CuproBraze®

BRAZING HANDBOOK

LUVATA

Partnerships beyond metals

Forewords

The CuproBraze brazing handbook is a way to share the latest knowledge regarding the CuproBraze process. It deals with technical questions in general. The CuproBraze process is rather young and developments in different areas are still on-going. Therefore, all recommendations in the handbook should be seen as advice, sometimes better or other ways to success can be found. The handbook will be updated from time to time and if there are any questions or other matters which should be included, please contact editors.

The handbook is based on the original manuscript of Leif Tapper, who has retired when this edition comes out.

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Edition Nr 8, September 2006

Västerås, Sweden

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1. General

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 substantial loss in strength.

A Brazing Center has been established to build prototype heat exchangers based on these new alloys and to demonstrate the CuproBraze® process. As a result, CuproBraze® technology is now being applied globally in the manufacture of advanced heat exchangers using the new brazing process described in this manual.

Brazing furnaces have been developed for all capacities of production including batch, semi-continuous and continuous furnaces. This handbook provides an update on CuproBraze brazing technology in use today, and it will be regularly updated with the latest knowledge of the process.

It details trends in the selection of furnaces, the application of filler materials, the assembly of components and the control of brazing operations. The CuproBraze process was specifically developed for the manufacture of automotive and heavy-duty industrial heat exchangers.

By using high-strength and high-conductivity copper and copper alloys, it is possible to manufacture strong, efficient and compact heat exchangers at a low cost with an environmentally friendly process.

1.1 Efficient heat exchangers

The high thermal conductivity and high strength of new copper and brass alloys have changed the rules of design for mobile heat exchangers.

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 heat exchangers of all shapes and sizes, like mobile radiators, heaters and charge air coolers.

In recent years, designers have demanded lighter fins and tubes and hence stronger alloys for more-compact, lighter 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.

1.2 Technology development

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 CuproBraze technology, which is a new process now being applied globally in the manufacture of advanced heat exchangers. CuproBraze technology was specifically developed for application to automotive and heavy-duty industrial heat exchangers. For example, it enables the manufacture of charge air coolers that can withstand higher temperatures than existing equipment, allowing the transportation industry to reduce emissions and increase fuel efficiency by replacing temperature-challenged aluminum charge air coolers with copper-brass counterparts.

1.3 Effects of annealing

The alloys used in conventional copper and brass radiators are designed for soldering below 450ºC. When subjected to high temperatures for long periods, these conventional alloys, soften due to annealing, a well understood metallurgical effect. Annealing rearranges the positions of metal atoms in the metal lattice through solid-state diffusion effectively removing the deformations that would otherwise strengthen the alloys. The resulting decrease in yield strength is particularly steep for metals previously strengthened by rolling or other deformation-hardening processes.

Annealing is time and temperature dependent. Because annealing is based on solid-state diffusion, metals and alloys can significantly lose strength well below the melting point; however, annealing is much more pronounced at temperatures close to the melting point. Process engineers and radiator designers have long been confronted with an “either-or” type of dilemma. Brazing processes promised strong bonds at the joints but brazing weakened the bulk material because of softening. Heat-exchanger designers have been frustrated for several decades by these limitations. The industry had to wait for the development of anneal-resistant copper alloys before further advances could be made.

As an example, figure 1 shows the softening properties for standard fin copper and the CuproBraze fin copper.

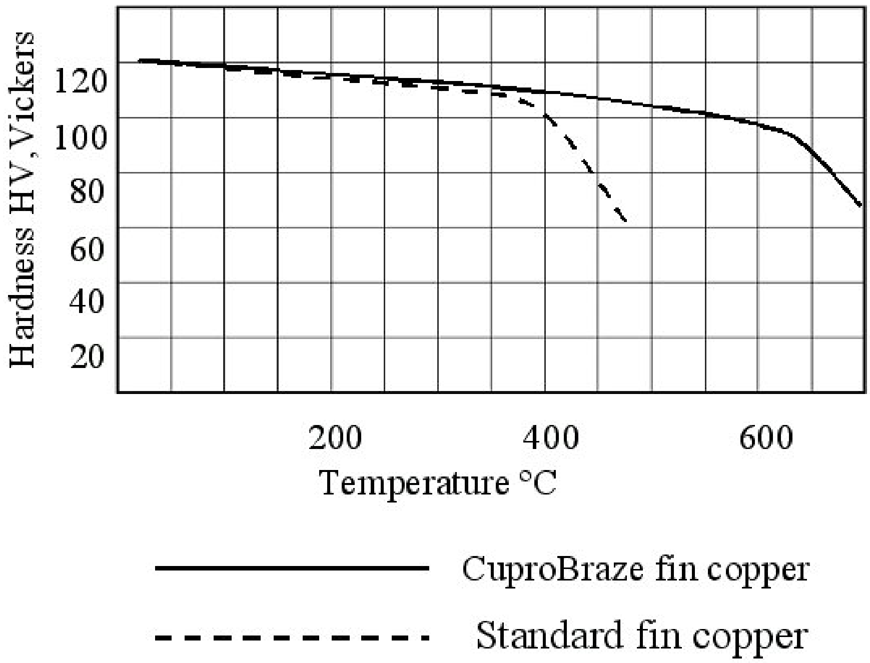


Figure 1. Examples of softening properties for standard and CuproBraze fin copper.

1.4 Soldering and brazing

For decades, manufacturers avoided annealing effects in copper-brass radiators by using solders that melted well below annealing temperatures. These solders were used to bond copper fins to brass tubes and brass tubes to headers, which are the essential steps in radiator 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 that also includes many specialized machines and furnaces have been developed around this industry. The basic process consists 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 450ºC and brazing uses filler metals that melt above this temperature. 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. The capillary force is dependent on the gap clearance, which means that the filler metal flows further into a closer than a wider gap. Oxide and contamination of the surface influence the capillary force negatively. Several factors affect the mechanical performance of the finished joint. For example, joint clearance and geometry are important. In general, the joint strength is higher for narrow joints. Other effects of geometry are the possibilities of slag entrapment and void formation in the joint.

Interactions between the filler metal and the base metal take place in both soldering and brazing. Because of the higher temperatures for brazing, however, interactions 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.

For more detailed information regarding soldering and brazing in general, see references 8, 9 and 10. Many of the companies who sell brazing materials also have useful information regarding brazing in general.

2. Copper alloys for CuproBraze

2.1 Fin material

2.2 Tube material

2.3 Brass material for headers, side supports and similar applications

2.4 Strength at elevated temperatures

2. Copper alloys for CuproBraze

Conventional deformation-hardened alloys soften when exposed to brazing temperatures. Fortunately, researchers faced this challenge and developed strong materials that could withstand the temperatures of brazing up to 670ºC and remain strong. Anneal resistant copper alloys are strengthened by mechanisms other than merely deformation hardening.

In this handbook the basics for the materials for Cuprobraze are described.

2.1 Fin material

The basic alloying element in this anneal resistant copper is chromium. The mechanism of the alloying is that it forms copper-chromium intermetallic compounds. During the casting operation most of the chromium is dissolved in the copper matrix. Before the final rolling procedure the material is annealed and some of the precipitates will be dissolved. In this state there is a lot of chromium in solid solution, and with the consequence that the electrical conductivity is much lower than for standard copper. The electrical conductivity is around 60% IACS, heat conductivity is proportional to the electrical conductivity. The material is delivered to customers in this condition. After the fins have been formed and assembled with the tubes and headers to a core, brazing is done in a furnace at 640°C to 660°C. The brazing process can be regarded as the last heat treatment for this copper alloy. During brazing the chromium in the solid solution precipitates out of solution from the copper matrix. The precipitates that have the greatest effect in preventing softening are 3 nanometers (0.000003 mm) in size. The result is a material that now exhibits an electrical conductivity of around 90% IACS and with the retained strength.

The most used temper for material for normal corrugated fins is called standard temper. For more complicated formed fins, copper in soft temper is recommended.

Nominal properties of the copper-fin alloy before and after brazing are listed in Table 1.

Table 1. Nominal mechanical properties of copper fin materials for CuproBraze .

Properties	**Unit**	**Standard temper**		**Soft temper**	
		Before brazing	After brazing	Before brazing	After brazing
Conductivity	% IACS	60	90	60	90
Yield strength	N/mm^2	340	260	122	160
Tensile strength	N/mm^2	400	330	264	297
Hardness	HV	120	100	69	77
Elongation A_{50}	%	1	10	35	28-30

Because soldering temperatures are not high enough to raise the thermal conductivity, this new copper-alloy fin material must not be used to make conventional soldered radiators. It should only be used for CuproBraze heat exchangers. The CuproBraze brazing operation is needed to restore the thermal conductivity. Additional physical properties for copper fin material are listed in Table 3.

The copper material for Cuprobraze will soften at a higher temperature compared with normal fin copper. Figures 2 and 3 show the softening for the copper fin material for CuproBraze at different holding times and temperatures.

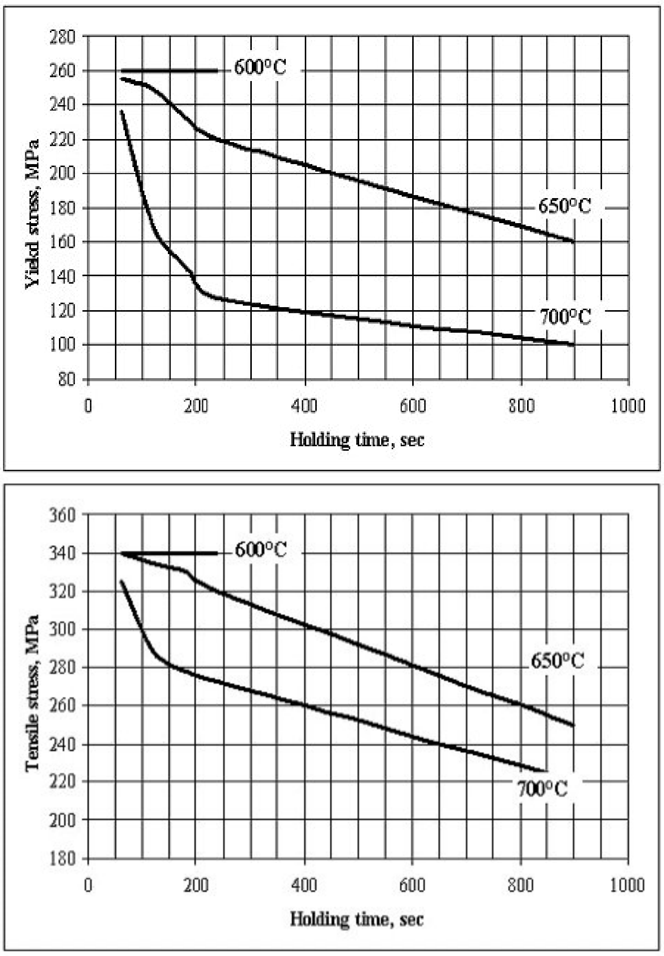
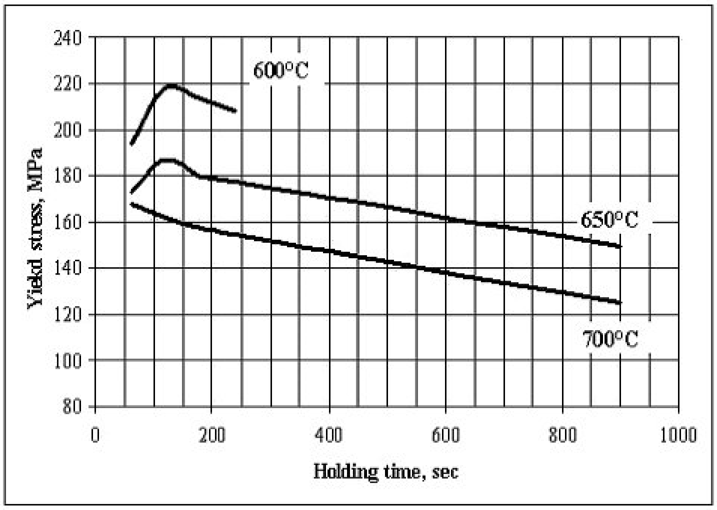


Figure 2. Yield and tensile stresses for standard temper at different temperatures and holding times.



