# Assuring Accurate Preheat Temperatures

*Accurate preheating prior to welding reduces the chances of cracking and other problems*

BY ROGER HORNBERGER

*Checking the surface temperature of a custom alloy.*

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**Welders know, and ASME codes reinforce, the need for preheating many ferrous metals prior to welding — Fig. 1. A successful weld unites the welding filler metal and the base metal into one entity; a good weld is at least as strong as the base materials being joined.**

With many materials, bringing the base metal "up to heat" before welding improves the chances of achieving a successful weld by reducing the danger of crack formation and other problems. As a result, there is less need for factory rework, and performance of the finished piece is enhanced.

## Cracks and How They Form

Weld cracking may occur due to thermal stresses imposed on the weld metal and adjacent heat-affected zones. In welding carbon and alloy steels, cracking often occurs in conjunction with the formation of hard, brittle areas — the result of rapid cooling during welding and the presence of hydrogen.

Weld metal shrinks as it cools, and this sets up stresses when the shrinkage is restrained by the surrounding colder metal. Also, the surrounding colder metal draws heat away from the weld zone. The rate of heat flow away from the weld is greater during welding of thick sections and in metals having a high thermal conductivity. In metals that are susceptible to quench hardening, such as high-carbon and alloy steels, the rapid extraction of heat from the weld area can result in the formation of hard, brittle regions.

Preheating can help to minimize the thermal gradients in the weld area, thereby reducing the resulting thermal stresses. Also, by reducing the cooling rate, preheating can prevent or minimize the formation of hard, brittle areas during welding of some types of steel.

Controlled preheating provides a simple and well-known solution to welding problems that may occur as a result of rapid postweld cooling. Preheat temperatures are based on the type and composition of the metal being joined, and in order to be effective, preheat temperatures must be properly controlled.

## The Problem with Hydrogen

The presence of hydrogen greatly increases the possibility of cracking in the weld metal or heat-affected zone in welding carbon and alloy steels. Root cracks, toe cracks, underbead cracks, and transverse cracks are all common, given thermal stress and the presence of hydrogen.

In welding these materials, it is important to keep hydrogen away from the weld area. Hydrogen can come from electrode coatings, fluxes, base-metal contamination — even the atmosphere — and, in the case of a repair weld, from materials which were contained or handled by the

