TECH UPDATE

Research and Technology News from ARI July 1997

ARI and CDA Sponsor Research on Copper Joining Techniques with Future Refrigerants

Editor's note: This article ***summarizes*** *the results of this research project, sponsored by ARI and the Copper Development Association (CDA). An expanded summary can be found on ARI's homepage (http:\\www.ari.org). The final report can be obtained through the ARTI Refrigerant Database (see* New Report *below).*

Introduction

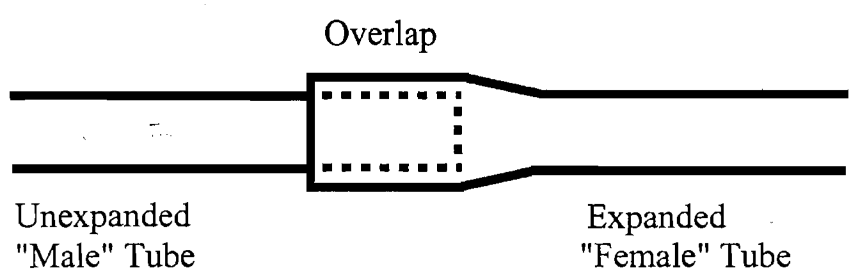
Poor quality braze joints in air-conditioning and refrigeration systems and their components are estimated to cost the industry $30 million to $90 million per year in refrigerant leaks and required rework. These costs are incurred as a result of tubing and fitting defects, imperfect braze joints made in factories by both automated furnaces and human braze operators, and as a result of field failures from poor installation, handling damage, and cyclic fatigue stresses.

This article details the results of a research project undertaken at Amalgamated Technologies Inc. (ATI) to ascertain whether current brazing techniques and methodologies for joining copper tubes are adequate for the alternative refrigerants proposed for future usage. ATI's final report (see *New Report* below) indicates that there are three key criteria for obtaining full integrity within a brazed joint:

- full seating of the unexpanded male portion of the tube (inside tube) into the female swaged socket formed by the expanded tube (see Figure 1),
- full penetration of the braze material into the female swaged socket, and
- a good fillet radius on the outside of the brazed "overlap."

Figure 1

"Tube in Socket" Braze Joint



The research indicates that if the above three criteria are met, the brazed joints will be every bit as strong as the tubing itself.

Methodology

Five facilities of four major manufacturers were visited to identify representative tubing configurations and braze materials for incorporation into the test. All manufacturers visited were found to use similar brazing technology. Similar brazing difficulties were seen at each plant. Inconsistent tube length beyond the endsheets led to overexpanding and cracking of the tubing through the joint region. Various amounts of oil residue from tube forming operations contaminated the braze joints, and led to heavy smoke and poor braze quality. These and other difficulties resulted in rework and additional expense for the manufacturers.

As a result of the visits to the manufacturers, three brazing materials and four tube types were selected for testing. Both 5/16" (8 mm) and 3/8" (9.5 mm) tubes were tested, each with and without fins.

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New Report ♦ New Report ♦ New Report

Scott A. McCracken and Roy E. Beal (Amalgamated Technologies, Inc.), **Evaluation of Joining Techniques for Copper Tubing in AC&R Applications**, June 1997. *Contact:* ARTI Database c/o James M. Calm, Engineering Consultant, 10887 Woodleaf Lane, Great Falls, VA 22066-3003 (reference RDB#7501). Final report. See article on page i. ♦