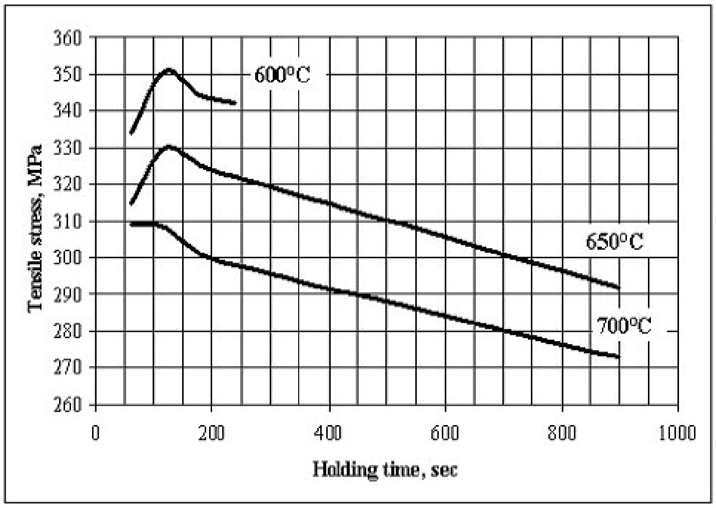


Figure 3. Yield and tensile stresses for soft temper at different temperatures and holding times.

2.2 Tube material

The conventional brass that is used for radiator tubes is of composition 65 -70% copper and 30-35% zinc. The brass alloy that has been developed for higher temperature joining purposes is basically a brass composed of 85% copper and 14% zinc. Figure 4 compares the softening of the yield strength for normal 1070 brass and the anneal resistant brass. To achieve anneal resistance, a mechanism had to be introduced in the material to avoid re-crystallization. The principle that is utilized in this alloy is the use of precipitates that prevent the material to re-crystallize. The brass is alloyed with about 1% iron.

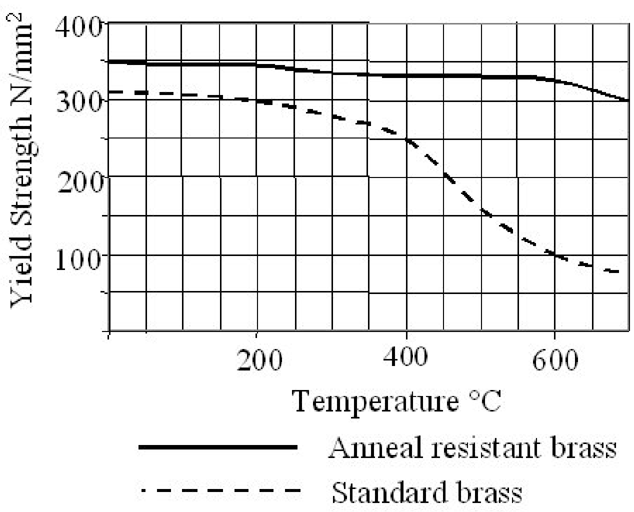


Figure 4. Comparison of SM 1070 brass with the anneal resistant brass.

The iron forms particles that are about 0.2 micrometers in size. That fact, in combination with a very small grain size gives a very high resistance to re-crystallization. Nominal mechanical properties for brass tube materials, before and after annealing, are listed in Table 2. Additional physical properties for the tube material are listed in Table 3.

The basic contribution to softening resistance is the fine grain size coupled with the grain size retention even after being subjected to temperatures as high as 670°C. The grain size of the base material is adjusted to 3 micrometers (0.003 mm).

Table 2 -- Nominal mechanical properties of brass tube material for CuproBraze .

Properties	**Unit**	**Tube brass** SM 2385, C66420 (CuZn14Fe0.9)	
		Before brazing	After brazing
Conductivity	%IACS	35	30
Yield strength	N/mm^2	340	270
Tensile strength	N/mm^2	420	400
Hardness	HV	130	115
Elongation A_{50}	%	25	30

Table 3 - Nominal physical properties of copper and brass materials for CuproBraze .

Physical properties	Unit	Fin copper SM 0502	Tube brass SM 2385,C66420	Header SM 2464
Density	kg/m^3	8900	8750	8500
Melting temperature	ºC	1083	1000 - 1025	910 - 930
Specific heat	kJ/kgºC	0.385	0.380	0.377
Thermal expansion 20-300ºC	ºC^{-1}	17.7x10^{-6}	19x10^{-6}	19x10^{-6}
Young's modulus of elasticity	N/mm^2	118 000	122 000	103 400

When using the tube material for HF-welding, note the differences in melting temperatures and melting ranges (A and B) compared with normal tube brass. See Figure 5 and table 3.

Table 3. Melting properties for tube brasses.

Brass alloy	Melting range ºC	$T_{solidus}$ ºC	$T_{liquidus}$ ºC
SM 1070	40	920	960
SM 2385	15	1010	1025

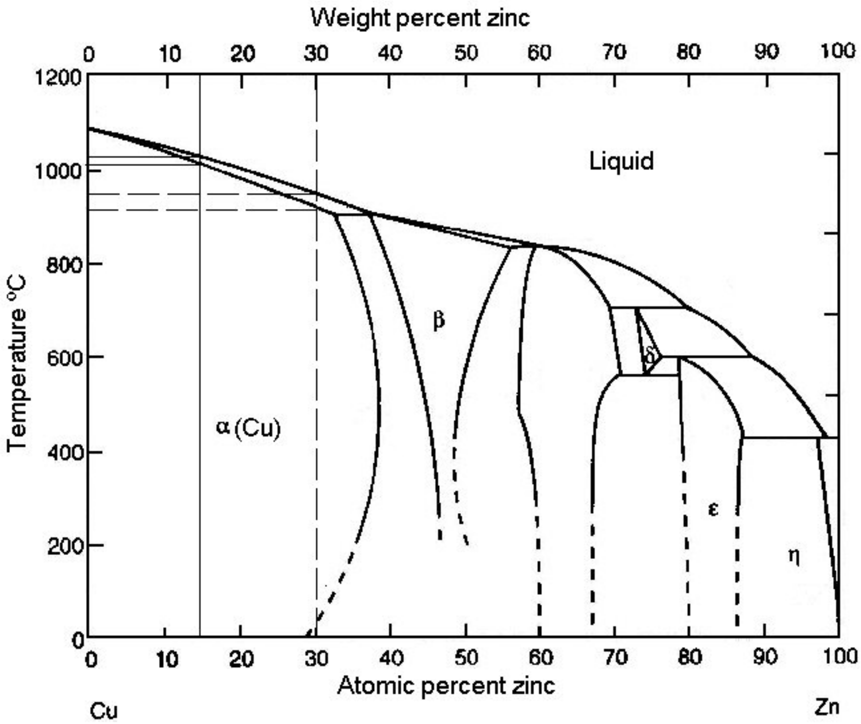
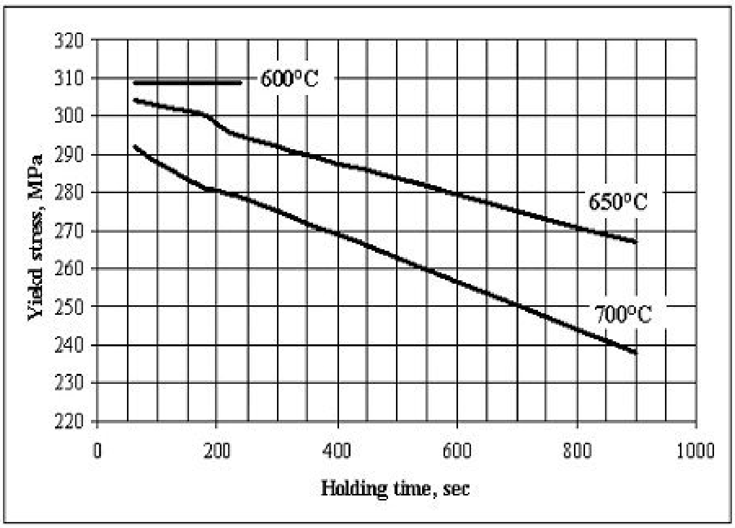


Figure 5. The binary phase diagram copper-zinc showing the differences in melting temperatures and melting range between normal tube brass (SM 1070 dashed lines) and the CuproBraze® tube alloy (SM 2385 solid lines).

This means that higher energy input in the welding coil is needed. The smaller melting range implies a closer control of the welding parameters. Thus the welding parameters have to be adjusted relative Cu70Zn30 brass.

In figure 6 the softening properties for the yield and tensile stresses at different temperature and holding times are shown.



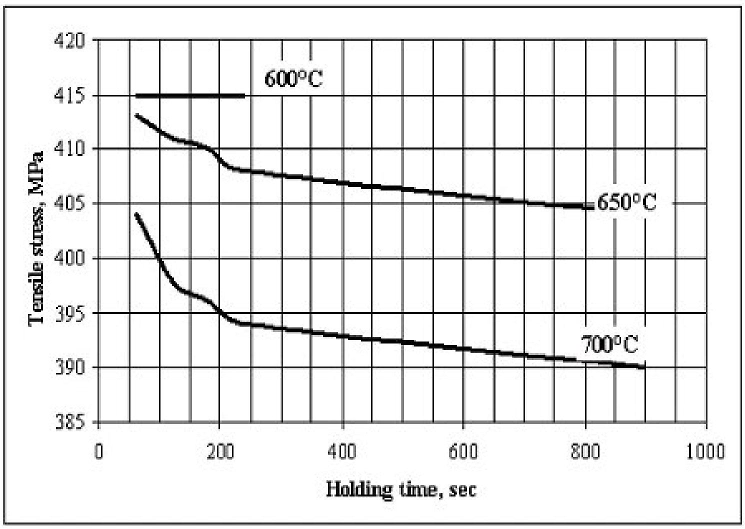


Figure 6. Yield and tensile stresses for tube brass at different temperatures and holding times.

2.3 Brass material for headers, side supports and similar applications

The header brass material is a Cu64ZnNi3 (C74400) brass. It was originally developed for lamp socket production requiring multiple forming processes. The material exhibits excellent forming properties and good mechanical properties even at elevated temperatures. The alloy is solution hardened by the nickel addition and that accounts for the retained mechanical properties after the brazing operation.

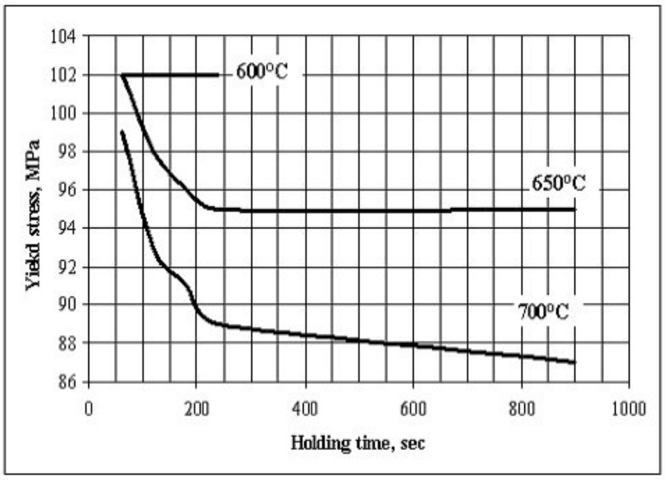
The mechanical data before and after the brazing process are shown in Table 4.

The physical properties of the header brass are shown in Table 3.

Table 4 -- Nominal mechanical properties of brass header material for CuproBraze .

Properties	Unit	Header material SM 2464 C74400 (Cu64ZnNi3)	
		Before brazing	After brazing
Yield strength	N/mm^2	115	105
Tensile strength	N/mm^2	350	340
Hardness	HV	70	67
Elongation A_{50}	%	70	75

In figure 7 the softening properties for the yield and tensile stresses at different temperature and holding times are shown.



