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WADD TECHNICAL REPORT 60-235

# HIGH TEMPERATURE TENSION PATCH AND THERMAL SIMULATION METHODS FOR STRUCTURAL TESTING

*Bernard C. Boggs*

*Engineering Test Division*

*JULY 1960*

WRIGHT AIR DEVELOPMENT DIVISION

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Project No. 1347
Task No. 13730

WRIGHT AIR DEVELOPMENT DIVISION
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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# Foreword

This report describes the use of RTV (room temperature vulcanizing) silicone materials for high temperature bonding agents in tension patch applications. It also describes their effect to external temperature distributions during elevated temperature structural testing. This work was done under the direction of Bernard C. Boggs, Project Engineer, assisted by Robert K. Davidson, Test Foreman, Strength Section, Structural Branch, Engineering Test Division. The work was accomplished in support of Project No. 1347, "Structural Testing of Flight Vehicles," and Task No. 13730, "Thermal Simulation Techniques" during the period October 1957 through December 1960.

Engineering assistance was provided by George Thomas and Donald Brammer for the work described in Section II.

## Abstract

The development of elevated temperature tension patches and shear loading straps using RTV (room temperature vulcanizing) silicone material as the bonding agent is described in Sections I and II. For tension patches, 2 x 2 inch backing plates are bonded directly to the surface for loading. The methods described resulted in tension patch applications which may be used satisfactorily to approximately 550°F under steady state temperature conditions. They may be used for transient heating to higher temperatures for short time duration. The current practice of installing built-in load fittings in the structure is costly and not representative.

Temperature and load simulation techniques are discussed in Section III.

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# List of Symbols

| | |
|---|---|
| C | constant involving $cw\tau$ computation. |
| c | specific heat of material. BTU/lb-°F |
| E | line voltage |
| F | degrees Fahrenheit |
| h | convective heat transfer coefficient. BTU/hr-ft²-°F |
| I | line amperage |
| K or Y | constant that includes efficiency, area, conversion factors, etc. |
| w | material density Lb/ft³ |
| $T_{aw}$ | Adiabatic wall temperature |
| $T_s$ | skin temperature |
| $dT/dt$ or $\Delta T/dt$ | change in skin temperature with time. °F/sec |
| $Q_o$ | KW/ft² Power output |
| $Q_o$ | $\eta\ Q_{i_2}$ BTU/ft² sec Power output |
| $Q_{i_1}$ | Power input. BTU/ft² sec |
| $Q_{i_2}$ | Calculated Power input BTU/ft² sec |
| $\eta$ | Efficiency of radiant heat system |
| $\tau$ | Material thickness. ft. |

# High Temperature Tension Patch and Thermal Simulation Methods for Structural Testing

Bernard C. Boggs

## Section I

## RTV Silicone Bonded Tension Patch Methods and Techniques

### Introduction

This section describes the techniques for using (RTV) room temperature vulcanizing silicone adhesive tension patches and shear straps to introduce loads into the structure under both ambient and elevated temperature test conditions.

Room temperature vulcanization of the tension patches is one criterion necessary to simplify the procedures since the application of heat and/or pressure is costly and time consuming. Another criterion is that the adhesive forms an elastic bond to preclude adverse local effects to the structure under test. Any inelastic bond, such as epoxy resin, presents problems as verified in the early elevated temperature static tests on the B-58.

The RTV silicone bonding method will serve for all ambient temperature static test loading. This material does not require an early high temperature post cure. It is usually obtained in the temperature survey during preparation and checkout for the first elevated temperature test condition.

The size of the tension load backing plate was selected to eliminate forming to surface contours. The structure is heated by radiant heating methods. The reflector assemblies used with the radiant heat emitters are attached directly to the structure. Heat distribution is affected by the plate area coverage; however, small plates with relatively high loads minimize this effect. The plate size was further dictated by the repolymerization characteristics of the catalyzed RTV silicone adhesive. Based on the foregoing, the standard plate sizes selected were 2 x 2 inches and 2 x 3 inches (Figures 1, 2, 3, 4, 5, 6 and 7).

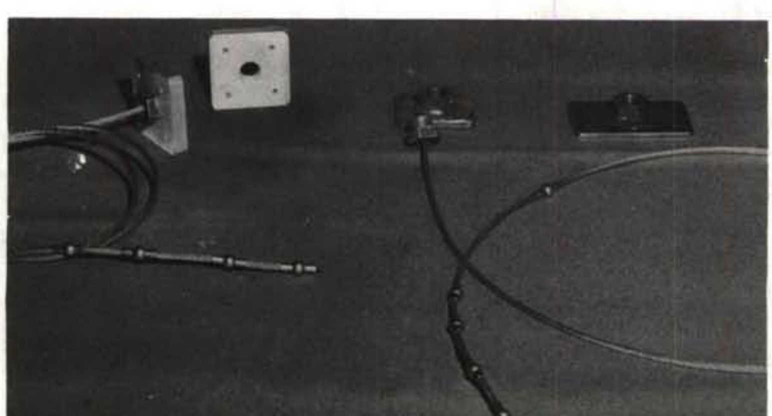
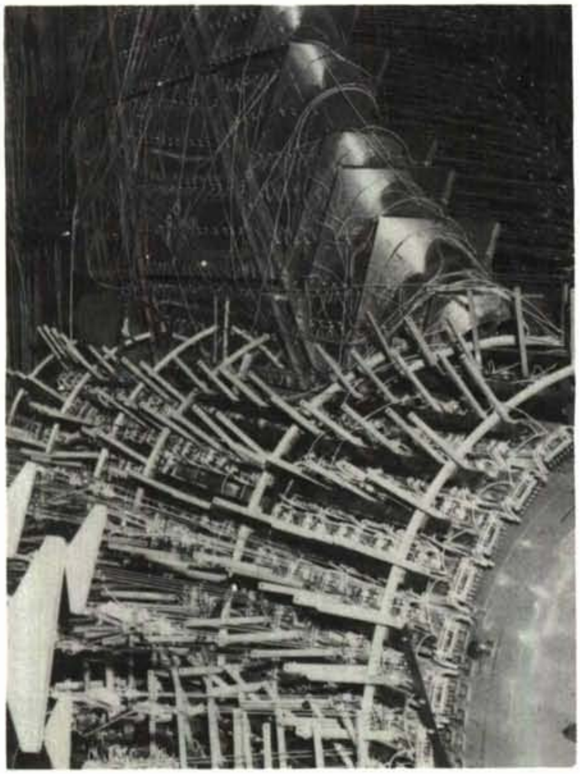


*Figure 1. Tension Load Plates*



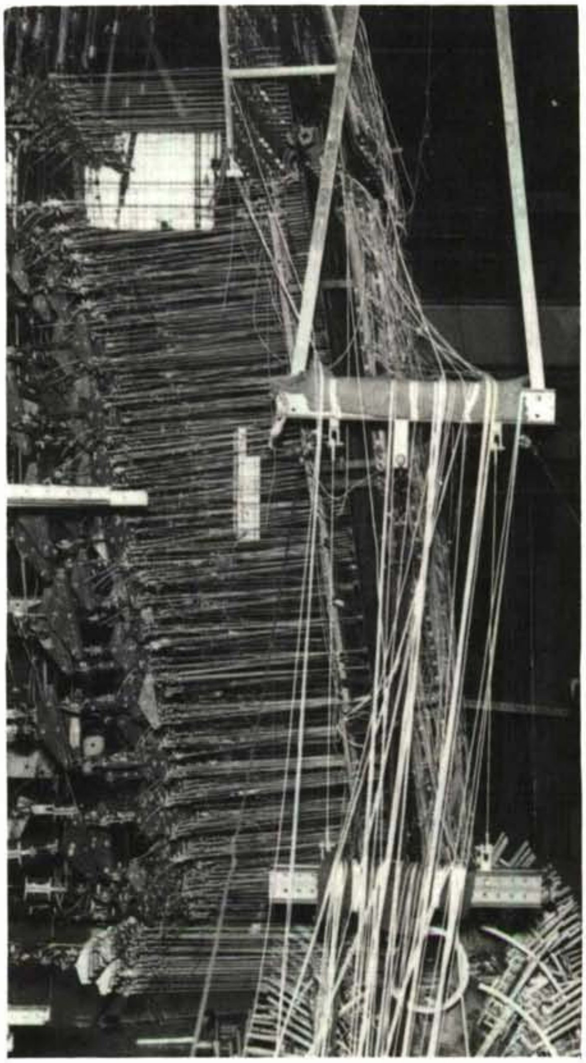


*Figure 2A and 2B. B-58 Fin and Rudder Elevated Temperature Test Using RTV Silicone Bonded Tension Patches.*

*Figure 3A and 3B. B-58 Wing Tip Elevated Temperature Test Using RTV Silicone Bonded Tension Patches*

*Figure 4. F-106 Engine Heat Test Using RTV Silicone Bonded Tension Patches and Shear Straps*

*Figure 5A and 5B. Typical RTV Silicone Bonded Tension Patches on B-58 Wing Leading Edge*

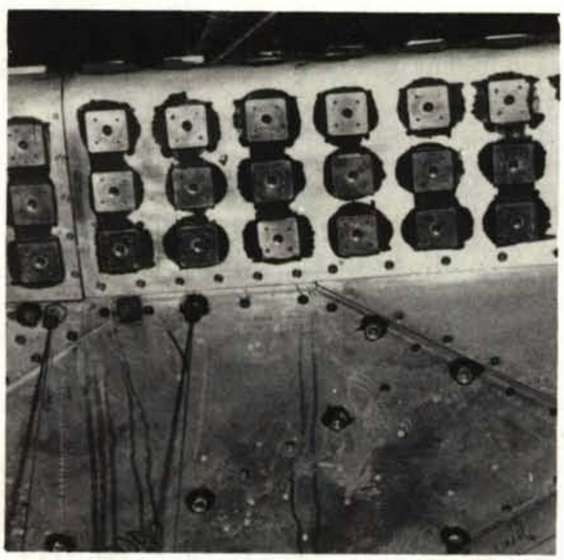


*Figure 6A and 6B. Typical RTV Silicone Bonded Tension Patches on B-58 Elevon Section*

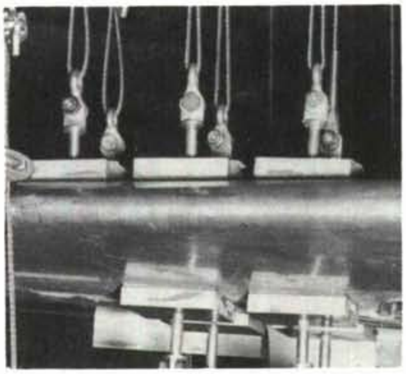


*Figure 7. RTV Silicone Bonded Tension Patches Under Load*

Also to be considered in metal-to-metal bonding using elastic adhesive materials is whether it can be used on a production installation with a high degree of reliability. Compared to existing tension patch methods for room temperature testing the reliability of RTV silicone materials after two years use are better.

Present indications are that a better reliability potential exists for the silicone materials under conditions of ambient temperature use. Bond stresses per unit area used are higher in capability than the neoprene sponge patch method. The use of silicones in the temperature range of 350°F to 600°F for long periods is dependent upon further improvements in the time-temperature-load capabilities.

