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FIELD EVALUATION OF ZINC-BASED SOLDERS
FOR COPPER AND COPPER ALLOYS

Roy E. Beal

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25 March 1976

Prepared for the
U.S. Department of the Interior
Bureau of Mines
Washington, D.C. 20240

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FOREWORD

This report was prepared by IIT Research Institute, Chicago, Illinois, under USBM Contract Number H0252054. The contract was initiated under the Bureau of Mines Metallurgy Program. It was administered under the technical direction of Metallurgy with Mr. M. M. Fine acting as the Technical Project Officer.

This report is a summary of the work recently completed on this contract during the period 1 June 1975 to 25 March 1976. This report was submitted by the authors on 25 March 1976.

This Final Report is designated internally as IITRI-B6136-3. The program was managed by Roy E. Beal, Assistant Director of Metals Research, with support by Roy C. Hill, Assistant Metallurgist, and J. Newlan, Technician.

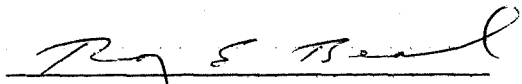

Roy E. Beal
Assistant Director
Metals Research

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FIELD EVALUATION OF ZINC-BASED SOLDERS FOR COPPER AND COPPER ALLOYS

1. INTRODUCTION

The Bureau of Mines has recently developed a new high-temperature soldering system for use on copper and copper alloys. This field evaluation program is designed to demonstrate the transfer of the technology developed and the utility of the new solder system for application to the automobile radiator. The system uses a unique sacrificial metal coating method to promote spontaneous wetting and spreading of the zinc alloy solders on copper and copper alloy substrate. Appropriate fluxes were developed in the original Bureau program.

The original work was verified during the first quarter which essentially accomplished Task I, process familiarization. Alloy rod to plate samples were successfully joined. Metallurgical and mechanical property evaluations gave good strength values. Three samples of the 95Zn-5Al and three of 89Zn-7Al-4Cu rod to plate configurations were submitted to the Bureau.

Under Task II engineering data were developed to define and optimize the processing sequence so that simulated radiator joint capsules could be fabricated and examined (Task III). The most effective joining method used was furnace heating of the capsule with preplaced solder and flux. Some capsules required further attention by hand to produce joints for testing. The nickel plating provides a good wetting surface. The 95Zn-5Al alloy appears to be most satisfactory in making a radiator type joint. Most difficulty appears to be with the flux composition which results on occasion in sporadic wetting and formation of holes in the soldered joint.

Work was continued on producing satisfactory capsule joints to obtain samples for the Bureau of Mines. For comparative testing in the final task, a series of capsules was evaluated in antifreeze solution at 250°F with cyclic loaded pressure application of 30 psig for 5 min on and 5 min off. The test was in

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operation for over 1000 hr without joint failure. Another series of capsules was tested at 90 psig due to lack of failures at 30 psig. The capsule produced with 70Pb-30Sn solder exhibited failure at 250 hr, whereas all the zinc-based solders were still good at 1000 hr, clearly showing the superiority of the zinc-based solders over the present lead-tin solder. Other tests undertaken, such as the tensile-peel test, confirm this superiority.

2. MATERIALS

Solders: 95Zn-5Al; 89Zn-7Al-4Cu

Supplied by the Bureau in 1/8 in. diameter rod and small ingots.

Flux:	KCl 33	ZnCl ₂ 39.4
	NaF 53	NH ₄ Cl 5.3
	LiCl 17	

The flux is hygroscopic and is stored in a desiccator.

Base Metals: Copper and brass plate and rod,
nickel plated before soldering.

3. SOLDERING ROD AND PLATE SAMPLES

3.1 Soldering Procedure

Early Bureau wetting studies were performed under vacuum conditions; during the developmental work, suitable fluxes evolved to allow spreading in the open atmosphere. A visit was made to the Bureau of Mines at Rolla, Mo., to review the soldering procedures developed there so that the IITRI program ensured the background expertise already available was correctly adapted.

One particular flux, detailed above, was recommended for procedural verification experiments. The process was stated to proceed better on copper. Both copper and brass specimens were made, and since the automobile radiator is principally made from brass, it was important to succeed with this material. With brasses, a recommended acid clean immediately followed by a Watts bath electrochemical nickel plating was

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used for part preparation for soldering. Flame heating of the specimens was stated to be satisfactory, and this procedure has been followed. Initial soldering procedures began with uniform heating of the plate specimens by a hot plate; then, flux was applied and heated together with the rod until the flux first baked to a white color and then changed to a gray liquid. Solder buttons, 3/16 in. in diameter, supplied by the Bureau were placed away from the heating flame and allowed to melt and flow under the flux blanket. Rapid heating was recommended and used to produce good joints. Overheating or prolonged heating was confirmed to be detrimental to successful soldering with the zinc alloy solders.

A number of plated specimens were provided by the Bureau. Evaluation of soldering procedures with these specimens and those made and plated at IITRI showed equivalent wetting and soldering action with the zinc-based solders. The flux used was compounded at IITRI and stored in a desiccator until required for use.

An intermediate soldering procedure adopted was to place the plates on the hot plate, apply a flattened solder preform and clamp the rod with a vise-grip for positioning above the preform. Flux was then placed around the solder, and the assembly heated with a Prestolite torch until the solder flowed to make the joint. The heat was then immediately removed, and after one minute the joints were water quenched.

The final soldering procedure adopted involved elimination of the hot plate and placing the base metal plate on a wire grid. A quantity of flux was applied to the plate, and the rod was pressed into the flux. Heating was accomplished with the Prestolite torch with the solder preform at one side away from the flame until the flux liquified and produced the joint. It must be noted that the simulated radiator header tank is only 0.025 in. thick material and will heat more rapidly than the plate specimens so far fabricated.

Many specimens of the plate and rod configuration now have been made, some of which are shown in Figs. 1 and 2. Three soldered with the 95Zn-5Al alloy and three soldered with the 89Zn-7Al-4Cu alloy have been submitted to Rolla.

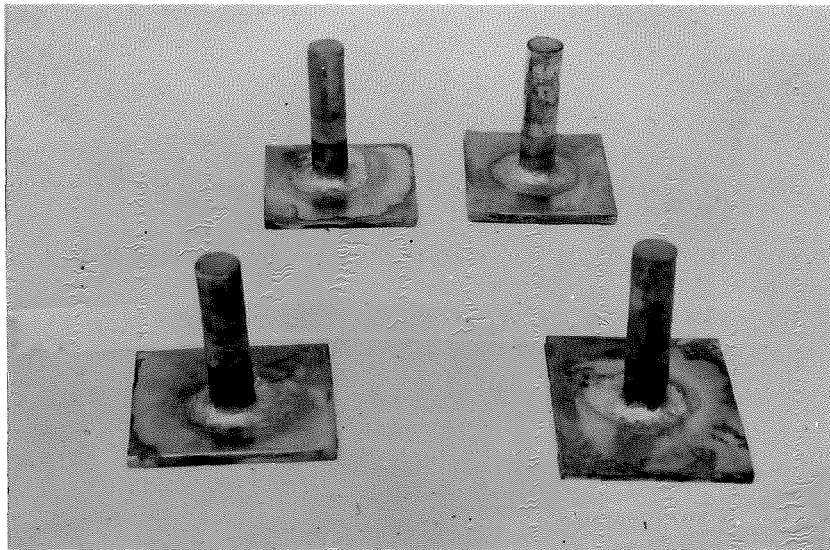
3.2 Metallurgical Examination

Good soldered profiles, equivalent to those of Schwaneke's earlier work for the Bureau of Mines, were achieved when heating conditions had been optimized as demonstrated in Fig. 3, which shows brass base metal joined with 95Zn-5Al in the unetched condition.

Plating thickness appears to have an important role relative to ultimate strength properties. Previously it was determined that a plating thickness of 10^{-3} cm is the maximum that is desirable for solder penetration and adequate strength properties. Figures 4 and 5 show that in the present investigation, at the same nominal plating conditions, specimens are made with dispersal of the plated nickel layer as in Fig. 4, or the plating may be retained as in Fig. 5. In each case the solder wetted and flowed well to make the joint. The specimen in Fig. 6 illustrates the intermediate stage where the plating on the flat piece is partly penetrated and that of the cylinder or rod is virtually intact. Now that we have made these observations, further attention will be given to the plating conditions to ensure that we produce optimized joints for our production simulation test program.

Specimens manufactured with the 89Zn-7Al-4Cu material illustrated in Figs. 7 and 8 again show good wetting and joint appearance with low porosity and dispersion of the nickel-plated layer. In the joint between rod and plate, Fig. 8, large dendrites--probably nickel-rich--are seen principally on the plate.

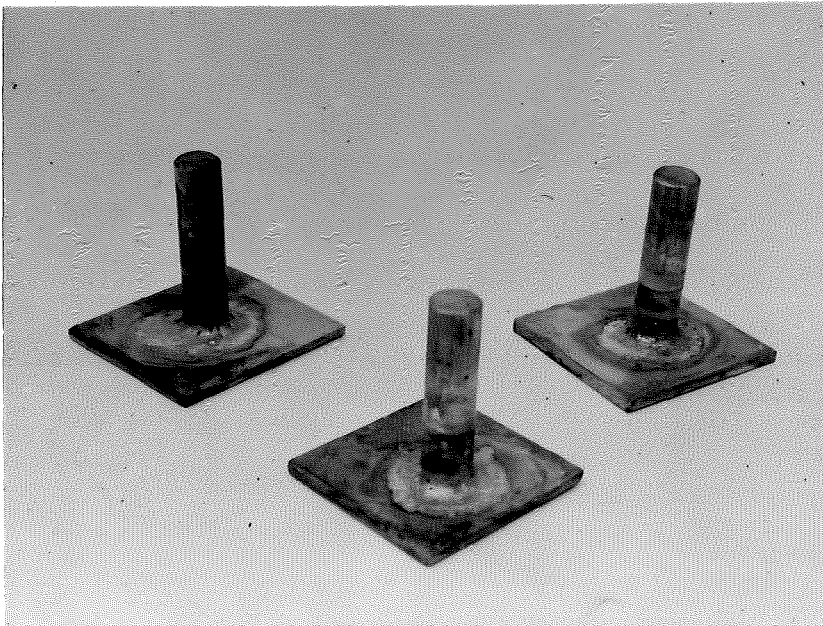
Mechanical property evaluations performed on the rod-to-plate type joint have given tensile strengths of 13,500 to 35,000 psi using the rod cross-sectional area plus the throat



Neg. No. 42237

Figure 1

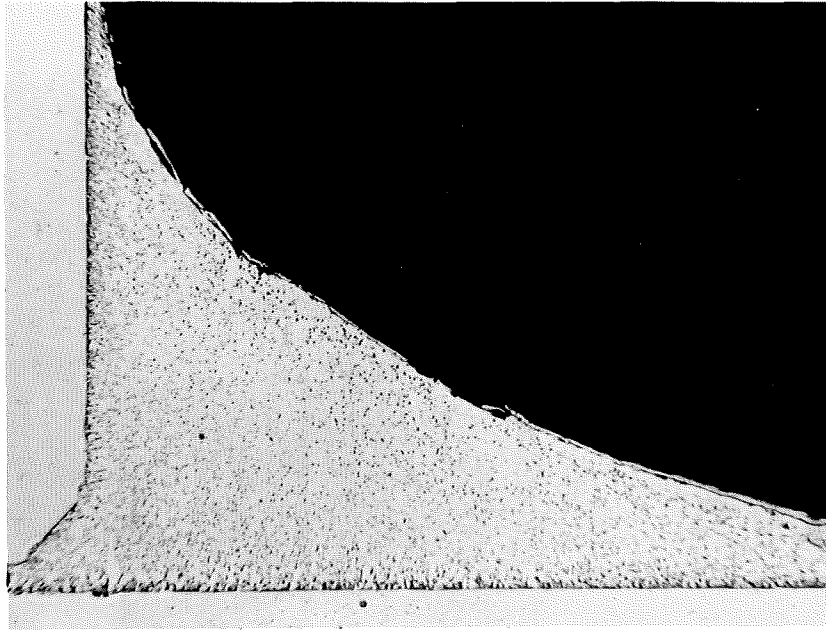
Copper and Brass Rods and Plates Soldered
with 95Zn-5Al



Neg. No. 42238

Figure 2

Copper Plates and Brass Rods Soldered
with 89Zn-7Al-4Cu

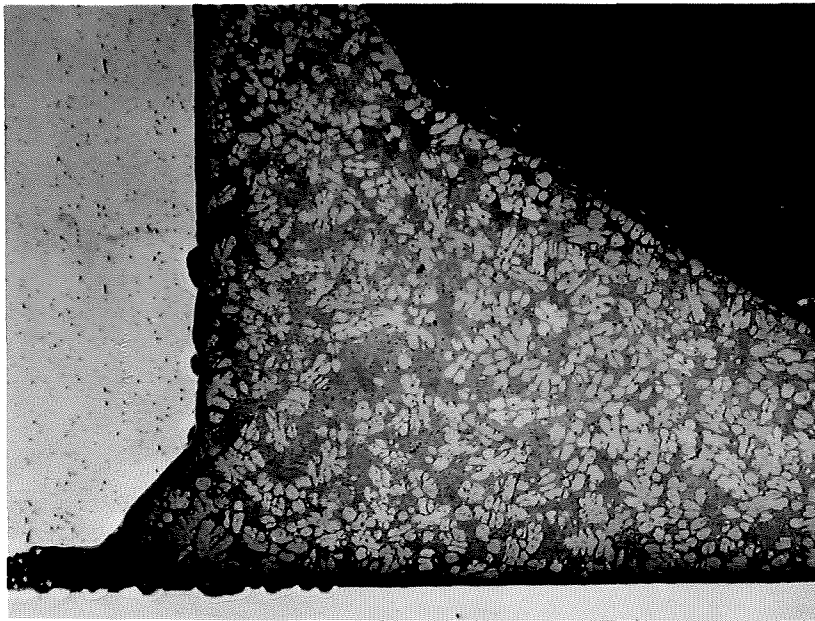


Neg. No. 42205

33X

Figure 3

Brass Soldered with 95Zn-5Al. Unetched.