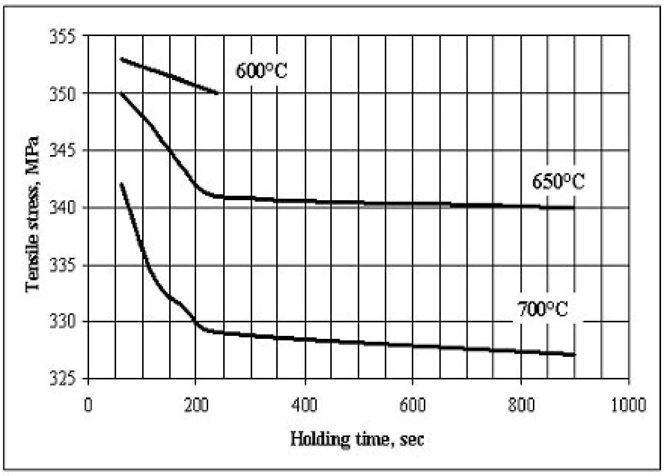


Figure 7. Yield and tensile stresses for header brass at different temperatures and holding times.

2.4 Strength at elevated temperatures

Besides being anneal resistant, the new copper-fin and brass-tube alloys have high strength at elevated temperatures. For example, when the operating temperature is increased from 0°C to 300°C the tensile strength of the brass-tube alloy only decreases from 400 N/mm2 to 260 N/mm2, and the tensile strength for copper-fin alloy only decreases from 350 N/mm2 to 260N/mm2. Similarly, the fin and tube alloys retain much of their yield strength at 300°C.

Figure 8 illustrates the strength at the specific temperature from room temperature to 300°C for the two alloys.

New generations of charge air coolers need to operate at temperatures around 300 ºC. The copper fins and brass tubes described here are well suited for such high-temperature service.

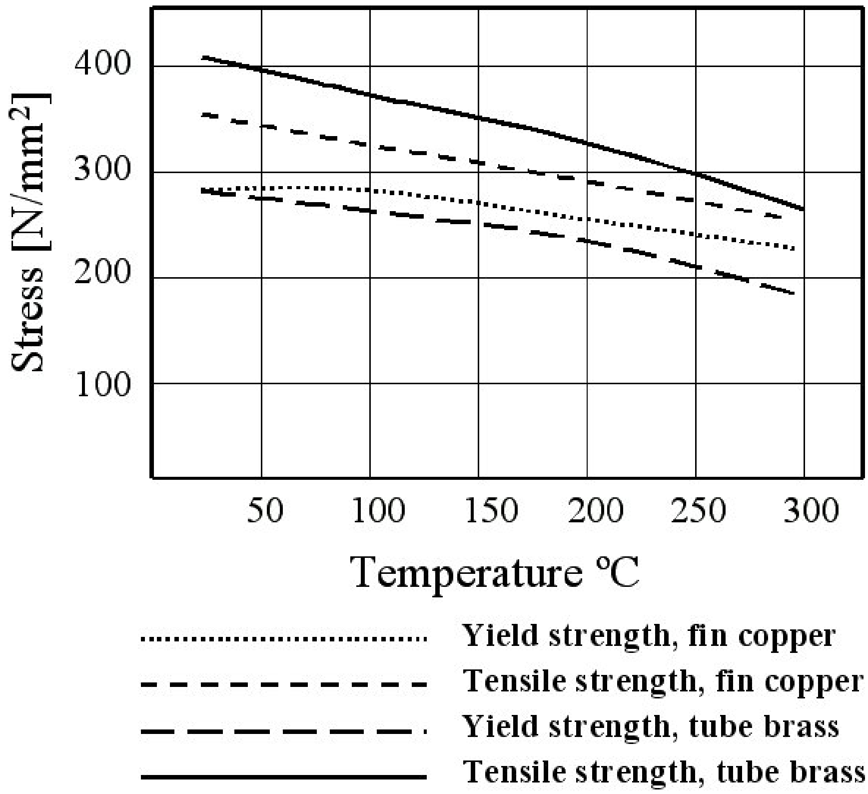


Figure 8. Tensile strength (Rm) and yield strength (Rp) of copper and brass materials for CuproBraze® at elevated temperatures.

3 Filler materials

3.1 Brazing powder
3.2 Brazing foil
3.3 Brazing paste

3 Filler materials

On the market, there are many well-known filler metals for normal brazing of copper and brass. Figure 9 shows melting ranges of some brazing-alloy families.

Cu-P alloys together with one or more other metals are a group of well known brazing materials for copper and copper alloys. A widely used brazing alloy for copper is CuP alloy with 6 %P. The melting range for this alloy is 707 – 850 ºC and could not be used for CuproBraze. Additions of silver and zinc in the CuP alloys decreases the melting point but still the temperatures are too high. Silver is also too expensive to be used for mass production of heat exchangers.

Except for the CuSnNiP-family, no filler metals have so far been found to be suitable for the CuproBraze process. The brazing filler metals used for joining CuproBraze fins and tubes belong to the lower temperature scale of the CuSnNiP-family. Table 5 lists the composition of the brazing alloys that are used in the CuproBraze process.

OKC600 alloy is patented by Luvata (U.S. Patent Number 5,378,294) but can be freely used for automotive and heavy-duty industrial heat exchanger applications. This alloy is mainly used for brazing powder.

VZ 2255 is mainly used for brazing foil but can also be used as brazing powder.

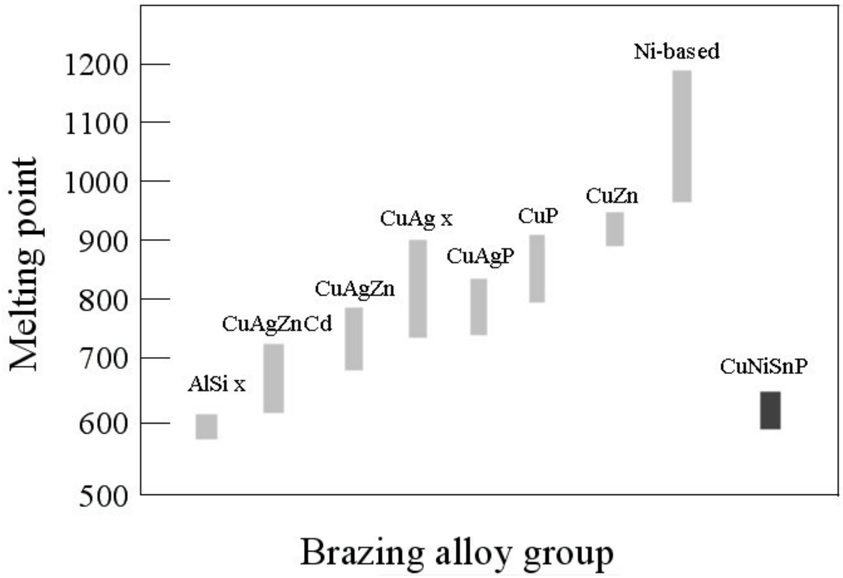


Figure 9. Brazing alloy families and melting ranges.

Table 5. Nominal composition of brazing filler metals for CuproBraze.

Brazing alloy	Copper, Cu%	Nickel, Ni%	Tin, Sn%	Phosphorus, P%	Melting range ºC
OKC 600	Balance	4.2	15.6	5.3	600 - 610
VZ 2255	Balance	7.0	9.3	6.5	600 - 630

3.1 Brazing powder

Cold forming of the filler metals in table 5 is virtually impossible, which means that roll bonding (cladding) of the filler metal on the tube or fin material is not possible. OKC600 filler metal alloy is only available as powder, which can be mixed into brazing-pastes.

The powder is produced by gas atomizing the molten material into spherically shaped, fine-grained powder. Atomization is normally performed using a protective gas such as nitrogen as atomizing media. The atomization parameters are set for a maximal particle size of about 90 µm. Water atomizing of this alloys is not possible due to reactions between the water and the particles forming hydroxides on the surfaces which make brazing impossible.

Depending on the powder manufacturer, the average particle size is normally 15 µm to 30 µm. In practice, each atomized lot is passed through a sieve to exclude particles exceeding 90 µm. Figure 10 shows a typical powder size distribution.

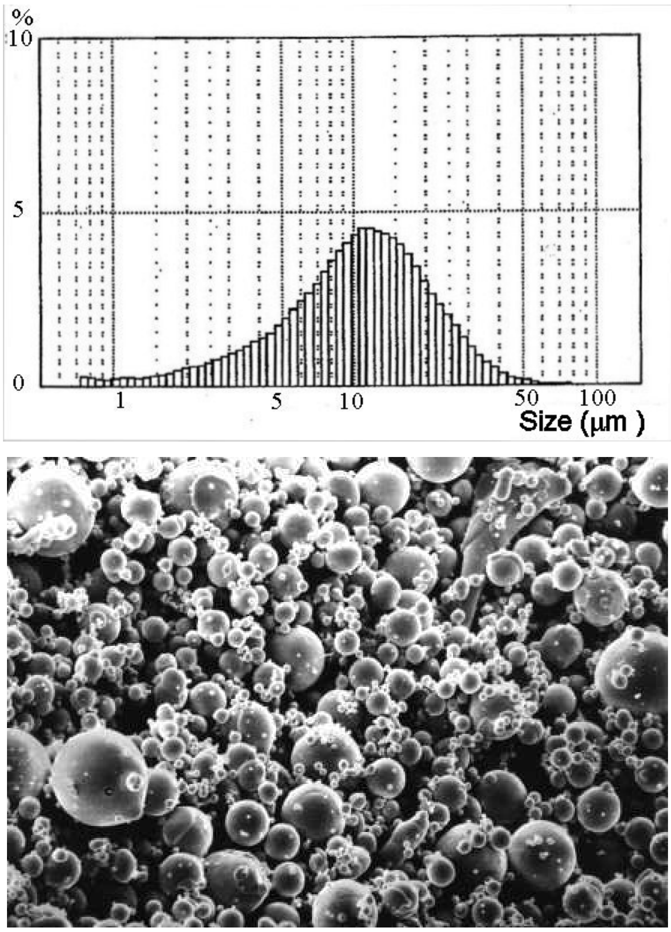


Figure 10. Typical particle size distribution and shape of OKC600 brazing powder.

The fresh atomized powder is very sensitive to oxidation. Therefore, some powder manufacturers reduce the powder to remove surface oxidation. The powder must be protected against oxidation and humidity during manufacturing, transportation and storing. The product data sheets and storing instructions should be carefully followed. In case the powder oxidizes during transport or storage, reconditioning by reduction treatment might be possible by powder manufacturers. (Reduction is the reverse chemical reaction to oxidation).

3.2 Brazing foil

An organic free brazing foil (VZ2255) with a thickness from 20 µm to 40 µm is available for the CuproBraze process. The foil is made in one process step to the final dimension by a Rapid Solidification process (RS). Due to the amorphous structure the brazing foil is completely ductile meaning it could be bent during application without breaking.

In some cases the brazing foil can be more practical than paste and should be considered as an alternative or complementary brazing material to the paste - depending on the process requirements, heat exchanger design and production volume. Especially for brazing inner fin to tubes for charge air cooler and oil cooler and for multi-tube radiator designs the foil could be considered as an alternative brazing material.

The brazing result and joint properties of the foil will be the same as for OKC600 powder/paste. Brazing foil and brazing paste can be combined in one brazing procedure in the same heat exchanger.

The foil (figure 11) is available in the widths of 15-115 mm and a thickness of 20-40 µm. (Contact the foil manufacturer for updated dimensions)

Figure 11: Brazing foil VZ2255 in different foil widths.

3.3 Brazing paste

To make it possible to apply the brazing powder for brazing of the cores, it is mixed with a binder to a suitable brazing paste. The binder is mostly specific for each paste manufacturer, which means that pastes from different manufacturers should not be mixed together. Application can then be done by means of conventional commercial application methods.

The binder is a chemical or a mixture of chemicals and is specific for each paste manufacturer. The binders can contain quite different kinds of chemical groups which mean that mixing of pastes with different kinds of binders can destroy the application and/or the brazing properties. The binders are chosen to decompose or evaporate cleanly below the brazing temperature and without leaving residues on the brazed samples. The binders are also chosen to be environmentally friendly.

All pastes are premixed and are ready to use after stirring. The stirring recommendations from the paste manufacturer should be followed in order to secure good paste applicability. There are pastes with different viscosities to be used at different kinds of joints, as well as different application methods. Contact the paste manufacturer to use the right kind of paste.

There are two main different types of binder system, solvent-based and thermoplastic. The solvent-based binders are dissolved in a solvent. The solvent is evaporated during drying, leaving a hard binder and if the binder is mixed with brazing powder, it will give a hard coating after drying which only could be re-dissolved in a solvent.

