article four will help you write a WPS that, in the author's words, "will do more than collect dust."

If you look at the label on any food item — candy bar, cookies, box of brownie mix — you will see a list of ingredients. The label does not provide the quantity of each ingredient, but it does list the ingredients in order of the greatest to least amount used. It would be impossible, based solely on the information provided on the label, to duplicate the exact recipe the manufacturer used.

The welding documents some contractors provide are a lot like the label on a box of brownie mix. They list only the basic information needed to meet the applicable code, but fail to list important information the welder needs to replicate the test weld.

What information should be included in the welding documentation? What information is helpful, but not crucial, to making an acceptable weld? Volunteers who sit on the committees that develop our welding codes and standards have been discussing this subject for many years. They have agreed on common language and basic definitions, but they do not necessarily agree on the content of the WPS or how the WPS is to be qualified.

Welding variables that are critical to making acceptable welds are categorized as essential variables. Welding variables that do not have a profound influence on the mechanical properties of the weld or those that are associated with the skills of the welder are categorized as nonessential variables.

What is an acceptable weld? One definition is "a weld that meets the minimum requirements of the applicable welding standard." The minimum requirements would include mechanical properties such as tensile strength, ductility, and soundness. The welding standard may invoke notch toughness requirements when service conditions, such as low-temperature applications, require toughness. There is not just one welding standard that is suitable for all applications. Different service conditions and applications require different welding standards. Each welding standard has unique requirements for qualifying welding procedures and welders, as well as different fabrication requirements to satisfy those service requirements.

While space limitations prevent us from exploring every possible welding variable, we can look at several variables that play an important role in the deposition of sound welds. In this article, we will categorize welding variables as essential or nonessential using the definitions in the next paragraph. A word of warning: make sure you review the requirements of the applicable code or standard when qualifying or documenting a welding procedure, because no two standards are in full agreement when it comes to categorizing every welding variable as either an essential or nonessential variable.

Note, that as we said previously, essential variables are those that have a significant influence on the mechanical properties, such as tensile strength and ductility. Nonessential variables are those that do not have a significant influence on tensile strength or ductility of the completed weld. Also, those variables that are dependent on the welder's skills to make a sound weld are classified as nonessential variables.

Essential Variables

Base Metals

One of the first factors to consider when making a weld is the base metal or metals to be joined. Some base metals are easily welded, some are more difficult, and others are downright ornery to weld. Base metals are grouped as ferrous or nonferrous metals. Ferrous metals can be further classified as low-carbon, medium-carbon, high-carbon, high-strength low-alloy, and high-alloy steels, as well as ferritic stainless, martensitic stainless, austenitic stainless, duplex stainless, and precipitation-hardened stainless steels. The nonferrous metals include alloys of aluminum, copper, nickel, titanium, and many more. Some of the nonferrous metals are further classified as refractory or reactive metals. Welding standards usually group the base metals into families that have similar chemistry and weldability. ASME groups the various base metals by P- or S- numbers. AWS B2.1, *Specification for Welding Procedure and Performance*

Qualification, uses M-numbers and NAVSEA S9074-AR-GIB-010/248 uses S-numbers to group the base metals. A change from one P-, M-, or S-number group to another affects the mechanical properties; therefore, base metals are classified as essential variables.

Welding Process

A welding process must be selected once the base metal is known. Not all base metals can be easily welded with every welding process that is in use. Welding standards list the welding process as an essential variable. If you change the welding process, but nothing else, the chances of obtaining a sound weld with the required mechanical properties will be in question. Consider what happens if we change from the gas metal arc welding process to the shielded metal arc welding (SMAW) process. That change would require a change in the type of filler metal, a different power supply, and a switch from a welding gun to an electrode holder. In addition, shielding gas is no longer required. As you can see from the example, a change in the welding process can involve several changes associated with the welding process.

Once the base metal and the welding process are determined, a suitable filler metal may have to be selected. The filler metal must be compatible with the base metal and the welding process. Filler metals are typically grouped by an F-number based on chemistry, flux type (if a flux system is used to shield the molten weld pool), and ease of use if it is a SMAW electrode. A change from one F-number to another will usually result in a change in chemistry and mechanical properties. Imagine a switch from an F-6 (low-carbon steel) filler metal to an F-3X (a copper-based alloy) filler metal. Even if the base metal and the welding process have not changed, the mechanical properties surely will since iron and copper do not play well with each other. The F-number is an essential variable.