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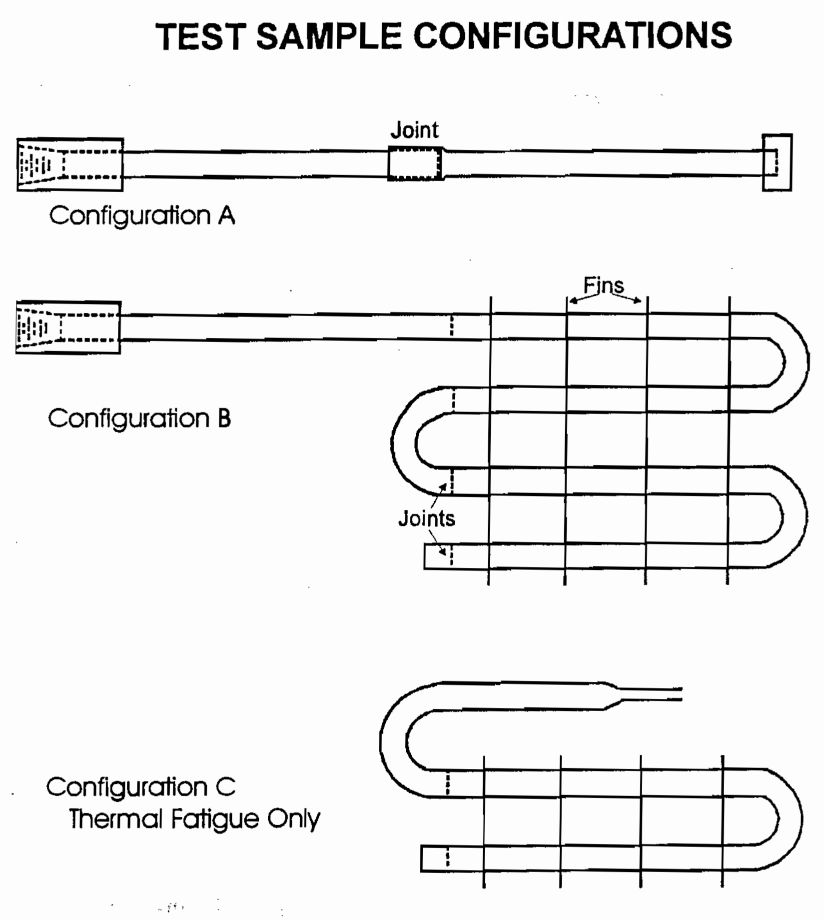
The four types of tubing were configured into three test sample types, depending on the test procedure to which they were subjected. These three types of test samples are shown in Figure 2. As can be seen, each sample contains at least one "telescoping" joint, where one tube is expanded to form a female socket, to allow an unexpanded tube to slip inside and form an overlapping joint.

All tube samples were measured for wall thickness and thickness variation, and were marked at the thinnest point. The test samples were manually brazed with a production style double flame, air-acetylene torch. No flux was used, and samples were not back purged.

The intent of the work was to ascertain what parameters affect the integrity of brazed joints in copper tubes. In equipment applications, sound joints are considered those that do not leak or develop leaks during normal operation. For the accelerated stress testing performed in this effort, tube/joint strength and endurance were utilized as indicators of joint soundness. Four different test procedures were performed in this evaluation: static burst pressure, vibration cyclic fatigue life, thermal cyclic fatigue life, and pressure cyclic fatigue life.

Figure 2



Static Burst Testing

In hydraulic tests, all three braze alloys proved to be stronger than the tubing, as no samples failed because of filler metal separation within the braze joint. Samples that were well brazed and had no tubing defects or mechanical damage failed at the highest pressure levels, very close to the theoretical burst strength of the tube itself.

However, most samples failed at reduced pressure below the theoretical burst strength. There were two distinct categories of these reduced pressure failures:

(1) Mechanical imperfections: Included tube wall thickness variation, tube surface damage from hand expansion operations, and points where the tubing is pinched against the steel end sheet.

(2) Incomplete filler penetration: Partial penetration joints have reduced burst strength and usually fail within the telescoping joint regions. The step of expanding the tubing to make the female socket stretches and thins the tubing wall. In addition, the tubing is fully softened by brazing heat. For maximum burst strength, there must be full filler penetration to prevent the thinned wall of the outside tube from being exposed to internal pressure.

Poor braze filler penetration is largely due to the difficulty of achieving even, uniform heating with a manually-applied gas flame. The report notes that excessive joint overlap hinders full braze penetration, and offers no strength advantages.

Vibration Cyclic Fatigue Testing

The most significant result of the vibration testing was demonstrated by the 3/8" (9.5 mm) diameter tubes which were tested for one hour with alloy BCuP-6. Because of filler metal characteristics and braze technique, each of these samples had virtually no fillet at the edge of the brazed joint. The lack of fillets caused a stress concentration at the base of the joints, which resulted in premature cracking and a significantly reduced group average life span. Filler metals with high silver content are highly fluid outside of a capillary space, and naturally leave only very small fillets. Specific attention is needed from a brazing operator to build up a proper fillet with the higher-silver braze alloys.

The primary conclusion from vibration fatigue testing is that vibration survival requires a sound joint with full penetration and a proper fillet.

Thermal Cyclic Fatigue Testing

Thermal fatigue was explored by an apparatus that exposed pressurized tub-

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ing samples on a rotating wheel to a temperature range of 40°F to 270°F (4°C to 132°C). Samples were heated by natural gas burners, then quenched in a trough of water cooled by refrigeration. Tests were performed on 5/16" (8 mm) Configuration C samples only.