The pastes have normally long shelf life. For detailed information regarding the paste properties, contact the paste manufacturer.

► **Important**

Do not make a mixture of pastes from different manufacturers, as they may not use the same binder system.

4. Paste application

4.1 Paste on tubes
4.2 Paste on fin tips
4.3 Tube-to-header joints

4. Paste application

Brazing pastes are used to form joints between the tubes and the fins as well as to join the tubes to the header. Tank to header and other kinds of joints can also be brazed
For tube-to-fin joints, brazing paste can be applied either on the tube surfaces or on the fin tips, see figure 12

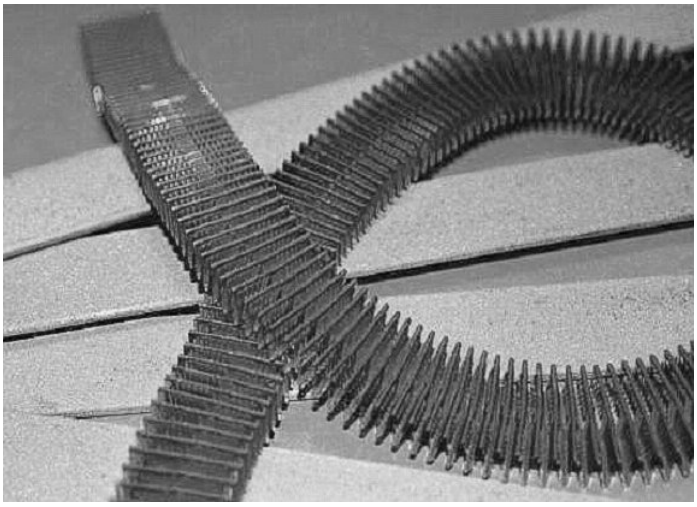


Figure 12. Paste applied on the fin-tip or as tube coating

A layer of paste can be applied on the surfaces of the heat exchanger parts by many different methods, such as spraying, dipping, roll coating etc.

Except for the thermoplastic pastes, the pastes have to be dried, normally with warm air. Good temperature control during heating and drying is needed to prevent overheating and subsequently poor brazing results. The brazing properties of the pastes can be destroyed above 130ºC. Instructions from paste suppliers must be followed.

Most of the brazing pastes involve some kind of solvent, which can form effluents during drying. Contact the paste-manufacturer for more information.

► **Important**

Do not overheat the paste during drying.

4.1 Paste on tubes

4.1.1 Spraying

The method most commonly used today is spraying with commercial spray guns. As an example, tube coating, manually as well as automatic spraying is illustrated in figures 13 and 14. Due to the drying time for the paste, it is so far not possible to have the spray coating in line with the tube welding equipment. By turning the tubes 90º, it is possible to match the coating speed with the welding speed.

As pastes from different manufacturers can have different spraying properties as well as drying time, the settings of the applying parameters sometimes have to be changed.

The coating is not a homogenous brazing metal, instead it is formed with particles and binder and after drying can also be porous, which means that the coating thickness for a certain weight could differ from spraying methods as well as type of paste. Therefore the amount of brazing metal should be measured as weight/area.

Coatings should be evenly applied with a coating weight of 150-250 g/m2 after drying, formula 1 shows a calculation of the amount of paste on tubes related to these values. Table 6 shows these amounts of paste related to some tube dimensions. The better the tolerances of the tubes and fins, the thinner the layer can be. It is recommended to start with the thickest (heaviest) coating.

$$A = L \times 2(H + W) \times P \quad [1]$$

Where

A: the amount of dried paste on the tube
L: the length of the tube
H: the height of the tube
W: the width of the tube
P: the preferred amount of paste/m^2

Table 6. Recommended amount of paste for some tube dimensions

Tube Dimensions mm	Amount of paste g/m^2	Amount of dried paste g/m tube
16x2	150	5.4
16x2	250	9.0
19x2	150	6.3
19x2	250	10.5
40x4	150	13.2
40x4	250	22
60x6	150	25.8
60x6	250	43

Pastes which have a high metal content and which leave a smooth surface after drying are preferred.

It is recommended not to coat the tube ends. If the tube ends are coated it can sometimes have a negative influence on the joint quality of the tube-header joints.

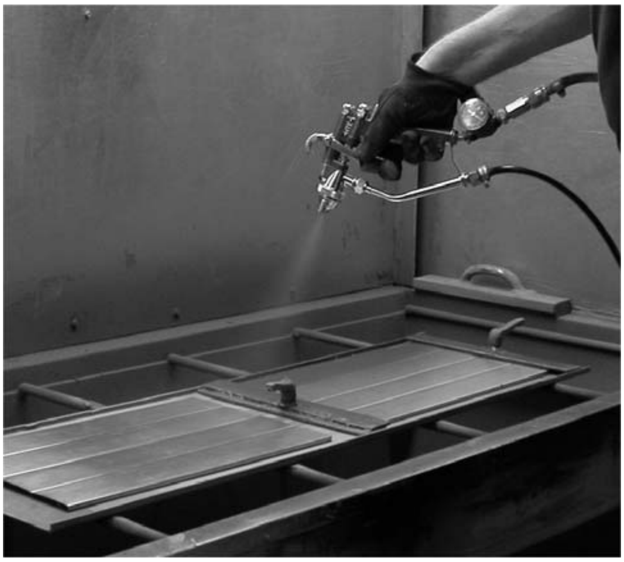


Figure 13. Manual tube spraying of charge air cooler tubes.

Figure 14. Automatic spraying of paste on radiator tubes. Both sides are sprayed simultaneously. The picture shows the upper spray gun.

Depending on the storage area atmosphere, the coated tubes can be stored for days up to several months. The storage should be clean and with no contamination of the coating.

This coating method consumes more paste than needed for the tubes (over-spraying). Work is going on to minimize this amount.

4.1.2 Development of tube coating methods

Work is going on to develop not only the paste spraying but also other coating processes, e.g. thermal spray. The new developments will probably be commercially available during 2007, with options for coating online tube-mill or offline, whichever is preferred.

► **Important**

The amount of filler metal for all tube coating methods shall always fulfill the amounts shown in table 6.

4.2 Paste on fin tips

Consumption of brazing paste could in most cases, depending of the fin density, be lowered by applying the paste on the tips of the fins rather than on the tubes. Thermoplastic pastes, as well as some solvent-based pastes, are suitable for fin-tip application.

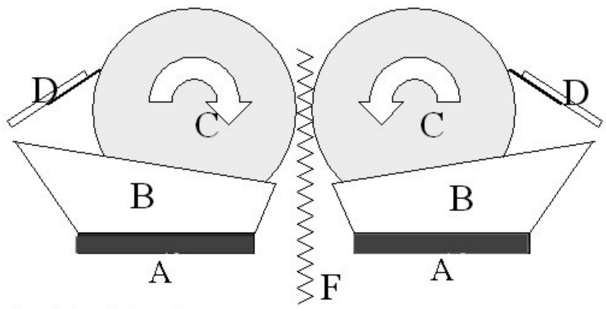
The coating thickness is measured by weighing; the recommended amount of paste on each tip is 0.3 mg/mm to 0.5 mg/mm of fin width. Again, the better the fit between fin and tube the smaller the amount of paste application on the tips. Table 7 shows some examples of amount of paste for some fin widths and density. In the table fpi is the number of fin tips per inch.

The fin tips are coated by contact with paste coated rolls. When using thermoplastic paste, the fins pass through a pair of rollers and are coated in one step. This principle is shown in figures 15 and 16. When using solvent-based pastes, the tips of the fins are coated on one side at a time with drying between.

Depending of the storage atmosphere, the coated fins can be stored for days up to several months. For all types of storages, it should be clean and with no contamination of the coating.

Table 7. Example of the amount of paste on the fin tips.

Fin width mm	**Paste** g/tip	**Paste,** g/m fin		
		15 fpi	**20 fpi**	**25 fpi**
16	0.008	4.7	6.3	7.9
20	0.01	5.9	7.9	9.8
40	0.02	11.8	15.7	19.7
60	0.03	17.7	23.6	29.5
80	0.04	23.6	31.5	39.4
100	0.05	29.5	39.4	49.2



A: electrical heaters
B: containers for hot thermoplastic paste
C: Hot rolls
D: Scrapers to set the amount of paste on the rolls
F: fin

Figure 15. Principle for coating fin tips with thermoplastic paste.

Figure 16. Fin-tip coating in practice.

4.3 Tube-to-header joints

A dedicated paste (sometimes called slurry) is recommended for tube-to-header joints. This paste has a lower viscosity than the pastes for tube or fin-tip coating and can be applied by pouring or spraying. Normally the paste is applied on the airside of the header. The volume of the paste is around double the volume of the filler metal in the joints after brazing. The visible amount of paste should therefore be more than what the joints are expected to be after brazing. The amount of paste required is typically 0.5 g (dry weight) per tube end for 16mm wide tubes and 1.8 g per tube end for 60x6mm tubes. These quantities are just guidelines, as the amount of paste is influenced by the geometry of the joint. Formula 2 shows guideline for calculating the amount of paste for other tube dimensions.

$$E = (H + W)/36 \quad [2]$$

Where

E is the amount of dried paste on the tube end
H is the height of the tube
W is the width of the tube

And for a total amount on a header

$$N \times (H + W)/36$$

where ***N*** is the quantity of tubes in the header

For multi row cores it is important that the paste is evenly distributed at all joints.

In practice, a small amount of flux can be added to this kind of paste to make the brazing process more forgiving when slightly oxidized components are used. Developments are in hand to find a flux-less paste for this application, too. The paste application methods are well suited for automation. Figure 17 illustrates the principle of paste application to headers. For small production the paste can be applied manually as shown in figure 10. When coating and drying manually, do not overheat the paste. The brazing properties will be destroyed if the paste is heated above 130ºC.

It is recommended to braze the parts within 1-2 days after applying header paste, depending on the storage atmosphere.

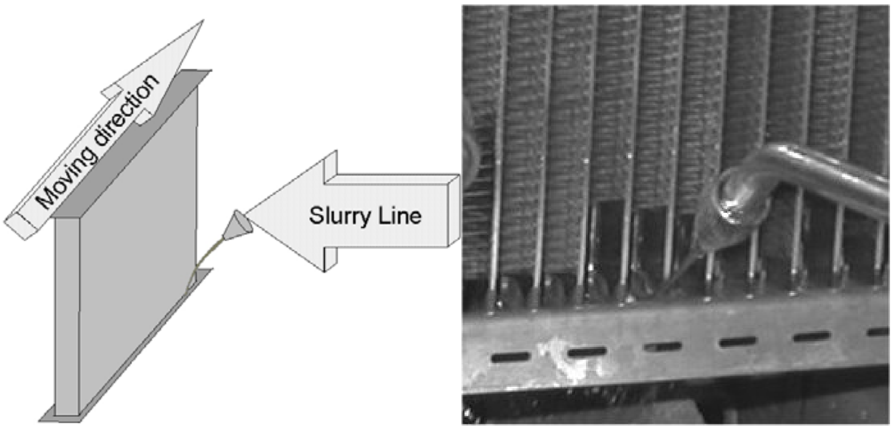


Figure 17. Method of applying paste on headers. In an automatic line, the paste can be applied on both sides simultaneously.

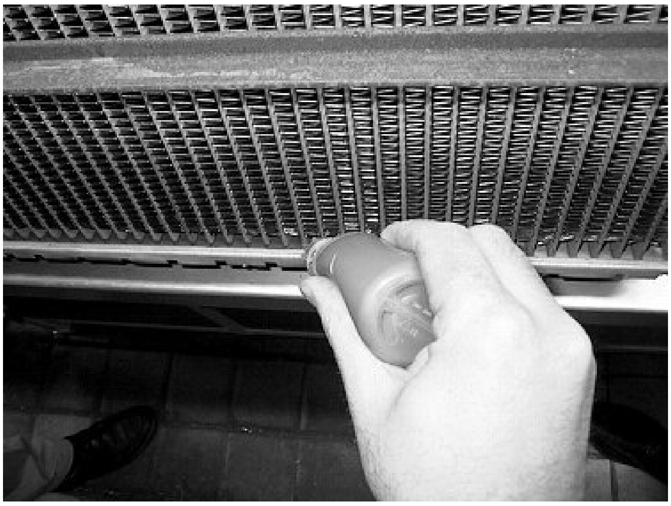


Figure 18. Manual applying of header paste.

