## Key Concepts in Welding Engineering

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# Fundamentals of 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 base metal temperature at the time when welding is to be performed between the first and last welding passes, cannot be permitted to 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 slows the cooling rate in the weld metal and base metal, producing a more ductile metallurgical structure with greater resistance to cracking; (2) the slower cooling rate provides an opportunity for hydrogen that may be present to diffuse out harmlessly, reducing the potential for 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 weld metal notch toughness.

## When Should Preheat Be Used?

In determining whether or not to preheat, the following 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.

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 need for preheat also increases.

## 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 beam-to-column connection made of ASTM A572-Gr50 jumbo sections (thicknesses ranging from 4 to 5 in [100-125 mm]) is to be fabricated with a low-hydrogen electrode, then a minimum prequalified preheat of 225°F (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 350°F (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 code is specified, and the need for preheat has been established, how does one determine an appropriate preheat temperature? 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 the chemical composition, a greater degree of restraint, higher levels of hydrogen 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:

$$CE = C + \frac{(Mn + Si)}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Ni + Cu)}{15}$$

From the critical cooling rate, a minimum preheat temperature can then be calculated. AWS D1.1-96 states 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).

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 120°F (50°C) 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 somewhat 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.

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Preheating carbon steel to a precise temperature generally is not required. Although it is important that the work be heated to a minimum temperature, it usually is acceptable to exceed that temperature by approximately 100°F (40°C). However, this is not the case for some quenched and tempered (Q&T) steels such as A514 or A517, 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 interpass temperature should be checked to verify that the minimum preheat temperature has been maintained just prior to initiating the arc for each pass.

## Summary

- Preheat can minimize 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 maximum and minimum preheat temperatures must be followed closely for quenched and tempered steels.

## For Further Reading...


*ANSI/AWS D1.1-96 Structural Welding Code: Steel.* The American Welding Society, 1996.

Bailey, N. *Weldability of Ferritic Steels.* The Welding Institute, 1995.

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Stout, R.D. and Doty, W.D., *Weldability of Steels.* Welding Research Council, 1971.

*The Procedure Handbook of Arc Welding.* The James F. Lincoln Arc Welding Foundation, 1994.