Reliability is important for fatigue testing under conditions of high temperature. The work reported herein was not directed at fatigue test load simulation; however, this data has been obtained after the basic report was prepared and is contained in the Addendum.

Another combination investigated for use with patch plates was normal silicone rubber and RTV silicone bonding techniques. (The procedure for installing the patches was similar to the present neoprene rubber tension patch method.) Heating the structure was adversely affected because of the high insulating effects of the silicone rubber. This method was more complex than direct bonding and is not advantageous. This method is currently being developed for conduction heater patches under an Air Force contract.

Static test loading for flight vehicles requires methods for external load simulation of all test environments. Considerable research and development effort has, and is being, expended to simulate all environmental conditions except in the area of simulated loadings. These vehicles must be loaded in addition to the other test simulated techniques.

Internal load fittings built into the structure during production assembly is costly and not representative of the basic structure. The method is not suitable to all test applications. The method and approach are sound and should be useful in advancing structural testing technology.

## RTV Silicone Adhesive Bonding Materials

The materials used in this study were commerical products produced by the Silicone Products Division of the Dow Corning Corporation and the General Electric Corporation.

This material is a room temperature vulcanizing silicone product which was developed for potting, caulking, encapsulating, and sealing applications. It possesses good electrical properties and forms an excellent bond to metal, plastic, or glass with the proper use of a silicone primer. Vulcanized silicone rubber is flexible and resilient and will resist temperature extremes, ozone, oils, solvents and aging. Present temperature limits are approximately -130°F to 600° F.

The RTV silicone material used in this study was of a putty or paste consistency. The pourable types generally resulted in a thin bond due to the inability to control the bonding process.

Polymerization is a chemical reaction which changes the mixture to a compound that possesses different physical properties; the end result of this polymerization, or vulcanization, is a strong elastic silicone rubber. Although the ultimate strength of the RTV silicone is low when compared to the brittle adhesives, or metals, it is an excellent material for tension patch applications. Neoprene rubber tension patch material is worked to a maximum of 15 psi and has a failing strength of approximately 50 psi. However, RTV silicone has a potential of 400 psi or greater failing strength. Therefore, only one-eighth of the loaded area need be covered with patches to develop equivalent strength, subject, of course, to local structural considerations that might preclude this maximum use.

## RTV Catalyst

The curing agents, or catalysts, used in RTV silicones are normally liquid metallic soaps. They are used in amounts of 1 per cent, or less, by weight. Some are diluted in paste form for accuracy in weighing. The catalysts are commercial products produced by Dow Corning Corporation, General Electric Corporation, and Nuodex Products.

The catalyst will normally determine the upper temperature level at which the silicones may be used. Some have good heat stability while others tend to soften at the higher temperatures.

The primary differences in the respective catalytic agents are their effects on the silicone material with respect to pot life, curing time, material thicknesses, and release characteristics.

## Primer

Silicone materials will not adhere to nonsilicone materials without a primer. Primers are low viscosity liquids which, on exposure to air, polymerize by the process of hydration, or evaporation. When applied to a metal surface in a thin layer, it will form a hard tenacious film. The RTV silicone will polymerize and bond itself to this film in its curing cycle. The adherence of this primer-silicone bond is greater than the cohesive strength of all known silicone rubbers.

The metal primers used in these tests were commercial products produced by Dow Corning Corporation and General Electric Corporation.

Priming of porous surfaces is not effective and is difficult to use satisfactorily on brass and bronze alloys. This effect was checked by sand-blasting load plates and light sanding of the basic bonding surface. It is possible to obtain satisfactory results with RTV silicone on lightly sand-blasted surfaces, but this procedure is not recommended.

## Test Combinations

The possible combinations of RTV silicone, catalyst and primer mixtures is unlimited. The mixtures are selected to give the following properties as desired: room temperature cure to maximum strength; 100 per cent cohesive bond strength in a minimum time; workability; pot life; maximum temperature with and without post or accelerated cure; elongation; strength; viscosity (uncatalyzed); and good time-at-temperature-and-load history. Combinations of present day RTV silicone did not indicate any significant increase in the load-temperature capability. This limitation is inherent in the material properties and can be changed only through basic polymer research. The effort described in this report involved practical considerations and applications of commercial products. The effort was directed toward obtaining one combination of RTV silicone, catalyst and primer for tension load patches up to 600°F.

The material combinations that were used in the tests are noted in the table below

Table 1
Selected Silicone Adhesives Catalysts, and Primers for Tension Load Plates

| RTV SILICONE | CATALYST | PRIMER |
|---|---|---|
| DC 5302 -- 5303 Silastic* | | DC A4014 |
| | | GE 81822 |
| | | GE SS-67 |
| | | GE XS-4004 |
| DC 5137A -- 5138A Silastic* | | DC A4014 |
| DC 501 Silastic* | A | DC A4014 |
| GE RTV 20 Silicone | LT-16 | GE SS-67 |
| | L-24 | GE 81822 |
| | T-773 | |
| GE RTV 60 Silicone | LT-16 | GE SS-67 |
| | L-24 | GE 81822 |
| | T-773 | GE XS-4004 |
| | | DC A4014 |
| GE RTV 90 Silicone | Thermolite 12 | GE SS-67 |
| | LT-16 | GE 81822 |
| | L-24 | GE XS-4004 |
| | T-773 | DC A4014 |

All catalyst except "A" are distributed by Nuodex Products Co. for the General Electric Silicone
*Silastic is a trade name of the Dow Corning Co.

## *Factual Data*

The tension backing plates for these tests were made from steel and aluminum plates of various thicknesses and dimensions (Figure 1). The final test plate sizes were selected to eliminate forming to the surface contour of the structure and to minimize the effects of re-polymerization at high temperature. When the RTV silicone material is closed off from air, as in this application, the curing time is increased considerably. This curing time is affected by the primer and several other factors. If the primer is not in a solid state at the time of silicone application, it will effectively slow down the curing cycle and prevent a 100 per cent cohesive bond. When heated above a critical level the primer is the nucleus for re-polymerization. A high percentage of catalyst will exhibit the same relative effect. The catalyst reacts uniformly throughout the rubber when it causes re-polymerization. (Varied tendencies are exhibited depending on the materials used.) The difference in reactions of many of the combinations tested was very slight such that they could be ignored at the higher temperatures; however, experimental tests must be performed to determine those variables that might be significant.

The RTV silicone patch method differs from the room temperature neoprene rubber method as follows: the backing plate is smaller; the RTV silicone replaces the neoprene sponge rubber; the primer replaces the cement; backing plate forming to contour is not required; and, advance preparation is not required as in the older method. (To obtain the same point load that is desired, the working load on the smaller patch must be increased.) Because of the small patch size, the number of load points will normally be increased. Greater unit load capability is available, but this capability must be tempered by local structural considerations.

## *Test Discussion and Data*

Initial effort was limited to a small number of test plates that were bonded face to face with RTV silicone materials and tested after an arbitrary cure time. One test method used 1/2 - inch silicone sponge rubber bonded with Dow Corning RTV Silastic. This supplemented work by Convair, Fort Worth, Texas, Report S.D.R. 9.9, dated 10 December 1957, "High Temperature Tension Patch Investigation." The results of the tests were less promising from a load and heat simulation aspect than the metal-to-metal bonding technique.

The optimum patch sizes selected were 2 x 2 inches and 2 x 3 inches fabricated from 1/8-inch steel and 3/8-inch aluminum (Figure 1). These selections were based on heating rates, maximum temperatures, and area coverage required for the B-58 static test program. Experimentation was directed at meeting B-58 static test requirements for a satisfactory loading method at elevated temperatures. The development effort was governed mainly by the B-58 static test schedule commitments and was started too late to be usable. Installation techniques were developed concurrently with the materials evaluation effort, and were constantly in need of revision. Patch failures were experienced and corrected accordingly as the test program progressed. Design data curves were not available at that time for the tension patch load capabilities. Initially, cohesive bonds were difficult to obtain but improved to an inconsistent area. Techniques were developed to obtain a cohesive bond failure by a brief room temperature cure combined with a post cure in incremental steps to 200° F for a short period (Figure 8). This has proved

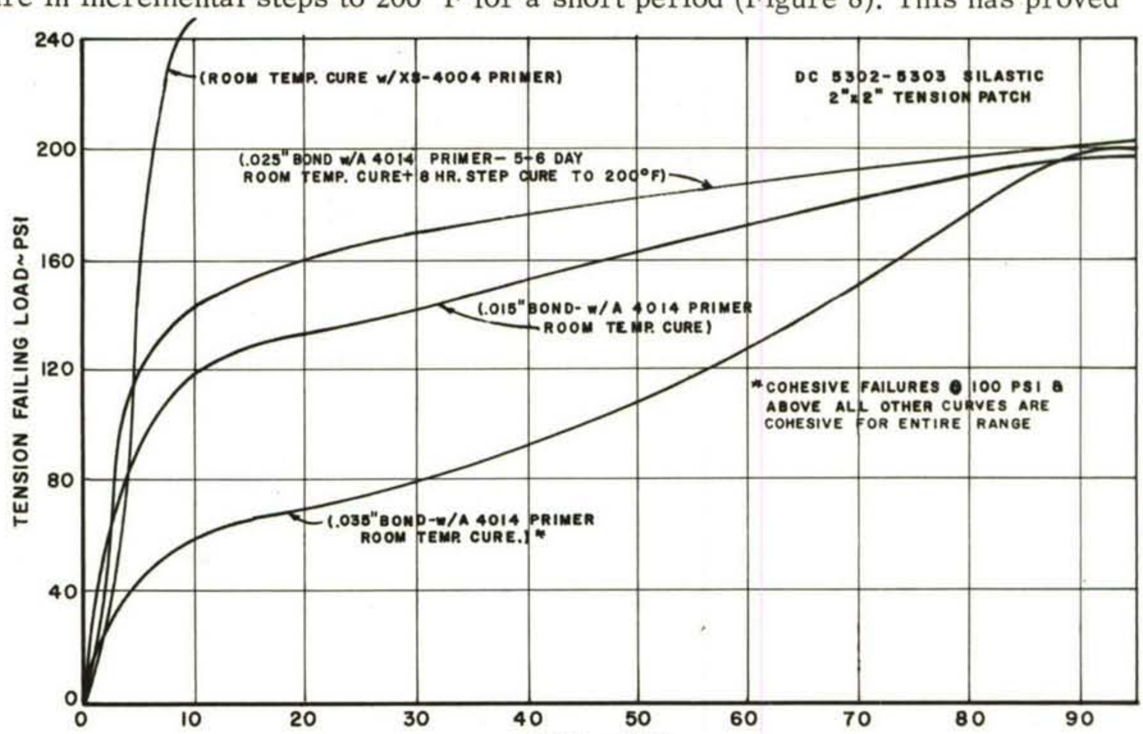



*Figure 8. DC RTV 5302-5303 Silicone Bonded Tension Patch Failing Load vs Room Temperature Cure*

relatively successful. An attempt was made to relate this effect to atmospheric temperature and humidity changes. No definite correlation could be made and is assumed not to be a major factor.