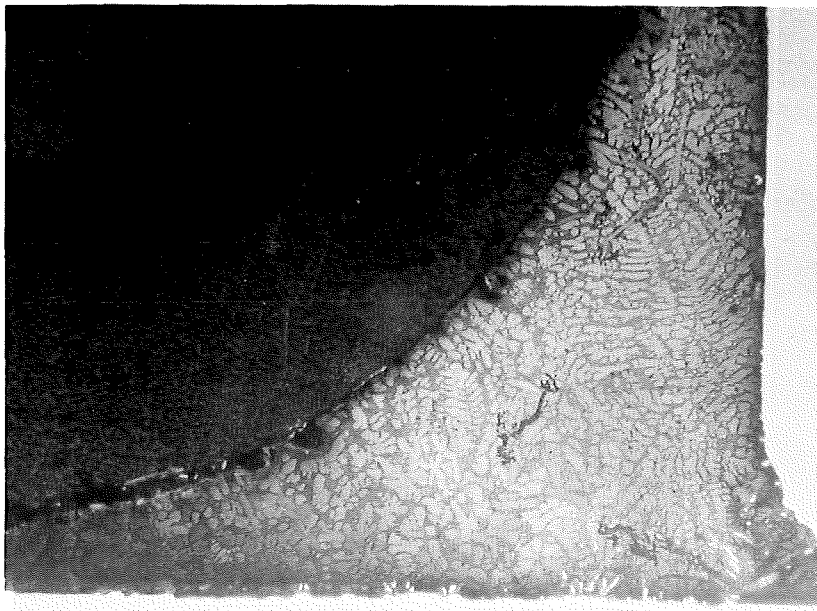


Neg. No. 42207

50X

Figure 4

Brass Soldered with 95Zn-5Al. Note that most of plating appears dissolved.



Neg. No. 42214

40X

Figure 5

Brass Soldered with 95Zn-5Al with Plating
Present in Completed Joint.

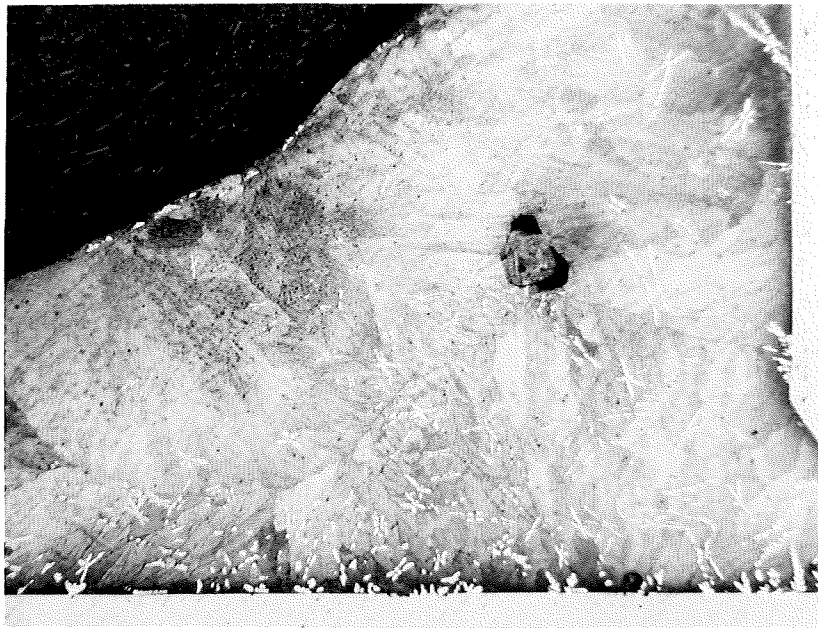


Neg. No. 42210

65X

Figure 6

Brass Soldered with 95Zn-5Al. Plating
on plate partly penetrated, but still
intact on rod.

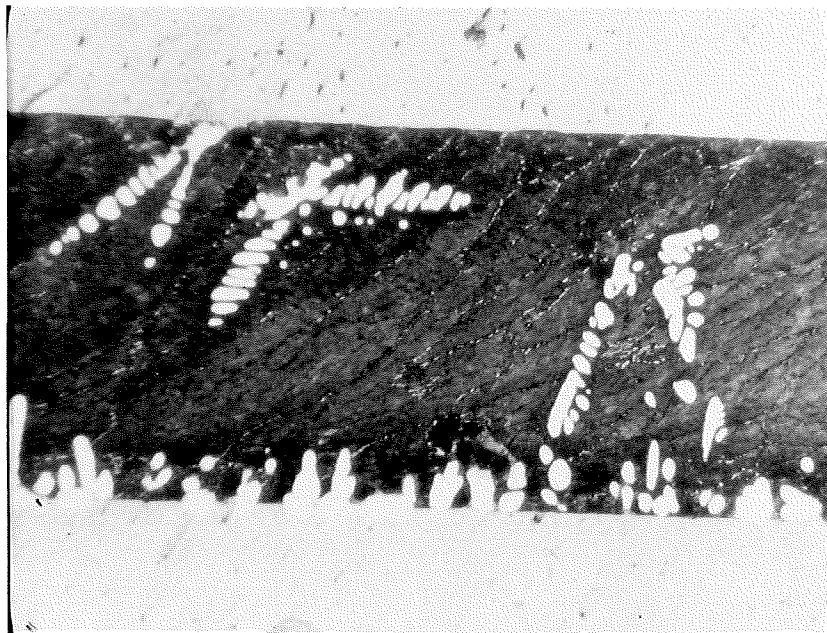


Neg. No. 42250

40X

Figure 7

Brass Rod and Copper Plate Soldered with
89Zn-7Al-4Cu, Plating Dissolved or Dispersed.



Neg. No. 42249

160X

Figure 8

Large Dendrites Observed in 89Zn-7Al-4Cu
Soldered Joint Between Plate and Rod.

depth of the solder fillet as the unit joint area. Further work is needed to produce consistent joint strengths at the upper end of the range and may be beyond the scope of this present effort. However, every endeavor will be made to optimize the soldering process operation for strength property development.

4. SOLDERING OF SIMULATED RADIATOR JOINTS

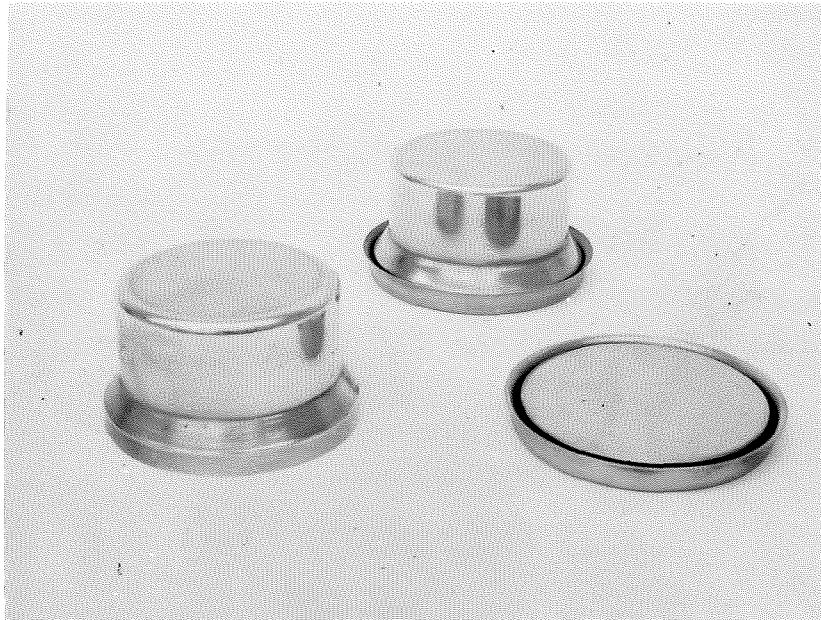
4.1 Capsule Manufacture

A quantity of simulated radiator header tank capsules were manufactured from Alloy 260 radiator tank brass, as illustrated in Fig. 9. The radiator header plate joint was produced by spinning a groove into the tank brass, similar in dimensions to the actual radiator header plate joint, as shown on the right. On the left of Fig. 9 is the tank portion of the capsule, approximately 2 in. in diameter shaped to fit the header plate. The complete assembly ready for soldering is depicted in the rear of the same photograph.

4.2 Solder Procedures for Simulated Radiator Joints

The simulated radiator parts are first nickel plated in a Watts bath for 20 sec using 7 amps at 4 v. The plating of the header tank was relatively easy. The grooved section of the header plate was more difficult to plate. Trials were made at different electrode positions until a thin nickel plate was observed in the groove. Parts are then thoroughly washed and stored ready for the soldering operation.

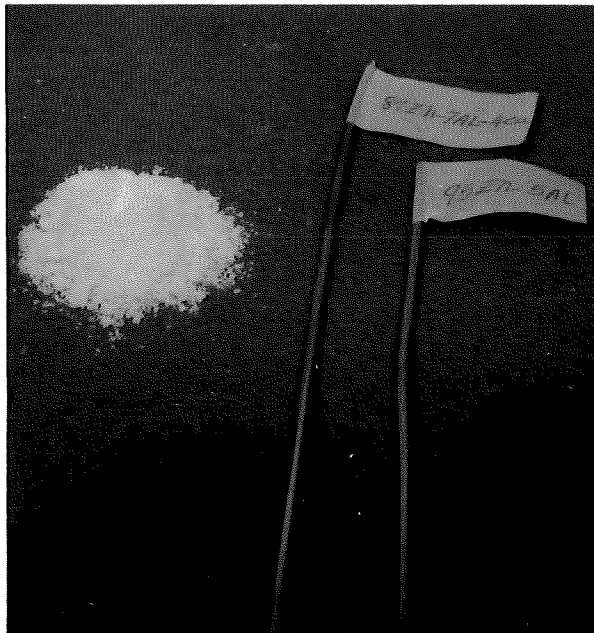
Materials for soldering are shown in Fig. 10. Rings were made of the solder wire of appropriate composition. Powdered flux is applied to the joint. The ring is placed in the joint area as shown in Fig. 11. After several trials with torch heating, furnace heating was tried and found to be more successful in producing a good soldered joint. An assembly ready for the furnace is presented also as Fig. 11. Heating of the



