EXECUTIVE Report

CuproBraze Heat Exchangers for Locomotives Resist Elevated Temperatures, Fatigue and Corrosive Elements

Resistance to Exhaust Gases Bodes Well for EGR Applications

As outlined in *Cu*proBraze *Executive Report* Number 65 [1], the high thermal conductivity of copper fins is essential to the high heat-transfer efficiency of *Cu*proBraze air-to-air coolers (ATACs), or charge-air coolers (CACs). Yet there are other physical properties that bode well for *Cu*proBraze alloys and coatings in these applications. Foremost are three interdependent attributes that could be dubbed "the three resistances" of *Cu*proBraze:

1) Resistance to elevated temperatures and pressures
2) Resistance to fatigue
3) Resistance to corrosion

These three resistances add up to durability, reliability and long service life for *Cu*proBraze CACs and, consequently, reduced downtime for on-highway trucks, off-road diesel equipment, power plants and locomotives.

They are readily demonstrated in the laboratory and, more importantly, a large body of evidence now includes field experience from OEMs and end-users. The verdict is clear: *Cu*proBraze heat exchangers are tough enough to withstand the harsh environments associated with charge-air cooling applications.

The CAC Environment

It is hard to exaggerate the harshness of the environment that a CAC must withstand. Besides dissipating heat energy as rapidly and efficiently as possible, it must also withstand searing temperatures, intense vibrations and aggressive chemicals.