Joint Design

Joint design usually falls into the nonessential variable category. The mechanical properties of the completed weld are not dependent on the groove design. Switching from a V-groove to a bevel groove is not going to change the mechanical properties of the weld.

However, there are times when a change in the groove detail will affect the properties of the welded joint. Consider a joint between dissimilar base metals. The two base metals have different alloy compositions and different mechanical properties. The completed weld is a composition of both base metals and the filler metal used. The exact composition of the weld (and its mechanical properties) are dependent on the volume of base metal mixed with the volume of filler metal in the molten weld pool.

Let's examine a weld joining a sheet of carbon steel (ASTM A36) to a sheet of stainless steel (ASTM A240 Type 304 alloy). The weld joint is a square groove detail that is joined with a single weld bead. A 309 filler metal is typically used for this combination of base metals. The completed weld may consist of 40% carbon steel, 40% stainless steel, and 20% filler metal. Now consider what happens if the groove design is changed to a V-groove. The completed weld now consists of 15% carbon steel, 15% stainless steel, and 70% filler metal. The alloy composition of the completed weld has been changed and a corresponding change in the mechanical properties of the weld can be expected. ASME Section IX and AWS codes use the A-number to define the chemistry of ferrous weld deposits. A change in the A-number results when there is a change in the chemistry of the weld. A change in weld chemistry will result in a change in the mechanical properties, therefore the A-number is an essential variable.

Nonessential Variables

The welder controls some variables that have little impact on the mechanical properties of the completed weld. Assuming the welder is skilled, as demonstrated by his or her passing the welder performance test, variables such as arc voltage, amperage, and travel speed typically have little effect on the chemistry or mechanical properties of the weld. These are usually considered to be nonessential variables.

Arc Voltage

Using SMAW as an example, variations in the arc length maintained by a skilled welder will result in minor fluctuations in arc voltage. A minor change in voltage is not going to affect the heat input or the chemistry of the weld deposit sufficiently to dramatically alter the mechanical properties. Therefore, as we have defined it, voltage is a nonessential variable.

Welding Amperage

Turning once again to the SMAW example, welding amperage for a given electrode diameter is restricted to a narrow range. If the welder increases amperage above or below the manufacturer's recommendation, the welding arc becomes unstable and an unacceptable weld results. Welds that meet the mechanical properties of the applicable code can be expected if the welder uses the electrode within the amperage range the manufacturer recommends. In this example, amperage is a nonessential variable.

Travel Speed

An increase or decrease in the travel speed has little effect on the mechanical properties of the weld assuming voltage, amperage, and the other variables remain unchanged. For a given electrode diameter, the travel speed is largely dependent on the melt-off rate of the electrode, which is a function of the amperage. The welder can use a weave bead or stringer bead technique. Either technique can produce a sound weld with the mechanical properties the code requires. Since a change in travel speed does not profoundly affect the weld's mechanical properties, travel speed is a nonessential variable.

In review of our discussion, a change in an essential variable has a profound effect on the mechanical properties of the weld, while a change in a nonessential variable has little effect on the mechanical properties of the completed weld.

Supplementary Essential Variables

Thus far, we have not broached the subject of notch toughness. Notch toughness adds a new element to the problem of developing welds with suitable properties. Supplementary essential variables are those variables that must be considered when notch toughness requirements are invoked. Ferrous metals such as the carbon and high-strength, low-alloy steels are the base metals most affected by low service temperatures. Carbon and low-alloy steels are divided into P-, M-, and S-numbered groups, which are further divided into groups that are only considered when notch toughness requirements are invoked. Filler metals take on a more important role in meeting notch toughness requirements so the electrode classification and possibly the manufacturer are classified as supplementary essential variables. Heat input is a factor in determining notch toughness. Voltage, amperage, and travel speed are important considerations in determining heat input (designated as Q). Q is a supplementary essential variable, thus voltage, amperage, and travel speed must be controlled within specified limits.

Summary

It is important to remember that the requirements of various welding standards have been tweaked to meet specific service requirements. Each welding standard defines essential, nonessential, and supplementary essential variables differently. Therefore, to properly develop welding documentation, the CWI must first review the applicable welding standard to determine which welding parameters are defined as essential, nonessential, and supplementary essential variables. Welding documents have to properly address the three types of variables in order to serve as the foundation of a successful welding program.

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