▶ **Important**

The brazing properties will be destroyed if the paste is heated above 130 ºC during drying.

5. Fabrication and assembly of components

5.1 Tube fabrication
5.2 HF-welded tubes
5.3 Folded tubes
5.4 Fins
5.5 Headers
5.6 Surface conditions.
5.7 Brazing fixtures and assemblies

5. Fabrication and assembly of components

All furnace brazing operations, among them CuproBraze, require narrow tolerances. Generally, closer tolerances and well-defined joint gaps result in better and stronger joints, see figure 19.

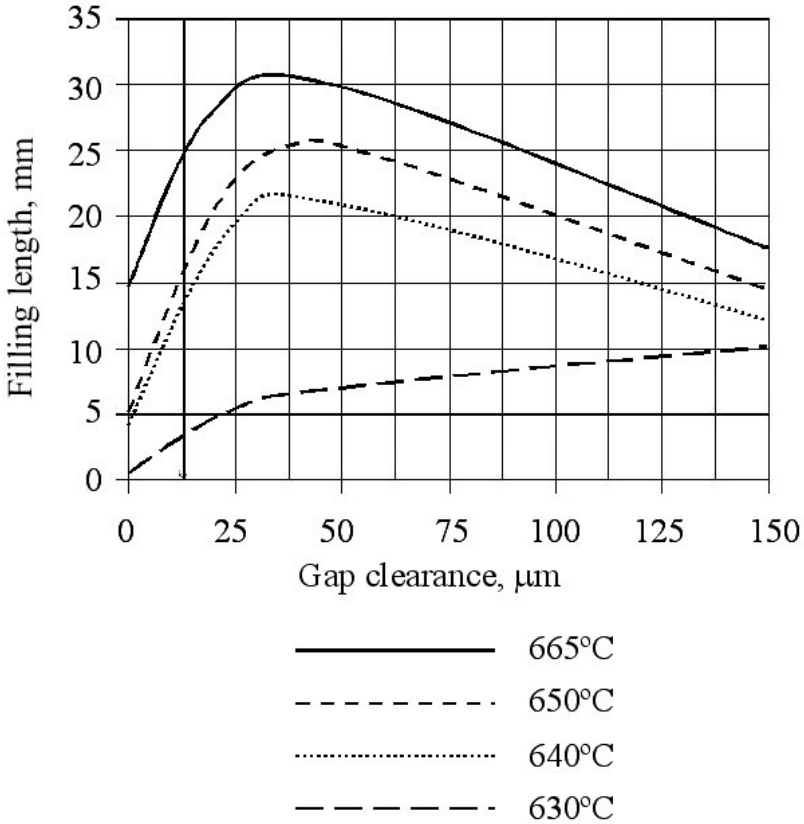


Figure 19. Diagram showing filling length in gap with different clearance.

Another factor to take into account is that the brazing alloy is in powder form and it builds up a thicker layer than a solid metal. The geometry of the tubes and fins and the tube pitch in the header should be adjusted accordingly.

5.1 Tube fabrication

Several types of brass tubes can be used to manufacture CuproBraze heat exchangers. These tubes are uniformly made from strip because thin gauges are required for lightness and efficient heat exchange.

Tube fabrication requires that the edges of the strip are reliably bonded together. The tube seams can be sealed during the brazing process or they can be welded prior to the brazing process.

Tubes for use in the CuproBraze process should be specified with a crown that is higher compared to the crowns of tubes for use in a soldering process. The crown (see Figure 20) should be 0.4mm to 0.8mm for tube widths 12mm to 25mm. A higher crown results in a more consistent bond between tube and fin, see chapter 11.

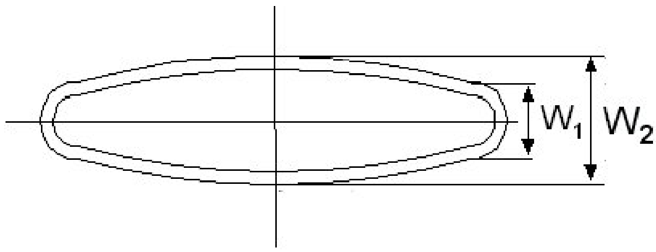


Figure 20. Definition of the crown on the tube. Crown is $W_2 - W_1$.

► **Important**

Tubes for use in the CuproBraze process should be specified with a crown that is higher compared to the crowns of tubes for use in a soldering process.

5.2 HF-welded tubes

High frequency (HF) welded tubes are most commonly used today for CuproBraze heat exchangers because their contoured shape is uninterrupted around the circumference of the tube. As a result, a consistent gap can be achieved between the tube and the header. HF-welded tubes are commercially available.

When welding tubes of brass strip for CuproBraze, note the differences in the material performance as described in part 2.2. as this can effect the settings of the welding parameters.

When bare CuproBraze tubes are produced, careful rinsing and drying are needed to avoid discoloration.

►   **Important**

Note the differences between normal and CuproBraze tube materials when HF-welding

5.3 Folded tubes

Folded tubes can be made of thinner brass strips (gauges down to about 0.080 mm). In the solder process the most common folded tube uses the lock-seam fold. This type of tube can also be used for the CuproBraze process but new tube designs offer advantages over the lock-seam design. The folded design (called snap-over) and B-fold design are just two types of tubes being tested for CuproBraze heat exchangers. Spraying of paste on the surfaces of the tubes does not result in a leak-tight seal at the seams. Folding methods include injecting the overlapping parts with a bead of brazing paste in the tube mill. Paste injection has to be performed correctly for optimal brazing results. To get optimal fatigue properties of the tubes, the paste injection should secure complete joints on the water side of the tubes. Figure 21 shows cross section of one type of folded tube.

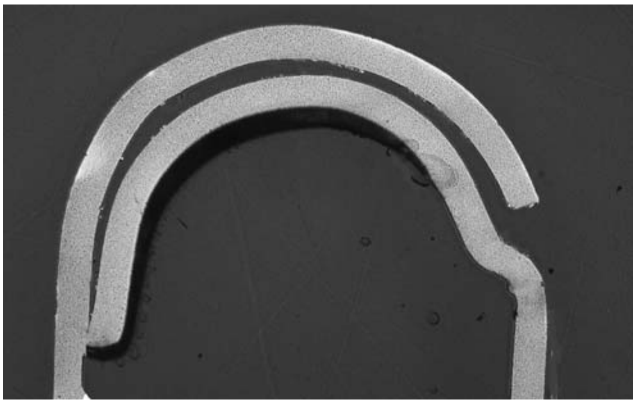


Figure 21. Cross section of one type of folded tube after forming.

5.4 Fins

Consistency in the fin amplitude is also important. Inconsistency in the fin height can result in a gap that is too large between fin tip and tube, and a low percentage of correctly brazed tube-to-fin bonds. Also unnecessary amounts of brazing paste on the tubes will be used. Variations from fin-tip to fin-tip should be at an absolute minimum.

5.5 Headers

The holes in the header can be designed and manufactured in different ways. (See Figure 22.) For the CuproBraze process, pierced holes are recommended using a two-stage operation, which creates a continuous collar of contact surface area between the header and the subsequently inserted tube. This shape draws braze alloy from the surface of the header into the joint by capillary action. The optimum capillary action is reached at 0.05 mm joint clearance which means that the optimal size for the gap between header and tube is 0.05mm and this gap should not exceed 0.1mm. No tears are allowed in the joint section.

Stiffening ribs on the header are also beneficial (See Figure 23). Besides functioning as reinforcement, ribs lower the slurry consumption. Paste flowing into the wells around the tubes is not wasted on areas between tubes. When header gauges are smaller than 0.8mm (0.03in), extra care is recommended with tabbed header design from the strength point.

The type of oil used in the stamping process normally leaves unwanted residues after brazing, this negatively influences the brazing of the tube-header joints.

► **Important**

If the stamping oil gives this problem, which can be seen as dark surface of the header after brazing, the headers have to be degreased before assembling.

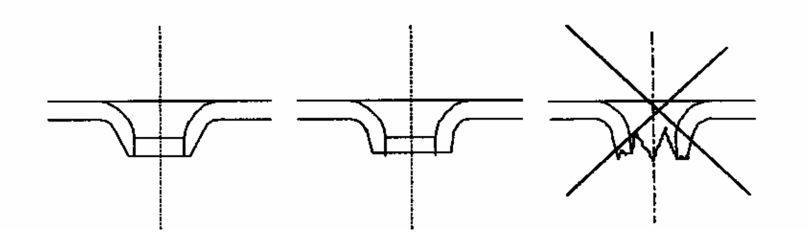


Figure 22. Pierced holes (left and middle) in header are recommended. Lanced holes (right) are used for soldering but are not recommended for brazing.

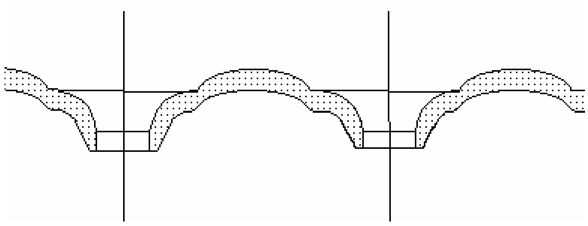


Figure 23. Stiffening ribs on header.

► **Important**

Optimal size for the gap between header and tube is 0.05mm, this gap should not exceed 0.1mm.

5.6 Surface conditions

At the brazing temperature, the surfaces of the components to be joined, as well as the brazing powder must be free from any non-metallic films, such as organic residues and metal oxides. In the brazing process, there is nothing, which can remove any dirt, heavy oils and oxides. To be able to wet and alloy with the components, they have to be clean before brazing. All storing of the components must be done in such a way that no contamination of any dust, chemicals and oxides take place, especially the paste coated parts that are very sensitive.

Most types of oils on copper and brass surfaces will form black or even invisible organic residues after heating in nitrogen atmosphere. The residues will be very thin films, which sometimes can be difficult to remove.

Oils with low boiling point do not normally form this kind of organic residues.

► **Important**

The oil on the surfaces after fin and tube production, are normally not harmful.

5.7 Brazing fixtures and assemblies

As previously mentioned, the brazing powder builds up a thicker layer than a solid metal of the same weight. This extra thickness must be taken into account when specifying tube pitch in headers and brazing-fixture devices.

The tube pitch (see figure 24) in the headers is a function of the tube width and fin amplitude with an allowance for a brazing paste layer. The allowance for brazing paste in turn depends on the tube dimension, the core width and the fin design. The brazing paste allowance has to be determined with actual components. As a guideline, increasing the pitch by 0.10mm often works well, resulting in a complete brazed joint between fin and tube. But for optimal brazing result, it is recommended to check the brazing result between the tubes and the fins for the first sample before further work. Figure 25 illustrates the shape changes of the tubes during compression of the core. See also figures 20 and 23.

The virgin tube has a convex belly, when the tube is compressed it starts flattering. If it is compressed too much, the tube walls will be bent inwards in the centre and become concave.

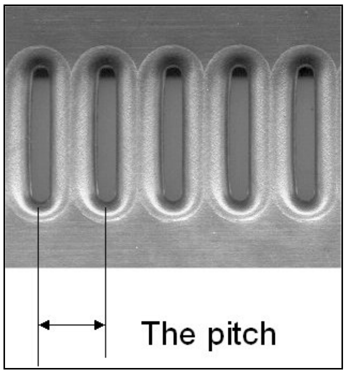


Figure 24. Definition of the tube pitch.

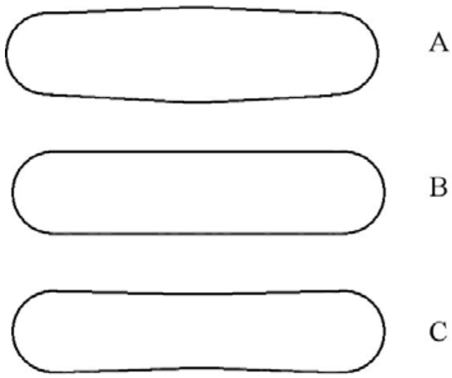


Figure 25. The figure illustrates what happens to the tubes during compression of the core. The virgin tube (A) is convex, when the core is compressed to right dimension the tube sides are flat (B). If the core is compressed too much, the tube is formed like a "dog-bone" (C).