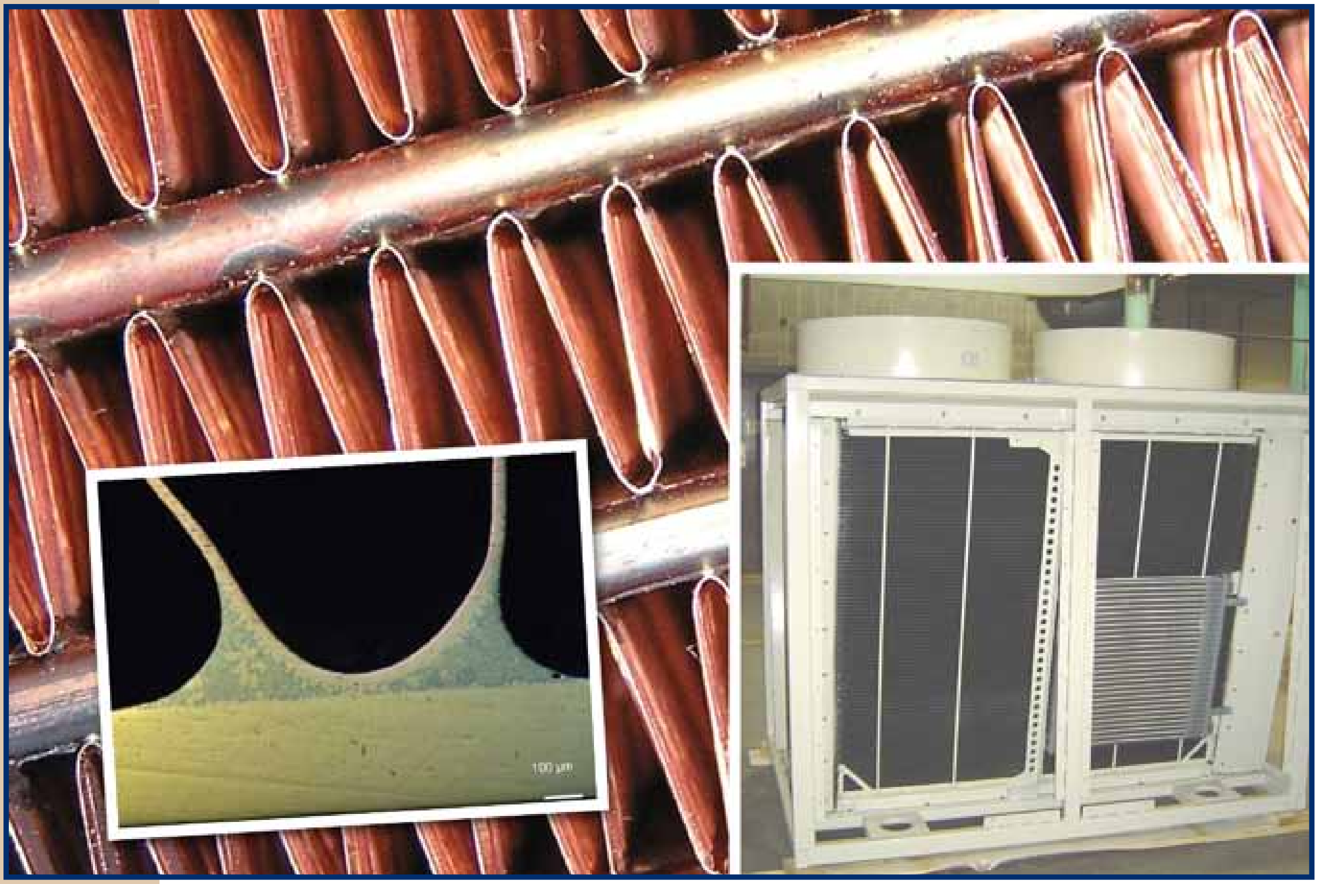
Elevated Temperature Resistance

The hot compressed gases received directly from the turbochargers are typically near 200 °C, or nearly 400 °F. For comparison with the melting points of various metals, the usual practice is to convert to the absolute temperature (Kelvin) scale, by adding 273. The result (473 K) is just more than one-half the melting point of aluminum (934 K) but only 35 percent of the melting temperature of copper (1356 K); and only 37 of percent the temperature at which the *Cu*proBraze brass alloy (SM2385) begins to melt (1283 K) [2].

New generations of CACs may even need to operate at even higher temperatures, perhaps even as high as 300 °C (573 K). Furthermore, *Cu*proBraze alloys are anneal resistant even at the high brazing temperatures of the *Cu*proBraze process. They maintain a high tensile strength and yield strength into these elevated temperatures, high above the temperatures at which aluminum alloys certainly would fail. The steep drop in the tensile strength and yield strength of aluminum alloys above 200 °C results in reliability issues for aluminum CACs.

Fatigue Resistance

Another factor to consider in CAC applications is fatigue, which occurs when repeated application of stresses *below the yield strength* have a deleterious effect on a metal. Each cycle of applied stress introduces defects in the metal lattice. Vibrations from the diesel engine and the road add cyclic stress to the internal pressure of a CAC. Anneal-resistant alloys inhibit the heal-



Young Touchstone used the *Cu*proBraze process to braze these serpentine copper fins to flat brass tubes for this locomotive charge air cooler application. The electrochemical potential is about the same for the fins, tubes and filler material so there is little tendency toward galvanic corrosion.

ing of defects yet fatigue-resistant alloys prevent defects from accumulating and forming microcracks. *Cu*proBraze brass alloys are both anneal resistant and fatigue resistant.

Previously, an important series of experiments at the Brazing Center of Luvata Sweden AB in Sweden compared fatigue failure rates at various temperatures for components made from brazed copper-brass, soft-soldered copper-brass, silver-brazed copper-brass and brazed aluminum. The experiments were conducted at 25 °C, 100 °C, 200 °C and, finally, 275 °C.

The results provide empirical proof that brazed copper-brass heat exchangers are more durable than the alternatives not only at ambient temperatures but also at the elevated temperatures at which charge air coolers typically must operate [3,4].

Corrosion Resistance

The corrosion resistance of *Cu*proBraze heat exchangers has been extensively studied and results published in technical journals [5]. In one investigation, four different accelerated corrosion tests compared *Cu*proBraze to soldered copper-brass radiators and brazed aluminum radiators. The results showed that *Cu*proBraze heat exchangers were generally more corrosion resistant than soldered copper-brass heat-exchangers and very competitive with aluminum heat exchangers.

