Dynamic material testing by temperature cycling, tensile testing of brazed aluminium joints

Introduction

Aluminium brazing is now the preferred process for the production of heat exchangers such as radiators, condensers, evaporators and heater cores. For the brazing process, it is usually necessary to employ a flux to remove the native oxide film present on all aluminum surfaces. One brazing process that is now recognized worldwide uses a potassiumfluoroaluminate flux, which successfully removes the oxide film on aluminum, does not react with aluminum in molten or solid state and whose residue remains on the surface as a very thin adherent film with a thickness in the range of 1–2 µm. The flux residue is non-hydroscopic and non-corrosive in standard applications.

With certain techniques of fluxing, small amounts of this residue may be present on the internal surfaces of the heat exchanger and therefore in contact with the medium flowing through the heat exchanger. When brazing heat exchanger cores in a continuous furnace, it is possible that some flux residues will be in contact with the refrigerant. However, it is more likely that the refrigerant will be in contact with flux residues from flame-brazing operations. After brazing in continuous tunnel furnaces, it is common to flame-braze tube-to-tube and tube-to-fitting joints as a second operation. The presence of flux residues on the inside of the joint cannot be avoided in flame-brazing. Due to the nature of the process, the morphology of the residue is not as homogenous and also thicker than the flux residue layer that may be formed on the internal surfaces by continuous furnace brazing. The combination of R 134a and a polyglycol lubricant, which can be regarded as a standard for automotive air-conditioning is a fairly strong solvent due to the polarity of the two substances. Further contaminants are to be expected within the cycle such as water and abraded material from the compressor.

The stability of flux residue on the surface of aluminum and the influence of flux residue on the stability of the R 134a oil system was investigated in a test apparatus over the course of temperature cycles. Furthermore, tensile tests were carried out on flux-brazed tubes.

Temperature Cycles

Test Apparatus

The basic construction of the test apparatus is shown in the flow diagram.

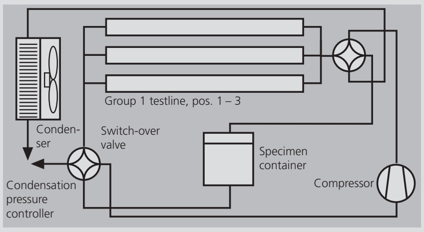

Diagram 1

The single-stage compression refrigeration machine was filled with R 134a and a polyalkylenglycol. This refrigeration machine oil was developed for automotive air-conditioning systems. The test apparatus includes two test sections. Three tubes with brazed joints were installed in one test section. Thermocouples were used to determine the temperature of the tubes at the entry and the outlet of the tubes. The other test section was equipped with a stainless steel sample container. This container was filled with a bundle of perforated plates (see figure 1). Aluminium coupons with flux residues on the surface were fixed onto these perforated plates. Thermocouples measured the temperature inside the container at the top and the bottom. The two test sections were connected with four-way valves to feed them with hot or cold refrigerant, alternately. The valves were switched automatically with a time relay. At the outlet of the test section, 40 µm sieve filter were used to hold back solids. Thermocouples measured the temperature at the entry and at the outlet of the test sections.