In later tests, the primer used was a colorless liquid and applied film thicknesses were difficult to judge. The primer was applied with a bristle brush on the assumption that other methods of application would not be practical or economical on a major patch installation. Every consideration was directed toward an end technique which would be 100 per cent reliable under normal static test laboratory conditions and which would not require specialized personnel. (Such a series of compromises proved unsuccessful.) While controlled conditions are necessary, properly trained technicians can maintain the quality control required to assure reliability.

Tension patch and shear strap specimens were prepared and tested for long periods of ambient temperature cure and for several combinations of ambient and step elevated temperature post curing. The shear straps were tested for tangential and perpendicular point loads, singly and in combination. The combined loading was limited by material thickness, local stress distribution in the bond, and overall combined stresses. The method was determined practical for combined vertical and side load on a single shear strap. The area tested was in 2 inch by 10 inch multiples (Figure 4). Three-eighths inch holes spaced 1-1/2 inches along the strap were added (centerline) to aid in curing. All tension load plates have a 3/8 - inch or larger diameter hole for the same reason. In addition, the holes provide some internal stress relief at high temperatures.

The patches were tested for tension, moment, torsion, and shear loads and for combinations of tension-shear and moment loads. Typical torque values for 2 x 2 inch plates averaged 500 inch-pounds, whereas 2 x 3 inch plates resisted 1000 inch-pounds when the tension ultimate was from 180 to 200 psi. Tests for combined load use do not show any difference between ultimate strength for shear, tension, or torsion. Failures occurred when combined stresses equaled the tension ultimate over the higher stressed area of the bond.

On the F-106 static test airplane the tension patches were used with loads inclined in excess of 45 deg from the normal while developing a nominal 30 psi patch load. Normal load angularity will have no appreciable effect for normal working loads and temperatures up to 400° F as verified by time-temperature-load data of this type at 530° F (Figure 9).

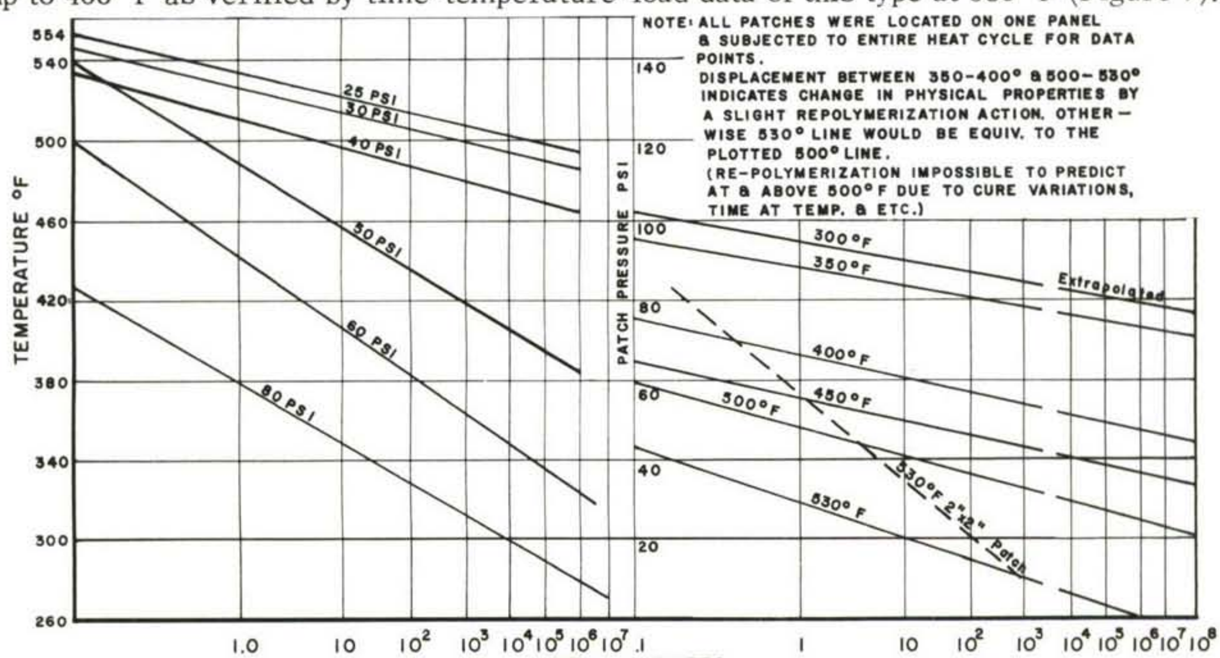



*Figure 9. DC RTV 5302-5303 Silicone Bonded Tension Patch Failing Load vs Time vs Test Temperature*

No load restriction will be required for small load angles. Torsion values are mentioned as an indication of strength and this is one way to remove the patches. Care should be exercised in removing patches from non-rigid structures.

Elevated temperature tests were conducted in a cylindrical radiant heat oven using GE T-3 quartz tube infra-red lamps mounted on the inner surface (Figure 16). The test plate was suspended in the center of the oven and allowed to reach temperature. Iron-constantan thermocouples were used to monitor the temperatures. The lower plate was attached to a fixed fitting, and load was applied to the top plate by a hydraulic tension load strut, or a predetermined dead load, suspended by the hydraulic strut. Stainless steel test panels were patched to simulate a typical installation for combined time, temperature, and load design data curves (Figure 9).

The data derived during this program had considerable scatter; however, the curves were drawn on the conservative side of the resulting band. Scatter of test results may be reduced by practical experience and experimentation with primer, application techniques, catalyst, and cure cycles. Various combinations of RTV silicone materials contributed little to the scatter of test results.

The selection of Dow Corning RTV 5302-5303 Silastic was based on (1) the relatively long pot life of the catalyzed material, and (2) viscosity. Figures 8 through 15 present test data obtained for the more important silicone materials used in tension patch bonding. Figures 8 and 9 may be used for design data to determine allowable working values.

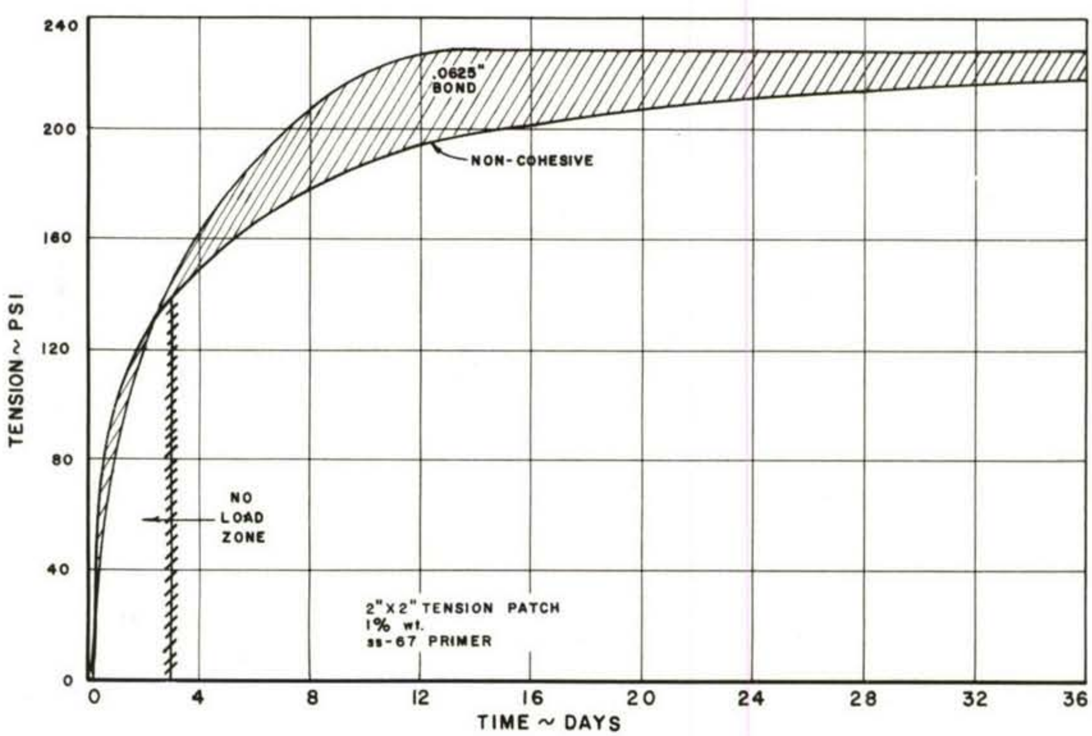



*Figure 10. GE RTV 90 Silicone Bonded Tension Patch Failing Load vs Room Temperature Cure. LT-16 Catalyst*

For practical applications, these materials simplify the job in that a larger amount may be prepared for use. The mixing may be done on a rubber mill to insure consistency. Although other manufacturers market RTV silicone materials that will serve as well as those specified herein, neither the qualifying vendors nor the determination of applicable military specification is the purpose of this study.

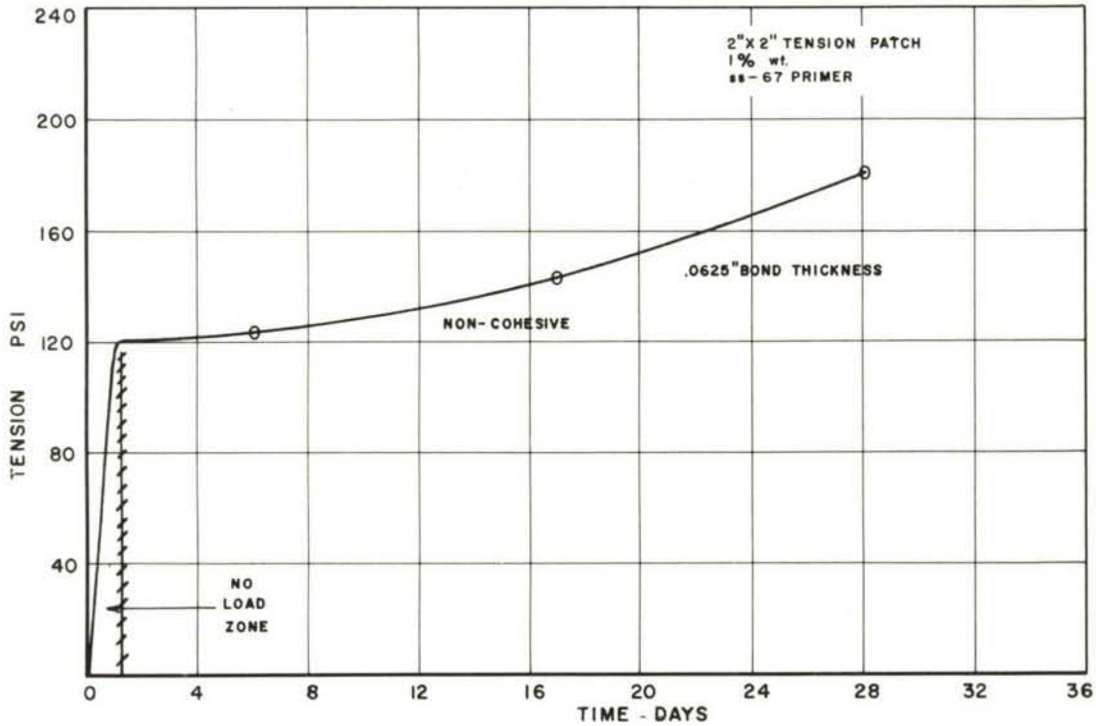



*Figure 11. GE RTV 90 Silicone Bonded Tension Patch Failing Load vs Room Temperature Cure. L-24 Catalyst*

