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

COLD-WORKED CARBON STEELS

This issue of the newsletter will be a discussion of cold working, the effects on the microstructure and mechanical properties, and the changes caused by heat treatment of plain-carbon steels. When the shape is changed, for example to form a hollow tube from a solid billet, the steel is said to be "worked." At elevated temperatures, it is referred to as "hot working", and at room temperature it is "cold working."

The plastic deformation associated with cold work increases the internal energy of the distorted and "worked" crystal structure. This has been called the "stored energy of cold work." The measurable effects of cold work are to increase the tensile strength and hardness and decrease the ductility. The stored energy can be removed by heat treatment. At elevated temperature, atomic mobility is easier; and the cold-work effects are relieved by a process called "recovery and recrystallization."

The heat treatment alters the distorted grains to a more equiaxed configuration and is accomplished in a stress-relief anneal. The first stage is recovery, a reduction of the residual stress but little change in grain shape. The next step is the formation of small strain-free crystals, and finally their increase in size, grain growth. The actual recrystallization temperature depends on the degree of cold work. The more severely deformed the microstructure is, the lower the recrystallization temperature will be. For plain-carbon steels, the onset of recrystallization is about 900°-950°F.

Recrystallization is not a phase change, as ferrite will stay ferrite; but the shape of the ferrite grains will be altered. Thus cold work is defined as plastic deformation below the recrystallization temperature. For boiler tubes similar to SA-178 Grade A or SA-210 A-1, cold working is usually done at room temperature; but any temperature below about 900°F would be considered "cold working."

There are several metal-working operations. Such operations as swaging and bending of boiler tubes are the two most commonly used in the fabrication of boiler components.

Figure 1 shows the effect of cold work on the microstructure of a swage in a plain-carbon steel, SA-178 Gr A.

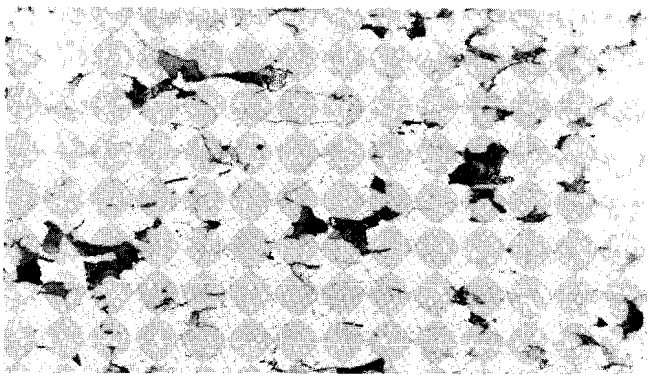

Figure 1. Swage. 500x, etched.

The swage changed the tube diameter from 3 in. to 2 in.

The effects of a cold-worked microstructure can be readily measured. Both the tensile strength (UTS) and yield strength (YS) will

increase, while the ductility will decrease (% Elongation). Hardness also will increase.

These changes in the mechanical properties are illustrated in Table I. In this example the changes are dramatic. Note also how close together the YS and UTS are in the cold-worked or swaged condition.

TABLE I

CONDITION	TS KSI	YS KSI	EL %	R_B
TUBE	55.5	36.6	31	57
SWAGE	76.5	71.5	13	86
H T*	57.0	42.0	29	67

*HEAT TREATED 1150°F, ½ HR.

The most obvious effect of reduced ductility is in the rolling of swaged tubes into a header. The rolling operation itself is a cold-working operation. With little ductility left in an already cold-worked material, expansion of the tube by more cold work will lead to fracture of the swage.

The effects of cold work in carbon steels can be relieved by a heat treatment. Depending on the amount of cold work, the stress relief begins at a temperature of about 900°-950°F and is complete at a temperature of about 1100°F. The heat treatment that this cold-worked swage was given was 1150°F for 30 minutes. The effect of this stress-relief anneal has been to reduce the ultimate tensile strength, yield strength, hardness, and increase the ductility. For all practical purposes, the heat-treated condition is the same as the initial condition of the tube. The microstructural effects of the recrystallization are to relieve the effects of cold work and alter the shape of the crystals. The microstructure will recrystallize, and the severely distorted ferrite grains will be replaced by more equiaxed, as shown in Figure 2.

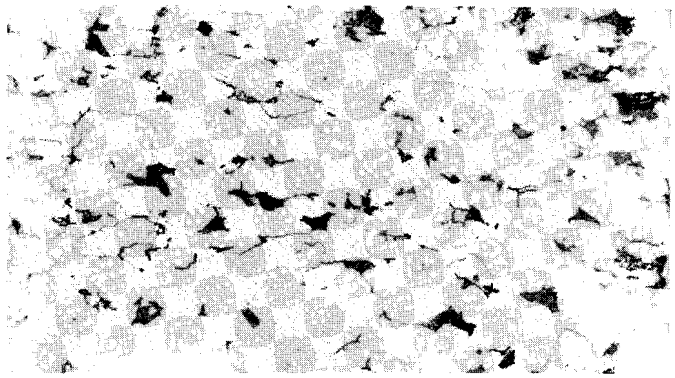

Figure 2. Heat Treated 500x, etched.

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