The excellent corrosion resistance of *Cu*proBraze products is due in part to the fact that the copper fins, brass tubes and filler materials all have about the same electrochemical potential so there is little tendency for galvanic corrosion.

Protective Coatings

High-performance coatings further improve corrosion resistance and make thickness reductions possible without risks from corrosion. Several coating technologies are commercially available for external surfaces. Electrophoretic coatings can increase the lifetime of a *Cu*proBraze heat exchanger by 2.5 to 3 times compared to an uncoated heat exchanger. A new option is powder coating with a multi-nozzle spray gun, which gives good results with respect to corrosion resistance and thermal performance and has a lower cost compared to an electrophoretic coating.

Such coatings clearly prolong the lifetime of the heat exchangers They cover the entire external surface in contrast to cosmetic coatings, which typically cover only 10 percent

Rectangular fins are an alternative to triangular fins. *Cu*proBraze alloys are suitable for harsh environments and the square-wave fins are especially easy to clean. Young Touchstone used the *Cu*proBraze process to bond these rectangular fins to flat brass tubes in this locomotive charge-air cooler application.

of the external surface. In truth, cosmetic coatings decrease lifetimes. An uncoated heat exchanger has a lifetime that is about 30 percent longer than the lifetime of a cosmetically spray-coated heat exchanger.

Inhibitor Systems in Coolants

Coolants for radiators use inhibitor systems that prevent all kinds of internal corrosion. Generally speaking though, copper alloys are less sensitive to a bad coolant than aluminum. Tests were performed to compare corrosion in coolants for *Cu*proBraze materials with corrosion in coolants for the copper-based materials used in soft-soldered radiators. The test results were similar, which means that the coolants that fulfill the standard requirements with copper materials are considered compatible with materials used with *Cu*proBraze. In a study on a mixed-metal cooling system, there was no indication of micro-galvanic corrosion on aluminum caused by copper.

Exhaust-Gas Corrosion

Another form of internal corrosion could occur when exhaust gas circulates through the brass tubes of a charge-air cooler. Coating solutions promise corrosion resistance against exhaust gases so they can be re-circulated through *Cu*proBraze charge-air coolers.

Exhaust gases include extremely corrosive elements, most notably sulfur, so the development of a corrosion resistant surface for this application has been a challenge.

In anticipation of emissions regulations, diesel fuels with sulfur concentrations of less than 15 ppm became mandatory in 2006 because of the damaging effects of sulfur on exhaust after-treatment systems. Nonetheless, some sulfur remains in the diesel fuels and hence exhaust gases.

Meanwhile, exhaust gas recirculation (EGR) has emerged as an effective strategy for reducing NOx production in the combustion chamber. High oxygen levels during combustion contribute to the formation of NOx. The engine exhaust is a readily available source of oxygen-depleted gas so if it could be cooled and mixed with the charge air then oxygen levels could be reduced in the combustion chamber. The result would be less NOx in the exhaust.

In recent years, at least one diesel engine manufacturer pursued advanced EGR as a primary means for reducing NOx emissions without the need for exhaust after-treatment. According to Navistar, its 2010-compliant

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For information about the *Cu*proBraze process or ICA's *Cu*proBraze consulting services, please contact the International Copper Association at: cuprobraze@copper.org. For European inquiries contact: ndc@eurocopper.org.