Neg. No. 42251

Figure 9

**Simulated Radiator Header Tank Capsules
Showing Both Parts and Assembly.**



Neg. No. 42883

1X

Figure 10
Solder Wire and Flux Powder Used



Neg. No. 42875

1/2X

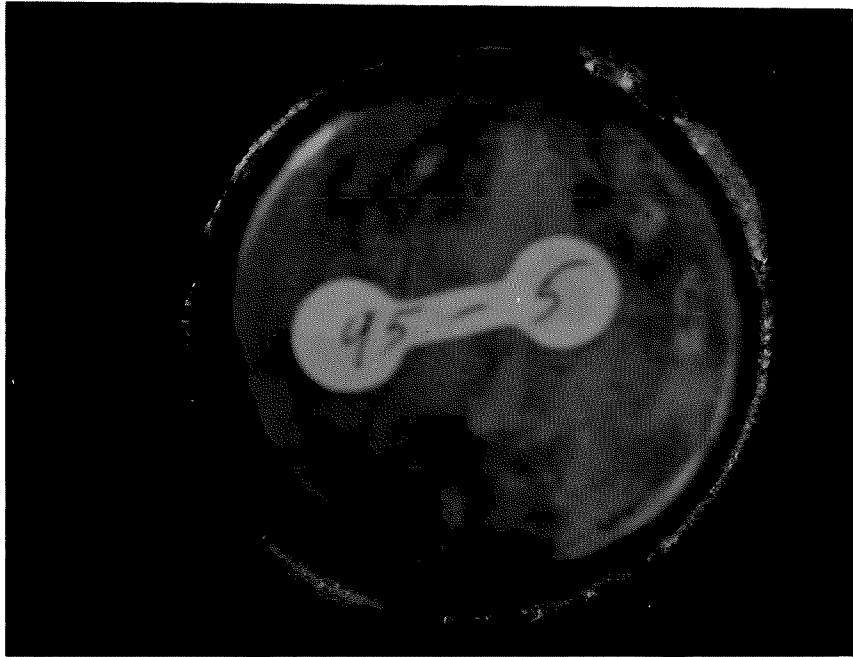
Figure 11
Radiator Capsule Assembled with Flux and Solder
Ready for Processing

assembly is performed in an electrically operated oven. Best processing conditions were established at a furnace setting of 1000°F. The basket is lowered into the furnace, and soldering takes place after approximately 15 sec. After solder flow has taken place, the capsules are removed and cooled. A number of the furnace soldered joints required additional manual soldering to produce a joint sound enough for testing. Typical soldered joints with the two zinc-based materials are shown in Fig. 12. The 95Zn-5Al joint in Fig. 12a shows good wetting for most of the joint with two small incompletely wet areas, partly due to insufficient solder alloy in the joint. The 89Zn-7Al-4Cu solder did not wet and flow so readily as the 95Zn-5Al solder as shown in Fig. 12b. Here several areas of unwet solder and base metal are seen.

The 70Pb-30Sn and 97.5Pb-1.0Sn-1.5Ag soldered joints being used for comparison purposes showed excellent wetting and spreading during the furnace soldering operation as clearly shown in Fig. 13.

The zinc-based solder joints that did not flow as well as those shown in Fig. 12a were improved somewhat by additional torch soldering. When reheating the joints by torch, it was found very difficult to melt and wet additional zinc solder to the originally furnace soldered joint. With liberal fluxing the solder metal simply did not want to flow. This was especially so in the region of the holes in the solder, which appeared to be flux-filled with residual material from the furnace operation. However, with persistence, the types of joint illustrated in Fig. 14 were produced.

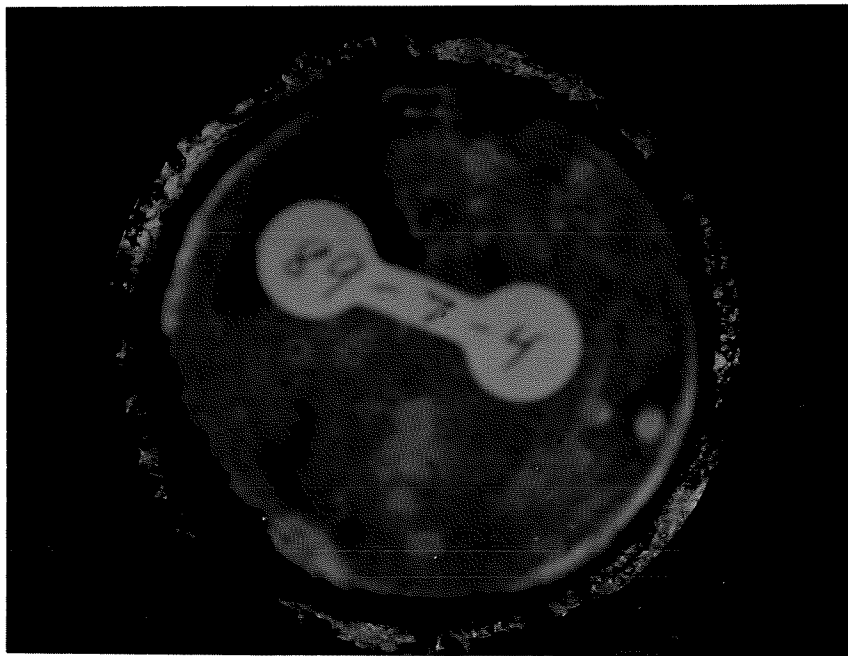
Observations of fluxing action during soldering revealed that absorbed water boils off first, leaving a white crystalline flux which then melts into a gray-colored liquid. Immediate contact with the solder wire and liquid flux results in a brightening of the surface with an obviously vigorous cleansing action. At solder flow point, rapid spreading and wetting with



Neg. No. 42687

1.5X

(a) 95Zn-5Al



Neg. No. 42686

1.5X

(b) 89Zn-7Al-4Cu

Figure 12

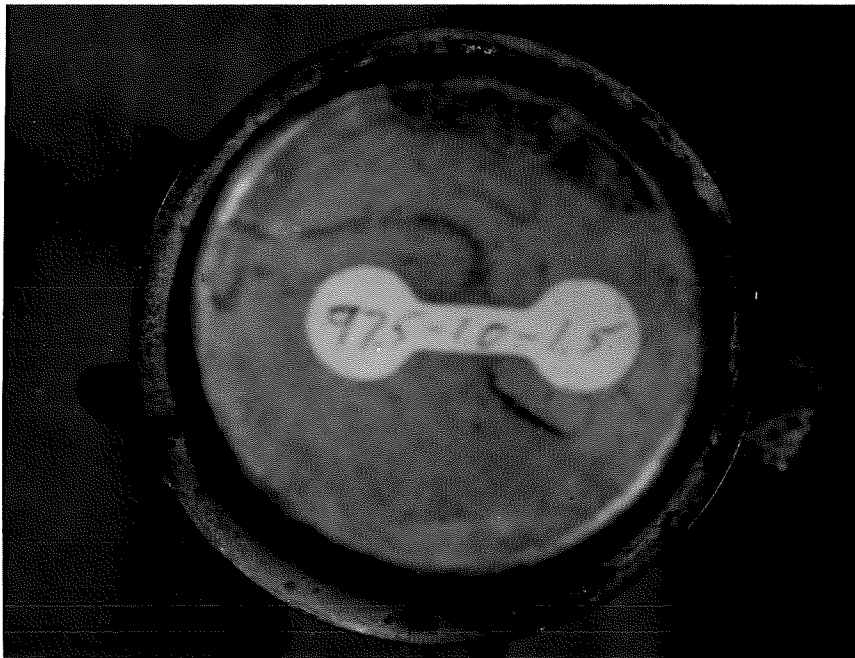
Typical Zinc Soldered Joints after Furnace Processing



Neg. No. 42689

1.5X

(a) 70Pb-30Sn



Neg. No. 42690

1.5X

(b) 97.5Pb-1.0Sn-1.5Ag

Figure 13

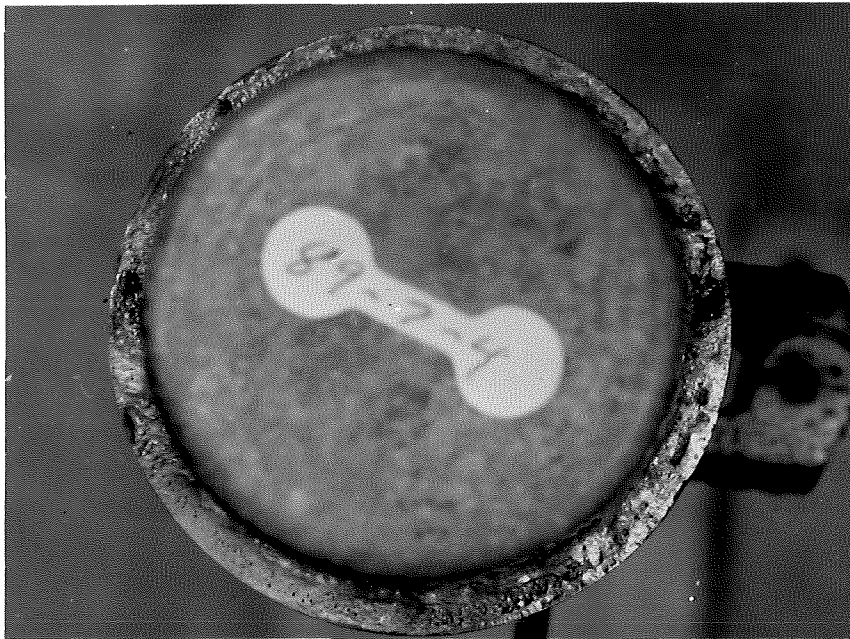
Typical Soldered Joints Produced by Furnace Processing Using Lead-Tin Solders and Zinc-Ammonium Chloride Flux.



Neg. No. 42688

1.5X

(a) 95Zn-5Al



Neg. No. 42685

1.5X

(b) 89Zn-7Al-4Cu

Figure 14

Zinc-based Soldered Joints after Furnace Processing
and Some Additional Torch Soldering

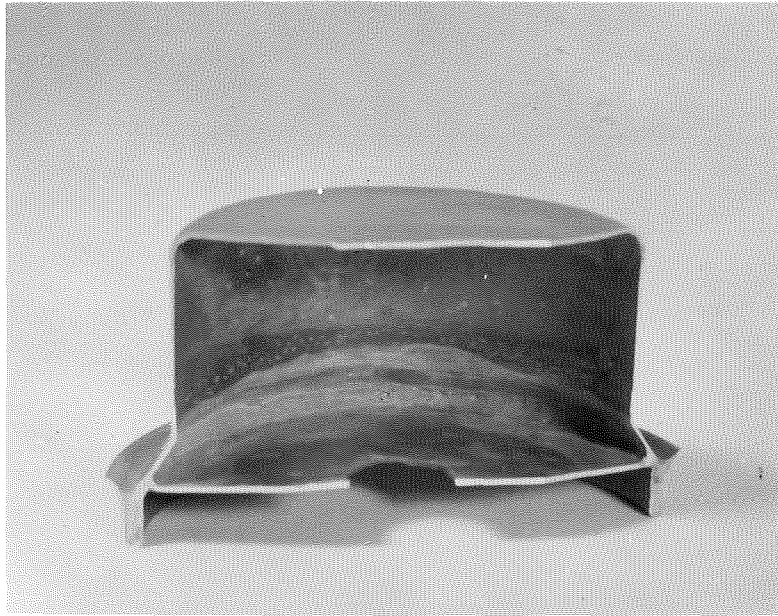
the simulated radiator joint takes place. As the joint is solidifying, flux appears to have some boiling action which causes the formation of the holes observed in previous figures. Some further flux development really is needed before manufacture of these joints can be considered easy. The solders themselves, particularly the 95Zn-5Al material, appear to be good for wetting the nickel-plated surfaces to produce the soldered joint.

4.3 Examination of Soldered Joint Quality

After soldering, several radiator header tank capsules were sectioned to examine the quality of the soldered joint. The 95Zn-5Al material is illustrated in Fig. 15. The inside fillet formed during soldering is very good and continuous with no visible defects, and is typical of furnace soldered joints with the 95Zn-5Al solder alloy. A macro cross-section, shown in Fig. 15b, shows the same material with excellent solder flow filling the joint cavity. A good capillary action is also illustrated by the inside fillet of Fig. 15b with a good final fillet shape. A similar examination of joint quality is illustrated in Fig. 16 for the 89Zn-7Al-4Cu solder alloy. In this case internal flow and wetting to form the inside fillet has not been as good as with 95Zn-5Al solders, although considering the dewetting and holes on the outside of the joint the inside fillet looks very good. A typical cross-section of the 89Zn-7Al-4Cu soldered joint is presented as Fig. 16b. Good solder flow with a good fillet shape is illustrated. A more comprehensive assessment of joint quality by sectioning will be made in the final report.

