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What is Preheat?

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Preheat - Introduction

This new department is a response to our readers and was inspired by a discussion regarding the need to emphasize the significance of welding engineering fundamentals. Our purpose here is not to reveal "ground-breaking material; rather, the goal is to re-examine a series of topics essential to the science, mathematics, and technology of welding. In this inaugural column, we will explore the purpose and importance of preheat and its role in the fabrication of welded members.

What is Preheat?

Preheating involves heating the base metal, either in its entirety or just the region surrounding the joint, to a specific desired temperature, called the preheat temperature, prior to welding. Heating may be continued during the welding process, but frequently the heat from welding is sufficient to maintain the desired temperature without a continuation of the external heat source. The interpass temperature, defined as the temperature between the first and last welding passes, can not fall below the preheat temperature. Interpass temperature will not be discussed further here; however, it will be the subject of a future column. Preheating can produce many beneficial effects; however, without a working knowledge of the fundamentals involved one risks wasting money, or even worse, degrading the integrity of the weldment.

Why Preheat?

There are four primary reasons to utilize preheat: (1) it lowers the cooling rate in the weld metal and base metal, producing a more ductile metallurgical structure with greater resistant to cracking; (2) the slower cooling rate provides an opportunity for any hydrogen that may be present to diffuse out harmlessly without causing cracking; (3) it reduces the shrinkage stresses in the weld and adjacent base metal, which is especially important in highly restrained joints and (4) it raises some steels above the temperature at which brittle fracture would occur in fabrication. Additionally, preheat can be used to help ensure specific mechanical properties, such as notch toughness.

When Should Preheat be Used?

In determining whether or not to preheat, the following array of factors should be considered: code requirements, section thickness, base metal chemistry, restraint, ambient temperature, filler metal hydrogen content and previous cracking problems.

If a welding code must be followed, then the code generally will specify the minimum preheat temperature for a given base metal, welding process and section thickness. This minimum value must be attained regardless of the restraint or variation in base metal chemistry; however, the minimum value may be increased if necessary. An example is illustrated in the next section.

When there are no codes governing the welding, one must determine whether preheat is required, and if so, what preheat temperature will be appropriate. In general, preheat usually is not required on low carbon steels less than 1 in. (25 mm) thick. However, as the chemistry, diffusible hydrogen level of the weld metal, restraint or section thickness increases, the demand for preheat also increases. There are several methods to determine the required preheat temperature for a given base metal and section thickness that will be discussed in the next section.

What Preheat Temperature is Required?

Welding codes generally specify minimum values for the preheat temperature, which may or may not be adequate to prohibit cracking in every application. For example, if a bed-to-column connection is to be fabricated with a low-hydrogen electrode made of ASTM A572-Gr50 and A36 jumbo sections (thickness ranging from 4 to 5 in.), then a minimum prequalified preheat of 225F (107 C) is required (AWS D1.1-96, Table 3.2). However, for making butt splices in jumbo sections, it is advisable to increase the preheat temperature beyond the minimum prequalified level to that required by AISC for making butt splices in jumbo sections, namely 350F (175 C) (AISC LRFD J2.8). This conservative recommendation acknowledges that the minimum preheat requirements prescribed by AWS D1.1 may not be adequate for these highly restrained connections.

When no welding codes are specified, and the need for preheat has been established, how does one determine an appropriate preheat temperature? As a basis for discussion, consider AWS D1.1-96, Annex XI: "Guideline on Alternative Methods for Determining Preheat" which presents two procedures for establishing a preheat temperature developed primarily from laboratory cracking tests. These techniques are beneficial when the risk of cracking is increased due to composition, restraint, hydrogen level or lower welding heat input.

The two methods outlined in Annex XI of AWS D1.1-96 are: (1) heat affected zone (HAZ) hardness control and (2) hydrogen control. The HAZ hardness control method, which is restricted to fillet welds, is based on the assumption that cracking will not occur if the hardness of the HAZ is kept below some critical value. This is achieved by controlling the cooling rate. The critical cooling rate for a given hardness can be related to the carbon equivalent of the steel, which is defined as:

$$(Mc + Si) (Cr + Mo + V) @i + Cu) CE = C + N' + N' + 6.5 Si$$

From the critical cooling rate, a minimum preheat temperature can then be calculated. (Blodgett's paper entitled "Calculating Cooling Rates by Computer Programming" outlines a calculation procedure based on cooling rate, heat input, plate thickness, temperature at which cooling rate is critical, preheat temperature, thermal conductivity and specific heat.) It should be pointed out, however, that "although the method can be used to determine a preheat level, its main value is in determining the minimum heat input (and hence minimum weld size) that prevents excessive hardening" (Annex XI, paragraph 3.4, AWS D1.1-96.)

The hydrogen control method is based on the assumption that cracking will not occur if the amount of hydrogen remaining in the joint after it has cooled down to about 120F (50C) does not exceed a critical value dependent on the composition of the steel and the restraint. This procedure is extremely useful for high strength, low-alloy steels that have high hardenability. However, the calculated preheat may be too conservative for carbon steels.

The three basic steps of the hydrogen control method are: (1) Calculate a composition parameter similar to the carbon equivalent; (2) Calculate a susceptibility index as a function of the composition parameter and the filler metal diffusible hydrogen content; and (3) Determine the minimum preheat temperature from the restraint level, material thickness, and susceptibility index.

How is Preheat Applied?

The material thickness, size of the weldment and available heating equipment should be considered when choosing a method for applying preheat. For example, small production assemblies may be heated most effectively in a furnace. However, large structural components often require banks of heating torches, electrical strip heaters, or induction or radiant heaters.

A high level of accuracy generally is not required for preheating carbon steels. Although it is important that the work be heated to a minimum temperature, it is acceptable to exceed that temperature by approximately 100F (40C). However, this is not the case for quenched and tempered (Q&T) steels, since welding on overheated Q&T steels may be detrimental in the heat affected zone. Therefore, Q&T steels require that maximum and minimum preheat temperatures be established and closely followed.

When heating the joint to be welded, the AWS D1.1 code requires that the minimum preheat temperature be established at a distance that is at least equal to the thickness of the thickest member, but not less than 3 in. (75 mm) in all directions from the point of welding. To ensure that the full material volume surrounding the joint is heated, it is recommended practice to heat the side opposite of that which is to be welded and to measure the surface temperature adjacent to the joint. Finally, the steel temperature should be checked to verify that the minimum preheat temperature has been established just prior to initiating the arc for each pass.

Summary

- Preheat can prevent cracking and/or ensure specific mechanical properties such as notch toughness.
- Preheat must be used whenever applicable codes so specify; when no codes apply to a given situation, the welding engineer must determine whether or not preheat is needed, and what temperature will be required for a given base metal and section thickness.
- Annex XI of AWS D1.1-96 provides guidelines for alternative methods of determining proper amounts of preheat: the HAZ hardness control method, or the hydrogen control method.
- Preheat may be applied in a furnace, or by using heating torches, electrical strip heaters, or induction or radiant heaters. Carbon steels do not require precise temperature accuracy, but induction or radiant heaters, maximum and minimum preheat temperatures must be followed closely for quenched and tempered steels.

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