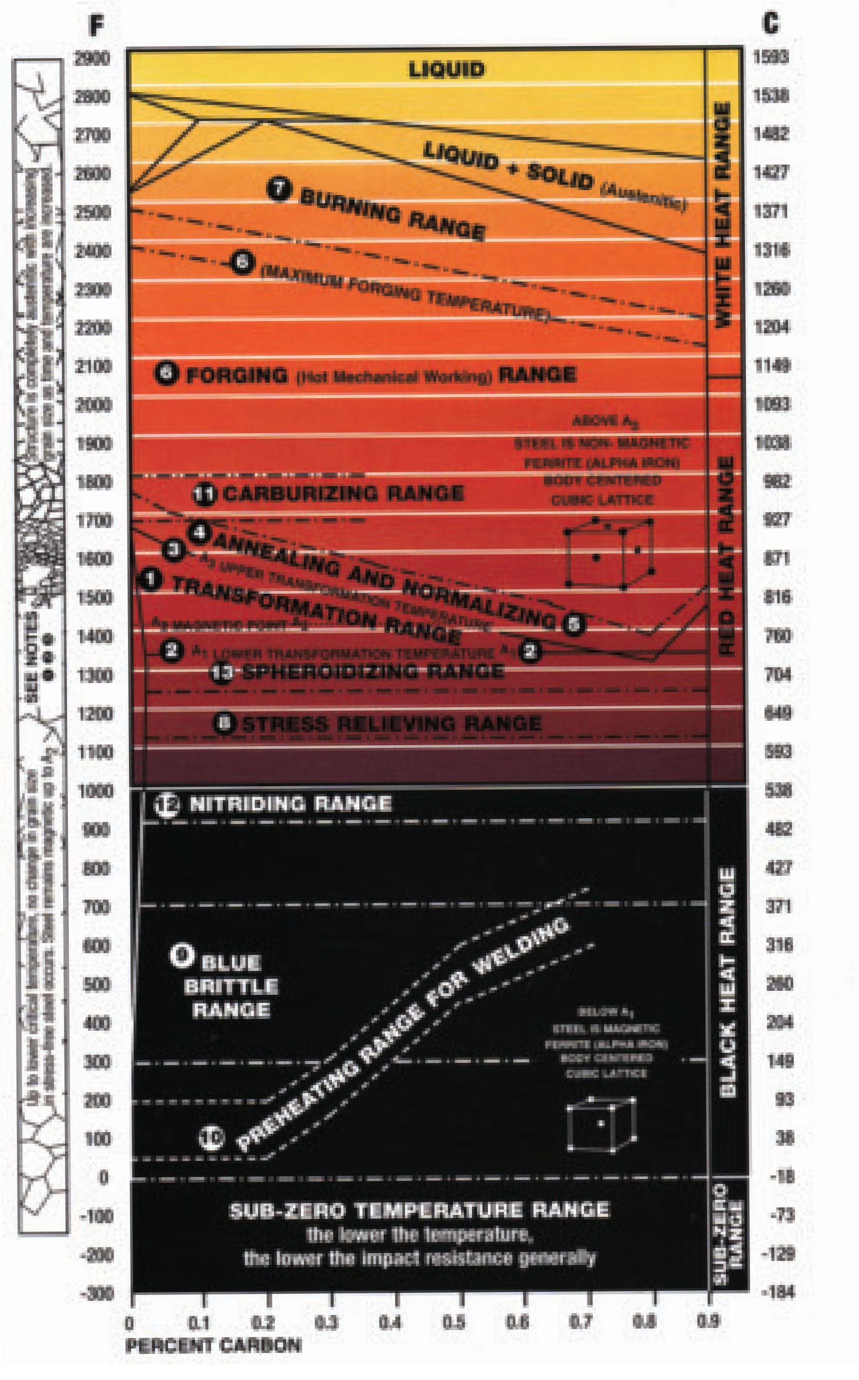

*Fig. 1 — A basic guide to ferrous metallurgy.*

*1. **Transformation Range**. In this range, steels undergo internal atomic changes that radically affect the properties of the material.*

*2. **Lower Transformation Temperture** ($A_1$). Termed $Ac_1$ on heating, $Ar_1$ on cooling. Below $Ac_1$ structure ordinarily consists of ferrite and pearlite (see below). On heating through $Ac_1$, these constituents begin to dissolve in each other to form austenite (see below), which is nonmagnetic. This dissolving action continues on heating through the transformation range until the solid solution is complete at the upper transformation temperature.*

*3. **Upper Transformation Temperature** ($A_3$). Termed $Ac_3$ on heating, $Ar_3$ on cooling. Above this temperature the structure consists wholly of austenite, which coarsens with increasing time and temperature. Upper transformation temperature is lowered as carbon increases to 0.85% (eutectoid point).*

- ***Ferrite** is practically pure iron (in plain carbon steels) existing below the lower transformation temperature. It is magnetic and has very slight solid solubility for carbon.*
- ***Pearlite** is a mechanical mixture of ferrite and cementite.*
- ***Cementite** or iron carbide is a compound of iron and carbide $Fe_3C$.*
- ***Austenite** is the nonmagnetic form of iron and has the power to dissolve carbon and alloying elements.*

*4. **Annealing,** frequently referred to as full annealing, consists of heating steels to slightly above $Ac_3$, holding for austenite to form, then slowly cooling in order to produce small grain size, softness, good ductility, and other desirable properties. On cooling slowly the austenite transforms to ferrite and pearlite.*

*5. **Normalizing** consists of heating steels to slightly above $Ac_3$, holding for austenite to form, then followed by cooling (in still air). On cooling, austenite transforms giving somewhat higher strength and hardness and slightly less ductility than in annealing.*