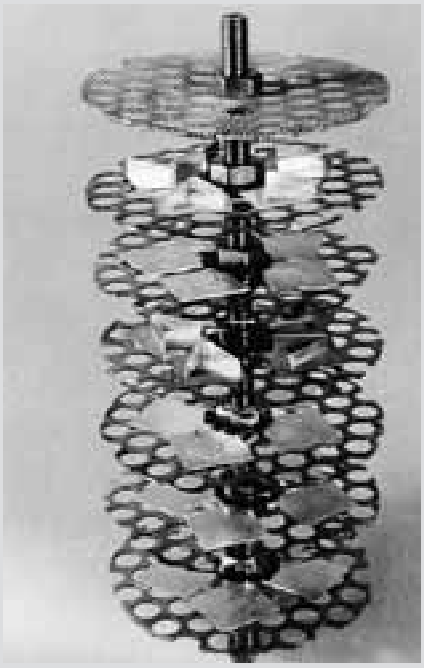

Figure 1, Aluminium coupons with flux residues

Sample Preparation

The test samples used for this investigation were 40 coupons with flux residues, 10 brazed angle-on coupons and 3 tube-to-tube specimens. Coupons measuring 25 mm x 25 mm x 0.35 mm were cut from braze sheet. The braze sheet consisted of AA4343 clad onto AA3003. The flux was uniformly dispersed over the surface. The flux loading values were 2 g/m^2, 4 g/m^2, 5 g/m^2 and 20 g/m^2. The flux was molten under nitrogen. Angle were brazed onto the same kind of coupons.

The flame-brazed joints of the tubes consisted of AA1100 tube material with 10 or 8 mm external diameter and 1mm tube wall thickness. One tube consisted of aluminium copper joints. The filler metal consisted of an AA4047 ring. The tubes were assembled with the filler metal ring in place. An alcohol/flux slurry paste was applied around the joint. Flux loading was 25 to 30 g/m^2 . The tubes were brazed with a dual-headed torch.

Figure 2, Appearance of flux residues before test cycle

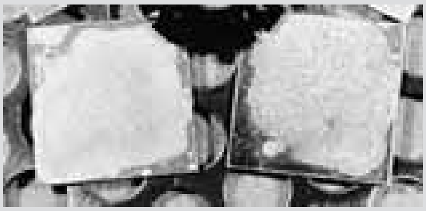

Figure 3, Appearance of flux residues after test cycle

Procedure

The samples were treated with temperature cycles between –10 and +110 °C. Pressure varied between 1 and 16 bar. The overall time of testing was 1131 h . Total number of cycles was 7179 with a cycle time of less than 10 minutes. The minimum temperature variation in the tubes was 110 K and 115 K in the sample container.

Results

The analysis of the refrigerant gave no reason to presume any interaction between the flux residue and the refrigerant. No concentration of K, Al or F was found in the refrigerant or the PAG oil.

After the test cycles, the coupons were carefully degreased. The weight was determined for all samples. There was no weight change observed which would conclude loss of flux from the coupons. The appearance of flux residues on the surface of the coupons did not change (see figure 2 and 3).

The brazed tube-to-tube joints showed a loss in weight due to the nature of the coupling fittings, which were used to connect the tubes to the test apparatus. No flux was found on the surface of the filter which was installed behind the tubes. However, the results are inconclusive and there might be a loss of flux from flame-brazed tubes

Lubricant analysis

Analysis	Before test	After test
Viscosity 40°C (mm^2/s)	41	41
Acidity mg KOH/g	0.11	0.10

Table 1

Results of the analysis of refrigerant R 134a

Compound	Vol % (GC) Before test	Vol % (GC) After 1017 h / 7179 cycles
R 134a	99.786	99.793
R 143a	0.017	0.020
R 125	0.019	0.023

Table 2

Solvay
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Pulsation Tension Test

The pulsation tension test was done with a servohydraulic testing apparatus (see figure 4). Five tubes were treated with a vibration frequency of 20 Hz and an amplitude (X) of 0.1 mm. The maximum force (F_{max}) was 700 N. The maximum number of load changes was 11 820 000. Three flame-brazed tubes consisted of AA1100 tube material with 8 mm external diameter and 1 mm tube wall thickness. Two tubes consisted of flame-brazed Al/Cu joints. All tubes were brazed with a filler ring AA4047 and an alcohol/non-hygroscopic flux slurry paste.