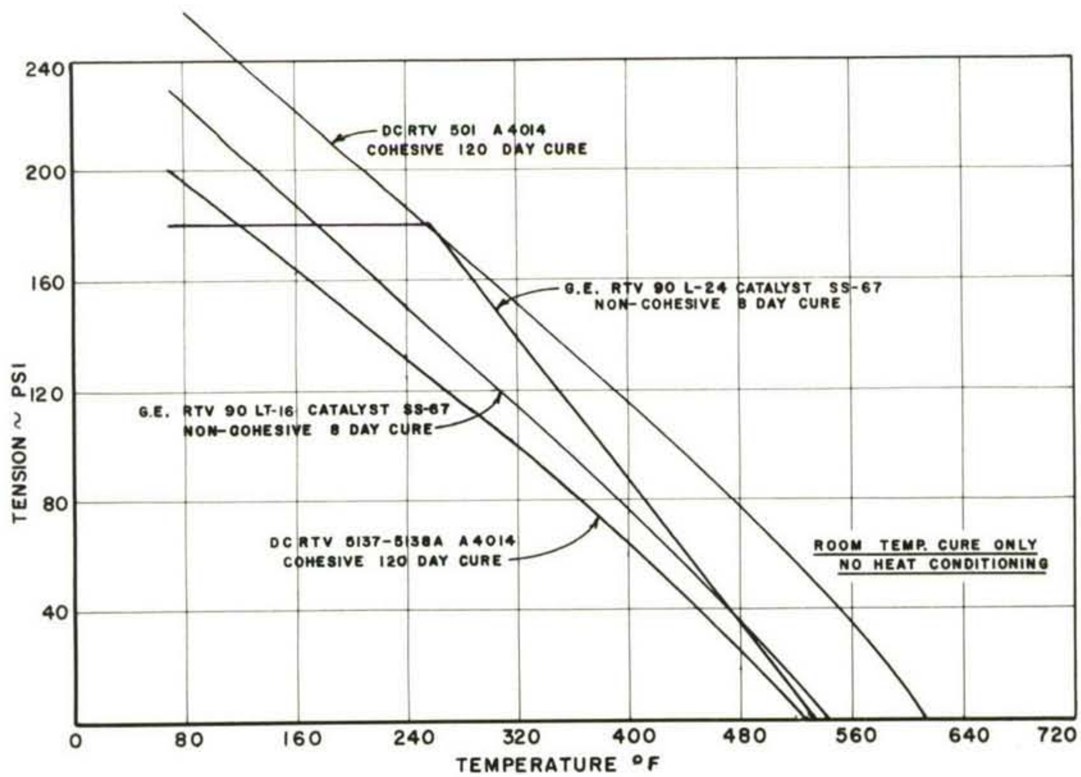



*Figure 12. RTV Silicone Bonded Tension Patch Failing Load vs Test Temperature*

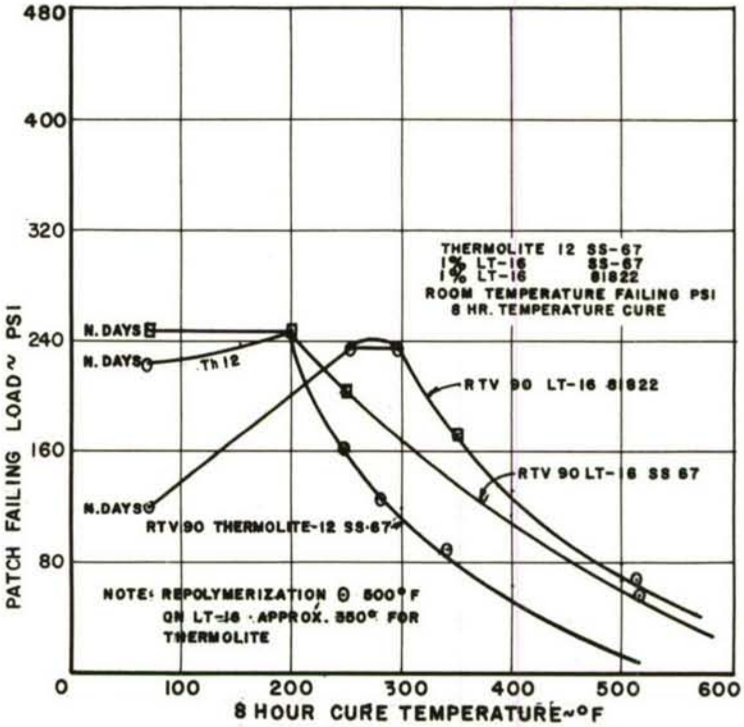



*Figure 13. GE RTV 90 Silicone Bonded Tension Patch Failing Load vs Temperature Cure*

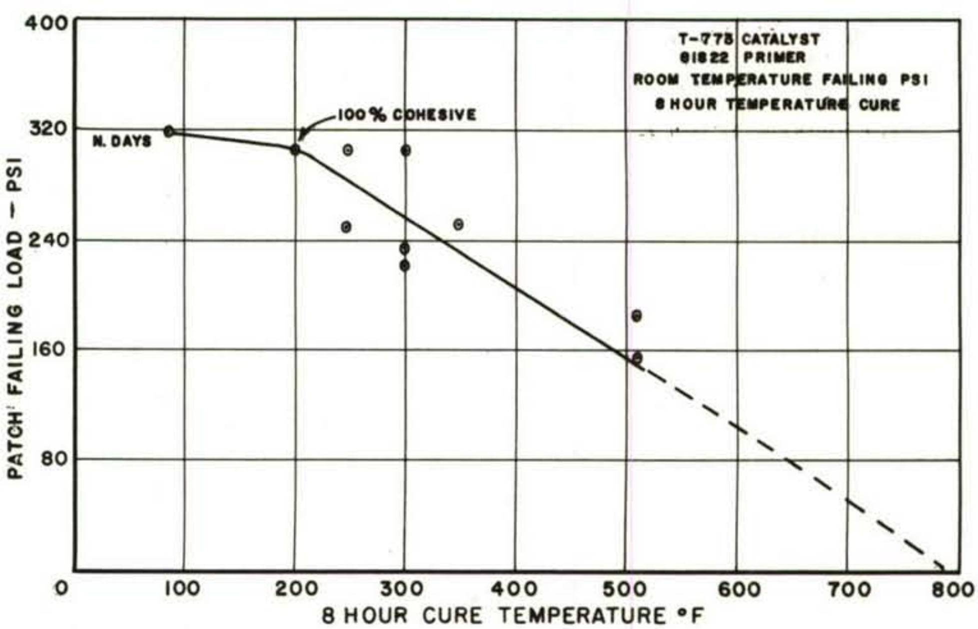



*Figure 14. GE RTV 20 Silicone Bonded Tension Patch Failing Load vs Temperature Cure*

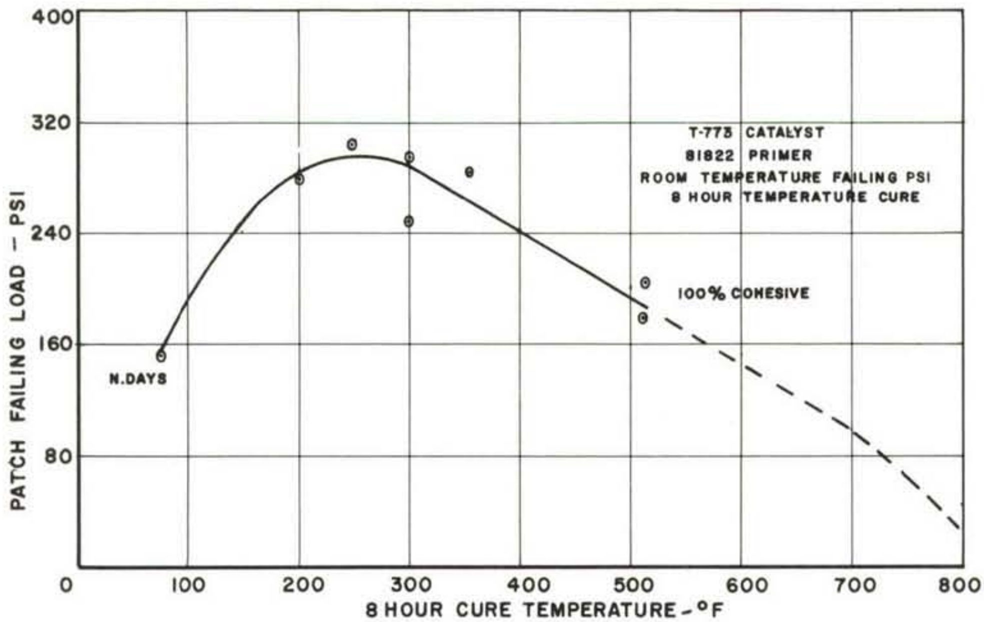



*Figure 15. GE RTV 60 Silicone Bonded Tension Patch Failing Load vs Temperature Cure*

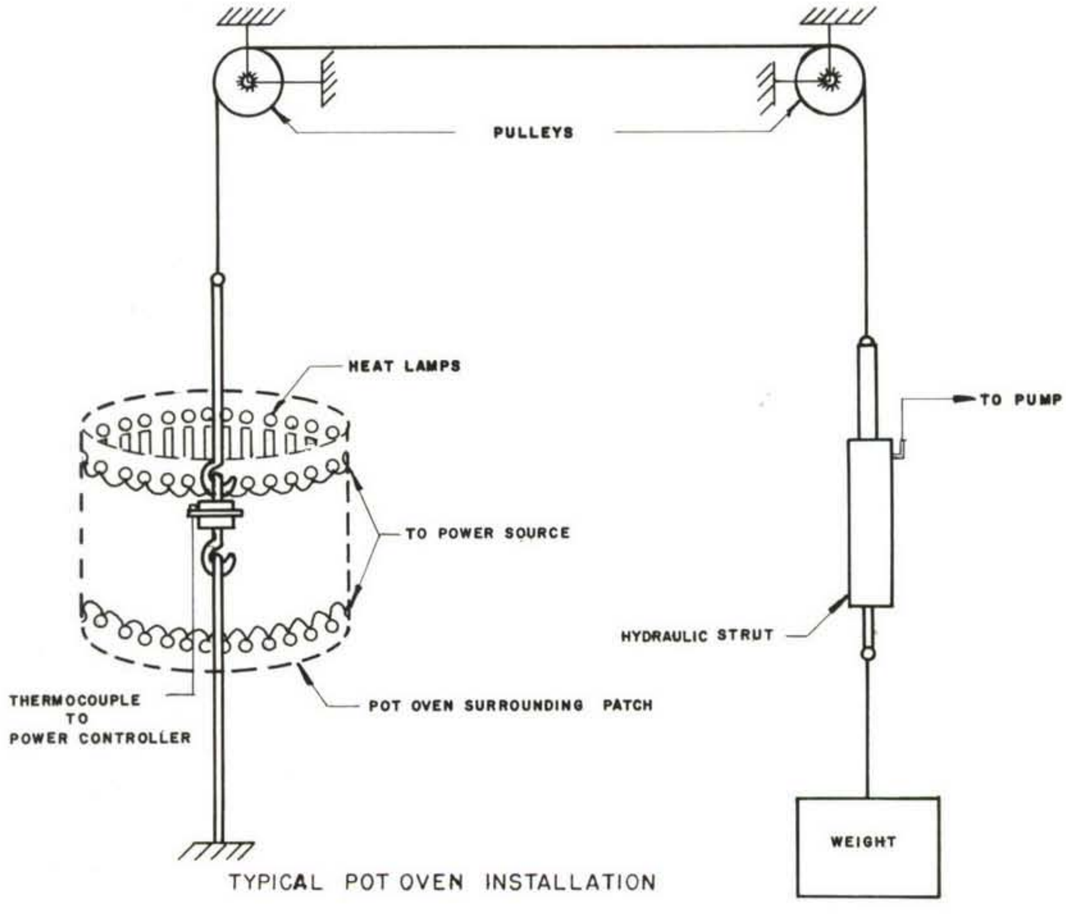



*Figure 16. Cylindrical Radiant Heat Test Oven and Patch Test Loading Sketch*

## Procedures

The following procedures are recommended to install tension patches to test structures with RTV silicone:

