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A VIEW FROM THE PENTHOUSE; USEFUL INFORMATION FOR THE WORLD OF BOILERS

HEAT-AFFECTED ZONES

This issue of the newsletter is the first in a series of articles on the metallurgical features of welds. The discussion will center on the metallurgical characteristics and the response of the base metal to the temperature cycle during welding. The heating and cooling of the base metal during welding will affect ferritic and austenitic steels in different ways. We begin with a discussion of the definition of a heat-affected zone (HAZ).

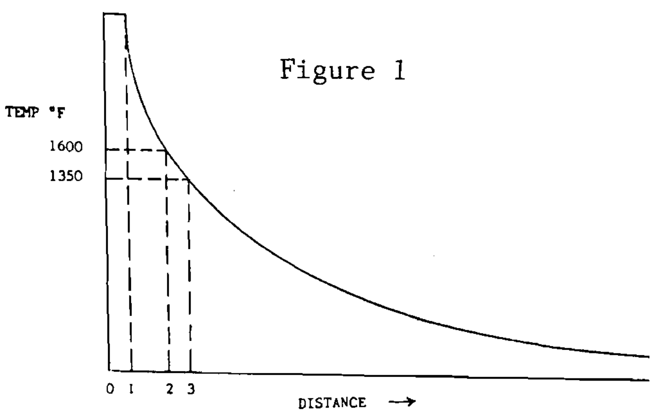

Figure 1

0 = CENTERLINE OF WELD
1 = EDGE OF FUSION ZONE
2 = 1600°F POSITION
BETWEEN 1-2 MICROSTRUCTURE IS ALL AUSTENITE DURING WELDING
3 = 1350°F POSITION
BETWEEN 2-3 MICROSTRUCTURE IS MIXTURE OF AUSTENITE AND FERRITE
POSITIONS 1-3 ARE HEAT AFFECTED ZONE

Figure 1 shows schematically the definition of the HAZ in ferritic steels superimposed on the temperature profile from the centerline of the weld into the base metal. For simplicity, Figure 1 shows the temperature profile on one side only. Heat flows away from the weld in two directions. In a thick component, a header or a drum for example, the weld is a semicylinder, and heat flows away in three directions. The temperature at the edge of the fusion zone is the melting point of the steel. The peak temperature decreases as we move away from the edge of the weld as shown in Figure 1.

For ferritic steels similar to carbon steel, T-11 or T-22, there is a transformation of the normal room-temperature microstructure as the temperature is increased. Ferrite and pearlite transform first to ferrite and austenite and then at a still higher temperature to all austenite. The first or lower transformation temperature from ferrite and pearlite to ferrite and austenite is called the lower-critical transformation temperature. The exact temperature depends on the composition but is about 1340°F for plain carbon steels. The addition of alloying elements changes this lower-critical transformation temperature. For T-11 it is approximately 1430°F, and for T-22 it is approximately 1480°F.

The transformation from ferrite and austenite to all austenite is called the upper-critical transformation temperature and this too depends on the composition. For example, in plain carbon steels similar to SA178A and SA210 A-1, the upper-critical transformation temperature changes with carbon content. At 0.1% carbon (SA178A), the temperature is about 1580°F, at 0.25% carbon (SA210 A-1), the temperature is about 1490°F.

The heat-affected zone (HAZ) in ferritic steels is defined as that region of the base metal near the edge of the fusion zone, or weld metal, that has a peak temperature during welding high enough to affect a transformation from ferrite and pearlite to ferrite and austenite or all austenite.

For the austenitic stainless steels, there is no transformation from ferrite to austenite. Austenitic stainless steels, similar to 304, 321, or 347, are austenite over the entire temperature range. There are, however, other changes that do occur at temperatures near the melting point.

The microstructure of the HAZ of austenitic stainless steels depends on the amount of cold work. For solution-annealed material, the usual case for boiler tubes, the HAZ will show only grain growth. This increase in size of the austenite grains begins at a metal temperature of about 1800°F or so. The base metal from the edge of the fusion zone to the peak-temperature isotherm of 1800°F will have enlarged grains. In heavily cold-worked stainless, as in support structures, the HAZ will first show some relaxation of the cold-worked microstructure at a temperature of about 1600°F and then the grain growth.

Cold-worked structures transform from a distorted microstructure to an annealed microstructure in two steps. Cold-worked grains recrystallize into strain-free but very small or fine grain sizes. The fine grain size changes to a coarse grain size by grain growth. Thus the HAZ of these cold worked materials will show grain growth next to the fusion line and a fine grain size at the 1600°F isotherm.

The microstructure of the HAZ of ferritic steels depends not only on the peak temperature, but also the cooling rate and alloy content. Rapid cooling or quenching of the austenite forms martensite, a hard, brittle material that can cause HAZ cracking. Slower cooling forms mixtures of ferrite and bainite or pearlite. Higher alloying materials, for example T-22, will more easily form martensite than the plain carbon steels. A cooling rate that forms ferrite in a low carbon steel, SA178A, will form all martensite in a higher alloy material, T-22. The same type of weld made in T-22 as made in SA178 will have a very different HAZ microstructure. In order to prevent the formation of martensite within the HAZ, slower cooling rates for these alloy steels are required. The most convenient way to accomplish this is by preheating.

The ASME Boiler & Pressure Vessel Code has non-mandatory guidelines for the amount of preheat recommended, and these are given in Table I.

TABLE I. SUGGESTED PREHEAT

MATERIAL	THICKNESS	PREHEAT TEMP.
Carbon steel	<1"	50°F
Carbon steel	>1"*	175°F
T-11	<½"	50°F
T-11	>½"	250°F
T-22	<½"	300°F
T-22	>½"	400°F

*Also >0.30%C.

Next time we will present several representative microstructures of both ferritic and austenitic stainless steels.

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