4.4 Microscopic Examination of Capsule Soldered Joints

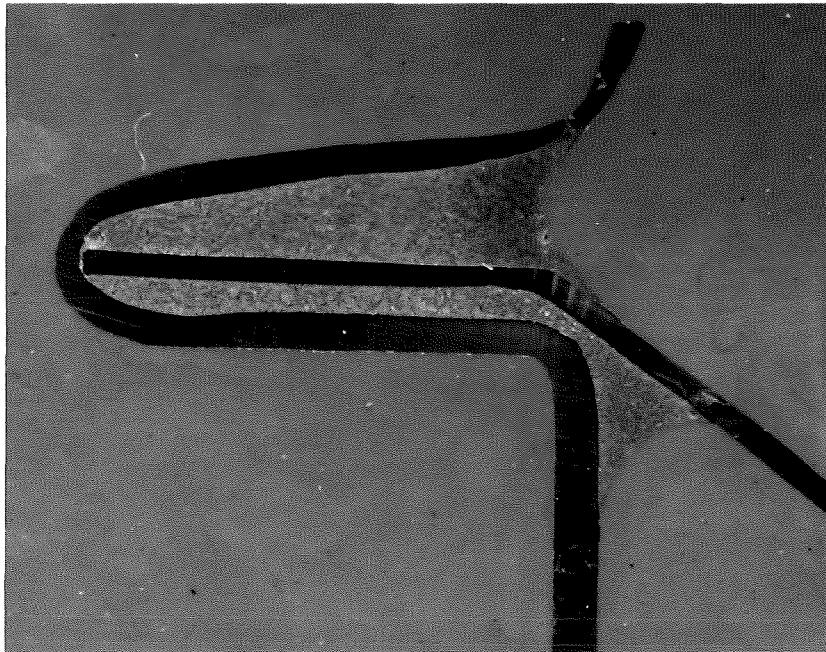
Relative surface wetting quality of the two zinc-based solders is visually presented in the photomicrograph of Fig. 17. The 95Zn-5Al solder has wet the surfaces of the header plate and tank section very satisfactorily. A uniform reaction zone



Neg. No. 42802

~1X

(a)



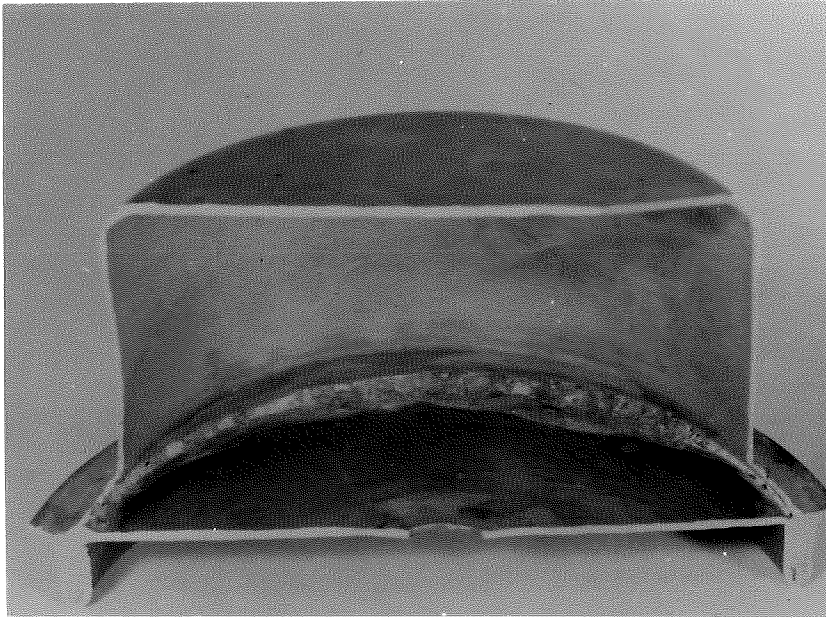
Neg. No. 42876

9X

(b)

Figure 15

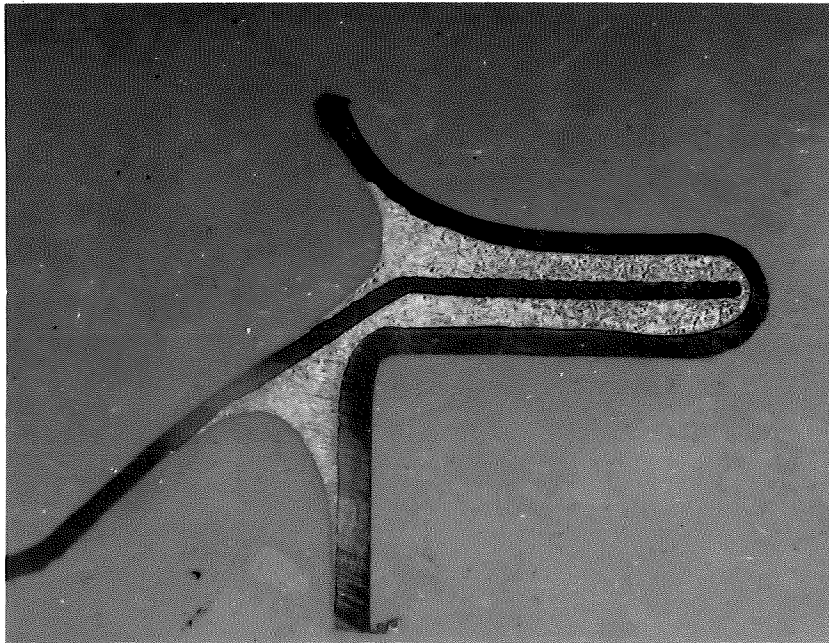
Half-section of Capsule and Macro-section of
the Completed Solder Joint with 95Zn-5Al Alloy



Neg. No. 42877

2X

(a)



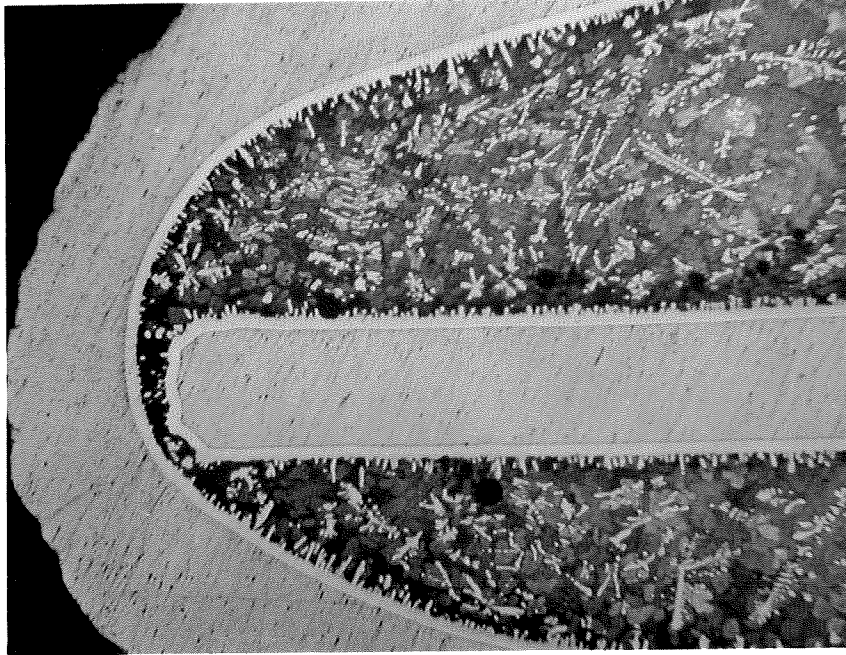
Neg. No. 42638

7X

(b)

Figure 16

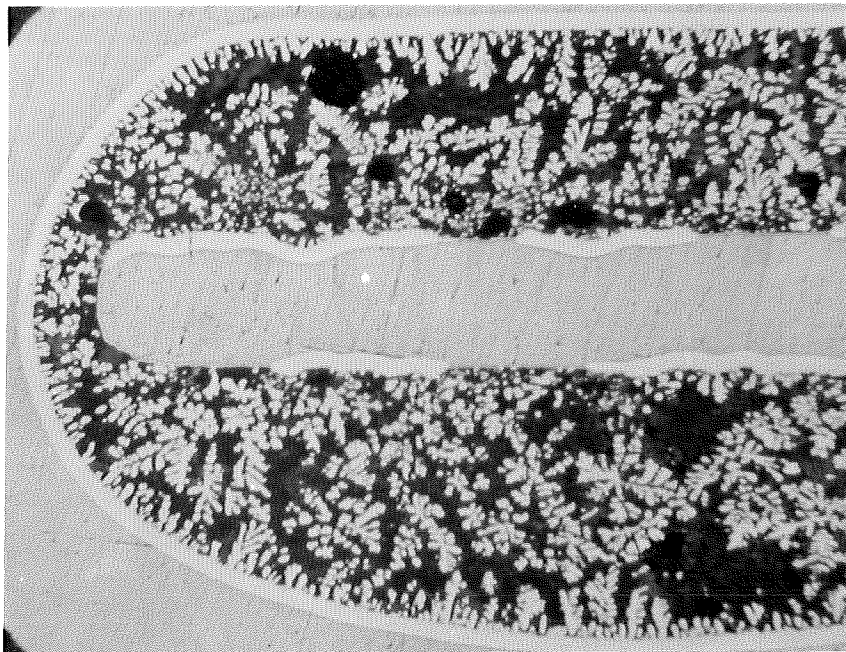
Half-section of Capsule and Macro-section of
Soldered Radiator Capsule Using 89Zn-7Al-4Cu
Solder



Neg. No. 42879

40X

(a) 95Zn-5Al



Neg. No. 42640

40X

(b) 89Zn-7Al-4Cu

Figure 17

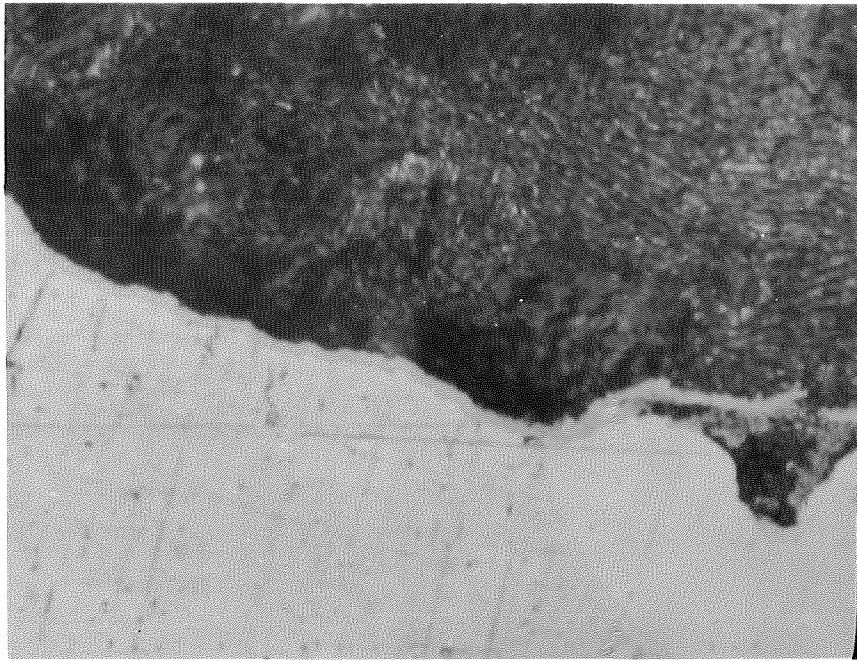
Radiator Capsule Joints Showing Relative
Wetting Quality and Surface Reactions

is observed with small dendrites growing from it on all the surfaces seen. The structure consists of fine dendrites in a fine-grained eutectic matrix. The 89Zn-7Al-4Cu solder has wet the header plate satisfactorily, but the tank section shows a variable-thickness reaction layer, denoting inferior wetting. Some of the original nickel plating can still be seen on the tank section areas not affected by the reaction zone. The microstructure reveals larger dendrites with less eutectic matrix present. The wetting action of the solders on the plated nickel surface of the simulated radiator capsule is illustrated by Fig. 18. Successful wetting of the joint appears to occur by stripping of the nickel plating off into the bulk solder with subsequent reaction between the zinc-based solder and the brass substrate. The reason for the small unwetted areas as in Fig. 18a remains unclear.