1. Preliminary preparation of surface area and tension patch backing plates.
   a. Remove all paint, paint primer, oil, grease, dirt, adhesive, etc.
   b. Clean surface area thoroughly with trichlorethylene or a suitable substitute.
2. Lay-out the surface for tension patch locations. Do not use grease-type pencils.
3. Final preparation of surface area and tension patch backing plates.
   a. Clean surface area with trichlorethylene or a suitable substitute.
   b. Thoroughly scrub the surface with a scouring powder and water; rinse with clean or distilled water.
   c. Wash surface with acetone and allow it to dry completely.
   d. If surface appears dirty or spotty, repeat any or all of the above procedures. (Remove only the construction lines under patch plates.)
4. Apply sufficient metal primer for coverage of the surface, patch backing plates, and shear straps.
   a. Prime only the area where patch or strap will be located.
   b. Apply the primer in a uniform layer of the proper thickness. Optimum amount of primer will be determined through experimentation or vendor literature. (Approximately 0.7 mils)
   c. Apply the primer with an air brush type sprayer. A camel hair brush for small applications will give satisfactory results, but will usually result in a non-uniform thickness.
   d. Allow sufficient drying time for the primer. Two or more hours may be required for the primer to become a hard tenacious film.

*Figure 17. Vacuum Pressure Method for RTV Silicone Tension Patch Application*

5. Prepare surface for vacuum blanket.
6. Mix the RTV silicone materials in accordance with manufacturer's specified procedures or as determined by experimentation. All refrigerated materials should be room temperature before mixing. Mix only the amount that can be used within the desired interval of pot life.
    a. Apply mixed silicone to patch plate or strap with a putty knife or spatula. Exercise caution to prevent movement that will cause displacement of the primer.
    b. Press plate downward at its desired location with sufficient force to flow the adhesive from under the plate to an approximate 1/16 inch thickness before applying vacuum.
    c. Limit area coverage for each lay to the mixing and pot life capabilities of the particular silicone material being used.
7. Apply a vinyl plastic blanket over the block of patches and apply from 2 to 4 inches Hg (Figure 17). This pressure should produce a bond approximately 1/32-inch thick during the pot life that remains (Figure 18). A separate vacuum line to the control switch from the area being vacuumed will prevent surge.
    a. Leave vacuum control on for 4 to 12 hours depending on the patch location and RTV silicone curing time.
8. Remove vacuum blanket, clean surface, and trim off excess RTV silicone.
9. Approximately .075 ounce of catalyzed RTV silicone material is required for each square inch of tension patch plate area. Shear straps require approximately .125 ounce of silicone material for each square inch of strap contact area.

Care should always be exercised to insure cleanliness and to prevent contamination of tools, equipment and materials by uncatalyzed silicone materials. This is especially important where non-silicone materials are used in the same area with silicone materials. All materials and equipment used for silicone bonding should be kept isolated with respect to non-silicone materials. Good personal hygiene must be observed at all times while handling RTV silicone materials through the pot life of the catalyzed mixture to minimize the hazard of dermatitis or allergic skin rash.

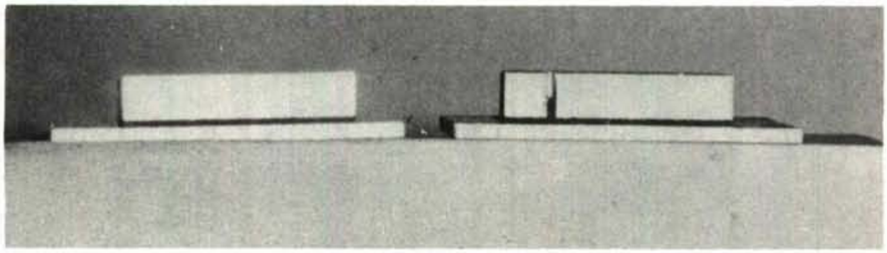


*Figure 18. Test Tension Patch Showing Average RTV Silicone Adhesive Bond Thickness*

## Conclusions

The work outlined here describes the initial effort applied to the development of a practical elevated temperature--room temperature tension patch.

The results from tests and from actual use on major structural test items have shown that this method is the most practical available. Room temperature vulcanization assures that the materials used are practical for most applications. Pressure on the patches during curing is undesirable but must be used on vertical and undersurface installations. A pressure cure up to 10 psi can be handled satisfactorily. Initial cure at temperature is impractical and should not be used unless required by special test conditions.

Post curing for increased patch capability can be accomplished without extra effort once the heating equipment is installed for an elevated temperature test condition. This can be done during a normal temperature profile or survey check preliminary to the actual test run.

Curing techniques pose some problems but these can be solved by laboratory experimentation. Temperature, load and time variables increase the complexity of the problem (while decreasing the capability of organic, inorganic, or a combination of these materials.)

Elasticity is important in preventing local effects (i.e. effective doubler) introduced to the structure and will also minimize the stabilizing effects that could be introduced in local buckling patterns or modes.

The thermal conductivity of the patch assembly is a variable that may be used as a beneficial aid. Under radiant energy, RTV silicone tension patches will conduct heat into the structure at a high rate to prevent ignition of the silicone. No fire hazard has been experienced for flux densities up to the maximum available in radiant heating applications. (The load capability at temperature with respect to time presents the only undesirable factor in this method. Improvements can be made, but it will continue to be the most serious limitation in adhesive capability.) Stability at elevated temperatures requires that the adhesive should be inert in the cured form to the extent that no toxic gases are produced.

The silicone materials used in this study were commercial products obtained from Silicone Products Divisions, General Electric Company, and the Dow Corning Company. Other manufacturers supply silicone products, however, from the literature available at the inception of this program, only Dow Corning appeared to have a satisfactory RTV silicone material.

RTV silicones cost from $3.52 to $4.75 per pound and the catalyst and primer each cost approximately $4.00 per pound.

# Section II

## Improvement Program for RTV Silicone Bonded Tension Patches

### Introduction

This test program was conducted to determine the practicability of using RTV silicone tension patch loading methods and to evolve techniques for the F-108 static test program at ambient and elevated temperatures. Efforts were concentrated on one RTV silicone, one catalyst and two metal primers which had promising characteristics based on the results referenced in Section I. Over one and one-half years practical test experience using other silicone and epoxy materials on the B-58, F-106, and other test programs, contributed to the success of this program.

The purpose of this test program was to determine the suitability of General Electric RTV 60 silicone in combination with silicone metal primers for use as an adhesive to bond tension patches to a test structure for use to temperatures of 600° F; and, to perfect methods and procedures for the mixing and application of the RTV silicone, catalyst, and primers.

### *Factual Data*

RTV silicone is a room temperature vulcanizing silicone product similar to natural rubber, but having excellent temperature stability up to 600° F. RTV silicone vulcanizes to form an excellent bond to metal, plastic, and glass and possesses high mechanical strength at the indicated temperature. The RTV silicone used in this test program was General Electric RTV 60 which showed the best stability at elevated temperatures during previous experimental studies (Figure 15, Section I).

The standard tension patch plates used are 2 x 2 inches. Various plate materials and thicknesses are used to fit specific heat and load requirements.

The adhesive should be a uniform 1/32-inch thickness under the plate (Figure 18). The curing agent, or catalyst, used with the RTV 60 was Nuodex Silicure* T-773. The catalyst is used in very small proportions, approximately 1/2 per cent by weight, to impart the desired characteristics to the silicones. Extra care must be taken to insure thorough dispersion of the catalyst into the mix.

Insufficient mixing will give poor physical properties because of the non-uniform vulcanizing of the RTV silicone. The curing time of the catalyzed RTV compound is directly related to the amount of catalyst used. The smaller the amount of catalyst, the longer the pot life and curing time for the mixture. Pot life is the time between addition of the catalyst and the point at which the compound becomes too rubbery to use. Curing time may be accelerated by heating the structure and patch. Tension patches are considered unsatisfactory unless a 100 per cent cohesive bond is effected.

To bond a silicone to non-silicone surface, a silicone primer is necessary. The two primers used in this test program were GE XS-4004, and 81822. If all procedures and techniques are executed properly the RTV silicone will adhere to a non-silicone surface with a force greater than the cohesive strength of the rubber.

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*Silicure is a trade name of the Nuodex Products Company.

## Techniques

The airbrush sprayer is satisfactory for applying primer. Using this technique, it is possible to apply a uniform primer coat which gives consistent cohesive bonding. Thickness of the primer is determined by test and experimentation on the materials on which it will be used. Hydration, or evaporation, of the primer is complete when it is no longer tacky to the touch. All materials used in mixing should be allowed to reach room temperature before they are mixed. A typical mix is 8 ounces of RTV 60 silicone with .96 cc of T-773 catalyst. This is a 1/2 per cent by weight mixture of catalyst to silicone. After accurately weighing the two parts, mix thoroughly and quickly. Vacuum may be used at this point for a few minutes to aid in removal of entrapped air. The silicone is then spread on the tension load plate with a spatula and the backing plate is placed in position.

A 6-ounce mix of RTV silicone will cover approximately 20 patches, .3 to .5 ounce of silicone used for each 2 x 2 inch patch. In the described program, all the load patches were laid within ten minutes after the catalyst was added to the RTV silicone. The patches were placed under vacuum for 30 minutes with 2 inches Hg. The elevated temperature cure was performed in an air circulating oven to 500° F, or in the cylindrical radiant heat oven (Figure 16 Section I) for temperatures in excess of 500° F.

The static testing at room temperature was accomplished using a manually loaded hydraulic strut. The elevated temperature tests were performed in the radiant heat oven which permitted load and temperature combinations. Many of the techniques used for applying patches at the beginning of the program were changed. The changes were incorporated to improve methods or to permit evaluation of the new methods.

