



New brazing processes using anneal-resistant copper and brass alloys

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Abstract

New brass and copper alloys offer high strength as well as excellent retention of strength at elevated operating temperatures. They can withstand high-temperature brazing processes without a substantial loss in strength. A brazing center has been established to demonstrate this new brazing process and evaluate the technology through prototype building. Manufacturing processes are now being applied globally in the manufacture of advanced heat exchangers using the new brazing process. Brazing furnaces have been developed for all levels of production including batch, three-chamber (semi-continuous) and continuous furnaces. This paper provides an update on brazing manufacturing technology in use today. It reviews current trends in the selection of furnaces, the application of filler materials, the assembly of components and the control of brazing operations. The impact of this new brazing process on the design and manufacture of mobile heat exchangers is discussed.

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1. Introduction

The high thermal conductivity and high strength of new copper and brass alloys have changed the rules of design for mobile heat exchangers. Lightness, strength and efficiency are the desirable properties of these materials for heat exchangers. Additionally, these materials are available at low cost and the processes are environmentally friendly. The new brass-tube and copper-fin alloys offer high strength as well as excellent retention of strength at elevated operating temperatures. They make copper and brass extremely attractive once again for mobile radiators, heaters and charge air coolers of all shapes and sizes.

Gustafsson and Scheel [1] list all of the important physical properties of copper and aluminum side-by-side and make a compelling case in favor of the use of CuproBraz^{®1} alloys in mobile heat exchanger technologies. More recent papers have described experiments relating to the metallurgy [2,3] and corrosion resistance

[4,5] of the new anneal-resistant alloys. Schmoor and Nadkarni report on recent developments in brazing pastes [6].

In recent years, designers have demanded lighter fins and tubes and hence stronger alloys for more compact, lighter weight and higher-efficiency heat exchangers. An important advantage of thin gauge material is that, besides reducing weight, the lower cross-sectional area allows air to pass more freely through the core of the heat exchanger. The relative ease with which air flows through a radiator core is measured as a lower air pressure drop for a given performance. A low air pressure drop is highly desirable in advanced design of efficient compact heat exchangers for fuel-efficient vehicles.

The use of thin gauges in compact heat exchangers requires new processes. The International Copper Association responded to the industry need for a new generation of copper–brass radiators by developing CuproBraz technology, which is a new process now being applied globally in the manufacture of advanced heat exchangers.

CuproBraz technology was specifically developed for application to automotive and heavy-duty-industrial

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¹ CuproBraz is a registered trademark of the International Copper Association.

80 heat exchangers. For example, it enables the manufac-
81 ture of charge air coolers that can withstand higher
82 temperatures than existing equipment, allowing the
83 transportation industry to reduce emissions and increase
84 fuel efficiency by replacing temperature-challenged alu-
85 minum charge air coolers with copper–brass
86 counterparts.

87 2. CuproBraz materials and technology

88 2.1. Effect of annealing

89 The alloys used in conventional copper and brass
90 radiators are designed for soldering below 450 °C (842
91 °F). When subjected to high temperatures for long
92 periods, these conventional alloys soften due to anneal-
93 ing, a well-understood metallurgical effect. Annealing
94 rearranges the positions of metal atoms in the metal
95 lattice through solid-state diffusion, effectively removing
96 the deformations that would otherwise strengthen the
97 alloys. The resulting decrease in yield strength is particu-
98 larly steep for metals previously strengthened by rolling
99 or other deformation-hardening processes.

100 Annealing is time- and temperature-dependent.
101 Because annealing is based on solid-state diffusion,
102 metals and alloys can lose significant strength well
103 below the melting point; however, annealing is much
104 more pronounced at temperatures close to the melting
105 point. For comparison, on the absolute (Kelvin) tem-
106 perature scale, the melting points of aluminum, copper
107 and iron are 933.5, 1357.8 and 1811 K, respectively.
108 Some annealing occurs in copper alloys at 723 K (450
109 °C), which is only a little more than half the melting
110 temperature on the Kelvin scale. It is noteworthy, how-
111 ever, that this temperature is nearly 80% of the melting
112 point of aluminum. In fact, brazed aluminum radiators
113 undergo processing at brazing temperatures that
114 approach 98% of aluminum's melting point, which
115 results in considerable annealing of aluminum radiators.

