U. S. ARMY ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES
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REPORT OF CORROSION TESTS AND ANALYSIS OF COMPACT HEAT EXCHANGERS

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Prepared By
OSCAR OLDBERG
ENVIRONMENTAL EQUIPMENT DIVISION
MECHANICAL TECHNOLOGY DEPARTMENT
U. S. ARMY ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES

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FOREWORD

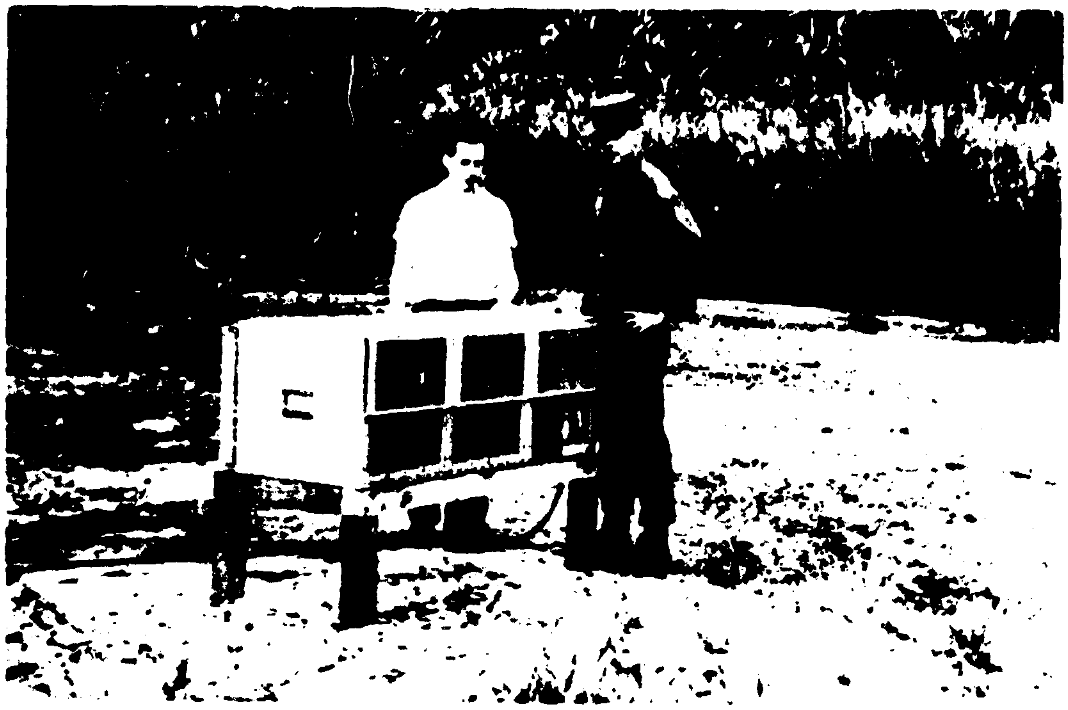
This progress report covers testing of military brazed aluminum heat exchangers in tropical salt atmospheres and analyzes resultant corrosion failures. The tests were initiated in March 1964 at Fort Sherman C. Z., Panama. Test plan preparation and overall project coordination was accomplished by Oscar Oldberg, Project Engineer, U. S. Army Engineer Research and Development Laboratories. Test site selection and initiation of tests was accomplished by USAERDL, in coordination with the U. S. Army Tropic Test Center, Panama. Conduct and reporting of tests was done by the USATTC. Detailed corrosion failure analysis and assistance in providing corrective measures were provided by Materials Research Support Laboratory, USAERDL.

These Panama tests are expected to continue until approximately July 1968.