In the CuproBraze process the parts go through a temperature-cycle from room temperature up to 650ºC, which means that the differences in the thermal expansion will influence the fixture design. Table 8 shows the thermal expansion coefficient and the expansion for 1 meter of the material from 25 ºC to 650 ºC.

Table 8. The heat expansion and the increase in length (Δl) from 25ºC to 650ºC for 1m long object.

Material	**Heat expansion coefficient** μm/mºC	**Δl** for 25º– 650ºC in mm
Copper fin SM 0502	17	10.6
Tube brass SM 2385	19	11.9
Header brass SM 2464	20	12.5
Steel	11	6.7
Stainless steel	15	9.4

The assembly and brazing-fixture system should allow for the convex shape of the core before brazing, due to build-up of brazing paste and the heat expansion of the fixture. For a 500mm x 500mm core, a typical dimension measured in the middle of the core is 502.5mm to 503mm.

Another requirement of the brazing fixture is the demand for a reduced mass that allows the fixture to follow the temperature of the radiator core as closely as possible. This arrangement prevents differences in dimensions due to temperature variations 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, favouring stainless steel instead of plain steel.

A slight flexibility in the fixture (to allow it to follow the core when the brazing paste melts) is also recommended, especially for larger cores.

Due to the differences of the heat expansion for header brass and the steel in the fixtures, especially careful work has to be done when designing the fixtures in the corner area of the cores. Figure 26 shows schematically what happens in this area during brazing.

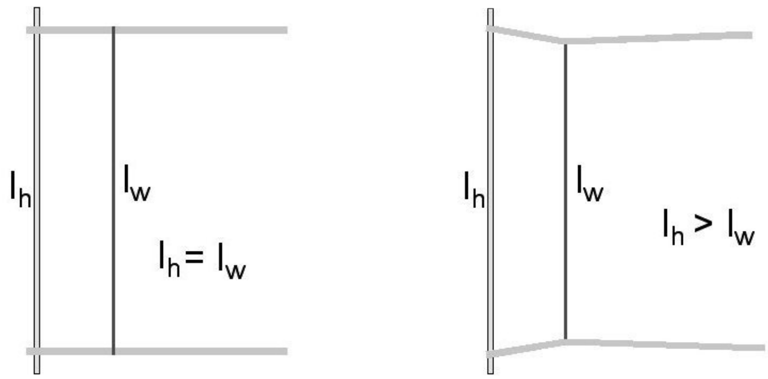


Figure 26. Principles for the influence of the heat expansion in the corner of the core. At room temperatures (left) and at brazing temperatures (right).

In figure 26, l_h is the distance between the outer tubes and l_w is the length of the steel fixture. At brazing temperature, the steel fixture is shorter than the distance between the outer tubes. If the steel part is too short from the beginning or the fixture is placed too close to the header, the outer tubes will be crushed and leakage in the tube-header in the corner area will appear.

It is 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.

6. Brazing operation

6. Brazing operation

Because the amount of flux in the CuproBraze process should be zero or absolutely minimal, and the parts should be oxide free after brazing, an inert atmosphere is needed to prevent oxidation of the parent and filler materials. As the brazing temperature is much lower than the melting points for the copper and brasses, the temperature differences in the parts during the brazing process are not critical. As the CuproBraze process covers parts from around 100 g up to more than 100 kg it is not possible to advise exact settings of the furnaces.

6.1 Atmosphere

The primary function of the brazing atmosphere is to prevent oxidation. Furnaces for the CuproBraze process use high-purity nitrogen to displace oxygen from inside the furnace. The atmosphere of the furnace must have an oxygen content of less than 20ppm. The brazing powder is very sensitive when the binder starts to evaporate, If moisture and oxygen levels are higher than these levels, the powder and the base material have a risk of oxidation at temperatures exceeding about 200ºC the and the result is very poor joints. Thus the starting point of the brazing cycle is as sensitive for oxygen-content as the rest of the brazing cycle.

Mixing the brazing atmosphere with small amount of hydrogen (H_2) is not generally recommended. Hydrogen can sometimes react with the organic binder forming products which can have an influence on the brazing result. Before using hydrogen or hydrogen mixed atmosphere, the paste manufacturer should be consulted.

► **Important**

The oxygen content should be controlled from the time when the heating starts and no heat should be applied if the atmospheric conditions are not met.

6.2 Temperature and time

The difference in the melting points for the filler metal and the copper and brass materials is more than 300 ºC, which means that there is no risk to destroy the parts by melting. The temperature above the melting point for the filler metal (600 ºC) should be as short as possible but still gain a satisfactory brazing result. It means that the furnace must be able to heat up the load in the brazing zone with a steep ramp. A common value is more than 30 ºC per minute. The furnace must be able to operate up to 700ºC. Figure 27 shows a principle temperature-time curve for the CuproBraze process.

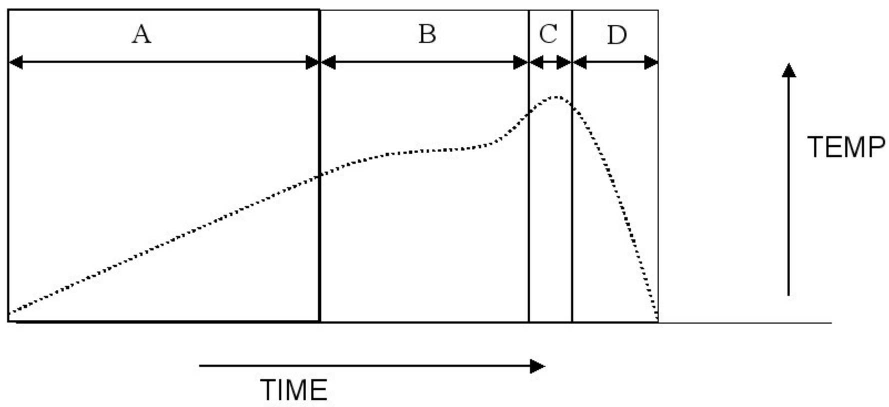


Figure 27. Principle temperature-time curve for the CuproBraze process.

In the part A, the sample is slowly heated up and the binder evaporates and/or is decomposed. When the binder disappears, it leaves the particles in the brazing paste without any protection from oxidation if the oxygen content is too high. The oxygen content should therefore be controlled from the time when the heating starts and no heat should be applied if the atmospheric conditions are not met. The brazing result will be poor if the brazing powder is oxidized before it starts to melt. Note that some big heat exchangers as well as "one shot" parts can include a lot of small half closed volumes, which could influence necessary time to reach satisfactory oxygen content. Good convection in the furnace is therefore recommended.

By the rather slow heating rate in this zone, the temperature differences in the samples are minimized, and the distortion of the sample due to heat expansion can also be minimized.

In part B the whole core will be preheated to just under the melting point of the brazing metal. To minimize the temperature-difference in the core at brazing, the part B should be designed so the temperature in the whole sample is as equal as possible when the brazing part is entered. In some batch furnaces, there is no pre-heating and in that case furnace settings that minimize the temperature differences in the sample have to be used.

Part C is the brazing period. When the temperature exceeds 600ºC, the brazing filler metal (powder or foil) starts to melt. When it melts, metallurgical reactions (diffusion) starts and the extent of the filler-substrate interaction is the most important. The filler interaction on the fin material is when it starts to be alloyed with tin, forming a copper-tin alloy close to the joint. It does not influence the performance except for exceptional long brazing times, where some loss of thermal performance (up to 10 %) of the heat exchanger can occur. The governing factor for the brazing cycle in most cases is the brazing of the tube-header joints. In chapter 5 figure 11 it is shown that the brazing temperature has a big impact on the possibility to satisfactory fill gaps. In practice it has been found that to satisfactorily wet the surfaces and fill the joints, you should ensure that the temperature in the joints reaches 650ºC or for some cases even 670ºC.

As the alloying reaction starts when the molten filler metal wets the surfaces, the time above 600ºC should be as short as possible but long enough to reach complete brazing in tube-header joints., For small radiators, 3 to 4 minutes is typical. For bigger parts the time is guided by the tube-header brazing.

To reach short brazing times, usually the setting of the brazing part (A) of the furnaces is higher than 650ºC.

The effect of the brazing cycle on the tube-to-fin joints cannot be seen by the naked eye. During optimization of the brazing cycle, overshooting of the brazing temperature can sometimes happen, but it will not lead to any noticeable visual effect on the brazed heat exchanger as the melting point for copper and brass is far higher than the brazing temperature.

To minimize the risk for distortion of the joints during cooling (part D), it is recommended to have a low cooling rate down to around 550ºC, typical value 1ºC/s.

To prevent discoloration of the brazed parts, they should not leave the inert atmosphere until the part temperature is below 150ºC. In places where the ambient humidity is high the exit temperature should be even lower to prevent discoloration. Note: This discoloration is only a cosmetic effect and it will not deteriorate the brazed joint.

At least during optimization of the brazing cycle, it is highly recommended that some kind of measurement of the temperature with thermocouples mounted in the core should be used. To have full control on the brazing process, it is recommended to also have this equipment available to check the process every now and then during normal production. If it is not possible to use the thermocouples together with equipments outside the furnace, it is recommended to use them with a tracker following the sample through the furnace.

The brazed part should be cooled down as uniformly as possible at least in the first phase to prevent deformation. The temperature drop should be equal in the whole core. One way to achieve this is to slow down the cooling to around 550ºC. At that temperature, the filler metal in the joints is no longer molten.

To satisfactorily wet the surfaces and fill the joints, ensure that the temperature in them reaches 650ºC or for some new types of header pastes even 660ºC.

7. Selecting a furnace

7. 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 these specifications, the CuproBraze heat exchangers can be processed in batch, semi-continuous or continuous furnaces.

Selecting a suitable furnace requires knowledge of the temperature, time and atmospheric conditions of the process. All of the 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 high volume production.

7.1 Batch furnace

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; after brazing, the load is moved back into the purge chamber where it is cooled.

7.2 Semi-continuous furnace

In a semi-continuous furnace 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. This type of furnace is suitable for large parts or intermediate volume production.

7.3 Continuous furnace

A continuous furnace uses a conveyor-belt 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 a much longer time than the leading edge of the part.

7.4 Heating source

It is possible to heat all 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.

7.5 Process emissions

Process emissions are generated when the binder is volatilized during the first part of the heating cycle. These emissions must be properly managed to prevent contamination of the atmosphere in the furnace. The constant flow of nitrogen normally expels the vapour from the brazing atmosphere. As there is no oxygen available to burn the gas products in the furnace, the gases must either be burned outside the furnace or diluted with ambient atmosphere, according to the local regulations, requiring, in most cases, some kind of afterburner. The laws vary from country to country and state to state, so one must check with the local authorities before designing a furnace. The generated emission is influenced by the binder system and could be totally different between paste manufacturers. Further information regarding the emissions, and further handling of them, are obtainable from paste manufacturers.

► **Important**

Most of the binders form emissions. Contact the paste manufacturer to check if any kind of afterburner must be used.

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8. Corrosion Resistance

8. Corrosion Resistance

8.1 Cleaning after brazing

Normally, no cleaning is needed after the brazing operation.

8.2 Internal corrosion

The corrosion resistance of CuproBraze radiators is generally 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 micro-galvanic corrosion risk, considering that the noble metal (copper) deposits on the unnoble 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, the maintenance of the coolant is important. In general, however, copper alloys are less sensitive to a bad coolant than aluminum.

Corrosion test results in coolants for CuproBraze 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 a study on a mixed-metal cooling system, there was no indication of micro-galvanic corrosion on aluminum caused by copper. Therefore, the coolants that fulfill the standard requirements with copper materials are considered compatible with materials used in CuproBraze radiators, and vice versa. CuproBraze heat exchangers are compatible with mixed-metal cooling systems.

8.3 External corrosion

The risks of external corrosion caused by galvanic attacks is minimized by the fact that the materials in CuproBraze radiators, including the copper-fin alloy, brass-tube alloy and the brazing alloy, have about equal mutual nobility. The brass-tube alloy contains 85 percent 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 strengthening coating for tubes. Corrosion test results 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, CuproBraze 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 CuproBraze was usually even and thus predictable.