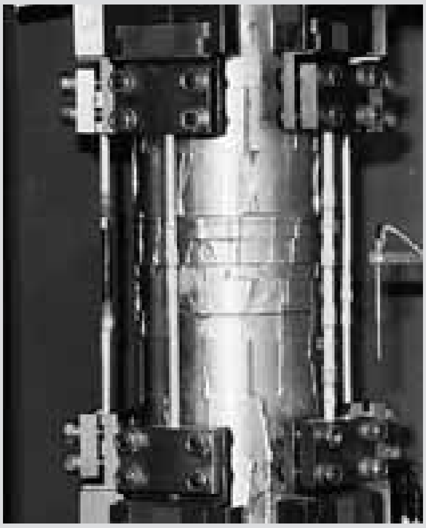

Figure 4, Servohydraulic testing apparatus

Results

a) Tension Test

Diagram 2 shows the result of the tension test with an extruded aluminiumtube without brazed joints in comparison to a tube with a flame-brazed joint. There is a strong increase in ductility after brazing due to the thermal treatment. The maximum force for the dynamic tests was limited to 700 N, due to the elongation limit of the flame-brazed tubes.

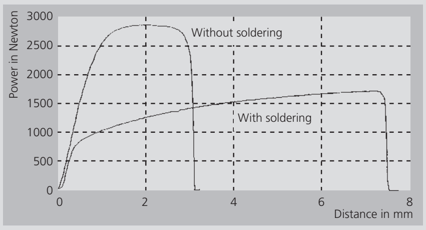

Diagram 2, Tension test with an extruded aluminiumtube

b) Dynamic Pulsation Tension Test

The stiffness value (C) is a good characteristic criterion for the stability of the samples during the pulsation tension test.

$$C = \frac{(F_{max} - F_{min})}{(X_{max} - X_{min})}$$

Diagram 3 shows the stiffness value for a tube with Al/Al joints and diagram 4 shows a tube with Al/Cu joints.

One tube broke next to an Al/Cu joint (see figure 5), due to thermal softening of the aluminium during the flame-brazing.

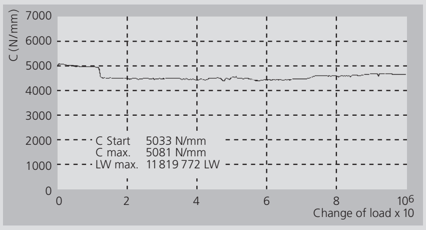

Diagram 3, Stiffness value for a tube with Al/Al joints

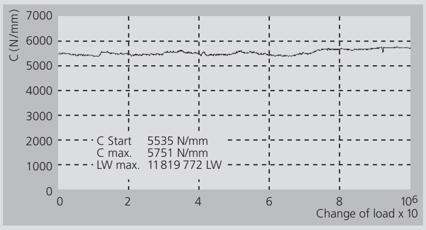

Diagram 4, Stiffness value for a tube with Al/Cu joints

Results of the pulsation tension test

Joint	Stiffness C (N/mm)	Maximum alternations	Comment
Al/Cu	6329	1 225 000	broken next to joint
Al/Cu	5534	11 820 000	
Al/Al	5033	11 820 000	
Al/Al	4983	11 820 000	
Al/Al	5132	11 820 000	

Table 3

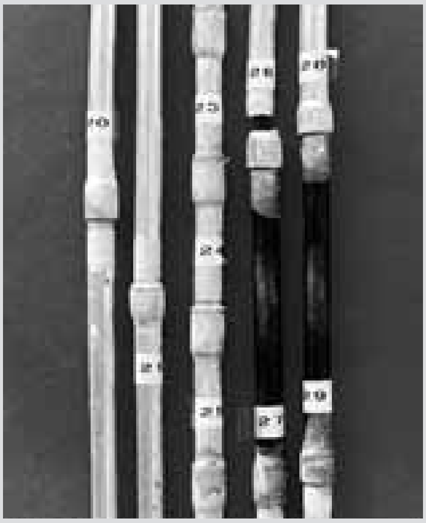

Figure 5, Tubes after pulsation tension test

Conclusion

The stability of the mixture of R 134 a and polyglycol lubricant as found in automotive air-conditioners in the presence of flux residue was proven. The flux residues generated by the continuous furnace brazing process adhere strongly to the surface of aluminum. Even if there is a loss of flux residues from flame-brazed tubes, no change in the quality of the refrigerant system was determined.

The pulsation tension test demonstrated the excellent static and dynamic properties of flame-brazed joints of Al/Al tubes and Al/Cu tubes.

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