*6. **Forging Range** extends to several hundred degrees above the upper transformation temperature.*

*7. **Burning Range** is above the forging range. Burned steel is ruined and cannot be cured except by remelting.*

*8 **Stress Relieving** consists of heating to point below the lower transformation temperature, $A_1$, holding for a sufficiently long period to relieve locked-up stresses, then slowly cooling. This process is sometimes called process annealing.*

*9. **Blue Brittle Range** occurs approximately from 300° to 700°F. Peening or working of steels should not be done between these temperatures, since they are more brittle in this range than above or below it.*

*10. **Preheating For Welding** is carried out to prevent crack formation.*

*11. **Carburizing** consists of dissolving carbon into surface of steel by heating to above transformation range in presence of carburizing compounds.*

*12. **Nitriding** consists of heating certain special steels to about 1000°F for long periods in the presence of ammonia gas. Nitrogen is absorbed into the surface to produce extremely hard "skins."*

*13. **Spheroidizing** consists of heating to just below the lower transformation temperature, $A_1$, for a sufficient length of time to put the cementite constituent of pearlite into popular form. This produces softness and in many cases good machinability.*

- ***Martensite** is the hardest of the transformation products of austenite and is formed only on cooling below a certain temperature known as the $M_s$ temperature (about 400° to 600°F for carbon steels). Cooling to this temperature must be sufficiently rapid to prevent austenite from transforming to softer constituents at higher temperatures.*
- ***Eutectoid Steel** contains approximately 0.85% carbon.*
- ***Flaking** occurs in many alloy steels and is a defect characterized by localized microcracking and "flake-like" fracturing. It is usually attributed to hydrogen bursts. Cure consists of cooling to at least 600°F before aircooling.*
- ***Open or Rimming Steel** has not been completely deoxidized and the ingot solidifies with a sound surface ("rim") and a core portion containing blowholes that are welded in subsequent hot rolling.*
- ***Killed Steel** has been deoxidized at least sufficiently to solidify without appreciable gas evolution.*
- ***Semi-Killed Steel** has been partially deoxidized to reduce solidification shrinkage in the ingot.*
- ***A Simple Rule:** Brinell Hardness divided by two, times 1000, equals approximate tensile strength in pounds per square inch. (200 Brinell ÷ 2 × 1000 = approx. 100,000 tensile* strength, lb/in.$^2$).

*Fig. 2 — A temperature indicator is used to check the surface temperature on a gear.*

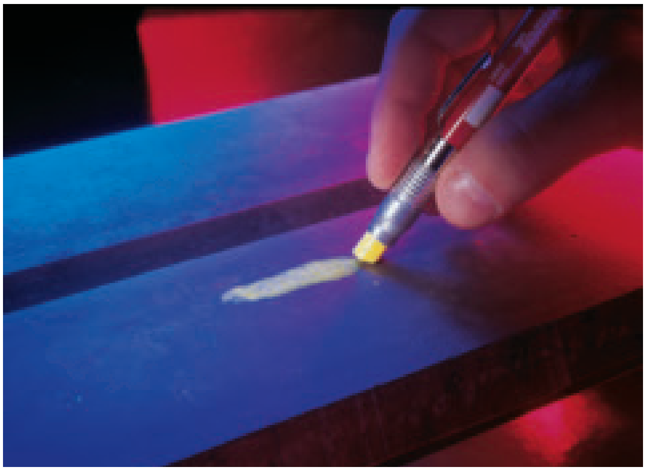

*Fig. 3 — The melted mark left by a temperature crayon.*

equipment being repaired.

Preheating can be very helpful in preventing hydrogen absorption because it allows the hydrogen to escape.

## Moisture and Porosity

It's important to eliminate moisture during welding. Outdoors it's ever present. Even indoors, there's the problem of condensation from humidity, particularly if the metal is cold.

High welding temperatures will vaporize any surface moisture; the vapor can enter the weld pool, causing porosity in the completed weld, which reduces its strength and ductility.