For the majority of the samples, there was no indication after 62,000 cycles that any kind of failure was imminent. The primary conclusion from thermal cyclic fatigue testing is that normal temperature cycling of a refrigeration coil in operation is not detrimental to the coil itself.

Pressure Cyclic Fatigue Testing

This test simulated pressure cycling effects of refrigeration system operation. Testing was limited to 5/16" (8 mm) and 3/8" (9.5 mm) Configuration B samples only. Samples were rapidly pressurized and depressurized until failure. The cyclic fatigue test procedures were performed at multiple cyclic stress levels. The high stress, short duration testing at one-minute and one-hour life spans resulted in failures similar to static burst testing, as almost every sample failed in a braze joint. Most samples would fail at score marks in the joint tubing, or at a poor penetration braze joint. [Note: score marks are mechanical deficiencies that are generally not incurred in production heat exchangers. However, some of the tubes in this experiment were found to have score marks produced during hand expansion operations.]

The 24-hour life span group provided the most interesting data. The lower cyclic stress resulted in a sudden and dramatic shift in failure mode. Instead of failing on or near the braze joints, the majority of the 24-hour group samples of both tube sizes failed in the hairpin bends of the coils.

The primary conclusion from the pressure cyclic fatigue testing is that maximum working strength requires full penetration braze joints, and elimination of score marks and other mechanical imperfections.

ATI's Observations

Static Burst Test

- Braze filler strength and hardness have little to do with the strength of a brazed joint.
- Burst strength is most influenced by the effectiveness of braze filler penetration.
- Burst strength of one sample type was influenced by mechanical damage. Failure occurred on score marks at reduced pressure regardless of braze quality, braze alloy, or location of the thin side of the tubing wall.
- Penetration, braze quality, and filler characteristics are very important.

Vibration Fatigue Test

- Joints with poor penetration can fail rapidly from cracking within the braze filler material. Hence, joints that look good and hold pressure can fail from vibration in transport or operation.
- Improper braze fillets will cause failures from stress concentrations.
- If the proper fillet radii are formed, higher silver content brazing alloys do not appear to be superior.

Thermal Cyclic Fatigue Test

- Normal temperature operation of a refrigerant coil is not detrimental to the coil — burst strength actually increased.

Pressure Cycling Fatigue Test

- No correlation between braze alloys and failures.
- One-minute and one-hour samples failed on the braze joints.
- 24-hour samples failed primarily in the hairpin bends. (ATI theory: Tubing was initially too hard and subsequent work hardening induced shift in failure locations.)
- At cyclic pressures of 75 - 80% of burst strength, the characteristics of the tubing itself became the dominant factor for pressure cyclic endurance.

Other Observations and Recommendations

- Very little difference between the three braze alloys used.
- The overlap region of telescoping joints needs to be reduced to one tube diameter or less. Less heating demand, less filler quantity, better ability to achieve full braze penetration.
- Need to prevent overheating of joints (reduces filler fluidity).
- Better joint integrity arises by:
  - eliminating all oil on tubing to be brazed,
  - tightening tube concentricity,
  - reducing unused overlap on return bends,
  - preventing mechanical damage from tooling,
  - eliminating saw chips and other debris,
  - controlling tube lengths to eliminate tube splits during swaging and flaring operations.

Conclusions

Conventional brazing technology is capable of achieving high quality joints. Today's gas heating methodology and the braze alloys tested are capable of good performance. However, reaching the full potential of today's technology may require some factories to improve current application. It is suggested that tube and coil forming operations be performed more carefully, and that existing braze technology be implemented more effectively.

This study identified that full penetration of the brazed joint was essential to optimum performance. Consistent, full

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penetration brazing is difficult to do with a manual torch, and is hindered by excessive joint overlap. Generous fillets at the outside of telescoping brazed joints are necessary for vibrational fatigue resistance. In the test, the non-silver-content braze alloys performed as well as the higher-silver content braze alloys in achieving full penetration and proper fillet shape (with the exception of BCuP-6 for fillet shape). Mechanical damage and imperfections from coil forming, tube manufacturing, heat exchanger construction or handling operations negatively influence burst strength and endurance.

It is concluded that manufacturing quality and service life will be enhanced from improvements in the heating process to provide better uniformity and temperature control, improvements in joint design, and improvements in tube and coil forming operations.