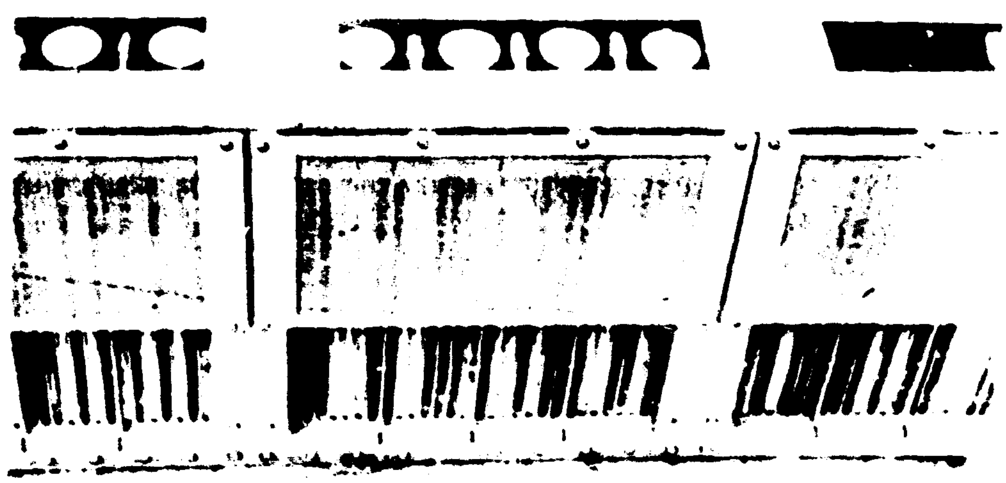
MILITARY COMPACT HEAT EXCHANGERS NEED CORROSION PROTECTION

Field reports received over the past few years indicate corrosion failures of heat exchanger coils used in military air conditioners in the Hawk missile system. These were particularly prevalent in coastal areas with atmospheres of high salt content expectancy, which would normally be most reactive to the brazed aluminum constructions. This plate and fin design produces maximum performance and minimum weight and consequently finds application in mobile systems. Since some operation must be expected under these tropical salt atmospheres, it was decided to conduct a field type investigation into the nature of the corrosive attack and possible methods of prevention or alleviation.

The accumulation and interpretation of random field data is at best difficult and usually inconclusive due to uncontrolled variables. It was decided that pertinent results could best be obtained by the exposure of test sections under equal conditions at the same test site. Accordingly, a test console (Fig 1 & 2) was designed to accommodate twelve pressurized heat exchanger test sections, with fans to draw equal air volumes thru each section at approximately 800 ft./min. face velocity. Screens of 16 mesh were provided to shield the upper half face of each test exchanger while the lower half was left open to receive direct ambient air in order to determine the effects of collection of foreign material. A pressure gage mounted on each exchanger test section provided means of determining the advent of leakage or failure.



Coil Corrosion Test Console
Fig.1



Console View Showing Test Sections
Fig.2

The Test Plan shown as Appendix - Test Plan was followed with daily recordings made of ambient temperature, humidity, and test section gage pressures. When failure of condenser sections was noted these were returned to U. S. Army Engineer Research and Development Laboratories (USAERDL) and leak points and corrosion effects examined by the Materials Research Lab.

SELECTION OF TEST SITE

Selection of the test site was made by representatives of USAERDL and of U. S. Army Tropic Test Center. The test console was located approximately 300 yards from the Caribbean Beach facing the prevailing wind off the water at Fort Sherman, Canal Zone.

Salt-fall conditions vary throughout the world and are heaviest in oceanic islands and coastal areas which have a range of 25-300 lb/acre/yr[1]. Extreme exposure situations produce higher values such as the 4400 lb/acre/yr recorded at the beach breakwater of Fort Sherman approximately 1200 yards from the test site. Salt-fall in the United States is relatively low ranging from ½ to 1 lb/acre/yr in the interior portion to approximately 15 lb/acre/yr in the Miami area. Cape Hatteras, N. C. reports 10 lb/acre/yr. Salt-fall at the Fort Sherman heat exchanger test site was relatively heavy at 208 lb/acre/yr based on recordings made in other nearby test sites. Relative humidity ranged from 90 to 100% during night and early morning to 70 to 80 during the daytime. The heat exchanger test site thus represents an accelerated condition for most applications, but provides an exposure representative of heavy salt-fall which would be encountered by some military units in tropical salt environments.