5. TESTING OF RADIATOR CAPSULES UNDER SIMULATED AUTOMOTIVE RADIATOR OPERATION CONDITIONS

Radiator header tank capsules soldered with each of the candidate zinc-based solders and two tin-lead solders are shown (Fig. 19) ready for test at 30 psig, cycled 5 min on and 5 min off, at 250°F in a 50/50 water/antifreeze mixture.

A schematic diagram of the test circuit is presented as Fig. 20. The arrangement is to provide the radiator headers with a realistic pressure, temperature, and antifreeze environment for tests. Air pressure is used to pressurize a vessel half-filled with a 50/50 water/antifreeze mixture, which is connected to the simulated radiator capsules. Air is bled from the system to make sure that the simulated headers contain antifreeze solution. The test array is placed in a hot-box to allow a temperature of 250°F to be applied to the header tanks. A timer is provided, connected to an air relief valve and the antifreeze pressure circuit to impose a 5 min pressure on and 5 min pressure off cyclic test to the header tanks. The test array is depicted in Fig. 21a and in operation in the hot-box in Fig. 21b.



Neg. No. 42882

1000X

(a) Unwetted region in a soldered joint



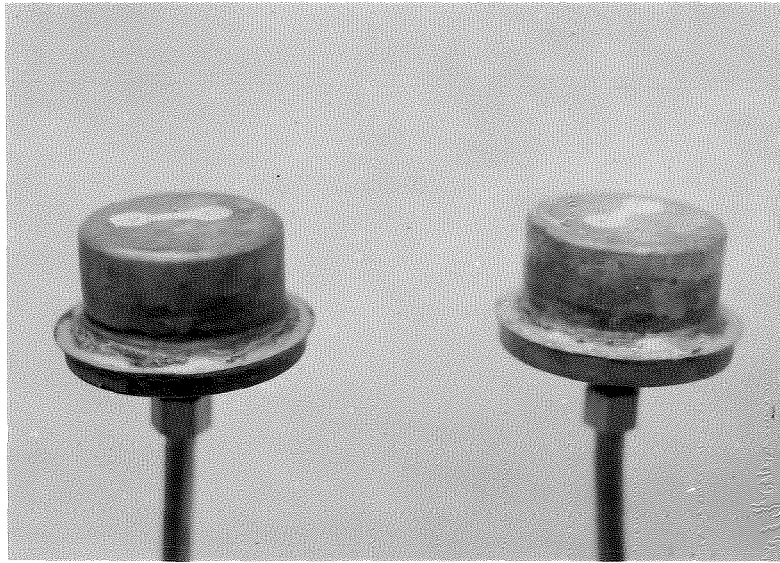
Neg. No. 42881

250X

(b) Reaction layer of solder based material
lifting the nickel plate from the brass
surface

Figure 18

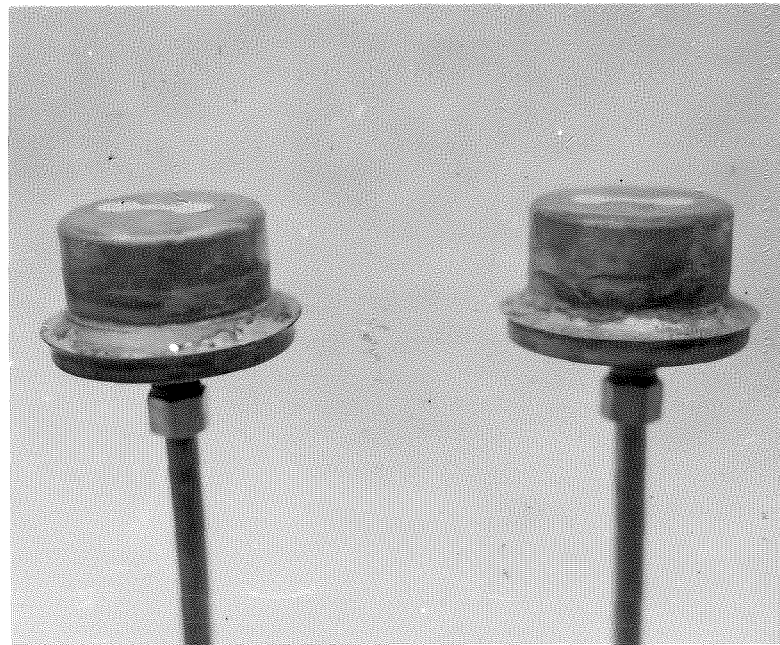
Wetting Action of 95Zn-5Al Solder on Plated
Nickel Surface of Simulated Radiator Capsule



Neg. No. 42755

1/2X

(a) 95Zn-5Al



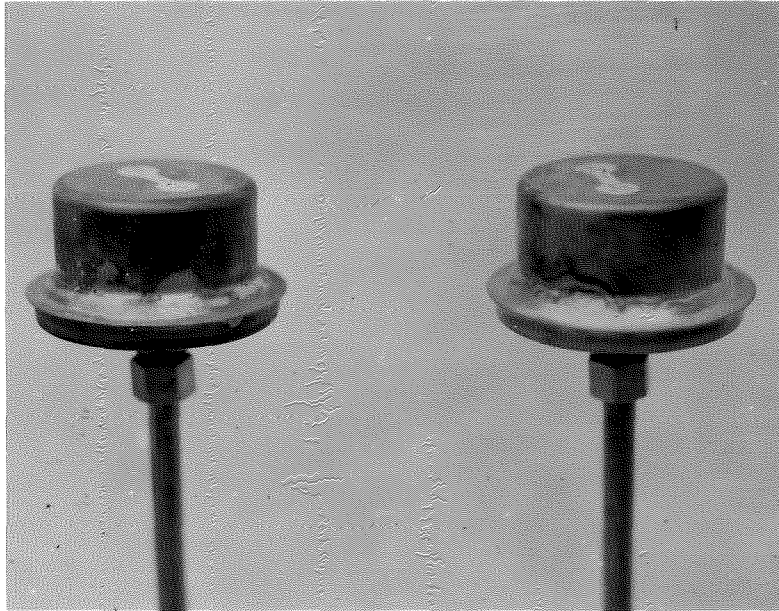
Neg. No. 42754

1/2X

(b) 89Zn-7Al-4Cu

Figure 19

Simulated Radiator Header Tank Capsules
Assembled and Ready for Operation Test



Neg. No. 42753

1/2X

(c) Tin-lead and tin-lead-silver solders

Figure 19 (cont.)

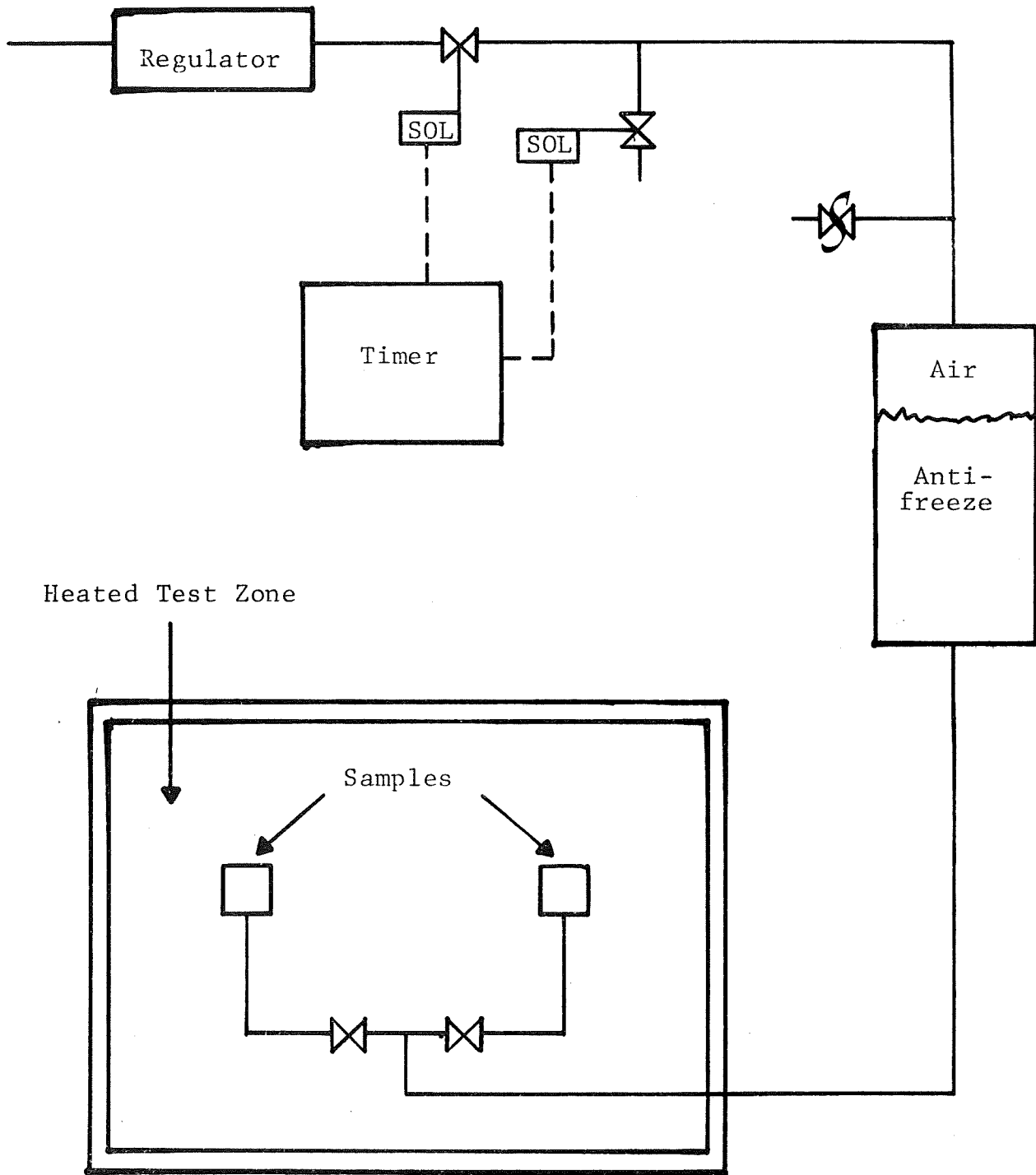
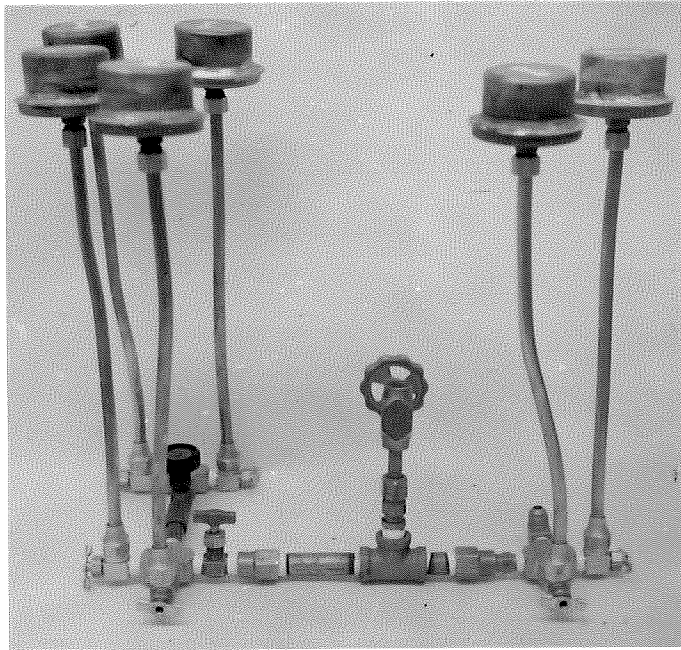
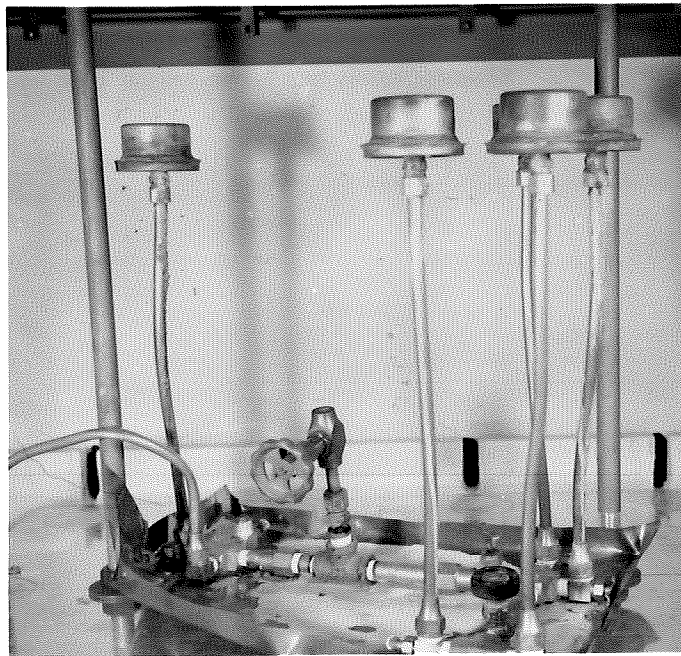


Figure 20
Schematic Diagram of Radiator Capsule Test



Neg. No. 42756

(a)



Neg. No. 42805

(b)

Figure 21

Simulated Radiator Headers (a) after Assembly
and (b) under Test at Elevated Temperature
and Pressure

The test was interrupted after 1000 hr with only two samples showing any signs of failure. Figure 22 shows a capsule that failed in the brass at the upper rim causing weeping of the coolant and, secondly, a 89Zn-7Al-4Cu capsule that was weeping through porosity and shrinkage paths in the solder joint. Half-sections of these two test samples are presented in Fig. 23. Some corrosion of the soldered joints was noted but no serious attack.