To help answer questions in these areas, a continuation effort is underway (results expected first quarter 1998). In this continuation, an alternate braze technology (induction heating) will be utilized to ascertain the benefit of uniform heating on braze penetration into the joint, and different overlap ratios and female cup profiles will be evaluated to determine their impact on braze penetration ability and joint integrity. Look to future issues of *Tech Update* for the results from this effort. ♦

Upcoming Conferences

18th Annual Energy and Technical Services Conference — Generating Ideas in a Changing Market; August 10-13, 1997; Monterey, Calif. *Contact:* Davette English, Food Marketing Institute, 800 Connecticut Avenue, NW, Washington, D.C. 20006; (202) 429-4517; fax: (202) 429-8479.

HVAC Controls; Sept. 16-18, 1997; Denver, Colo. *Contact:* James Kay, Clemson University, P.O. Box 912, Clemson, SC 29633-0912; (864) 656-2200; fax: (864) 656-3997. ♦

ARI Submits Comments on ASHRAE Draft Standard 62-1989R

ARI's General Standards Committee met with an ARI Ad-Hoc Working Group on 10 June 1997 to discuss the public review draft of ASHRAE Standard 62-1989R, *Ventilation for Acceptable Indoor Air Quality*. The purpose of the meeting was to review comments from ARI's many product sections and develop industry consensus comments on the draft standard. Starting with over 125 section comments, the two ARI groups developed 79 consensus comments. With General Standards Committee approval, ARI submitted these comments to ASHRAE before the 28 June – 2 July 1997 Annual Meeting in Boston.

The draft standard represents a major change from the current 1989 standard, which has been adopted, in whole or in part, in many building codes. As such, the revised standard may significantly affect the air-conditioning industry and the products it manufactures (see for instance the article in the January 1997 edition of the *ASHRAE Journal*). With requirements for ventilation system design, operation and maintenance, the draft standard may also affect many related and allied industries.

While most of the 79 comments made specific recommendations for revising the draft standard, several themes were apparent in the comments. ARI submitted some "general" comments to reiterate these more fundamental opinions. These general themes are as follows:

- ARI feels that wherever possible, performance criteria rather than prescriptive criteria should be used in the draft standard. As a body of competing manufacturers, ARI feels that the draft standard should not dictate design, but rather state what results are required and allow innovation and the market to decide how to achieve those results.
- The requirements of the draft should treat competing technologies fairly. To do otherwise would constitute a restraint of trade. The draft standard should not limit existing technologies that have not been proven to be detrimental to indoor air quality.
- There is a need to reduce complexity wherever possible. Many people have already pointed out that the code authorities may not be ready to adopt such a complex standard. Even if adopted, the complexity of the standard may hinder compliance in the field. Several suggestions were made to reduce the complexity of the draft standard, including the use of separate certification programs to assure compliance of manufactured products.
- Many comments questioned the rationale for the major changes from the 1989 ANSI-approved standard.
- ARI also questioned the potential for the draft standard to unnecessarily increase liability for many members of the industry, a concept noted by others reviewing the draft standard.

Individuals who would like a complete set of ARI's comments should contact Dave Godwin of ARI staff.

Based on discussions held at the June meeting of ASHRAE Standing Standards Project Committee (SSPC) 62, it seems that many of ARI's comments will be addressed. However, because SSPC 62 plans to issue a second public review draft, they are not required to respond to all 8000+ comments they have received, although they may do so anyway. Nonetheless, it behooves all ARI members to pay careful attention to the second public review draft and provide their comments on that draft.

ASHRAE SSPC 62 is targeting November 1997 to approve a second draft, which means the second review period would start around February 1998. ARI members wishing to join the Ad-Hoc Working Group to review this draft should contact Dave Godwin of ARI staff. ♦

