

# EXECUTIVE Report

## Experiments Demonstrate Durability of Brazed Brass Joints

*Fatigue Testing at Various Temperatures Proves Superiority of Copper-Brass for Heat Exchanger Applications*

**F**atigue is a process by which a material is weakened by cyclic loading. The fatigue stress may be below the ultimate tensile stress, or even the yield stress of the material, yet still cause catastrophic failure.

Recently, Anders Falkenö conducted an important series of experiments at the Brazing Center of Luvata Sweden AB in Västerås, Sweden. An apparatus was constructed that was capable of fatigue testing at temperatures up to several hundred degrees Celsius. Falkenö and his associates then measured fatigue failures rates of components made from brazed copper-brass, soft-soldered copper-brass, silver-brazed copper-brass and brazed aluminum.

In brief, the results provide empirical proof for claims the brazed copper-brass heat exchangers are more durable than the alternatives not only at ambient temperatures but also at the elevated temperatures at which radiators and charge air coolers typically must operate.

This executive report briefly describes the experimental apparatus and procedures and summarizes a handful of the results of the recent research. For detailed results, the reader is urged to refer to the original paper [1].

### Fatigue Basics

Fatigue is a big subject for the simple reason that it greatly complicates the applications of metals. Fatigue failures are not readily predicted from values of yield stress, yet design engineers must account for them. Well-designed fatigue experiments allow for statistical predictions of fatigue failures in the field, and product design decisions can be made accordingly based on the experimental results.

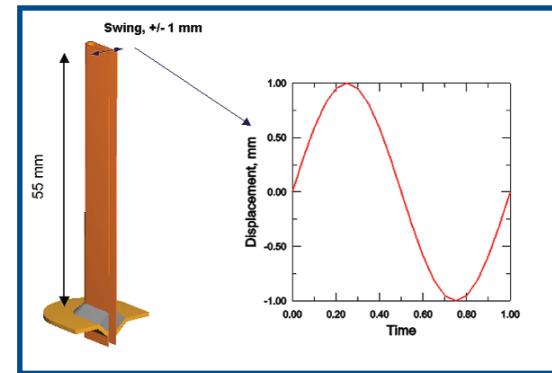
Fatigue allows a metal to fail by the accumulation of damage from repeated applications of a load, i.e., cyclic stress or cyclic strain. Every cycle of stress introduces a minute amount of damage into the metal-atom crystalline lattice. (Each “grain” within a bulk metal has a more or less regular crystalline structure.) This damage is cumulative, eventually leading to the formation of microcracks, and ultimately leading to the failure of the component.

Strain that causes permanent damage is called “plastic deformation” in contrast to elastic strain, which is completely

reversible. The amount of plastic deformation per cycle depends on the intensity of stress in the zone of material undergoing fatigue. Fatigue is generally characterized in terms of the number of cycles before failure at an arbitrary cyclic stress or strain. Some materials have a threshold fatigue stress below which no failure will occur despite many millions of cycles. Above that stress however, the number of cycles before failure typically decreases as the amplitude of the cyclic stress increases.

### Stress Intensification

Local stresses or strains generally are a complicated function of the geometry of the part; in this experiment, local stresses were calculated based on known displacements of the tube at a known distance from the joint using finite element analysis.



Displacement model of the tube specimen.

Finite element analysis studies show that, in the case of a heat exchanger, fatigue failure most commonly occurs in the tube near the tube-to-header joint, just beyond the brazing material. Stress intensification is highest there due to the geometry. The tubes farthest from the center of the heat exchanger are subject to the greatest strain, and this strain is most intense in the zone outside where the tube enters the hole [2].

It was possible to develop a meaningful experiment based on a single tube brazed into a hole in a header plate. The experimental apparatus was designed to repeatedly displace the tube by a fixed amount at a certain distance from the filler material. Finite

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is the leading organization for the promotion of the use of copper worldwide. The Association's twenty-nine members represent about 80 percent of the world's refined copper output, and its six associate members are among the world's largest copper and copper alloy fabricators. ICA is responsible for guiding policy, strategy and funding of international initiatives and promotional activities. With headquarters in New York City, ICA operates in 28 worldwide locations through a network of regional offices and copper development associations.

For general mailing information about the CuproBraze process or ICA's CuproBraze consulting services, please contact International Copper Association at [mrosario@copper.org](mailto:mrosario@copper.org). For technical information contact [cuprobraze@copper.org](mailto:cuprobraze@copper.org). For European inquiries contact [ndc@eurocopper.org](mailto:ndc@eurocopper.org).