8.4 Coatings

CuproBraze radiators are mechanically strong and facilitate thickness reductions High-performance coatings further improve corrosion resistance and make thickness reductions possible without risks from corrosion.

There are different ways to increase external corrosion resistance when reducing thickness. The easiest way is to leave the commonly used cosmetic coating off totally. An uncoated radiator has a lifetime that is about 30 percent longer than the lifetime of a cosmetically spray-coated radiator.

Electrophoretic coating is the best technical solution to increase corrosion resistance. It increases the lifetime by 2.5 to 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 just 10 percent of it, as is the case for most conventional cosmetic-spray coatings). They clearly prolong the lifetime of the radiators. These technologies are commercially available.

9 Special brazing processes

9.1 One shot brazing

9.2 Brazing of parts with internal turbulators (CAC).

9.3 Splitter fin together with CuproBraze

9.4 Brazing of steel parts

9 Special brazing processes

9.1 One shot brazing

One shot brazing is when all or most of the joints in the heat exchangers are brazed simultaneously in one brazing cycle and there are no metallurgical differences between one shot and other brazed joints. If the brazing parameters for all joints are fulfilled, the joints will be satisfactorily brazed. There are some points to be noted. If the one-shot brazed heat exchanger includes inner fins or other kind of joints inside the component, it must be ensured that the atmosphere around all joints fulfill the recommendations for the atmosphere stated in chapter 6.1. In most cases, purging inside the heat exchanger with nitrogen is necessary. To ensure good brazing results in all joints, the joint geometry as well as fixturing and paste application should be designed for furnace brazing. During the brazing process some movements between parts in the joints can take place due to stress relieving in stamped parts and also due to differences in thermal expansion between the parts. When designing for one shot brazing this should be taken into account. If possible, self-fixturing of the parts should be used.

The normal design for soldered tank-header joints, in most cases, has gaps that are too large for satisfactory brazed joints. The design for brazed joints should be in the recommendation earlier in this handbook, an optimal joint gap of 50 µm to a maximum 100 µm.

Figure 28 shows a normal geometry for soldering of header-tank. In figure 29 some improved header-tank designs are shown.

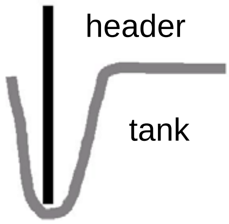

Figure 28. Typical joint for soldered header-tank. Gaps are too large

Figure 29. Alternative joint geometries for header-tank.

Many of the joints in “one shot” brazing are placed upside down or horizontally, it is therefore important to use a brazing paste suitable for this kind of joints.

The brazing paste should (if possible) be applied just outside the joints. During brazing the molten filler metal will be drawn into the joint by capillary force.

9.2 Brazing of parts with internal turbulators (CAC)

If fin tip application is used, fume from the binder is formed during the first part of the brazing cycle. Experience has shown that it is difficult to evaporate all fumes from the inside of the tubes before the brazing takes place, consequently having a bad influence on the brazing result. Therefore to avoid the risk of scraping off the paste on the tips during assembling, brazing foil is recommended to be used as filler metal for internal turbulators, especially for charge air coolers (CAC). The foil can be inserted together with the turbulators from the end of the tube, see figure 30.

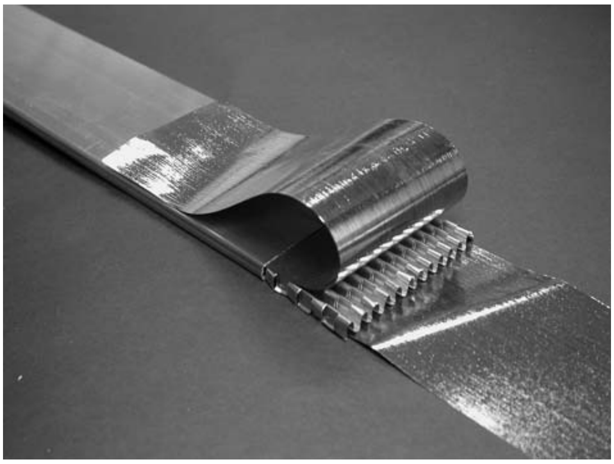

Figure 30. Brazing foil used for internal fin brazing.

When turbulators similar to normal fins for heat exchangers are used, they should be designed to take up some elastic movements during the brazing cycle. If very stiff turbulators are used they can form a split in the sample after brazing.

9.3 Splitter-fin together with CuproBraze

Splitter-fin is a method to solder thin copper fins to a centre strip, which together forms a strong fin-module, which is easy to use and has improved heat performance (figure 31). The splitter-fin-module is so far not possible to produce with CuproBraze brazing-paste but soldered splitter-fins are sometimes used in CuproBraze heat exchangers. In this case the fin material is SM 0502 (the normal CuproBraze fin material) and the soldered joints (lead-free) are used as “pre-joining). When the soldered joints between the fins and the centre strip are heated up to brazing temperature, the joints will be transformed to a copper-tin phase with similar composition appearing at the brazed fins in the CuproBraze process.

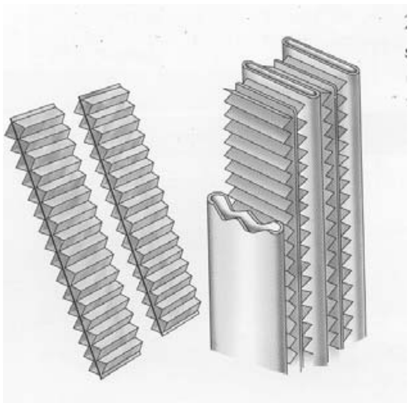

Figure 31. Splitter-fin modules to the left and the module inserted in a core to the right.

9.4 Brazing of steel parts

Brazing any steel parts is not recommended, due to formations of brittle Fe-P-film between the filler and the base metal.

10 Quality check

10.1 Visual inspection in general

10.2 Visual inspection of the tube-fin joints after cutting of the fin.

10.3 Cross sections of the joints.

10 Quality check

The brazing results can be checked by

- Visual inspection in general.
- Visual inspection of the tube-fin joints after cutting of the fin.
- Cross-sections of the joints.

10.1 Visual inspection in general

The part should be clean with no heavy oxidation (if flux containing paste is used on the headers, they will leave some black parts on the joints). The side supports should be straight with no splits in the cores.

10.2 Visual inspection of the tube-fin joints after cutting of the fin

As this inspection is destructive it should be used on only a minimum number of components. The fins are cut off and the completeness of brazed joints is investigated. It is recommended to check the tube-fin joints for the first samples when something in the production has been changed. The check should be repeated until the right quality has been reached. Figure 32 shows high quality brazed tube-fin joints.

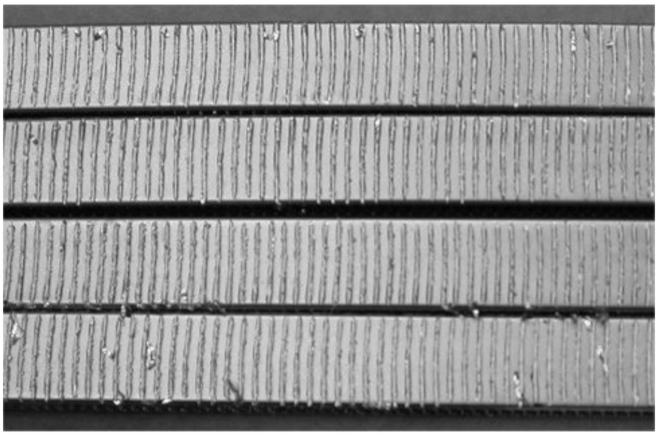

Figure 32. Examples of high quality brazed joints.

10.3 Cross sections of the joints.

Investigation of cross sections of the joints is a method to look at the joints in a scientific way. Cross sections of all kind of joints as well as welded tube joints can be studied. Except for examination of welded tube this kind of investigation is not needed for normal production.

Figures 33-35 show some typical examples of cross sections of brazed joints.

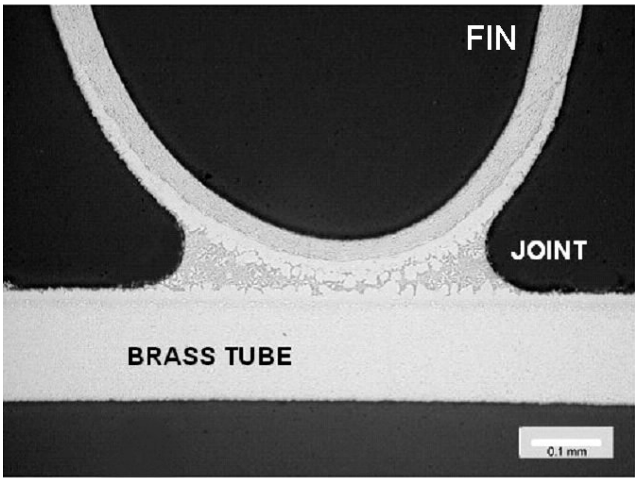

Figure 33. Example of tube-fin joint.

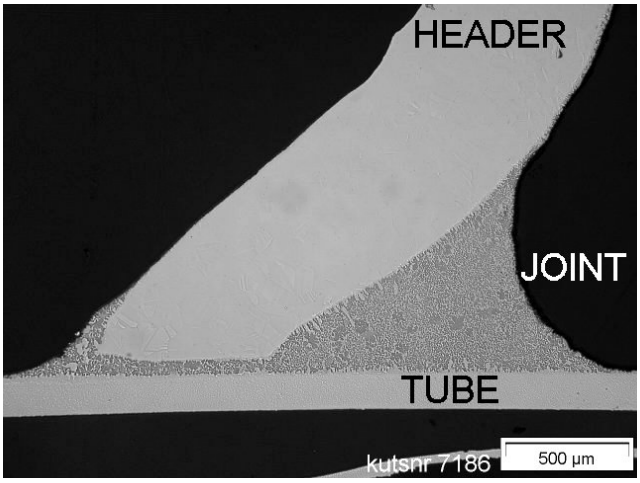

Figure 34. Example of tube-header joint.

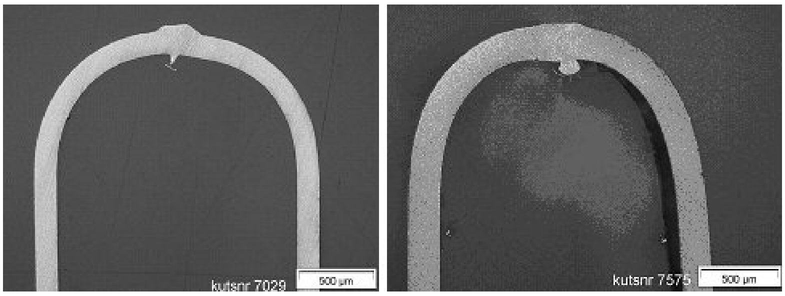

Figure 35. Examples of cross-sections of tube welds.

11. Reparability

11. Reparability

Reparability is one of the major advantages of CuproBraze heat exchangers.

11.1 Soldering

CuproBraze heat exchangers can be repaired both at the manufacturing plant and in the field with lead-free solders. In the CuproBraze 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 stainless steel can satisfactorily be used in repairing CuproBraze components. Some of these fluxes leave corrosive residues, so careful rinsing after repairing is essential.

11.2 Re-brazing

Another repair method at the manufacturing plant is to apply additional brazing paste at the failure site. In this case the component should be dried and re-brazed using the same brazing cycle as is normally used in manufacturing. During re-brazing the fins will become slightly softer, due to increased alloying of the fins, the thermal performance of the heat exchanger may somewhat decrease. The heat exchanger should be re-brazed with the opposite side up compared to the initial process, in order to keep tube-to-header joint sealed. It is advisable to check for any tube-to-header leaks and repair as necessary.

11.3 Brazing with AgCu filler metals

Repairing with conventional low melting AgCuZnSn filler metals together with a suitable flux is also possible. Rinsing recommendations from the flux manufacturer should be followed.

12. Troubleshooting

12. Troubleshooting

Crushed fins during assembling.