The first few plates of test patches were discarded because many of the patches were not completely covered with silicone and a number of patches of each plate were spread with silicone when the mixture was too stiff to give a uniform adhesive thickness or complete coverage. For RTV 60, the pot life of the catalyzed mixture is measured in minutes.

The pot life for the first few mixes had an inconsistent time interval and it was concluded that the problem was an inaccurate catalyst weight. An 8-ounce balance scale was used, but it did not have the required accuracy. An eye-dropper was then calibrated for 6 drops of catalyst per ounce of RTV Silicone.

This method was also unsuccessful although the operations were repeatable. Accuracy was obtained by using a 1 cc medical syringe calibrated to give an equivalent volume per unit weight. (This method was better and the variations in pot life now obtained were judged to be the human error in this determination.)

All test plates were prepared by sanding the surface lightly. The primer was applied using a camel hair brush with uniformly thin first and second coats applied at right angles to each other. This method was not completely satisfactory and was discontinued in favor of the airbrush spray.

## Test Results and Data

Physical properties of cured RTV 60 silicone tension patches are presented in Figures 19, 20, 21, 22, 23, 24, 25 and 26. These test curves give curing time, failing load at room and elevated temperature, and time to failure under load at elevated temperatures. Also presented is transient heat data under a constant patch load of 50 psi (Figures 27, 28 and 29). The curves are presented for ranges of 500° F, 1000° F, and 2000° F and terminate at the point of patch failure. This data was obtained from tests conducted on the plate shown in Figure 30. The open skin represents Thermocouple 1T, and the patched skin represents the average of Thermocouples 5 and 6. Plate temperature edge effects were not compensated for and require a rational interpretation of the data. The GE RTV 60 silicone patch test curves are self-explanatory. The difference between XS 4004 and 81822 primer test data is due to the primer thickness and percentage hydration at the time of patch lay. Since the XS 4004 primer is a fluorescent pine color, compared to the colorless 81822, it was easier to regulate the thickness and to obtain better test data. An attempt was made to determine the effects of ambient temperature and humidity on the pot life and cure time of each mix but the data was inconclusive.

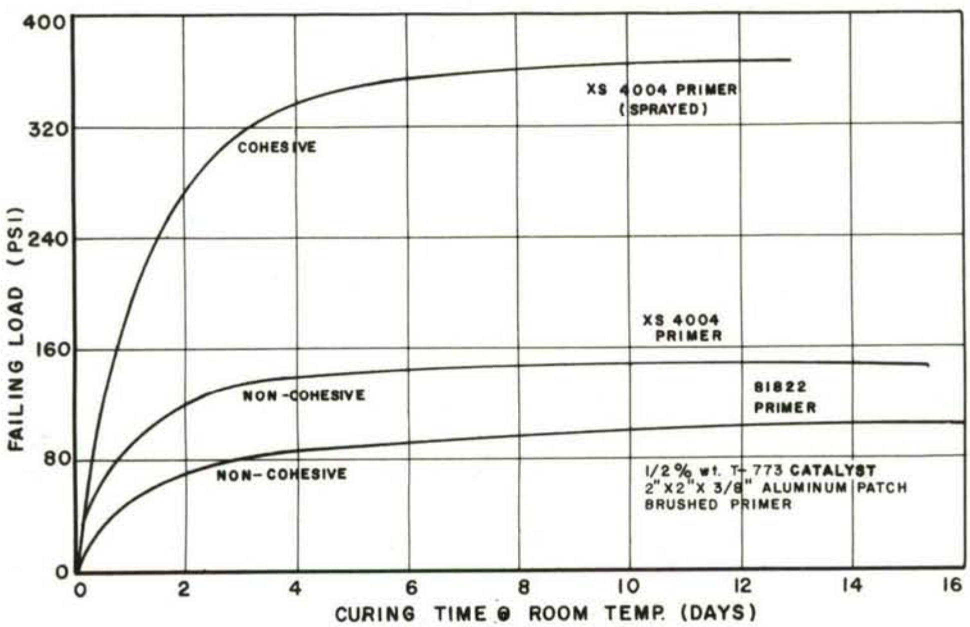



*Figure 19. GE RTV 60 Silicone Bonded Tension Patch Failing Load vs Room Temperature Cure*

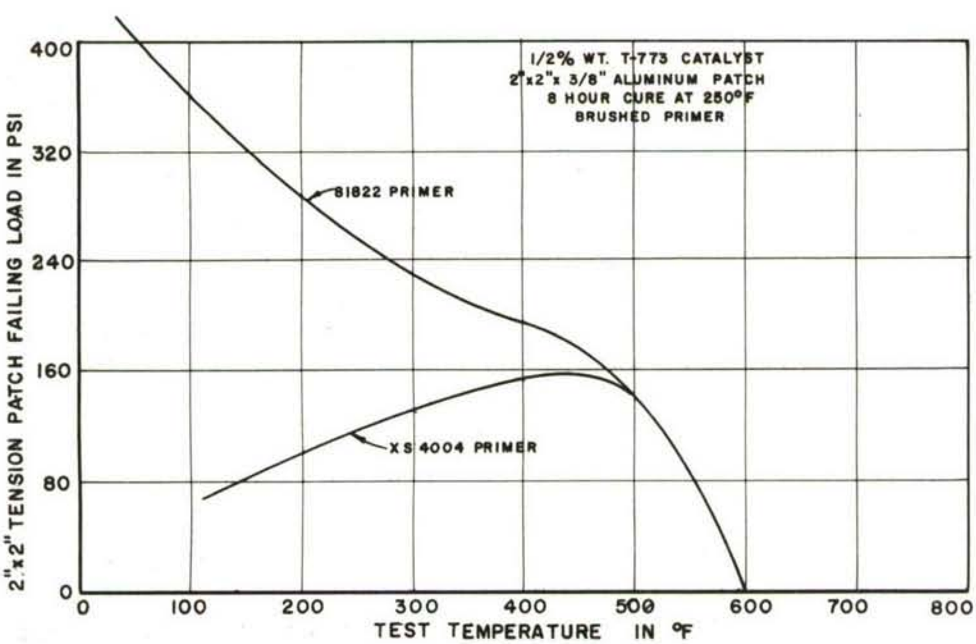



*Figure 20. GE RTV 60 Silicone Bonded Tension Patch Failing Load vs Test Temperature*

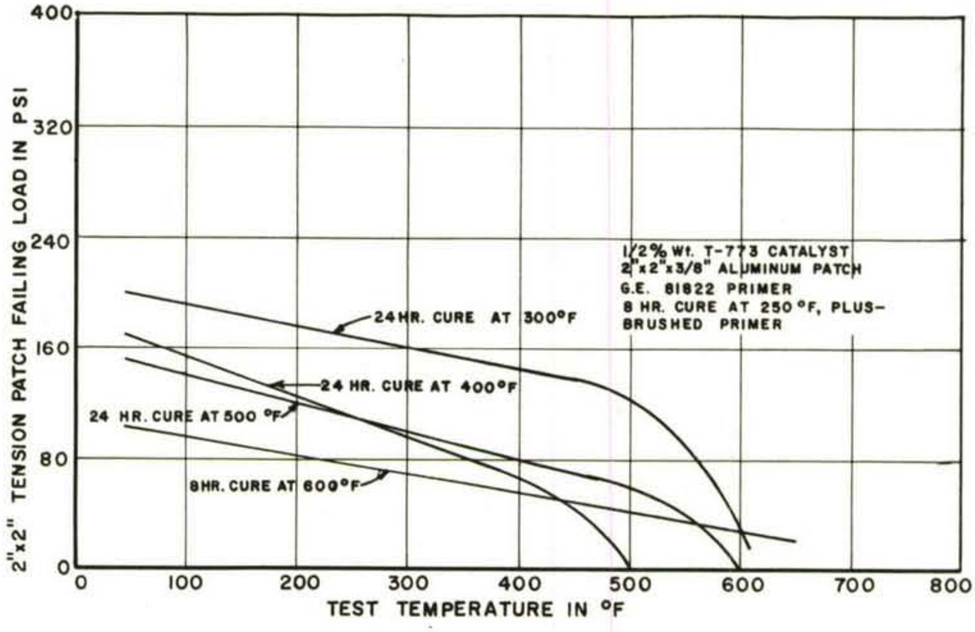



*Figure 21. GE RTV-60 Silicone Bonded Tension Patch Failing Load vs Test Temperature. Time-Temperature Step Cure.*

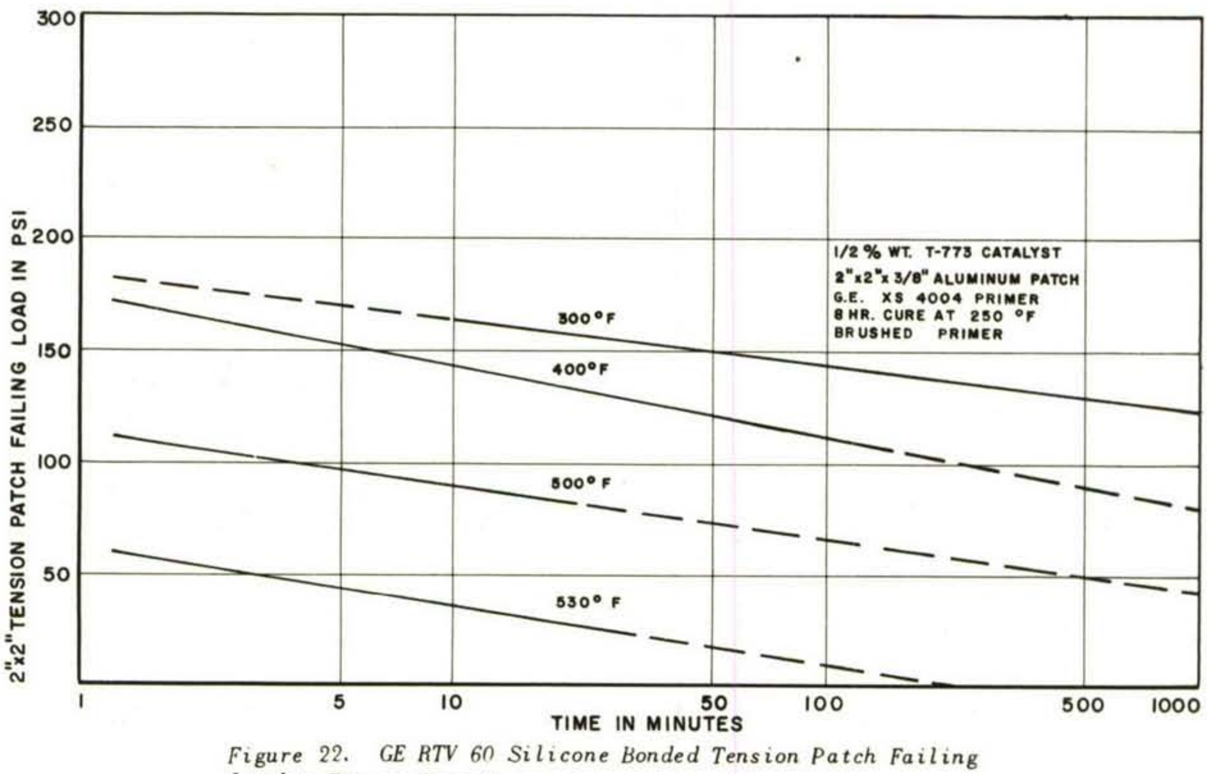



*Figure 22. GE RTV 60 Silicone Bonded Tension Patch Failing Load vs Time vs Test Temperature.*