Tech Update

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ARI/CDA Research

Research on Copper Joining Techniques Evaluates New Designs and Brazing Methods

Introduction

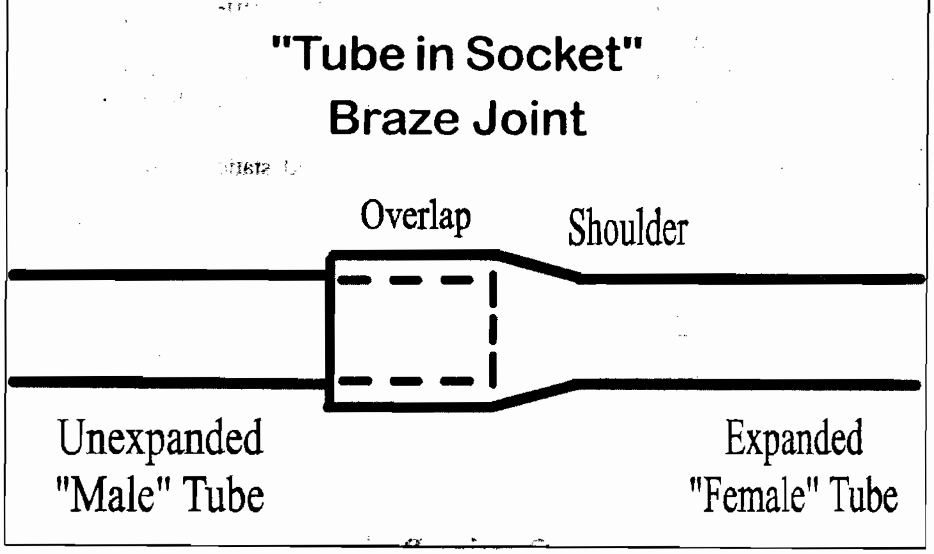
This article summarizes the results of the second part of a two-part research effort undertaken at Amalgamated Technologies Incorporated (ATI), sponsored by ARI and the Copper Development Association (CDA). The objective of Part 1 was to determine whether current braze joining technology for copper tubing is adequate for the higher operating pressures of alternative refrigerants proposed for future usage (see the July 1997 edition of *Tech Update*).

The objective of Part 2 was to ascertain whether experimental braze joint designs and alternate braze heating methodologies can economically provide improved brazing quality and higher product performance. See *New Report* for information on obtaining a copy of the final report.

The Part 1 research indicated that current brazing technology is capable of high quality brazed joints that likely can meet the requirements of the industry in the future. However, the research indicated that some minor aspects of current technology could be modified or improved to result in significant gains in refrigeration product quality.

The researchers speculated that tube joints made with less female socket depth relative to tube diameter, i.e., less overlap, would allow more effective brazing, thus improving the leak-tightness of the joints in each system, and raising product performance above and beyond that attained with current practice. The Part 1 report further speculated that an alternate heating method, which heats more rapidly and consistently than a conventional gas torch, would also increase braze joint integrity and performance.

Figure 1



In Part 2 of the research project, ATI tested both of these theories. The research indicates that more rapid heating does in fact improve braze joint integrity and strength over that attained with slower heating. The research also indicates that tube joint designs with less overlap do braze faster and more effectively with both slower and faster heating methods.

Methodology

Testing involved two heating methods. The "conventional" heating method was an acetylene gas torch, and the "alternate" heating method for more rapid heating was an industrial 2,500 watt inductive brazing unit.

The intent of the work was to evaluate these two heating methods and various joint designs for brazed joint strength, endurance, and relative ease of brazing. In equipment applications, sound joints are considered those that do not leak or devel-

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New Report ♦ New Report ♦ New Report

Scott A. McCracken, Roy E. Beal (Amalgamated Technologies Inc.), **Evaluation of Joining Techniques for Copper Tubing in AC&R Applications -- Part Two**, October 1998. *Contact:* ARTI Database c/o James M. Calm, Engineering Consultant, 10887 Woodleaf Lane, Great Falls, VA 22066-3003; e-mail: jmc@spectrum-internet.com (reference RDB8B01). Price may be determined using the order form available from ARTI and found on ARTI's web site (URL: http://www.ari.org/arti/order.html). Final report, 82 pages. See article on page i. ♦

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op leaks during normal operation. For the accelerated testing of Part 2, braze integrity of the various joint designs was assessed by mechanically testing for static burst strength and cyclic stress endurance. Because the Part 1 project demonstrated that braze joint performance is determined largely by the degree of braze filler metal penetration throughout the overlap region of a tube-in-socket joint, the integrity of the braze joints was also evaluated under that criteria.

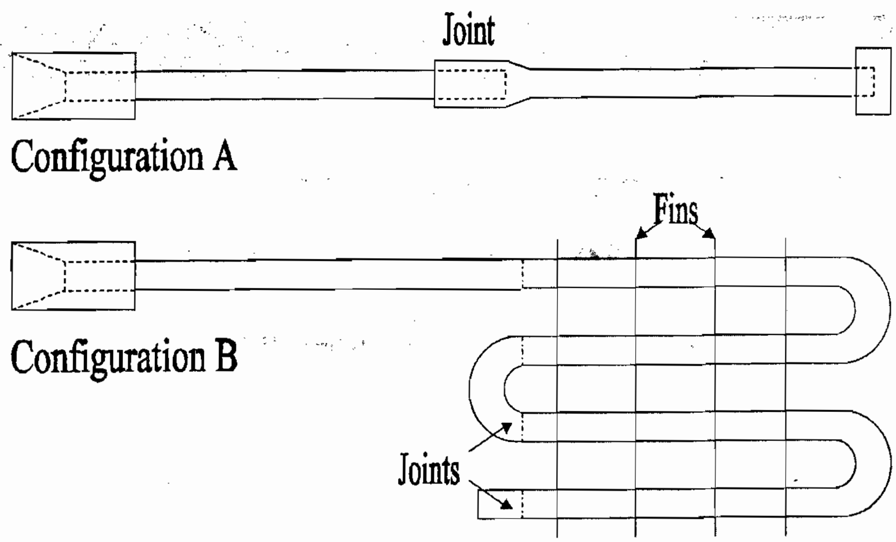
Two braze filler metals were selected: AWS BCuP-2 braze alloy, 0% silver, copper-phosphorus, and AWS BCuP-3 braze alloy, 5% silver, copper-phosphorus. Both 5/16" (8 mm) and 3/8" (9.5 mm) tubes were tested, each with and without fins.