TEST RESULTS

The length of time of exposure in months until leakage or failure occurs has been used as the measure of corrosion resistance. Since slight differences in coating thicknesses and some seasonal variations in weathering conditions affect failure time, variations of a month or two are not considered significant.

1. "Atmosphere Sea-salts Design Criteria Areas," by William B. Brierly, U. S. Army Natick Laboratories.

However, it was noted that test sections of similar construction and coatings usually failed within a two month range variation, indicating that differences in results of three or four months are significant.

Results are shown in Table I for various aluminum plate and fin brazed construction, and continuous tube and corrugated fin heat exchanger sections. A length of life of 1½ years in the Fort Sherman test has been determined to be acceptable performance. This is based on the consideration that major maintenance will be accomplished within this operational time frame.

TABLE I

ENDURANCE OF TEST SECTIONS IN CONSOLE

Coil Type & Coating	Months to Failure
Standard braze*- chromate conversion coating	4.4 (avg 5 sections)
Standard braze*- chromate conversion coating plus zinc chromate wash primer	7.5 (avg 2 sections)
Standard braze*- anodize coating (chromic acid)	2 (avg 3 sections)
Standard braze*- vinyl butyrate wash primer plus phenolic coating	17 (no failure to date)
Standard braze*- vinyl butyrate wash primer plus polyurethane coating	17 (no failure to date)
Brazed (#100 sheet for tube plate, Alclad surface outside - #12 fins) chromate conversion coating	8 (no failure to date)
Continuous tube with bonded fin black asphalt paint	14 (one leak, and some fins loose)
Continuous tube with bonded fin zinc chromate paint	17 (no failure to date)

*Brazing sheet #11

(Results as of January 1967)

The type of corrosion and failures which occur in these aluminum heat exchangers is shown in photomicrographs, Figs 3, 4, & 5. A porous condition in the braze sheet tube plate or primary surface develops, starting from an intergranular attack at the outside brazing surface. Some contributory effect caused by foreign materials such as bugs, leaves, and pollen was noted by comparing leaks in screened and unscreened areas of the test coils. However, leaks were also noted in the same coils in screened areas which were relatively free of foreign materials.

It is considered pertinent that the test section fabricated with #100 tube plate material with "Alclad" high zinc surface on the outside, and with only the chromate wash coating was still satisfactory after eight (8) months exposure on the test console. This life is already double the average life of the standard brazed construction with the same coating, with the test continuing. Major corrosive attack is expected to occur only on the braze material coated air fins, thereby creating an improved situation at the primary or refrigerant containing surfaces.

DISCUSSION

The environmental conditions surrounding the test console in Panama are particularly adverse since combinations of corrosive elements are present. Comparisons of the screened and unscreened coil test sections that were made to evaluate the effect of foreign material, indicated slightly more tendency toward leakage where concentrations of these materials was heavy. However, the major influence of the salt reactions was clearly shown by leaks in screened areas of the same coils which were relatively free of foreign materials.

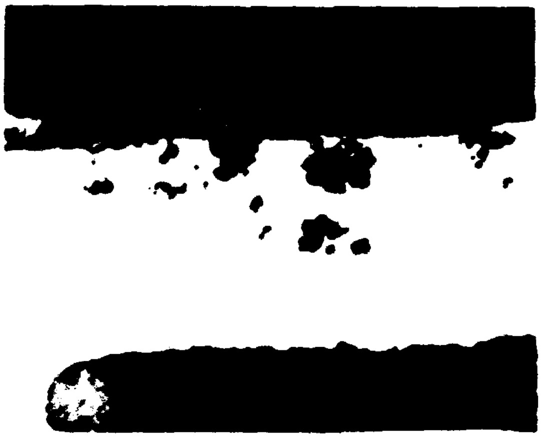


Fig.3 75X

Fig.4 75X

Fig.5 100X

Corrosion Photomicrographs

Laboratory salt fog testing of these brazed aluminum heat exchanger constructions proved to be of little value as an accelerated test. In some cases submersion of 2,000 - 4,000 hrs in salt fog test Method 6061 of Federal Test Method Standard 141 produced no failures, yet the same coated constructions failed in less time on the test console in Panama. This situation is believed to be due to the alternate wetting and drying conditions existing in the field, and also to the ability of salt crystals to become lodged at a fixed point where continuous reaction with the aluminum may occur. In laboratory salt fog testing a continuous washing action occurs over the surfaces which tends to dilute or weaken concentrated reactive points so that penetration is less rapid than in high salt natural environments.