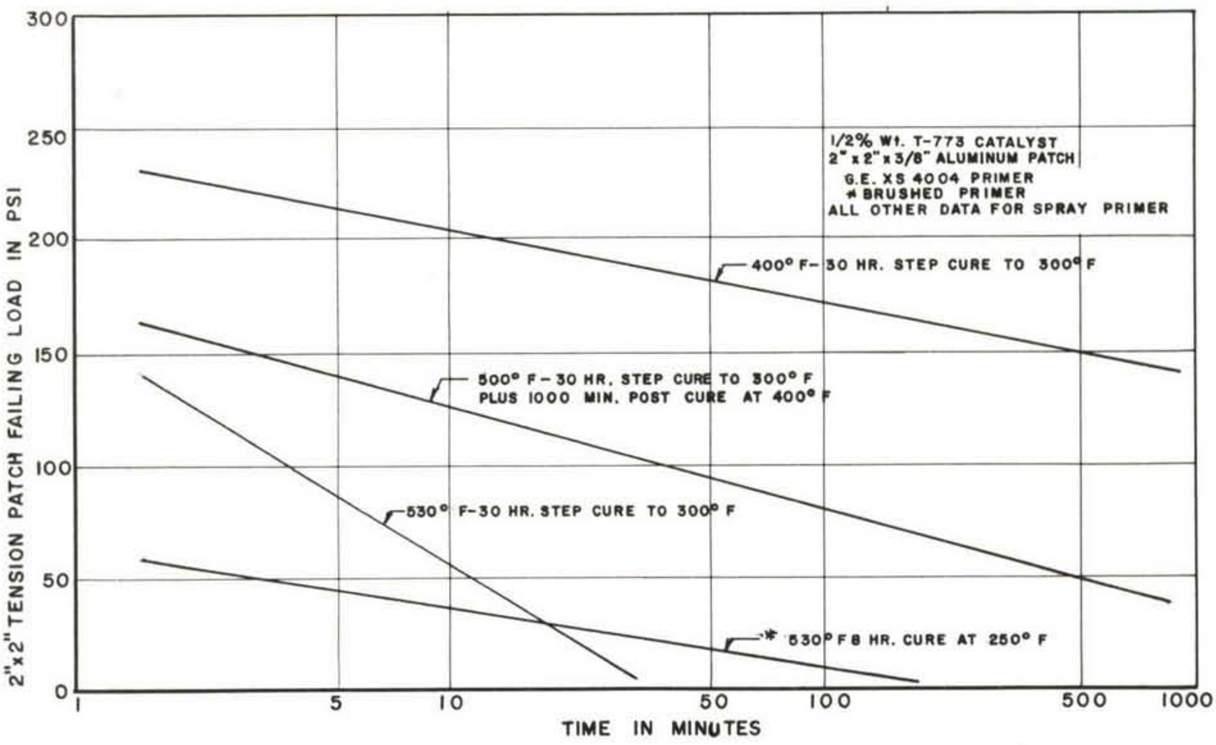



*Figure 23. GE RTV 60 Silicone Bonded Tension Patch Failing Load vs Time vs Test Temperature. Time-Temperature Step Cure.*

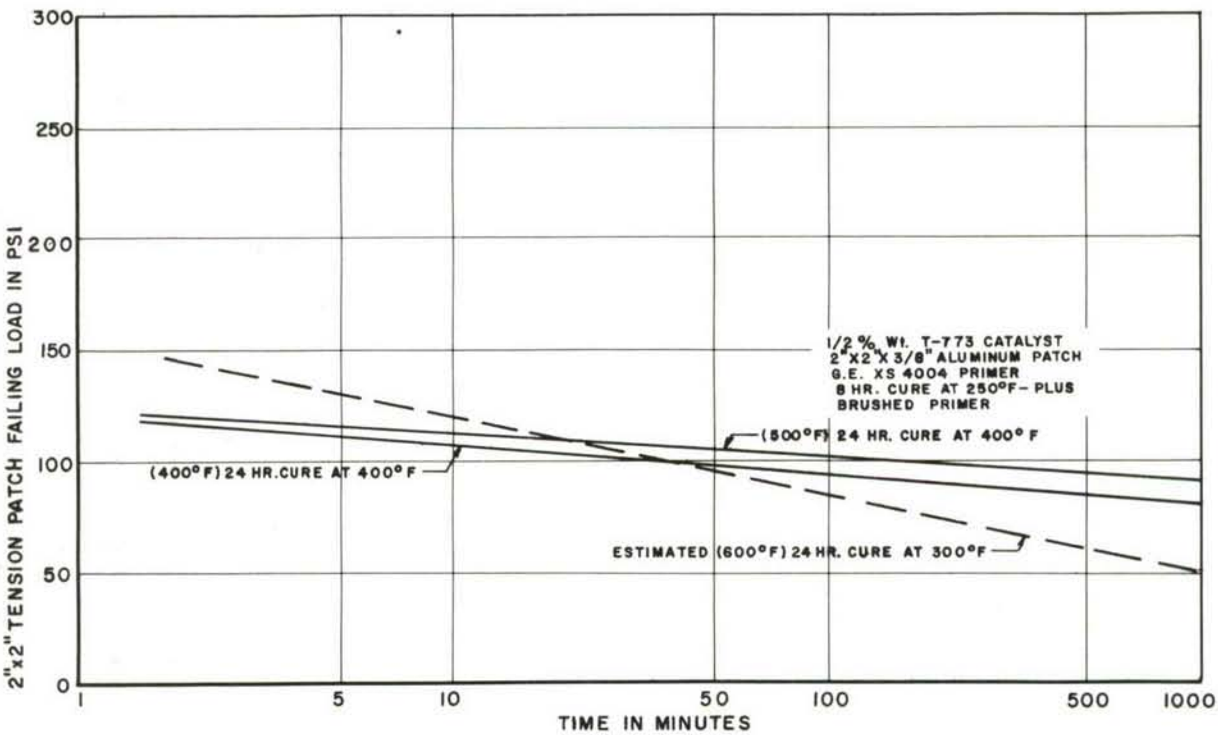



*Figure 24. GE RTV 60 Silicone Bonded Tension Patch Failing Load vs Time vs Test Temperature. Step Temperature Cure*

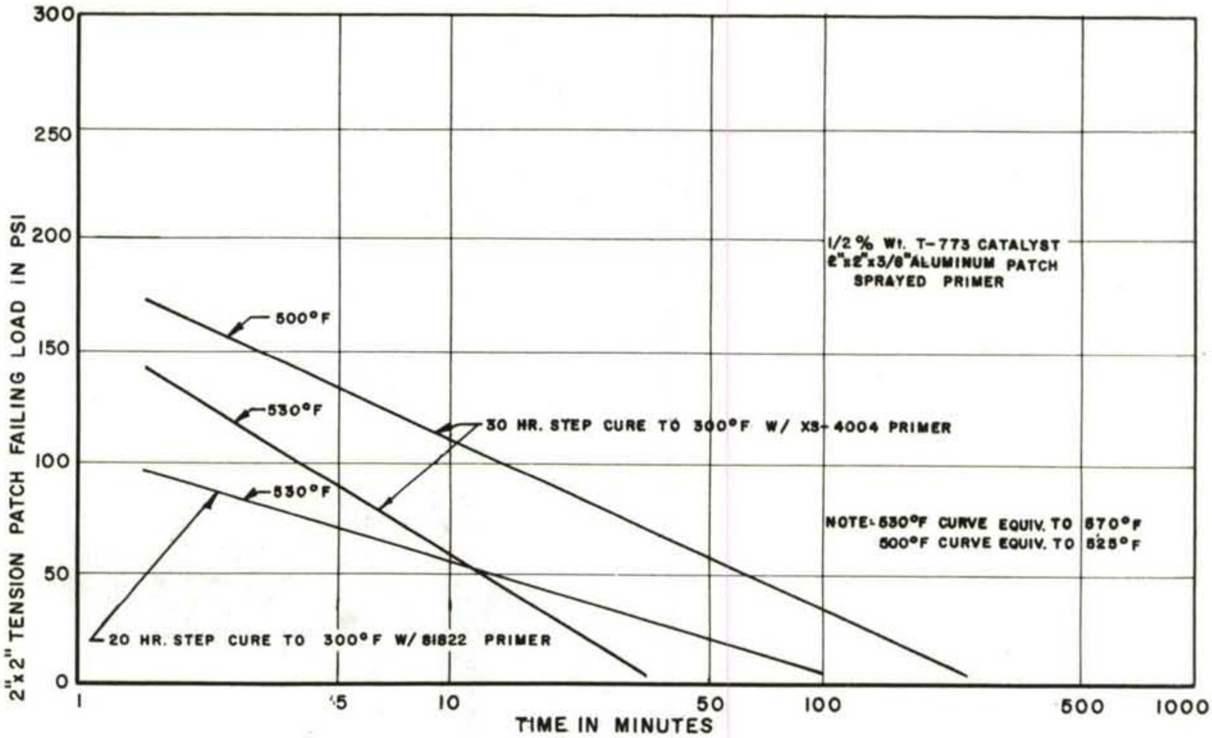



*Figure 25. GE RTV 60 Silicone Bonded Tension Patch Failing Load vs Time vs Test Temperature. Step Temperature Cure with Two Primers.*

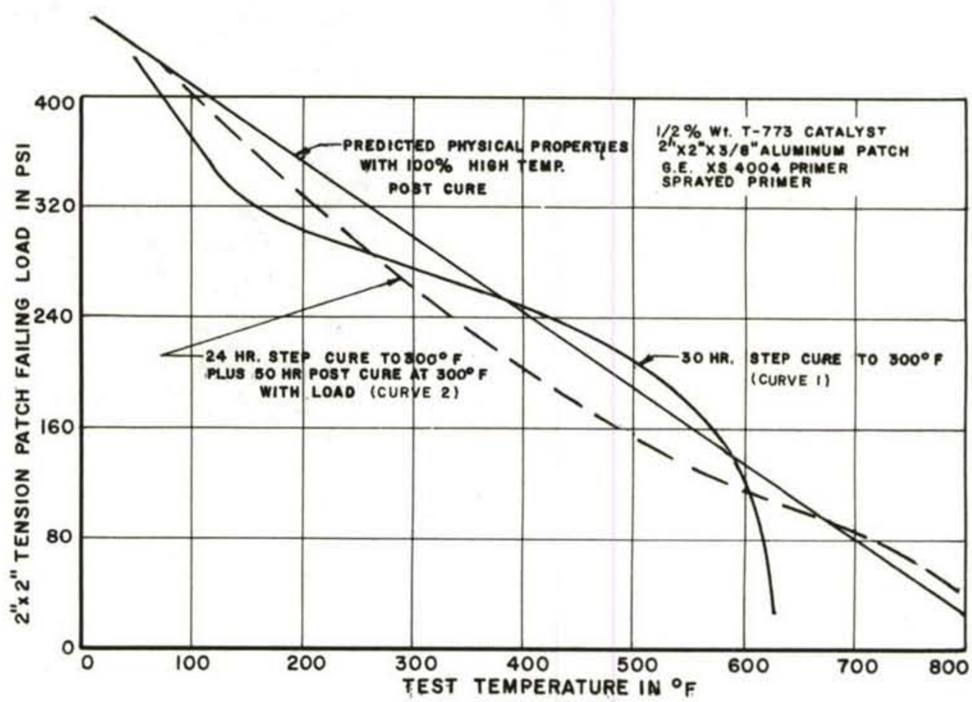



*Figure 26. GE RTV 60 Silicone Bonded Tension Patch Failing Load vs Test Temperature. Predicted and Actual Test Physical Properties.*