116 Process engineers and radiator designers have long
117 been confronted with an 'either–or' type of dilemma.
118 Brazing processes promised strong bonds at the joints
119 but brazing weakened the bulk material because of
120 annealing. Heat-exchanger designers have been frustrat-
121 ed for several decades by these limitations. The industry
122 had to wait for the development of anneal-resistant
123 copper alloys before further advances could be made.

124 2.2. Soldering and brazing

125 For decades, manufacturers avoided annealing effects
126 in copper–brass radiators by using solders that melted
127 well below annealing temperatures. These solders were
128 used to bind copper fins to brass tubes and brass tubes
129 to headers, which are the essential steps in the radiator
130 assembly. These methods are still widely employed

today to make heavy-duty radiators for truck and off-
road applications. A tremendous body of specialized
manufacturing expertise and process knowledge, includ-
ing many specialized machines and furnaces, have
developed around this industry. The basic process con-
sists of melting, flowing and solidifying the solder at
the joint, typically forming a metallic bond with the
soldered surfaces (or parent metals).

Soldering and brazing involve the same bonding
mechanism except that soldering is defined as using
filler metals that melt below 450 °C (which equals 723
K or 840 °F) and brazing uses filler metals that melt at
higher temperatures. In both soldering and brazing the
bonding mechanism is a reaction between the filler
metal and the parent metal or metals. Brazing and
soldering usually result in alloying, i.e. a metallic-type
bond forms at the interface.

Typically, the filler metal flows into the joint gap by
capillary force, solidifies and forms a bond. Several
factors affect the mechanical performance of the finished
joint. For example, joint clearance and geometry are
important. The relationship between the joint gap-width
and capillary force accounts for filler metal distribution.
One purely mechanical effect is the restraint on the
plastic flow of the filler metal, which is due to the
greater strength of the base metal. Other effects are the
possibilities of slag entrapment and void formation.

Interactions between the filler metal and the base
metal take place in both soldering and brazing. Because
of the higher temperatures for brazing, however, inter-
actions are usually greater for brazing than soldering.
The interactions are time- and temperature-dependent.
To minimize interactions, the brazing temperature should
be as low as possible, and the time period that the
materials are held at the brazing temperature should be
as short as possible.

125 2.3. CuproBraz materials

Conventional deformation-hardened alloys soften
when exposed to brazing-temperatures. Fortunately,
researchers faced this challenge and developed strong
materials that could withstand the high temperatures of
brazing and remain strong. Anneal-resistant copper
alloys are strengthened by mechanisms other than merely
deformation hardening.

CuproBraz fin material is made of copper that is
alloyed with chromium. The chromium precipitates grow
in the copper–metal matrix of the fins during the brazing
process. Although these chromium–copper precipitates
are only approximately 3 nm or 0.003 μm in diameter,
they play a vital role in strengthening the fin alloy
through a well-known mechanism known as precipita-
tion hardening.

Ironically, the precipitates strengthen the fins at tem-
peratures that in the past would have seriously weakened

185 fins made from conventional alloys. Interestingly, the
186 precipitation of the chromium in the copper fins restores
187 the electrical conductivity. Since thermal conductivity
188 on this type of materials tracks electrical conductivity,
189 the thermal conductivity of the fins is also restored. The
190 electrical conductivity is only 60% of the conductivity
191 of pure copper (IACS) before brazing but after brazing
192 the conductivity is restored to a minimum of 90%,
193 because the chromium atoms (which interfere with the
194 conduction of electrons) are precipitated out of most of
195 the copper–metal matrix. The thermal conductivity of
196 the CuproBraz copper-fin alloy after brazing is 377
197 W/m °C, which compares to 222 W/m °C for
198 aluminum.