An increased severity test was then employed to produce more rapid deterioration of the solders that had lasted longer than expected at 30 psig. The applied pressure was increased threefold to 90 psig, again using a 50/50 water/antifreeze mixture, the 5 min on and off pressure cycle, and a temperature of 250°F. Soldered capsules prior to the more severe test are shown in Figs. 24, 25, and 26. As we became more practiced with the zinc-based solders, better joints could be made, particularly with 95Zn-5Al, Fig. 25, which were almost as good as the lead-tin solders, Fig. 24. The 89Zn-7Al-4Cu solder continued to give wetting problems with the designated flux, and the best samples made are shown in Fig. 26. In attempting to make better joints with the 89Zn-7Al-4Cu solder, one capsule was destroyed by dissolution of the brass by the solder when prolonged heating was used to try and improve the joint, Fig. 27. Most significant in the manufacturing tests is the need for developing a better flux for the zinc-based solders because of the extreme aggressiveness and noxious fumes developed during soldering. The 95Zn-5Al soldered relatively well and should be further tested, perhaps in full-sized radiator trials.

After 250 hr at 250°F and a 90 psig pressure, the 70Pb-30Sn solder joint failed as shown in Fig. 28. Coolant weeped from a crack that gradually became larger until the test was stopped for specimen removal. The test was continued up to 1000 hr before it was terminated to examine the test capsules



Neg. No. 43032

1X

(a) 97.5Pb-1.0Sn-1.5Ag



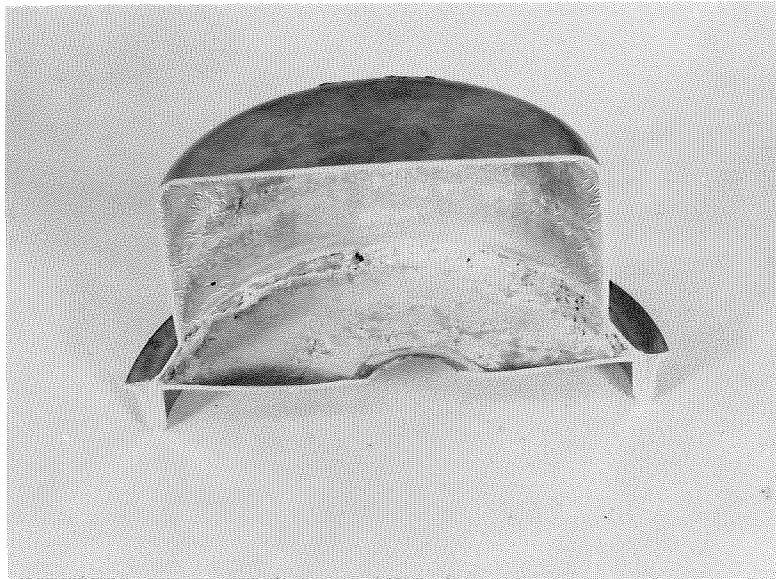
Neg. No. 43029

1X

(b) 89Zn-7Al-4Cu

Figure 22

Capsules that Failed after 1000 hr at 30 psi
Pressure Cycled at 5 min On, 5 min Off at 250°F



Neg. No. 43033

1X

(a) 97.5Pb-1.0Sn-1.5Ag



Neg. No. 43031

1.4X

(b) 89Zn-7Al-4Cu

Figure 23

Half-Sections of Capsules after 1000 hr Test
at 30 psi. (a) Failed in brass and not at
soldered joint.



Neg. No. 43027

1X

(a) 70Pb-30Sn



Neg. No. 43028

1X

(b) 97.5Pb-1.0Sn-1.5Ag

Figure 24

Capsules Soldered with Lead-Base Solders
Prepared for 90 psi Pressure Cycling.



Neg. No. 43024

1X

(a) 95Zn-5Al



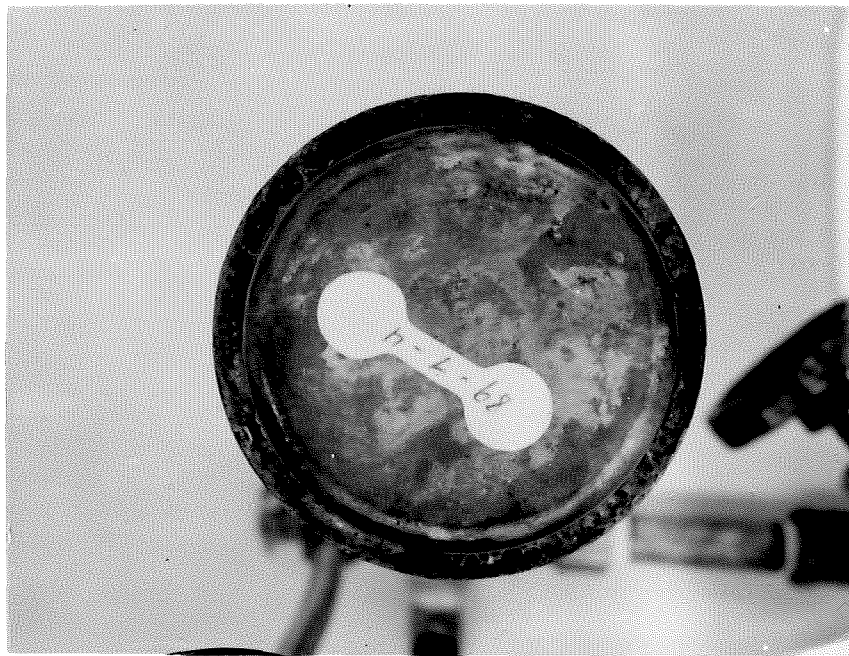
Neg. No. 43023

1X

(b) 95Pb-5Al

Figure 25

Capsules Soldered with 95Zn-5Al Ready
for Cycling at 90 psig.



Neg. No. 43026

1X

(a) 89Zn-7Al-4Cu



Neg. No. 43025

1X

(b) 89Zn-7Al-4Cu

Figure 26

Capsules Soldered with 89Zn-7Al-4Cu Prepared
for 90 psig Cyclic Test.



Neg. No. 43022

1X

(a)



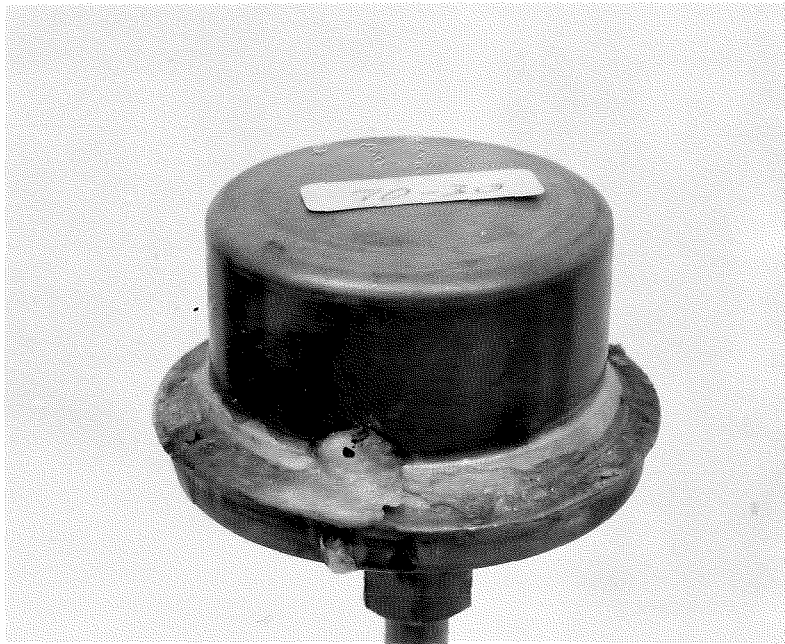
Neg. No. 43021

1X

(b)

Figure 27

Dissolution of Brass by Aggressive Solder-Flux
Reaction Caused by Prolonged Heating to Make
the Joint (89Zn-7Al-4Cu solder).



Neg. No. 43179

1X

(a) Coolant leaking from capsule



Neg. No. 43180

2X

(b) Crack in solder that failed

Figure 28

Weeping Fracture of Soldered Joint with 70Pb-30Sn
Solder after 250 hr at 90 psig and 250°F.

and complete the program. The test is much more severe than normal radiator duty. Failure of the commonly used radiator solder 70Pb-30Sn attests to the fact.

The zinc-based solders and the 97.5Pb-1.0Sn-1.5Ag soldered capsules all lasted the full 1000 hr without failure. A sectioned capsule of the 95Zn-5Al soldered joint is shown in Fig. 29. Cracks are present in the solder all around the inside of the capsule showing that cracking is proceeding, but the joint is still intact. An 89Zn-7Al-4Cu capsule is depicted in Fig. 30. Here, the mode of attack on the solder appeared to be by general corrosion rather than cracking. The corrosion was more severe than the 95Zn-5Al material, and of course the general joint quality is lower. Failure had not occurred, however, after the very severe simulated radiator operating test. The inside of a 97.5Pb-1.0Sn-1.5Ag capsule is seen in Fig. 31, as removed from test and after removal of some corrosion product. Some corrosion attack of the solder joint is seen with no cracking indications after 1000 hr at 90 psig and 250°F. Finally, the inside of a 70Pb-30Sn capsule is shown in Fig. 32. The solder joint had cracked around the internal periphery of the capsule producing a breakout crack at the surface as previously shown in Fig. 28.

A brief metallographic examination was made of the soldered joint after the severe test cycle. Figure 33 depicts the 70Pb-30Sn soldered joint demonstrating a typical joint separation initially within the solder alloy, tending to traverse to the joint interface, and continuing through the solder. The failure mechanism is identified as tensile-peel initiation with crack propagation by a stress-corrosion mode. Note the branches in the crack shown in Fig. 33b.

The cracks found in the 95Zn-5Al soldered joint are presented in Fig. 34. Again, fracture has occurred within the solder, but in addition, at the interface as shown in Fig. 34a. Some stress-corrosion branch cracking is seen in the same figure



Neg. No. 43410

1.25X

(a)



Neg. No. 43409

1.25X

(b)

Figure 30

Inside of Capsule Showing Cracking of 89Zn-7Al-4Cu Soldered Joint after 1000 hr at 90 psig and 250°F. No failure had occurred at this time.



Neg. No. 43410

1.25X

(a)



Neg. No. 43409

1.25X

(b)

Figure 30

Inside of Capsule Showing Cracking of 89Zn-7Al-
4Cu Soldered Joint after 1000 hr at 90 psig and 250°F.
No failure had occurred at this time.