## References

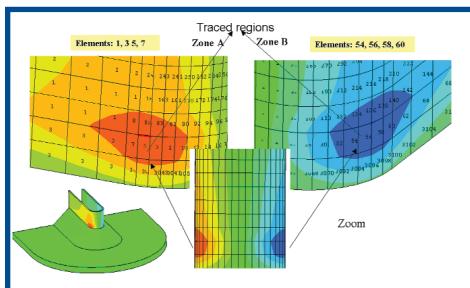
1. "Experimentally Driven Development of New Heat Exchanger Materials," Anders Falkenö, paper presented at 2006 SAE World Congress, Detroit, Michigan, April 3-6, 2006, SAE Technical Paper Series 2006-01-0727. Available at [sae.org](http://sae.org).
2. Finite element analysis performed by Chunhui Luo of Luvata is the subject of an internal paper.
3. "The CuproBraze Braze Handbook," Seventh Edition, October 2005, Edited by Leif Tapper with co-editors Markku Ainali, Anders Falkenö, and Robbie Robinson. Produced and published by Luvata. Available from Luvata or download from [www.cuprobraze.com](http://www.cuprobraze.com).

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element analysis estimates the stress distributions in the vicinity of the joint for various displacements. In fact, the finite element analysis was able to predict the location of tube failures, which occurred at the inner side of the tube in the region between the straight segments and curved segments and near to the filler.



Stress distributions from finite element analysis.

Based on the finite element analysis results, displacements of  $\pm 1$  mm were made at a distance of 55 mm from the filler material. This condition of cyclic strain best simulated real world displacements and brought about fatigue failure after a reasonable number of cycles for the samples being tested.



The tube specimen is mounted on a fixture (top), which can be enclosed by a heater (bottom).

## The Proof is in the Results

The basic experimental apparatus was effective in simulating the behavior of tubes under pressure. Many experiments were carried out to compare different combinations of tube brasses and filler materials, to determine which result in the most durable products. The apparatus allowed for a comparison of the number of kilocycles to failure at various temperatures.

As expected, the observed failure rates were statistical in nature. Specimens failed over a range of values of kilocycles. Failure rates are represented in terms of a Weibull distribution and a B10 parameter, which predicts the number stress cycles after which 10 percent of the specimens would fail. Although the main purpose of these experiments was not for a side-by-side comparison of copper-brass with aluminum, tube-to-header pieces from commercially available aluminum radiators nonetheless were obtained and tested on the apparatus.

The B10 value for brazed copper-brass components compared extremely favorably with the B10 values for aluminum components at all temperatures. At 25 °C, for example, the B10 value was 35.4 kilocycles for CuproBraze compared to 5.8 kilocycles for brazed aluminum; at 100 °C, it was 26.7 compared to 2.1; at 200 °C, it was 18.8 compared to 4.8; and, finally, at 275 °C, B10 values were 8.6 kilocycles for CuproBraze compared to 2.5 for aluminum.

Though based on a limited number of samples, these results provide convincing experimental evidence that corroborates or even proves the claim that brazed copper brass heat-exchangers are many times more durable than aluminum radiators.

## Directions for Further Research

More important even than proving the superiority of CuproBraze heat-exchangers, Falkenö and his colleagues have pointed the way to a simple experimental apparatus that allows for a rapid material survey of the fatigue behavior of a wide range of brazed, soldered or welded material combinations at a various ambient and elevated temperatures.

For more about CuproBraze filler materials and the mechanical properties of CuproBraze tube brass at various temperatures the reader is referred to the latest addition of the "CuproBraze Braze Handbook" [3].

It is noteworthy that the experimental apparatus is relatively simple to set up, so it is expected that more laboratories will adopt this procedure and additional experiments will be performed on various material combinations and heat exchanger geometries in the months and years ahead. According to Falkenö, "The aim was to develop a test method for the evaluation of heat exchanger materials at elevated temperatures. The wide variation of the test results should be checked against the failure detection system, brazing practice and the experimental setup. Also, the test methods can be fine-tuned by calculating and measuring the stresses that will occur in the heat exchanger under various conditions. We are encouraged by these initial results. Nonetheless, more work remains to be done."

This executive report has shared only a small fraction of the results, which are reported more fully in the SAE technical paper published by Falkenö [1]. ■