199 Because soldering temperatures are not high enough
200 to raise the thermal conductivity, this new copper–alloy
201 fin material must not be used to make conventional
202 soldered radiators; they should only be used for
203 CuproBraz heat exchangers. The CuproBraz brazing
204 operation is needed to restore the thermal conductivity.

205 Similarly, CuproBraz tubes are made from a brass
206 (i.e. copper that is alloyed with zinc) material that is
207 approximately 85% copper with approximately 1% iron
208 to prevent softening of the material during the brazing
209 operation.

210 2.4. Strength at elevated temperatures

211 Besides being anneal-resistant, the new copper-fin and
212 brass-tube alloys have high strength at elevated temper-
213 atures. For example, as operating temperature is
214 increased from 0 to 300 °C the tensile strength of the
215 brass-tube alloy decreases from 400 to 260 N/mm² and
216 the tensile strength for copper-fin alloy decreases from
217 350 to 260 N/mm². Similarly, the fin and tube alloys
218 retain much of their yield strength at 300 °C. Such high
219 strengths at elevated operating temperatures give these
220 CuproBraz alloys a clear advantage compared to cor-
221 responding aluminum alloys.

222 New designs of charge air coolers need to operate at
223 temperatures that are much higher than past operating
224 temperatures. The copper fins and brass tubes described
225 here are well suited for such high-temperature service.
226 Although widely used in past designs of charge air
227 coolers, aluminum alloys rapidly lose strength at these
228 elevated temperatures and are unsuitable for the new
229 designs of charge air coolers at reasonable material
230 thickness levels.

231 3. Application of filler and component assembly

232 3.1. Filler materials

233 The brazing filler metal that was developed for joining
234 CuproBraz fins and tubes belongs to the CuSnNiP-
235 family. This filler metal, called OKC600, is composed

236 of 4.2-wt.% nickel (Ni), 15.6-wt.% tin (Sn) and 5.3-
237 wt.% phosphorus (P) with the balance copper (\approx 75-
238 wt.% Cu). This alloy has been patented (US Patent
239 Number 5,378,294) but can be freely used for automo-
240 tive and heavy-duty industrial heat exchanger applica-
241 tions. The melting temperature is 600 °C with a melting
242 range of 10 °C.

243 The OKC600 filler metal alloy is available as a
244 powder, foil or paste. Cold forming of the filler metal
245 is virtually impossible.

246 OKC600 powder is produced by gas atomizing the
247 material into a spherically shaped, fine-grained powder.
248 Atomization is normally performed using a protective
249 gas such as nitrogen as atomizing media. The atomiza-
250 tion parameters are set for a maximal particle size of
251 approximately 90 μ m (i.e. 0.0035 inch or 3.5 mm).

252 Depending on the powder manufacturer, the average
253 particle size is normally 15–30 μ m (i.e. 0.6–1.2 mm).
254 In practice, each atomized lot is passed through a sieve
255 to exclude particle sizes exceeding 90 μ m. Some powder
256 manufacturers reduce the powder to remove surface
257 oxidation. The powder must be protected against oxi-
258 dation during manufacturing, transportation and storing.
259 The product data sheets and storing instructions should
260 be carefully followed. In case the powder oxidizes
261 during transport or storage, reconditioning by reduction
262 treatment might be possible by powder manufacturers.
263 (Reduction is a reverse chemical reaction to oxidation.)

264 Thin brazing metal foil with thickness down to 20
265 μ m and composition close to OKC600 is also available
266 for the CuproBraz process. In some cases, foil can be
267 more practical than paste and should to be considered
268 complementary to the paste, depending on the process
269 requirements.

270 Paste is a mixture of brazing powder and binder. The
271 purpose of formulating a paste is to facilitate application
272 of the powder to the parts to be brazed. Application can
273 then be done by means of conventional commercial
274 application methods. Binders can be water-based, sol-
275 vent-based or thermoplastic.

