BY DAN KAY

Q: We are brazing high-temperature alloys together with nickel-based brazing filler metals (AMS 4777), and have had problems with parts failing in service due to cracks right through the brazed joints. The vacuum furnaces we use for brazing appear to be fine, and cross-section evaluation of the failed parts showed that joint clearances were about 0.006 in. (0.15 mm) in the joints before they cracked. Why are these joints failing in service if we're doing our best to keep the parts really clean before and during brazing, and our vacuum brazing cycle appears to be correct according to our customer specification requirements?

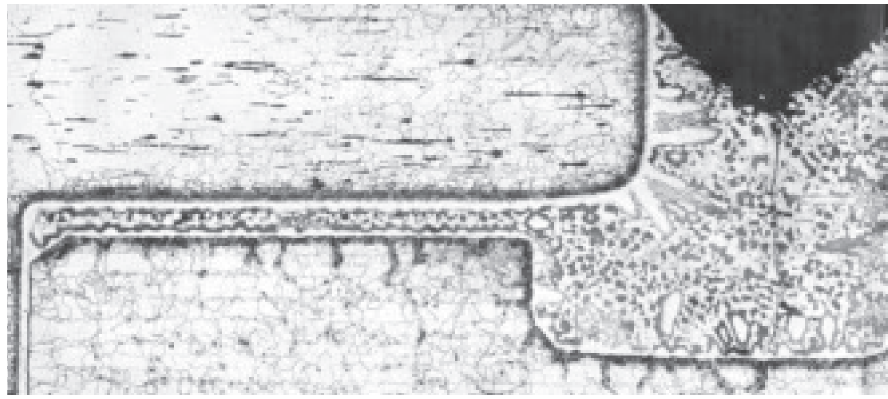

Fig. 1 — Variations in centerline structures in Ni-brazed joint, from extreme (right side of photo) to almost none at far left. (ASM Metal Progress *magazine, Dec. 1967.)*

A: You are experiencing a problem that many brazing shops face, namely that of correctly dealing with joint-clearance issues during nickel-brazing processes.

The hard, nonductile metallurgical phase-structures that form upon solidification of Ni-brazed joints must be carefully controlled, or else they can, and often do, result in cracks inside the joint during stressful service involving either mechanical or thermal cycling (or both). It can even occasionally happen during regular cooling from the brazing temperature when the part is first being brazed.

The famous photomicrograph in Fig. 1 clearly shows how a hard centerline matrix forms along the center of the joint (since solidification moves from the edge of the base-metal/brazed-joint interface toward the center of the joint). Note that this polished sample was very smooth, with no holes, etc. Thus, the dark structure down the center of the horizontal joint is merely a smooth layer that etches to a different shade of color than the rest of the alloy in the joint.

The last phases to solidify when brazing with nickel-based brazing filler metals (BFMs) will be those phases that are

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the lowest-melting, i.e., those phases rich in the temperature-lowering, eutectic-forming elements (meaning those that are rich in boron, silicon, or phosphorus). Remember, "eutectic" refers to the composition of an alloy that is the lowest melting point portion of the BFM. Thus, eutectic phases will not only be the first composition to start melting during heating of the BFM, but also will be the last to solidify during cooling. Thus, during cooling, these eutectic-phases will "migrate" toward the center of the joint as the "solidification-front" of the BFM moves from the base-metal/BFM interface toward the center of the joint, and will be forced to solidify right at the center of the joint.

Unfortunately, all of these temperature-lowering, eutectic-forming elements in nickel-based BFMs are also hardeners, that is, the alloyed phase-structures (chromium-borides, phosphides, etc.) resulting from solidification of these elements have virtually zero ductility. Thus, the last phases to solidify (in the center of the joint) will be hard, and nonductile. If the joint is thicker than only about 0.004 in. (0.10 mm) max, there will be enough of these temperature-lowering elements in the joint that the hard centerline eutectics that form can actually do so in a continuous line down the center of the joint, and cause the joint to become very prone to cracking under any kind of thermal or mechanical stress or strain.

Notice, however, the portion of the brazement shown on the far left side of Fig. 1, which is at a right angle to the larger horizontal joint structure in the photo. Because that joint on the far left side is very thin (less than 0.003 in. [0.075mm]), the amount of eutectic "hardener" available in that joint is minimal; so much so, that there is physically not enough of that temperature-lowering additive present to enable the formation of any kind of continuous centerline eutectic. Therefore, this thin joint will not have any continuous centerline eutectic in it, and it will behave in a very ductile fashion in service.

To further illustrate this concept, look at the photo in Fig. 2, which shows a polished cross section of a round pin that was nickel-brazed into a much larger-diameter round hole. Note how the solid pin drifted to one side of the hole, causing the joint on the right side of the

Fig. 2 — Round pin brazed into hole. As typically happens, the pin will drift to one side in the hole, resulting in a tight joint on one side and a wide joint-clearance joint on the other. In nickel brazing this can result in the formation of a continuous centerline eutectic in the wider section of the joint, as shown.

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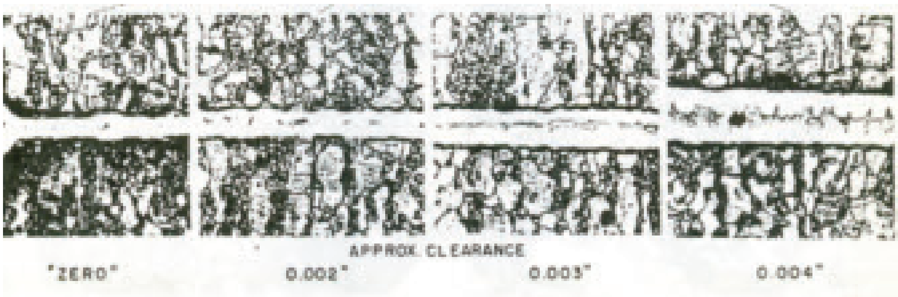

Fig. 3 — For proper nickel-brazed joint clearances, clearances at brazing temperature should be kept below about 0.003 in. (0.075 mm).

photo to be thin, with just a few spots of what is called a “noncontinuous centerline eutectic.” Those darks spots appearing in the joint on the right side of the photo are not voids, but are actually dark-etching centerline-eutectic phases, surrounded by ductile nickel-chrome solid-solution material. By contrast, the left side of the photo shows a wide joint that results in the formation of a continuous centerline-eutectic structure (notice the cracks progressing through that structure).

There appears to be a “threshold” clearance, above which continuous centerline-eutectics tend to form in nickel-brazed joints. As shown in Fig. 3, it appears that joint clearances less than about 0.003 in. will be okay, whereas those clearances larger than that are prone to the formation of continuous centerline eutectics, making them very susceptible to cracking in service.

Solution: To control formation of hard centerline eutectics in nickel-brazing, joint clearances must be kept to a minimum of about 0.000–0.003 in. (0.000–0.075 mm) max at brazing temperature. Joint thicknesses larger than this can result in the formation of a continuous centerline eutectic structure down the center of the joint, which can be highly prone to cracking in service.♦

This column is written sequentially by TIM P. HIRTHE, ALEXANDER E. SHAPIRO, and DAN KAY. Hirthe and Shapiro are members of and Kay is an advisor to the C3 Committee on Brazing and Soldering. All three have contributed to the 5th edition of AWS Brazing Handbook*.*

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Readers are requested to post their questions for use in this column on the Brazing Forum section of the BSMC Web site www.brazingandsoldering.com.

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