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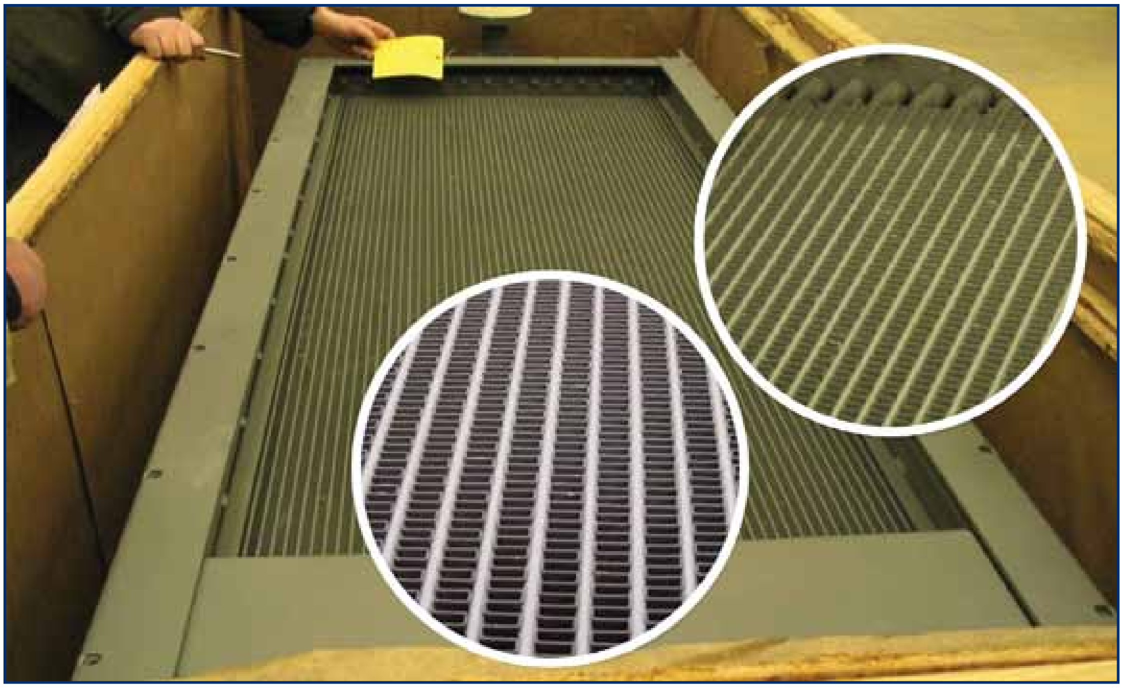

engines have four enhanced-engineering attributes that differ from previous generation engines. These are advanced fuel injection technology, advanced air management, a proprietary combustion bowl design and electronic calibration. More information about advanced EGR is available online at the Maxxforce website (www.maxxforce.com).

For other engine manufacturers, even though selective catalytic reduction (SCR) may be used to remove NOx from exhaust, EGR is still often used to reduce NOx levels to levels that can be managed by SCR. So, although there may be a choice between advanced EGR and SCR, the advantages of EGR are not in doubt.

Hot pressurized air is not corrosive to the internal surfaces of the brass tubes but even low levels of sulfur can be a concern. Consequently, Luvata Rolled Products in Sweden has developed a new anticorrosion coating specifically designed to prevent detrimental corrosion attacks in environments with condensed diesel exhaust gases [6].

Accelerated corrosion testing in synthesized diesel exhaust at condensation temperatures shows that corrosion develops a few micrometers below and along the surface of the new alloy but there is no penetration through the material. This new coating is promising to the design of heat exchangers for the diesel exhaust environment. Luvata is now starting pilot projects with interested customers.

*Cu*proBraze is ideally suited for diesel and electric locomotive applications. Bombardier overhauled 45 Class E Locomotives for South African Railways, installing *Cu*proBraze heat exchangers for cooling the electrical inverters and transformers.

Conclusion

In addition to high heat-transfer efficiency, *Cu*proBraze CACs show excellent resistance to elevated temperatures, fatigue and corrosion. It appears now that *Cu*proBraze CACs will also be practical in EGR applications where corrosion of the internal surfaces of the CAC tubes has been a concern. Further investigations are underway.

These "three resistances" of *Cu*proBraze are often deciding factors in the selection of CAC technologies, especially for use in heavy-duty applications where environments can be harsh, such as construction, agriculture, locomotives and power generators.

In a world that is increasingly concerned with service life, recycling, reparability and sustainability, a premium is placed on the durability of components. The excellent durability of *Cu*proBraze has been proven not only through accelerated laboratory testing but also has been corroborated by nearly a decade of field experience.

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