276 3.2. Filler application

277 For tube-to-fin joints, brazing paste can be applied
278 either on the tube surfaces or fin tips. A thin layer of
279 paste is applied on the flat surfaces of the heat exchanger
280 tubes using many different methods, including dipping,
281 roll coating or spraying. Tubes and fins normally do not
282 need precleaning.

283 The layer that is applied should be as thin as possible
284 to prevent problems with tube- or fin-deformation during
285 core building and compression. Most brazing pastes
286 have to be dried, normally with warm air, and instruc-
287 tions from paste suppliers must be followed because
288 too-high temperatures during the drying cycle can oxi-
289 dize the brazing powder and lead to a poor brazing

290 result. Pastes that have high metal content after drying
291 and leave a smooth surface after drying are recommend-
292 ed. Good temperature control is needed during heating
293 and drying to prevent overheating and subsequent poor
294 brazing result. The brazing properties of the pastes can
295 be destroyed above 130 °C (226 °F). Coatings should
296 be evenly applied and, typically, a coating thickness
297 (weight) of 150–250 g/m² (i.e. $3.4\text{--}5.7 \times 10^{-3}$ oz/
298 inch²) is required. The better the fit between tube and
299 fin the thinner the layer can be.

300 Consumption of brazing paste could, in most cases,
301 be lowered in another way by applying the paste on the
302 tips of the fins rather than on the tubes. Thermoplastic
303 pastes as well as some solvent-based pastes are suitable
304 for fin-tip application. The coating thickness is measured
305 by weighing; the recommended amount of paste on each
306 tip is 0.3–0.5 mg/mm of fin tip width ($2.7\text{--}4.5 \times 10^{-4}$
307 oz/inch). Again, less paste is needed for better fits
308 between fin and tube. Thermoplastic paste can be
309 applied to fin tips with rollers. The paste is picked up
310 on the two rolls as a thin, even layer, and, as the fins
311 pass between the rolls, the paste is transferred to the fin
312 tips.

313 Because the tube-to-header joint must be leak free,
314 enough molten braze filler metal must be in place during
315 brazing to fill the entire gap. A separate, dedicated-
316 slurry (i.e. a mix of powder, binder and solvent) is
317 recommended for tube-to-header joints. This slurry can
318 be applied by pouring or spraying. To make the brazing
319 process more forgiving when oxidized and/or dirty
320 components are used, a small amount of non-corrosive
321 flux can be added to the slurry. The slurry application
322 methods are well suited for automation.

323 A furnace brazing operation requires narrower toler-
324 ances than soft soldering. Generally, closer tolerances
325 and well-defined joint gaps result in better and stronger
326 joints. Another factor to take into account is that the
327 brazing alloy is in powder form and builds up a thicker
328 layer than a solid metal. The geometry of the tubes and
329 fins and the tube pitch in the header should be adjusted
330 accordingly.

331 Consistency in the fin amplitude is also important.
332 Inconsistency in the fin height can result in a gap that
333 is too large between fin tip and tube, and a low
334 percentage of correctly brazed tube-to-fin bonds. Varia-
335 tions from fin-tip to fin-tip should be at an absolute
336 minimum.

337 3.3. Tube fabrication

338 Several types of brass tubes can be used to manufac-
339 ture CuproBraz heat exchangers. These tubes are uni-
340 formly made from brass strip because thin gauges are
341 required for lightness and efficient heat exchange. Tube
342 fabrication requires that the edges of the strip be reliably
343 bonded together. The tube seams can be sealed during

the brazing process or they can be welded prior to the
brazing process.

High-frequency (HF) welded tubes are convenient to
use for CuproBraz heat exchangers because their con-
toured shape is uninterrupted around the circumference
of the tube. A consistent gap can be achieved between
the tube and the header. The drawback of HF-welded
tube is that the gauge is limited to a minimum of
approximately 0.12 mm (i.e. 0.005 inch) because the
edges of the strip must be butt-welded. HF-tubes are
sold commercially.