Again, preheating is beneficial. Warming the metal prevents condensation. It also vaporizes any moisture already present before the weld process begins, so it will not be vaporized by the heat of welding and absorbed into the weld pool.

## Cooling Slowdown

Preheating reduces the rate of heat flow away from the weld. This allows more time for redistribution of thermal stresses, thereby reducing the tendency for cracking. In some steels it helps to minimize the formation of hard, brittle areas in the weld and heat-affected zones, thereby promoting ductility and decreasing the risk of cracking.

## Is Preheating Always Needed?

The need for preheating increases with these factors:

1. Thickness of parts being welded

2. Lower temperature of the pieces to be welded

3. Low atmospheric temperature

4. Lower heat input

5. Higher speed of welding

6. Higher carbon content of the steel

7. Higher alloy content of the steel

8. Difference in mass between the pieces being joined

9. Complicated shape or section of the parts.

ASME B31.1, *Power Piping*, lists preheat requirements. In general, as noted above, steels with higher carbon and alloy content, and greater thickness, need preheat. In some cases, the required preheat temperature is only 50°F, minimum — a consideration for outdoor applications, but usually not important indoors. In many cases, however, preheat temperatures ranging from 175° to 400°F are advised.

ASME B31.3 lists requirements for chemical plant and petroleum refinery piping. Recommended or required minimum preheat temperatures range from 50° to 300°F.

Preheating is not necessary for chrome-nickel stainless steels, nor for nonferrous metals such as nickel and nickel alloys (Monel®, Inconel®), or aluminum and copper alloys. However, warming up to 200°F may be desirable to remove moisture condensation. Preheat may be desirable for thick sections of high-conductivity metals such as aluminum and copper.

## How to Preheat

Preheating is most commonly done using oxyfuel gas torches. Where more precise control of the preheat temperature is required, furnace heating, electric resistance heating blankets, or induction coils may be employed.

With local torch heating or other rapid heating methods, it is important to prevent overheating, and it is necessary to allow sufficient time to reach the desired uniform temperature throughout the thickness of the weld joint and surrounding metal. Also, in using gas torches it is important to prevent deposits of incomplete combustion products on joint surfaces or adjacent areas.

## Determining the Proper Temperature

One method for determining that the joint has reached the desired preheat temperature is a simple one: a temperature indicator made of materials with melting points calibrated to a guaranteed accuracy of 1%.

The most common temperature indicator for welding purposes is the stick or chalk type, which is usually supplied in an adjustable holder with a pocket clip similar to that on a mechanical pencil — Fig. 2.

Temperature indicators are made of materials with calibrated melting points. An indicator is stroked on the piece as heating proceeds.

When the temperature rating of the

selected indicator is reached, the dry opaque mark undergoes a phase change to a distinct melted appearance — Fig. 3.

## Phase-Change Accuracy

A wide variety of electric, electronic, infrared, and other instrumentation is available for temperature determination. However, none of these methods is widely employed in welding. Phase-change temperature indicators are preferred because they are accurate, simple to use, inexpensive, and make good thermal equilibrium with the surface to which they are in contact — Fig. 4.

Melting point, the temperature where phase change occurs, is a physical property of the raw material. It is not influenced by static electricity, ionized air, humidity, or being dropped on the floor — factors that can make electrical and electronic instrumentation function erratically. No setup time, calibration, and recalibration are required, and no operator training or experience are necessary. All the operator has to do is observe that the chalk mark has melted. The indicators are accurate within 1% of their stated temperature ratings measured in accordance with MTL-STD-45662. The materials used are calibrated on apparatus traceable to the National Institute of Standards & Technology.

Many practitioners consider welding an art as well as a science. Two or more pieces of metal are joined, with a bond that is as strong or stronger than the component materials. But in order to achieve this, weld quality must be good. Preheating is often necessary. With the ready availability of accurate, inexpensive temperature indicators, the correct preheat temperature can be assured. ♦

*Fig. 4 — A welder uses a temperature crayon to mark a piece close to a weld.*