Problem: The pitch does not match the coated tubes. Countermeasure: Increase the pitch or decrease the fin height.

The headers are black after brazing.

Problem: The headers have oil residues after brazing.
Countermeasure: Degrease them before assembling.

Bad brazing of tube-to-fin and soot-like residues on the tubes.

Problem: The brazing powder has been oxidized during heating. Countermeasure: Check the oxygen-content in the first part of the brazing cycle. Check the drying of the paste.

Insufficient brazed fin-tube joints along the center part of the tubes.

Problem: Example of insufficient brazing between tube and fins is shown in figure 36. The compression of the core was too high during the brazing operation.

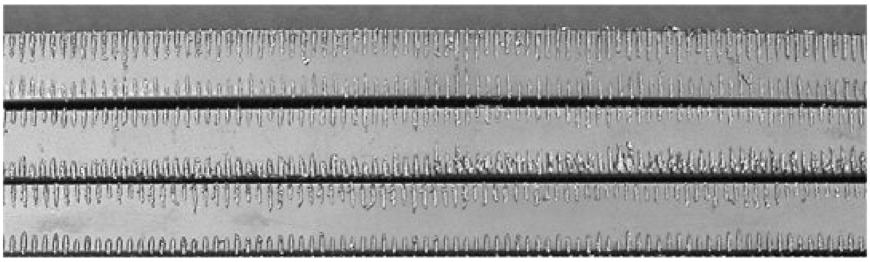

Figure 36. Examples of bad brazing between tubes and fins.

Countermeasure: Increase the pitch in the headers (0.05 – 0.1 mm). Check the fixturing. Check that the crown of the tubes is right.

<u>No brazing at the tube edges.</u>

Countermeasure: Decrease the pitch in the headers (by 0.05 – 0.1 mm).

<u>Unbrazed parts not uniformly distributed on the tubes.</u>

Countermeasure: Check the amount of paste on the tubes. Could be too small.

<u>Bad brazing of tube-to-fin with rough and dark surfaces.</u>.

Countermeasure: Check the brazing parameters and the fixturing of parts. All areas of the core have reach the brazing temperature.

Tube-header leakage - randomly distributed.

Countermeasure: Check the brazing time and/or temperature. Could be too low. Check the amount of paste on the tube-header joints. Check the surface conditions of the headers and on the tube ends.

Tube-header leakage in the corner area of the core.

Countermeasure: Check the fixturing close to the corner. Could be too tight.

The whole heat exchanger is dark.

Countermeasure: Check the oxygen content in the cooling part of the furnace. Check the exit temperature of the part.

13 Luvata Brazing Center

13 Luvata Brazing Center

To produce brazed prototypes in copper and brass and develop the CuproBraze process, Luvata has established a Brazing Center in Västerås. In the Brazing Center, it is also possible to show some steps of the process in production scale. An overview picture of the Brazing Center is shown on the cover of this book.

14. Getting started

14. Getting started

The interest in CuproBraze technology has accelerated in recent years. As a result, a global network of suppliers have formed the CuproBraze Alliance and stand ready to assist manufacturers in establishing volume production facilities based on the CuproBraze process. In addition, the Luvata Brazing Center in Västerås, Sweden is ready to demonstrate the brazing processes and help to evaluate the technology through prototype building. Manufacturing processes are now being applied globally in the manufacture of advanced heat exchangers using this technology.

14.1 Contacts

Luvata Sweden AB, with its CuproBraze Team and Brazing Center, supports its customers to get started with CuproBraze.

Website: www.luvata.com Contact: markku.ainali@luvata.com

14.2 Websites

www.cuprobraze.com
Website of the CuproBraze Alliance. General and specific information. Links to suppliers. Download this manual.

www.copper.org and www.copperinfo.com
Websites of the International Copper Association (ICA) and Copper Development Association.

ICA's CuproBraze Executive Reports online at
www.kellenpr.com/clientnews/cuprobraze_er.html

14.3 Regular publications

The CuproBraze Executive Report of the ICA provides updates on all aspects of CuproBraze technology, including news about suppliers, materials, equipment, production lines, manufacturers, product design, industry trends and marketing strategies. It is published approximately ten times per year and is available free-of-charge from the International Copper Association.

Other publications include the Luvata Newsletter which is sent to customers and will also be available at the website www.luvata.com and at www.cuprobraze.com.

14.4 Recent technical literature

Gustafsson and Scheel (Ref. 1) list all of the important physical properties of copper and aluminum side-by-side and make a compelling case in favour of the use of CuproBraze® alloys in mobile heat exchanger technologies. More recent papers have described experiments relating to the metallurgy (Ref. 2, 3) and corrosion resistance (Ref. 4, 5) of the new anneal-resistant alloys. In the current proceedings, Schmoor and Nadkami report on recent developments in brazing pastes (Ref. 6). The influence of the brazing parameters on the quality of the heat-exchanger made by the CuproBraze® process is described in (Ref 7).

14.5 References

1. Gustafsson B. and Scheel J., CuproBraze Mobile Heat Exchanger Technology, SAE Technical Paper Series 2000-01-3456.

2. Falkenö A. and Ainali M., OCP-materials, SAE 01 HX-18.

3. Tapper L. and Ainali M., Interactions between the materials in the tube-fin joints in brazed copper-brass heat exchangers, SAE 2001-01-1726.

4. Korpinen T., Electrochemical tests with copper/brass radiator tube materials in coolants, SAE 2001-01-1754.

5. Ainali M., Korpinen T. Och Forsen O., External corrosion resistance of CuproBraze radiators, SAE 2001-01-1718.

6. Schmoor H., and Nadkarni A. V., Brazing of copper brass radiators with new brazing pastes, Proc. IBSC 2003.

7. Falkenö A., Tapper L., Ainali M. and Gustafsson B., The influence of the brazing parameters on the quality of the heat-exchanger made by the CuproBraze® process. SAE 2003-04-0037.

8. Humpstone G. and Jacobson D. M. Principle of Soldering an Brazing. 1st ed. ASM. Materials Park, OH.

9. Soldering Manual. 2 ed. AWS, Miami, FL. 1977.

10. Brazing Handbook. AWS

15. CuproBraze in brief

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Materials

For the Cuprobraze process special copper and brass materials should be used.

- SM 0502 for fins
- SM 2385 for tubes
- SM 2464 for headers, side supports, tanks and others.

Brazing materials

Brazing powder (mixed with binder to a brazing paste) or brazing foil (rapid solidified) has to used. The brazing alloys are shown I table.

Brazing alloy	Copper Cu %	Nickel Ni %	Tin Sn %	Phosphorus P %	Melting range ºC
OKC 600	Balance	4.2	15.6	5.3	600 - 610
VZ 2255	Balance	7.0	9.3	6.5	600 - 630

OKC 600 is used for powder and VZ 2255 mainly for foil.

Brazing pastes

To make it possible to apply the brazing powder for brazing of the cores, it is mixed with a binder to a suitable brazing paste. The binder is mostly specific for each paste manufacturer, hence pastes from different manufacturers should not be mixed together.. Application can then be done by means of conventional commercial application methods.

All pastes are premixed and are ready to use after stirring. The stirring recommendations from the paste manufacturer should be followed in order to secure good paste applicability. There are pastes with different viscosity to be used at different kinds of joints, as well as different application methods. Contact the paste manufacturer to use the right kind of paste.

There are two main different types of binder systems, solvent-based and thermoplastic. The solvent-based binders are dissolved in a solvent. The solvent is evaporated during drying, leaving a hard binder and if the binder is mixed with brazing powder, it will give a hard coating after drying which only could be dissolved in a solvent.

The pastes normally have a long shelf life. For detailed information regarding the paste properties, contact the paste manufacturer.

► **Important**

Do not make a mixture of pastes from different manufacturers as they may not use the same binder system.

Brazing paste application at tube-fin joints

For tube-to-fin joints, brazing paste can be applied either on the tube surfaces or on the fin tips.

The most commonly used method for coating the tubesis spraying with commercial spray guns. It can be done by manually as well as by automatic spraying.

Coatings should be evenly applied with a coating weight of 150-250 g/m2 after drying. The better tolerances of the tubes and fins, the thinner the layer can be. It is recommended to start with the thickest (heaviest) coating.

It is recommended not to coat the tube ends. If the tubes ends are coated it can sometimes have a negative influence on the joint quality of the tube-header joints.

Consumption of brazing paste could in most cases, depending of the fin density, be lowered by applying the paste on the tips of the fins rather than on the tubes. Thermoplastic pastes, as well as some solvent-based pastes, are suitable for fin-tip application.

The brazing properties of the pastes (tube coating as well as fin-tip coating) can be destroyed if the temperature in the coating is above 130ºC during drying. Instructions from paste suppliers must be followed.

► **Important**

Do not overheat the paste during drying.

Brazing paste application at tube-header joints

A dedicated paste (sometimes called slurry) is recommended for tube-to-header joints. This paste has a lower viscosity than the pastes for tube or fin-tip coating and can be applied by pouring or spraying. Normally the paste is applied on the airside of the header. The amount of paste required typically is 0.5 grams per tube end for 16mm wide tubes and 1.8 g per tube ends for 60 x 6mm tubes. These quantities are just guidelines, as the amount of paste is influenced by the geometry of the joints and headers.

► **Important**

Do not overheat the paste during drying.

Brazing of parts with internal turbulators (CAC)

If fin tip application is used, fume from the binder is formed during the first part of the brazing cycle. Experience shows that it is difficult to evaporate all fumes from the inside of the tubes before the brazing takes place. Consequently having a bad influence on the brazing result. Therefore to avoid the risk of scraping off the paste on the tips during assembling, brazing foil is recommended to be used as filler metal for internal turbulators, especially for charge air coolers (CAC). The foil can be inserted together with the turbulators from the end of the tube.

Brazing fixtures and assemblies

The brazing powder builds up a thicker layer than a solid metal of the same weight. This extra thickness must be taken into account when specifying tube pitch in headers and brazing-fixture devices.

The tube pitch in the headers is a function of the tube width and fin amplitude with an allowance for a brazing paste layer. As a guideline, increasing the pitch with 0.10mm per tube often works well, resulting in a complete brazed joint between fin and tube. But for optimal brazing result, it is recommended to check the brazing result between the tubes and the fins for the first sample before further work.

In the CuproBraze process the parts go through a temperature-cycle from room temperature up to 650ºC, which means that the differences in the thermal expansion will influence the fixture design.

Brazing operation

Furnaces for the CuproBraze process use high-purity nitrogen. The atmosphere of the furnace must have an oxygen content of less than 20ppm from the time when heating starts. The brazing powder is very sensitive when the binder starts to evaporate, Therefore the starting point of the brazing cycle is as sensitive for oxygen-content as the rest of the brazing cycle.

► **Important**

The oxygen content should be controlled from the time when the heating starts and no heat should be applied if the atmospheric conditions are not met.

The difference in the melting points for the filler metal and the copper and brass materials is more than 300 ºC, thus there is no risk to destroy the parts by melting. The time above the melting point for the filler metal (600 ºC) should be as short as possible but still gain a satisfactory brazing result.

To satisfactorily wet the surfaces and fill the joints, ensure that the temperature in them reaches 650ºC or for some new types of header pastes even 660ºC.

To minimize the risk for distortion of the joints during cooling (part D), it is recommended to have a low cooling rate until around 550ºC, typical value 1ºC/s.

To prevent discoloration of the brazed parts, they should not leave the inert atmosphere until the component temperature is below 150ºC. In places where the ambient humidity is high the exit temperature should be even lower to prevent discoloration. Note: This discoloration is only a cosmetic effect and it will not deteriorate the brazed joint.

At least during optimization of the brazing cycle, it is highly recommended that some kind of measurement of the temperature with thermocouples mounted in the core should be used.

The effect of the brazing cycle on the tube-to-fin joints cannot be seen by the naked eye. During optimization of the brazing cycle, overshooting of the brazing temperature can sometimes happen, but it will not lead to any noticeable visible effect on the brazed part.

POINTS FOR SUCCESS

- Controlled furnace atmosphere with oxygen content less than 20 ppm.
- Correct amount of brazing filler metal.
- Right brazing temperature has to be reached.
- Suitable fixturing during brazing.
- Clean parts.
- Do not overheat paste during drying.