Folded tubes can be made of thinner brass strips
already down to approximately 0.080 mm (0.003 inch).
The most common folded tube uses the lock-seam fold.
The drawback of the lock-seam fold is that the seam
becomes an irregularity on the tube surface, which
makes it difficult to achieve a uniform gap in brazing
the tube to the header.

New tube designs offer advantage over the lock-seam
design. The overfold design (called snap-over) and B-
fold design are just two of many folds being tested for
CuproBraz heat exchangers. Applying paste only on
the flat surfaces of the tubes does not result in a leak-
tight seal at the seams. Folding methods include inject-
ing the overlapping parts with a bead of thermoplastic
brazing paste in the tube mill. Paste injection has to be
performed correctly for optimal brazing results.

371 3.4. Header and brazing fixture

372 The holes in the header can be designed and manu-
373 factured in different ways. For the CuproBraz process,
374 pierced holes are recommended using a two-stage oper-
375 ation, which creates a continuous collar of contact
376 surface area between the header and the subsequently
377 inserted tube. This shape draws braze alloy from the
378 surface of the header into the joint by capillary action.
379 No tears are allowed in the drawn section. The optimal
380 size for the gap between header and tube is 0.05 mm
381 (0.002 inch) and this gap should not exceed 0.1 mm
382 (0.004 inch).

383 Stiffening ribs on the header are also beneficial.
384 Besides functioning as reinforcement, ribs lower the
385 slurry consumption. Slurry flowing into the wells around
386 the tubes is not wasted on areas between tubes. When
387 header gauges are smaller than 0.8 mm (0.03 inch),
388 extra care is recommended with tabbed header designs
389 from the point of view of strength.

390 The brazing powder builds up a thicker layer than a
391 solid metal of the same weight, as previously mentioned.
392 This extra thickness must be taken into account when
393 specifying tube pitch in the headers and in the brazing-
394 fixture devices. The tube pitch in the headers is a
395 function of the tube width and fin amplitude with an
396 allowance for brazing paste layer. The allowance for
397 brazing paste in turn depends on the tube dimension,

the core width and the fin design. It has to be determined with actual components. As a guideline, approximately 0.10 mm per tube often works well, resulting in a complete braze joint between fin and tube.

The assembly and brazing-fixture system should allow for a barrel shape of the core before brazing, due to the brazing paste build up. For a $500 \times 500\text{-mm}^2$ ($20 \times 20\text{-inch}^2$) core, a typical dimension measured in the middle of the core is 502.5–503 mm (20.1–20.12 inch).

Another demand on the brazing fixture is a low-mass that allows the fixture to follow the temperature of the radiator core as closely as possible. This arrangement avoids differences in dimensions due to temperature differences that could lead to permanent deformation of fins or tubes. For the same reason, the fixture material should have a thermal expansion coefficient as close as possible to that of brass and copper. A slight flexibility in the fixture to follow the core when the brazing paste melts is also recommended, especially for larger cores.

It could be preferable to design with side supports that are mechanically attached to the header prior to brazing. These supports provide a well-defined gap during the entire brazing cycle for the outermost fins that are close to the header. In this manner, brazing voids or deformation of the fin or tube in the corner region can be avoided.

4. Processing of assemblies

4.1. Brazing operation

Because the temperature of brazing is much higher than that of soldering, an inert atmosphere is needed to prevent oxidation of the parent and filler materials. Selecting a suitable furnace requires knowledge of the temperature, time and atmospheric conditions of the process.

Recommendations for the furnace conditions are as follows. The primary function of the brazing atmosphere is to prevent oxidation. Furnaces today use high purity nitrogen to displace oxygen from inside the furnace. The atmosphere of the furnace must have a dew point of less than $-40\text{ }^\circ\text{C}$ and oxygen content of less than 20 ppm. If moisture and oxygen levels are higher than these levels, the powder and the base material risk being oxidized at temperatures exceeding approximately $200\text{ }^\circ\text{C}$ and brazing might not be complete.

