Q: We’re encountering some problems with low-carbon steel fixtures we purchased to hold parts in place during copper-brazing runs in our atmosphere furnace, which is a continuous-belt furnace. After a few months of use, the fixtures appear to be significantly distorted and are no longer usable for our work. We thought the belt speed through the furnace was such that we wouldn’t get large enough heat differentials to cause such distortion. Any thoughts as to why this is happening?

A: You mentioned that the fixtures were made of a low-carbon steel. Since the same type of distortion also occurs frequently with high-carbon steels, alloy steels, and cast irons, let’s look at this as a general issue with most grades of carbon steel.

I addressed a similar issue last year in this column for a different application issue, but it would be good to bring out some of that information here, for the benefit of today’s readers.

Distortion of Carbon Steel When Cycled through Large Temperature Extremes

Figure 1 shows two carbon-steel bars, which began as $\frac{3}{4} \times \frac{3}{4} \times 12$-in bars (12 x 12 x 300 mm), used as fixturing weights in a continuous-belt brazing furnace.

Notice that the bar on the left side of the photo has begun to swell and shorten after several hundred cycles through the furnace, operating from room temperature up to approximately 2000°F (1100°C), whereas the one on the right has been cycled thousands of times, resulting in significant shortening and thickening of the bar. Theoretically, if those two bars continued to be cycled through that furnace, they would continue to shorten and thicken until they eventually became round steel balls.

In Fig. 2, notice the thermal expansion curve for 1018 steel (typical of all carbon and alloy steels) as compared to all the other metals on the chart. As these different metals are heated, they all begin to grow, and even though the curves aren’t perfectly linear, they all are somewhat straight, except for that of 1018 steel, which shows a big “hiccup” in its curve. Notice how the 1018 steel actually begins to shrink when heated above 1300°F (700°C), and continues shrinking until about 1550°F (850°C), where the steel begins to expand once again during further heating.

The cause of the hiccup in the 1018 curve when it is heated is due to steel’s “polymorphism” (meaning “many forms”). When steel is heated, it changes its crystallographic arrangement of atoms from body-centered cubic (BCC) at room temperature to face-centered cubic (FCC) when it is heated higher than about 1670°F (910°C). Unfortunately for the steel, the FCC arrangement of atoms occupies less volume than the BCC arrangement (the atoms actually pull in to a tighter, closer arrangement of atoms), and the steel will therefore shrink when it transforms from BCC to FCC.

But this is only temporary, because on cooling the transformation reverses itself, and the steel changes from FCC to BCC. The distortion results from the difference in the amount of thermal expansion between the bars in the furnace. The warmest bar swells and the coolest one cools and shrinks because of this mismatch in volume changes.

back to BCC on its way back down to room temp. again.

**Many Expansions/Contractions**

Can you see the multiple expansions and contractions the steel goes through on each cycle? It expands on its way up to brazing temperature, but once it gets above about 1670°F (910°C), it transforms and begins to shrink to its new, smaller configuration. Once transformed, it then continues to once again expand until it reaches brazing temp. Then, after brazing, when it begins to cool back down, it starts to shrink, but suddenly stops shrinking and starts to expand again as it transforms back from FCC to BCC. Then, once transformed, it once again begins shrinking back down to its room temperature size. That’s a lot of expanding/contracting, growing/shrinking, for each carbon-steel fixture-component during each brazing cycle.

Please understand, too, that each such transformation depends on the reaction of that specific piece of steel (size, weight, mass, etc.) to the temperatures it encounters as it moves through the furnace. A slightly more massive piece will transform more slowly, whereas a lighter steel part would transform more quickly.

Now, if all of these parts, expanding and contracting at different times, and at different rates, are actually in contact with each other — or worse yet — brazed to each other, their various expansion/contraction rates may be sufficiently different — and strong — to cause other parts in the load to be affected and possibly distort as a result.

**Conclusion**

It is not recommended that carbon steel be used as a fixturing material, especially where tight dimensional control is needed during any brazing cycle. Instead, use stainless steels, or Inconel® materials, or other stable high-temp. alloys to build fixtures. Carbon steel fixturing, although it might seem like an ideal low-cost alternative for your fixturing needs, can actually cost you far more money than you want to spend, because of its limited life and potentially strong negative effect on the dimensional control of parts in the furnace.\(^{\text{[1]}}\)