The four types of tubing were configured into two types of test samples, depending on the test procedure used. Each sample contained at least one "tube-in-socket" joint, where one tube is expanded to form a female socket, to allow an unexpanded tube to slip inside and form an overlapping joint as shown in Figure 1 (page i). The two types of test samples are shown in Figure 2.

Tubing samples tested in Part 1 were supplied to ATI by the manufacturer with a shoulder angle of approximately 15°, and an overlap ratio of 150% of the diameter. This became the definition of a "conventional" joint design for Part 2. The experimental joint designs of Part 2 employed three different shoulder profiles and three different overlap ratios, as shown below in Figure 3.

Figure 2

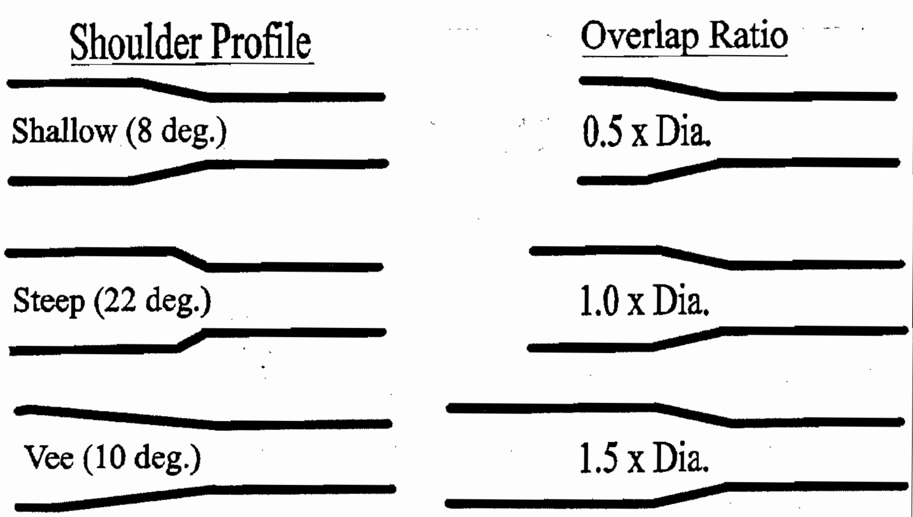
Test Sample Configurations



Three test procedures were utilized: static burst pressure, vibration cyclic fatigue life, and pressure cyclic fatigue life. The cyclic fatigue tests were performed at three different stress levels to establish stress-vs-life behavior of the brazed samples.

Figure 3

Experimental Joint Designs



Static Burst Strength Testing

Every braze joint of all designs and both heating methods had complete filler metal penetration, indicating that all joints were expected to perform well. There was no clear difference between the joint designs in terms of ease of brazing, as would be indicated by varying degrees of filler penetration. Optimum braze technique with both heating methods resulted in consistently good joints, which negated the relative differences in brazability between the various designs.

However, there were differences between the sample groups in terms of average burst pressure. Samples brazed with the inductive heater averaged five to eleven percent higher burst strength than corresponding samples brazed with the gas torch. This was due to the fact that the inductive heater made each joint in one-third the time or less, compared to the gas torch. Reduced braze time resulted in less annealing and less grain growth in the copper material, allowing the tube to retain more of the work-hardened strength imparted from swaging.

Also, joints with shorter female sockets (less overlap) heated faster than joints with longer overlap, for both heating methods. Under the gas torch heating method, the shortest joints brazed 12 to 15 percent

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faster and had higher static burst strength, compared to the longest joints. There was no difference in average burst strength between the three overlap lengths for inductive heated samples, because the inductive heater brazed all joints so quickly, nor was there essentially any difference in burst strength between the three shoulder profile groups. Even the Vee profile joints, with overlap engagement of only 25% of the diameter, achieved the full strength of annealed tubing itself, again due to proper braze technique more than inherent brazability.