Neg. No. 43408

1.25X

(a) As removed from test



Neg. No. 43411

1.5X

(b) As corrosion product was removed

Figure 31

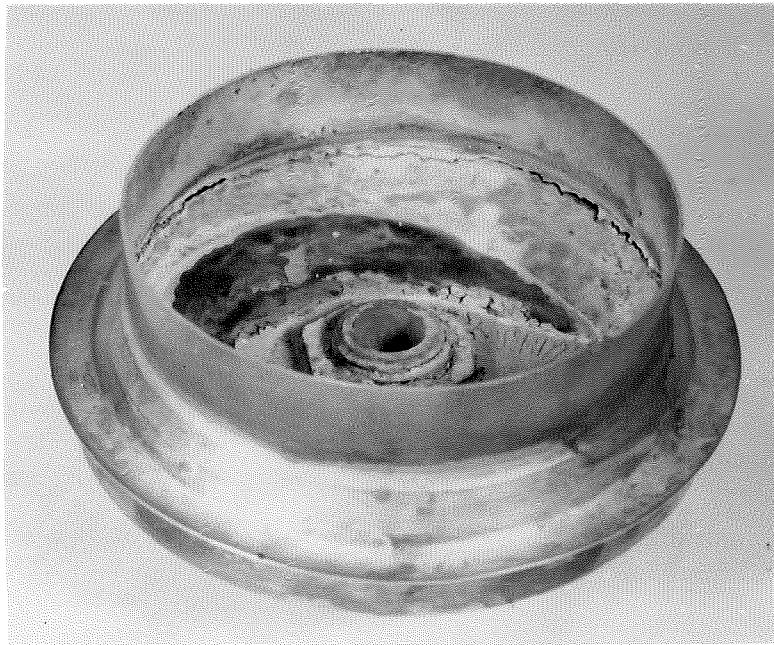
Inside of Capsule Soldered with 97.5Pb-1.0Sn-1.5Ag
after 1000 hr at 90 psig and 250°F. No failure had
occurred at this time.



Neg. No. 43360

(a)

1.25X



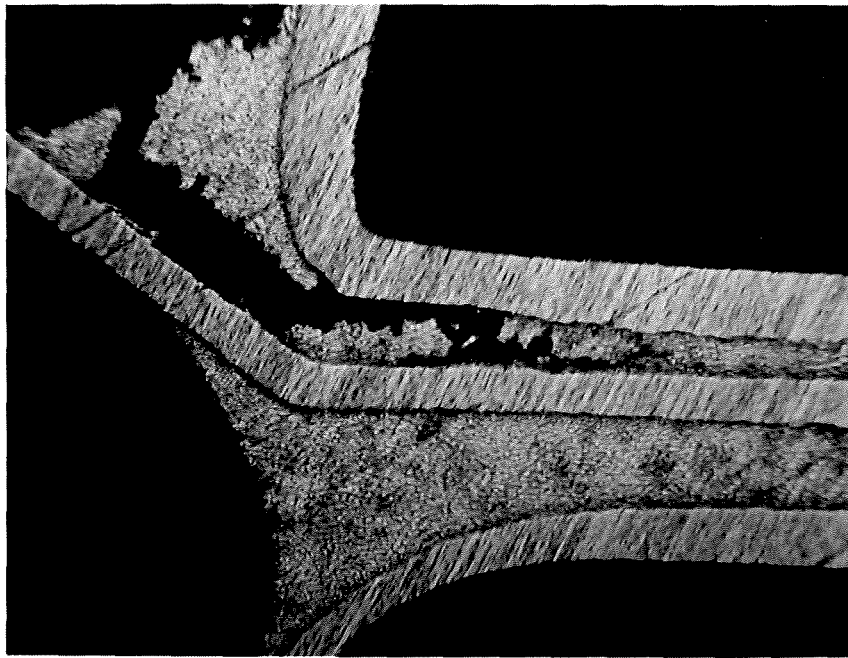
Neg. No. 43359

(b)

1.25X

Figure 32

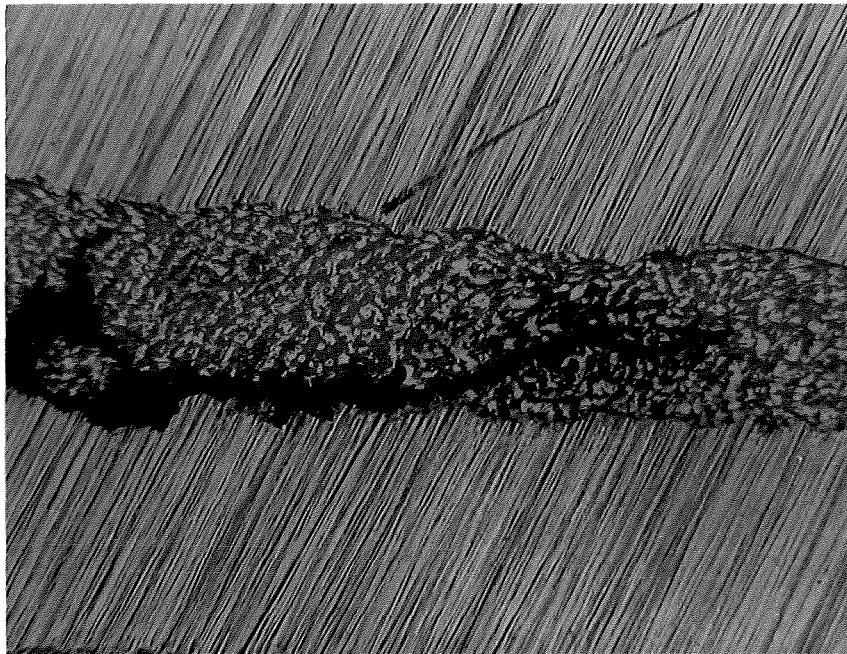
Inside Capsule with 70Pb-30Sn Soldered Joint
Showing Extensive Cracking All Around
the Internal Periphery.



Neg. No. 43542

16X

(a) Crack initiation in solder alloy



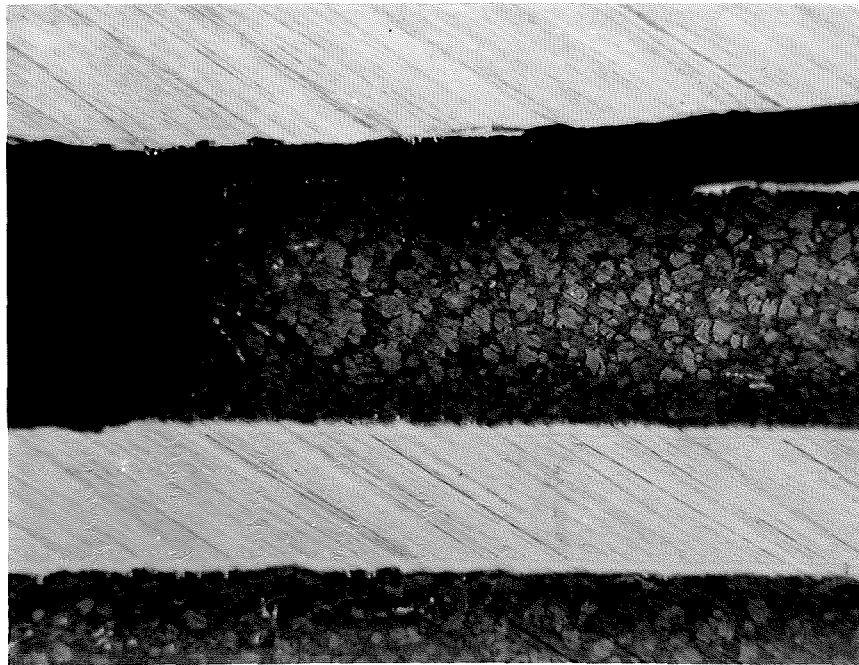
Neg. No. 43543

80X

(b) Crack propagation through solder

Figure 33

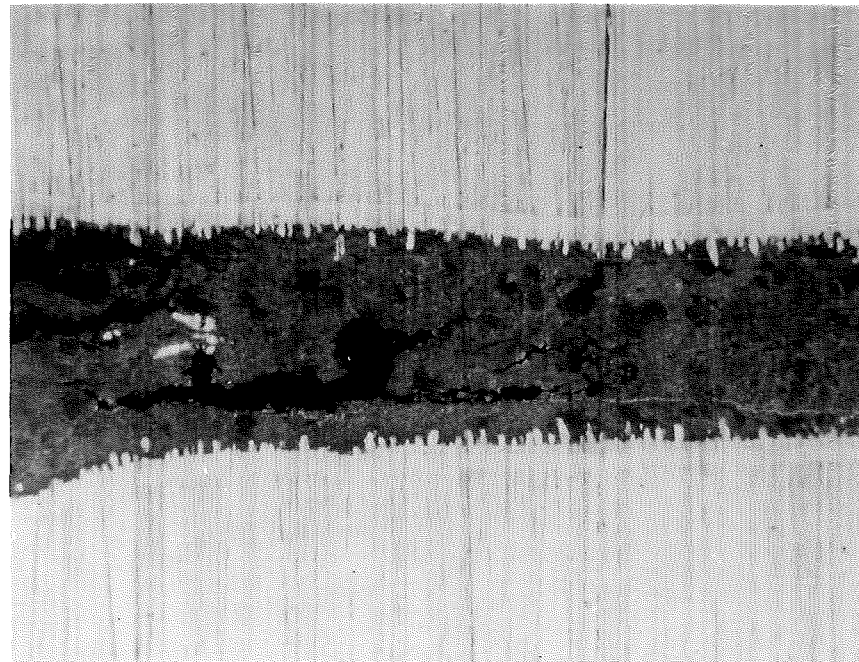
Cracking of Soldered Joint Made with 70Pb-30Sn
Alloy after 90 psig Test



Neg. No. 43538

40X

(a)



Neg. No. 43558

80X

(b)

Figure 34

Cracks in 95Zn-5Al Soldered Joint after 1000 hr
Test at 90 psig.

and in Fig. 34b. This joint had not failed, however, when the capsule was removed from test,

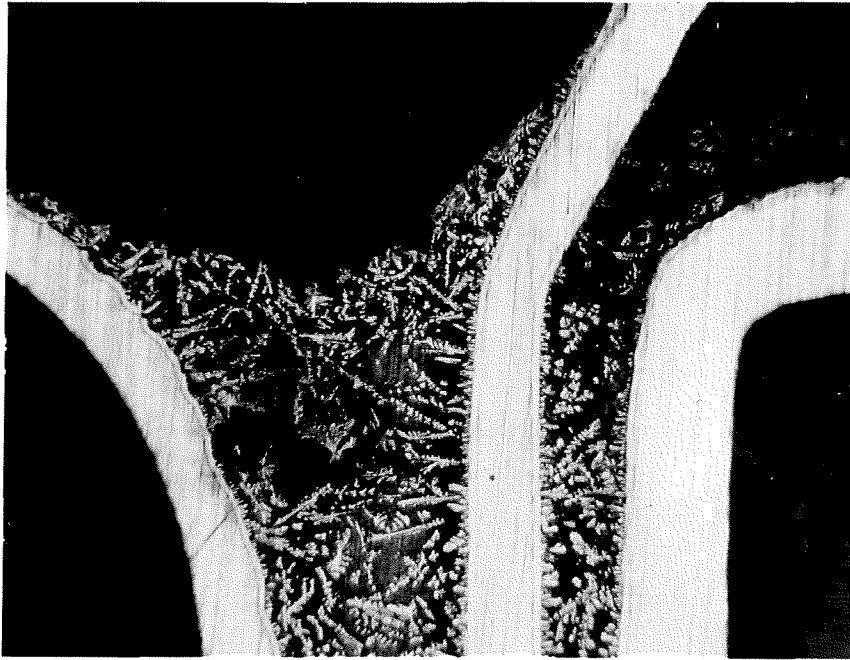
The corrosion found in 89Zn-7Al-4Cu joints is shown in Fig. 35. A layering effect at the corroding surface of the solder can be seen with a family of small branching cracks parallel to the solder surface. The interfacial solder reaction product does not appear to have been affected at all. This solder was obviously capable of lasting considerably longer than the 1000 hr test,

The interfacial product resulting when soldering with zinc-based solders was briefly examined as shown in Fig. 36 because of the twin layers of reaction product at the brass surface. Zone A near the solder is identified as ϵ phase, and Zone B is identified as γ phase; only traces of Al were found in these zones which were principally copper-zinc alloy layers. Note the eutectic rods growing directly from the surface dendrites on the brass surface. No nickel layer remnants were identified,

A limited number of tensile-peel mechanical tests were made on the soldered joints used on the test program. Results are shown in Fig. 37. Clearly, the 95Zn-5Al solder produces the strongest joint at room temperature. Tests were made at a strain rate of 0.1 in/min. The lead-tin solders show a typical fracture initiation peak and substantial propagation strength. The zinc-based solders have higher fracture initiation loads and then separate very rapidly. The preliminary nature of these observations must be recognized, and much further work is needed for positive strength comparison data to be developed.