In the work to evaluate protective coatings, heat exchanger test sections were fabricated by one manufacturer and thoroughly washed many times to preclude any effects of residual brazing process salts. Therefore, this sometimes questionable element is not a factor in comparing the above test results. Tests of other manufacturers' brazed aluminum heat exchangers resulted in corrosion failure rates approximately equal to those listed above for corresponding constructions and coatings.

CONCLUSIONS

Although these corrosion tests are expected to continue for another year, there are some useful conclusions which may be drawn from the results obtained to date. Two major considerations to be taken into account when using brazed aluminum heat exchangers for military environmental control units are highlighted from these corrosion observations.

1. The standard brazed aluminum construction must have an organic or equally resistive coating for protection against high salt atmospheres which exist in many areas of the world.

2. An improvement in corrosion resistivity through material and construction changes is also desirable to add to the benefits obtainable through protective coatings, such as use of Alclad for the prime surface.

APPENDIX - TEST PLAN

OBJECTIVE

Air conditioners with heat exchangers of the brazed aluminum plate and fin type that have been exposed to weather conditions in the Panama coastal areas have given continuous problems. The condenser coils have failed due to corrosion after being used in this area for only three months. Since air conditioners are being procured with these heat exchangers, it is imperative that any necessary corrective action be taken as soon as practical. At the present time there is no known suitable alternate heat exchanger of comparable weight and efficiency that can be used for light weight air conditioners.

A test console with various aluminum heat exchanger constructions and coatings is being built for the purpose of conducting tests in the Panama area to determine comparative life expectancies.

INSTALLATION

The console should be installed in the open at Fort Sherman, Panama, approximately 100-200 yards from the seashore without over head protection of trees or adjacent buildings. It should be set up on a wooden or masonry support structure or table 2½-3' above the ground, and directed so the prevailing winds strike the heat exchanger side of the console. Electrical power of 115V., single phase, 60 cycle 2 KW is required.

OPERATION

In general the unit should be operated continuously except during any periods of servicing inspection or motor lubrication. Each of the three main heat exchanger sections has a separate air circulating fan and the motors are connected in parallel, so that all fans should run continuously as far as possible. Each of the coil sections is divided into 4 elements. Each element shall be equally charged with refrigerant (22). A pressure gauge is mounted at the top of each element to indicate refrigerant pressure.

When any gage reading drops to a sufficiently lower comparative level so as to indicate a leak the respective element should be checked with refrigerant and leak detector to pinpoint the leak. If leakage is indicated from the core of exchanger, the element involved shall be removed from the console, packed "as is" condition, and air shipped as soon as possible to USAERDL, Fort Belvoir, Virginia. When a heat exchanger element is removed, the opening shall be partially covered with a 3" wide vertically installed strip of aluminum (on center of opening). This is required to maintain a normal air flow balance.

OBSERVATIONS & REPORTS

General observations shall be made each day to note general appearance of the outside face of heat exchangers, and to check gages for evidence of leaks. Gauge pressures and simultaneous outdoor temperatures should be recorded at least once per day. Collections of foreign materials, leaves, or pollen on the heat exchanger or screen faces should be noted but not removed unless the build up is sufficient to reduce air flow. If this build up becomes heavy and air flow appears appreciably reduced, photographs shall be taken and the core back blown with compressed air; unless seriously restricted, heat exchanger and screen surfaces should not be cleaned during the test. Water or other liquids should not be used to clean the coils.

Monthly reports with photographs are to be submitted. In addition to information on leaks, the reports should cover the nature and quantity of material build up on the heat exchangers and screens.

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