The joint design determined to be the "best" was the steep shoulder profile, with an overlap ratio of equal to the diameter. This design was selected because it was consistently at or near the highest average burst pressure, and also because it was compact and easy to fixture, and would likely be preferred in a factory environment.

The researchers constructed additional samples with this joint design using both heating methods and braze alloy BCuP-3, to determine if there would be any change of brazability with this filler metal. Alloy BCuP-3 contains 5% silver, and is less fluid within capillary spaces than alloy BCuP-2. These tests showed that all BCuP-3 samples had full penetration joints and strength equal to samples with alloy BCuP-2, with no reduction of brazability.

Summary of ATI's Conclusions

Static Burst Test

- Inductive heating delivered faster brazing and higher burst strength with each joint design.
- Joints with less overlap heated faster with both heating methods. This resulted in burst strength gains for gas torch heated samples, but no additional gains for inductive heated samples.
- Joint profile and shoulder angle had little or no effect on brazing properties and strength.
- The combination of steep shoulder angle and 1.0 x diameter overlap was selected as the "best" joint design for several reasons. The "best" joint worked equally well with alloy BCuP-3.

Vibration Cyclic Fatigue Test

- Inductive heated samples lasted longer than gas heated samples in 11 out of 12 groups.
- The Part 2 "best" joint design lasted longer than the conventional joint of Part 1 in eight out of twelve sample groups.

Pressure Cyclic Fatigue Test

- Coil tube protrusion length from the end sheet greatly affects performance. Less protrusion results in much higher static burst strength and cyclic fatigue endurance.
- Reduced protrusion length also results in more difficult brazing, which suggests a coil design tradeoff between higher strength and uniform braze joint quality.
- The inductive heater proved less suitable for coil joint brazing.

Other Observations

- The inductive heater brazed each joint for 6% of the energy cost, and three times faster than the acetylene torch.
- Coil quality and braze performance is compromised by mechanical tube damage and heavy oil contamination.

Vibration Cyclic Fatigue Testing

Vibration fatigue behavior of brazed joints was determined using an apparatus which mechanically induced a vibration-like motion in the samples while recording elapsed time. Configuration A samples with the best joint design, as concluded by static burst testing, were made with both heating methods and alloy BCuP-2.

Samples with the new joint in 3/8" tubing lasted longer than the conventional joints of Part 1 in three out of six groups. However, samples with the new joint design in 5/16" tubing lasted longer than the conventional joints in five out of six groups. At the lowest stress levels, the Part 2 joins lasted 475% to 652% longer than joints of Part 1.

Inductive heated samples lasted longer than gas torch heated samples in eleven out of twelve vibration sample groups. This is because metal with higher hardness and yield strength can bend more without yielding, and therefore has greater fatigue strength and longer cyclic stress endurance. As was seen in the burst testing, fast inductive heating results in less annealing of the copper and thus higher yield strength.

The primary conclusion from vibration fatigue testing is that the new joint design worked as well or better than the conventional design in most cases. In addition, samples brazed with the inductive heater were distinctly better than gas torch heated samples for this particular test.

Pressure Cyclic Fatigue Testing

Pressure cyclic fatigue behavior was determined using an apparatus which rapidly pressurized and depressurized samples to simulate pressure cycling effects of refrigeration system operation. Testing was limited to 5/16" and 3/8" Configuration B coil tubing samples only. ATI's prior experience with this test indicates that the most useful data is generated by pressure cycling at 70 to 95 percent of the static burst strength of the test coils. Prior experience also shows there can be considerable quality variation between coil production runs, so it is necessary to determine the static burst strength of each set of test coils before pressure cyclic testing can begin. For example, one set of coils supplied for Part 1 testing had mechanical score marks on the tubing from coil forming operations, and had 15% lower static burst strength than another batch of coils made without score marks. Thus in order to generate comparable pressure cyclic fatigue test data

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between different coil production batches, it is necessary to first determine the static burst strength of each batch.