The furnace must be able to cool the load at a maximum of $150\text{ }^\circ\text{C}/\text{min}$.

No heat should be applied if the atmospheric conditions are not met. The part should not leave the inert atmosphere if part temperature is above $150\text{ }^\circ\text{C}$. In places where ambient humidity is high the temperature should be even lower, to prevent discoloration. Part temperature uniformity must be within $\pm 7\text{ }^\circ\text{C}$ and the furnace must be able to operate at $700\text{ }^\circ\text{C}$.

The time above $600\text{ }^\circ\text{C}$ should be limited to a maximum of 3–4 min. The heat exchanger will lose thermal performance if the temperature is too high or held too long above $600\text{ }^\circ\text{C}$. On the other hand, the part will not braze if the temperature is too low or the time above $600\text{ }^\circ\text{C}$ is too short. The governing factor for the brazing cycle is the brazing of the tube-to-header joints. The effect of the brazing cycle on the tube-to-header joints cannot be seen by the naked eye. During optimization of the brazing cycle, overshooting of the brazing temperature can sometimes happen yet not cause a noticeable visual effect on the brazed heat exchanger.

4.2. Selecting a furnace

Factors to consider when selecting a suitable furnace are production volume, part size, available floor space, capital expense and operating cost. Based on the specifications outlined above, the CuproBraze radiators can be processed in batch, semi-continuous or continuous furnaces.

(1) A batch furnace uses the same door to load and unload the part. These furnaces can only produce one batch at a time. A load is purged with nitrogen, then moved into the brazing chamber, and after brazing, the load is moved back into the purge chamber where it is cooled.

(2) A semi-continuous furnace uses separate entry and exit doors. Parts are indexed from the loading area to the purge chamber, where the part is purged with nitrogen and then moved into the next chamber. The furnace simultaneously moves the purged part into the brazing chamber and a new part into the purge chamber. In a semi-continuous furnace, it is possible to have a part in each zone. This type of furnace is suitable for large parts or intermediate volume production.

(3) A continuous furnace uses a conveyor to continuously move parts through the furnace where they are continuously purged with nitrogen, brazed and then cooled. This type of furnace is for high volume production. A continuous furnace is not recommended for parts longer than 1000 mm because when the front of the part enters the heating zone, it conducts heat to the rear of the part. As a result, the trailing section of the part is held at temperature for much longer time than the leading edge of the part.

All these furnaces have heating and cooling sections. Batch furnaces and semi-continuous furnaces are suitable for any part size but limited with respect to production volume. Continuous furnaces are suitable for volume production but limited with respect to part size.

It is possible to heat all the three types of furnaces with electricity, natural gas, or propane/butane. In many countries, natural gas and propane are a cheaper source of energy than electricity, but they require more maintenance and have a higher initial cost. Gas burners also

require a gas-tight barrier between the combustion products and the brazing atmosphere. Such a barrier can be radiant tubes or a muffle.

Effluent is generated when the binder is volatilized during the first part of the heating cycle. This effluent must be properly managed to prevent contamination of the atmosphere in the furnace. The constant flow of nitrogen normally expels the effluent from the brazing atmosphere. When these fumes exit the furnace, the gases must either be burned or diluted with ambient atmosphere, according to the local specification. The law changes from country to country and state to state, so one must check with the local authorities before designing a furnace.

Normally no cleaning is needed after the brazing operation.

5. Corrosion and reparability

5.1. Corrosion resistance

The corrosion resistance of CuproBrazed radiators is better than that of soldered radiators and very competitive with that of aluminum.

When different metallic materials are used in the same cooling system, questions sometimes are raised about possible microgalvanic corrosion risk, considering the noble metal (copper) deposits on the non-noble metal (aluminum) surfaces. Inhibitor systems in the coolant are designed to prevent all kinds of corrosion in the cooling systems, including microgalvanic corrosion and, for this reason, maintenance of coolant is important. In general, however, copper alloys are less sensitive to bad coolant than aluminum.