6. CONCLUSIONS

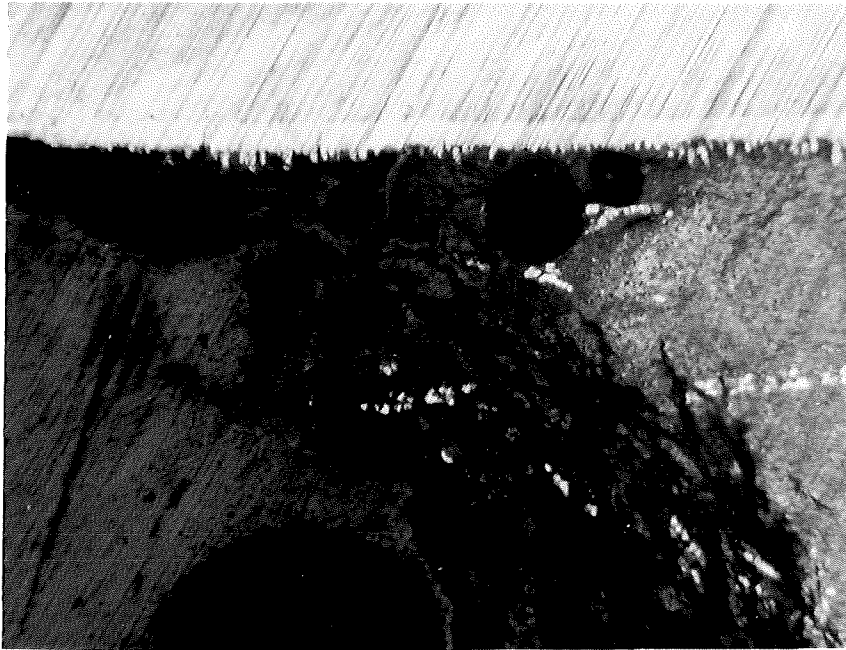
A field evaluation program has been executed to determine the effectiveness of a newly developed zinc-based solder soldering system for copper and copper alloys. The method involves



Neg. No. 43533

16X

(a) Cracked solder joint



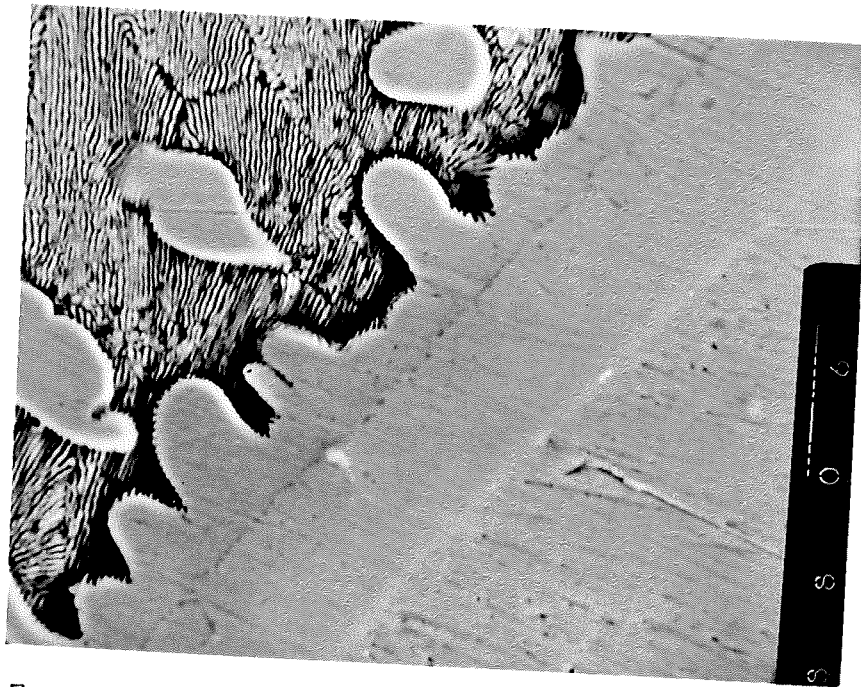
Neg. No. 43535

80X

(b) Crack initiation area

Figure 35

Cracks Developing in Joints Soldered with
89Zn-7Al-4Cu after 90 psig Test

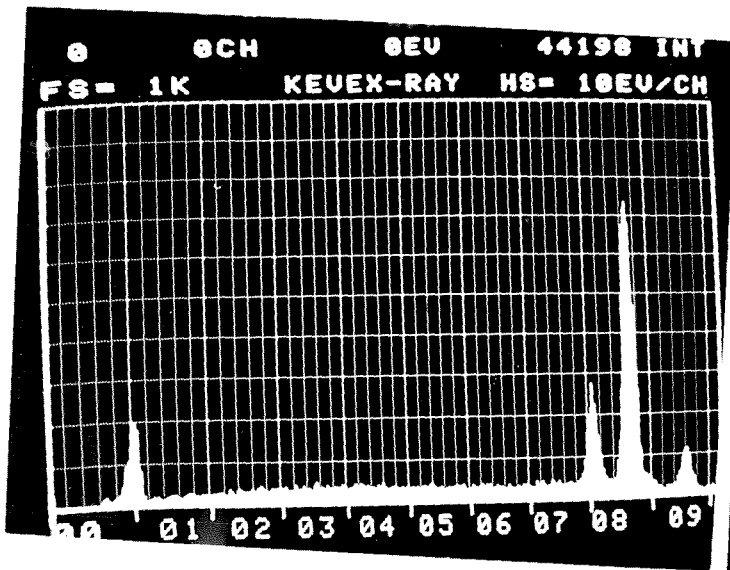


Zone A Zone B

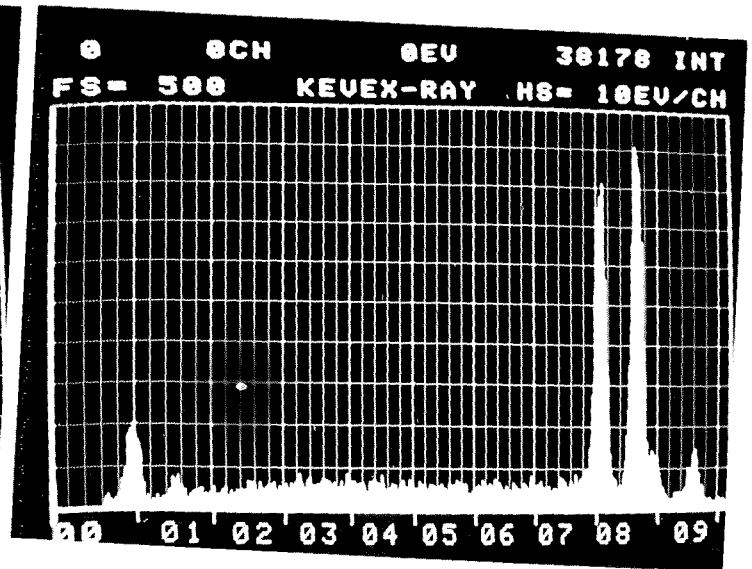
SEM No. 8806

1000X

(a) Interface between brass and 95Zn-5Al Solder



(b) Zone A, X-ray spectra



(c) Zone B, X-ray spectra

Figure 36

Interfacial Reaction Products Between 70Cu-30Zn Brass and 95Zn-5Al Solder. Zone A is ϵ phase and Zone B is γ phase, only traces of Al present.

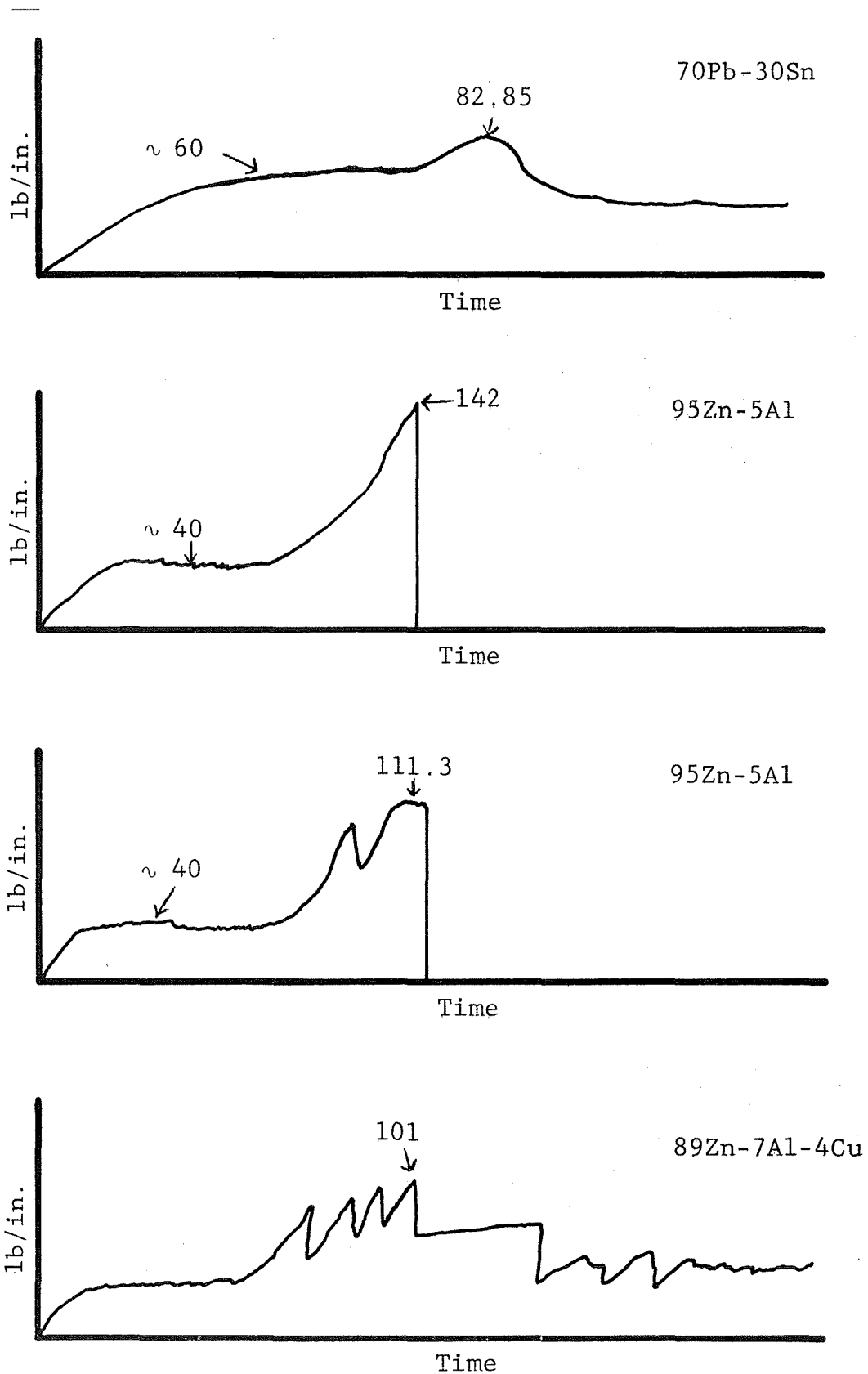


Figure 37

Tensile-Peel Properties of Capsule Soldered Joints
 at Room Temperature
 (All samples 1/4-1/8 in. wide.)

plating the brass or copper surface with nickel as a means of producing active wetting with a specially formulated flux composition and two candidate zinc-based solders.

Successful rod-to-plate joints were made repeating the steps in the process developed by the Bureau of Mines, and very good joint properties were achieved.

After some experimentation, a furnace soldering method was used to fabricate small capsules, directly simulating the joint configuration found in tank-to-header joints of automotive radiators. The radiator capsules were successfully soldered with both zinc-based solders. 95Zn-5Al solder produced better joints.

The radiator capsules were exposed to a simulated radiator life cycle at two pressure levels and cycled to 1000 hr or failure. The 70Pb-30Sn solder alloy normally used by radiator manufacturers failed the severe test after 250 hr, the remaining samples continuing for a full 1000 hr test program. This demonstrates that the new zinc-based solder system is capable of operating at more severe conditions than those experienced by today's automotive radiators. A 97.5Pb-1.0Sn-1.5Ag solder produced joints that also lasted the full test period.

The manufacture of simulated radiator header tanks and successful exposure to very severe operating conditions has verified the Bureau of Mines development effort and shown its direct applicability to the automotive radiator. Further work is needed on flux formulation before the system could be considered for practical radiator application. A program to demonstrate the effectiveness of the zinc-based solders in full-scale radiators is considered feasible as a result of this effort.