As was observed on some Part 1 coils, the coils supplied for Part 2 had severe score marks from coil forming machines. [Note: score marks and other mechanical deficiencies were present on coils used in this project. These marks were due to manual coil forming operations, and would not normally be incurred in production heat exchangers.] Because of the presence of score marks, it was a big surprise when the new Part 2 coils showed a tremendous increase in static burst strength over the static burst strength of coils tested in Part 1. The 5/16" coils supplied for Part 2 were 30% stronger than the Part 1 coils, and the 3/8" coils supplied for Part 2 were 63% stronger than the Part 1 coils. The only difference between the Part 1 and Part 2 coil batches was that the open ends of the hairpin tubes of the new coils were shorter in length than the tubes of the Part 1 coils. The Part 1 coil tubes of both 5/16" and 3/8" coils protruded 1.0 inch from the end sheet, while the Part 2 coil tubes of both sizes protruded only 0.5 inch from the end sheet.

Pressure cyclic testing was then performed with cyclic pressure at 60, 70 and 80 percent of the measured burst strength for the Part 2 coils of both tube sizes and both heating methods. Because the Part 2 coils had higher static burst strength than prior testing, the cyclic pressure levels were correspondingly higher as well.

In spite of severe score marks, the Part 2 coils lasted much longer than Part 1 coils at equivalent pressure levels. For example, 3/8" Part 2 coils lasted for 300 more pressure cycles at 1,478 psi than equivalent Part 1 coils lasted at that pressure. The Part 2 coils had significantly higher burst strength, longer fatigue endurance, and braze joints that were actually stronger than the rest of the coil. All three of these improvements over the Part 1 coils are credited to the reduced tube protrusion length from the end sheet of the Part 2 coils. Reduced protrusion length results in less unsupported tubing between the end sheet and the braze joint, and greatly enhanced coil properties.

For a summary of the researchers' conclusions, see page iii.

However, reduced tube protrusion made brazing more difficult, because the braze joints were in closer proximity to the coil. Shorter tube protrusion results in a greater heat-sink effect from the coil, causing brazing to take approximately twice as long as the coils with longer protrusion, for both heating methods. This suggests that there may be an optimum protrusion length for each coil design. Densely packed, multiple row coils may need longer protrusion to ensure the inner rows of tubes are effectively heated. Narrower or low density coils will effectively braze with less tube protrusion, and could take advantage of higher burst strength and fatigue life from the shorter tubes.

Both types of heating were used, but there was no difference between them in pressure cyclic fatigue life. The inductive heater was hindered by the close proximity of the steel end sheets. As a result, brazing took the same amount of time for both methods, leading the researchers to conclude that coil heating is a less suitable application for the inductive heater.

Conclusions

This study confirmed the conclusion of the Part 1 effort that full braze filler metal penetration of the joint is essential to optimum joint and system performance. The authors propose that a full filler penetration throughout the overlap region should become the industry definition of a good joint.

Conventional brazing technology is capable of producing high quality joints. However, there is potential to further raise quality and performance of refrigeration products in the future. This study indicates that reduced joint overlap can enhance brazability for all joints and heating methods. The report also shows that a fast, consistent heat method, such as that produced by the inductive brazing unit, can more effectively produce full penetration joints in suitable applications. ♦

Upcoming Conferences

Thermal Performance of the Exterior Envelopes of Buildings VII, Dec. 6-10, 1998; Clearwater Beach, Fla. *Contact:* Mia D. Prater, Oak Ridge National Laboratory, PO Box 2008, Oak Ridge, TN 37831-6070; (423) 576-7942; fax: (423) 574-9331; e-mail: unb@ornl.gov.

Renewable and Advanced Energy Systems for the 21st Century, April 11-14, 1999; Lahaina, Maui, Hawaii. *Contact:* Srinivas Garimella, Department of Mechanical and Aeronautical Engineering, College of Engineering and Applied Sciences, Western Michigan University, Kalamazoo, MI 49008-5065; (616) 387-3379; fax: (616) 387-3358; e-mail: srinivas.garimella@wmich.edu.

1999 International Appliance Technical Conference, May 10-12, 1999; West Lafayette, Ind. *Contact:* James Stevens, International Appliance Technical Conference, 1001 Starkey Road, #427, Largo, Florida 33771; (813) 969-1061; fax: (813) 969-0904; e-mail: JSteve1061@aol.com.

FMEA: How to Use Failure Mode and Effects Analysis to Improve Product Performance and Quality and Your Manufacturing Processes *along with* **Advanced Failure Mode and Effects Analysis (FMEA) Application Workshop**, April 12-16, 1999; Madison, Wisc. *Contact:* Engineering Registration, Dept. 107, The Wisconsin Center, 702 Langdon Street, Madison, WI 53706; 800/462-0876; fax: 800/442-4214; e-mail: custserv@epd.engr.wisc.edu; http://epdwww.engr.wisc.edu/. ♦

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