Corrosion test results in coolants for CuproBrazed materials (including tube brass SM 2385 and header brass SM 2464) are similar to test results for copper-based materials used in soft-soldered radiators. In our study on a mixed-metal cooling system, there was no indication of microgalvanic corrosion on aluminum caused by copper.

Therefore, the coolants that fulfil the standard requirements with copper materials are considered compatible with materials used in CuproBrazed radiators and vice versa. CuproBrazed heat exchangers are compatible with mixed metal cooling systems.

The risks of external corrosion caused by galvanic attacks is minimized by the fact that the materials in CuproBrazed radiators, including the copper-fin alloy, brass-tube alloy and the brazing alloy, have about equal mutual nobility. The brass-tube alloy is 85% copper, which means that the alloy is less sensitive to stress corrosion cracking and dezincification than conventional brass alloys.

The brazing alloy OKC600 (CuNiSnP-type) also provides an extra protective and mechanically strength-

ening coating for tubes. Corrosion test results were recently obtained and have been published. The references were soldered copper–brass radiators and brazed aluminum radiators. According to the results from four different kinds of accelerated corrosion tests, CuproBrazed radiators were generally more corrosion-resistant than soldered copper–brass radiators and very competitive with aluminum radiators. Generally, aluminum radiators were more prone to localized corrosion forms, whereas the corrosion form on CuproBrazed was usually even.

5.2. High performance coatings

CuproBrazed radiators are mechanically strong and facilitate down-gauging. High performance coatings further improve corrosion resistance and make down-gauging possible without risks from corrosion.

There are different ways to increase external corrosion resistance when down-gauging. The easiest way is to leave the commonly used cosmetic coating off totally. An uncoated radiator has approximately 30% longer lifetime than a cosmetically spray-coated radiator.

Electrophoretic coating is the best technical solution to increase corrosion resistance. It increases the lifetime by 2.5–3 times compared to an uncoated radiator. 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.

High performance coatings cover the entire external radiator surface, not only approximately 10% of it like conventional cosmetic-spray coating. They clearly prolong the lifetime of the radiators. These technologies are commercially available.

5.3. Reparability: soldering and re-brazing

Reparability is one of the major advantages of CuproBrazed heat exchangers compared to brazed aluminum heat exchangers.

CuproBrazed radiators can be repaired both at the manufacturing plant and in the field with lead-free soft solders. In the CuproBrazed process, copper–tin, copper–phosphorous and nickel–phosphorous compounds are formed during brazing. Due to decreased wetting of these compounds compared with brass and copper, efficient fluxes have to be used. Many of the fluxes used for brazing of stainless steel can satisfactorily be used for repairing CuproBrazed components. Some of these fluxes leave corrosive residues and careful rinsing of the joints is necessary.

Another repair method at the manufacturing plant is to apply additional brazing slurry at the failure site, dry it and re-braze it, using the same brazing cycle as is normally used in manufacturing. During re-brazing the

610 fins will become slightly softer, and due to increased
611 alloying of the fins, the thermal performance of the heat
612 exchanger may somewhat decrease. The heat exchanger
613 should be re-brazed with the opposite side up compared
614 to the first time, to keep tube-to-header joint sealed and
615 fix any tube-to-header leaks.

616 6. Conclusion

617 New brass and copper alloys offer significant advantages
618 over aluminum for mobile heat exchangers. These
619 new alloys were developed to retain strength at high
620 brazing temperatures; as a result, they can also withstand
621 much higher operating temperatures than aluminum
622 alloys. A brazing center in Västerås, Sweden was established
623 to demonstrate this new brazing process and
624 evaluate the technology through prototype building.

625 Manufacturing processes are now being applied globally
626 in the manufacture of advanced heat exchangers using
627 this technology.

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