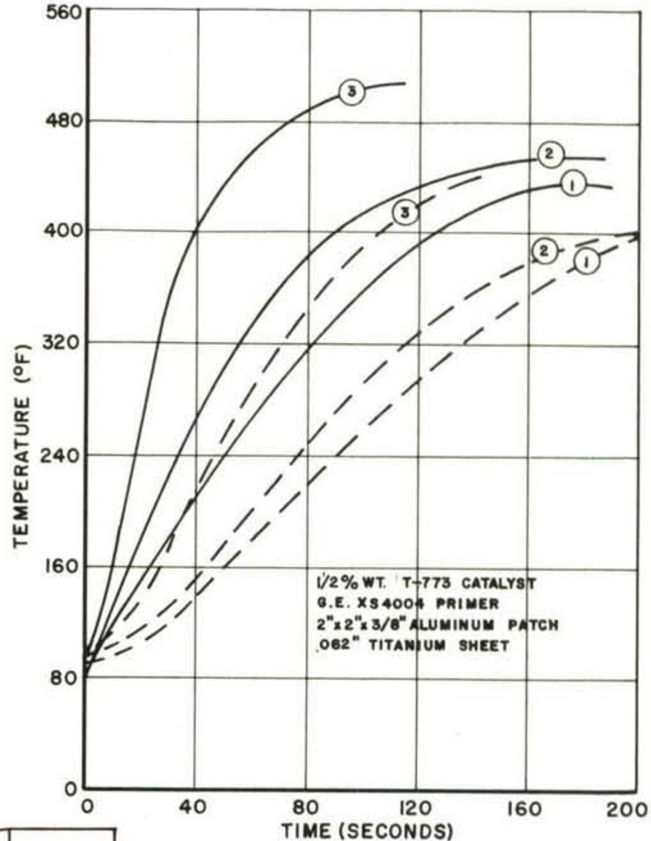



*Figure 27. GE RTV 60 Silicone Bonded Tension Patch Panel Transient Heat Simulation to 500° F. 50 psi Patch Load.*

*Code: Test Curves 1 to 3*

*——— Temperature T/C 1T*

*— — — Average Temperature T/C's 5 and 6*

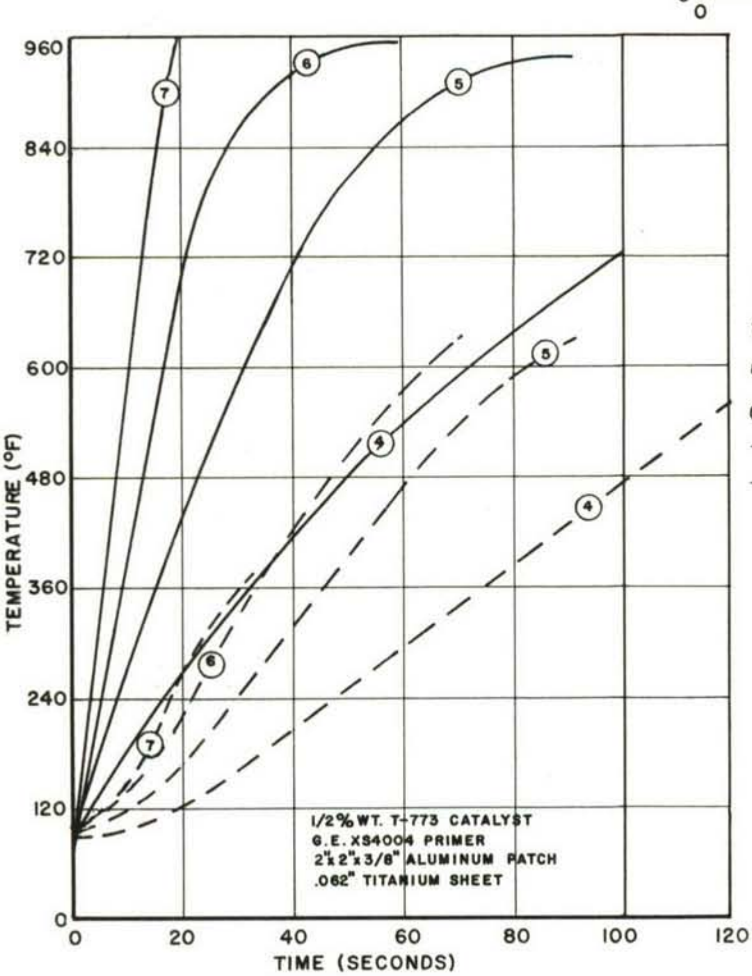



*Figure 28 G.E. RTV 60 Silicone Bonded Tension Patch Panel Transient Heat Simulation to 1000° F. 50 psi Patch Load.*

*Code: Test Curves 4 – 7*

*——— Temperature T/C 1T*

*— — — Average Temperature T/C's 5 and 6*

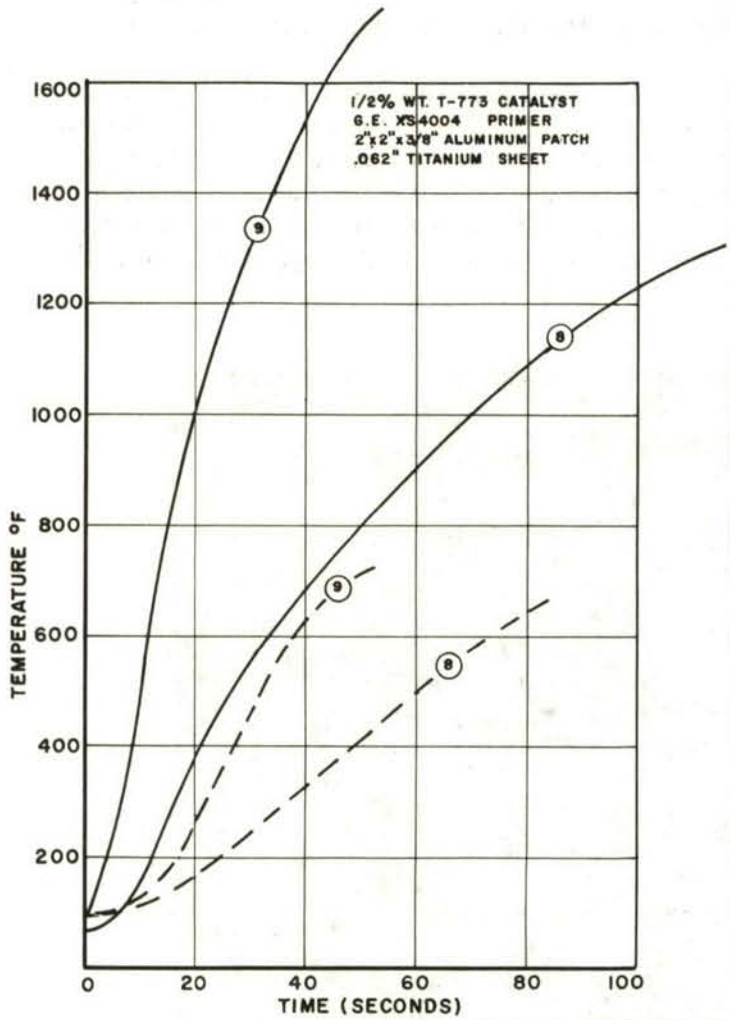



*Figure 29. G.E. RTV 60 Silicone Bonded Tension Patch Panel Transient Heat Simulation to 2000° F. 50 psi Patch Load.*

*Code: Test Curves 8 and 9*

*——— Temperature T/C 1T*

*— — — Average Temperature T/C's 5 and 6*

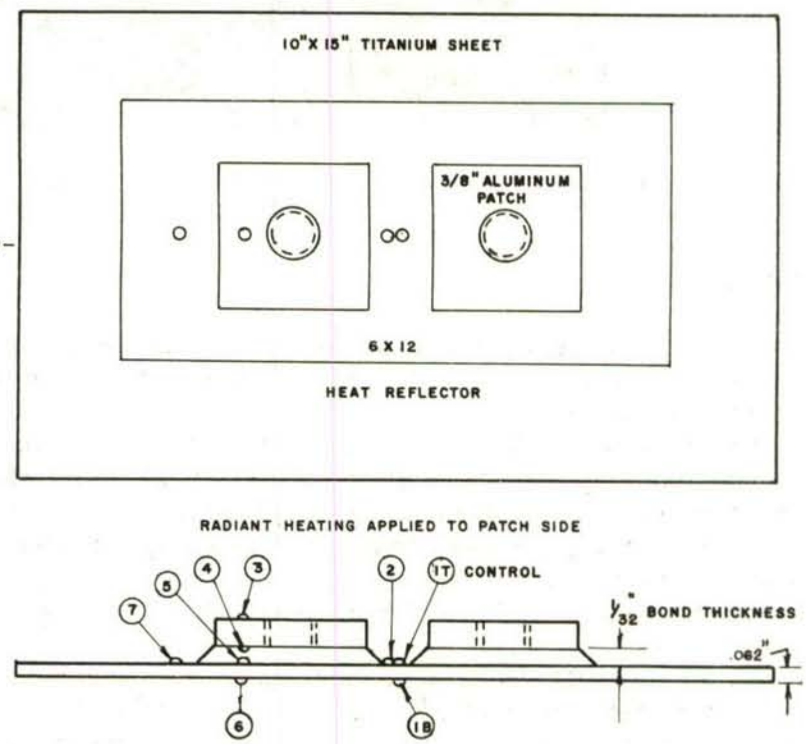



*Figure 30. Tension Patch and Thermocouple Geometry for Transient Heat Simulation with 50 psi Patch Load.*

The test plates were made back to back (Fig. 31) and were then cut into individual test samples for curing and testing.

The following cure cycle was used for the test data presented: 1 hr. at 125° F; 2 hrs. at 150° F; 2 hrs. at 175° F; 2 hrs at 200° F; 3 hrs. at 225° F; 3 hrs. at 250° F; 3 hrs. at 275° F; and, 14 hrs. at 300° F. This is not the optimum cure cycle for this material. Most data is based on a 4-day room temperature cure before using the test temperature cure. A long room temperature cure is desirable, but could not be done in the limited time available for this program. Most test data is presented in the Appendix, Tables 2 to 15.

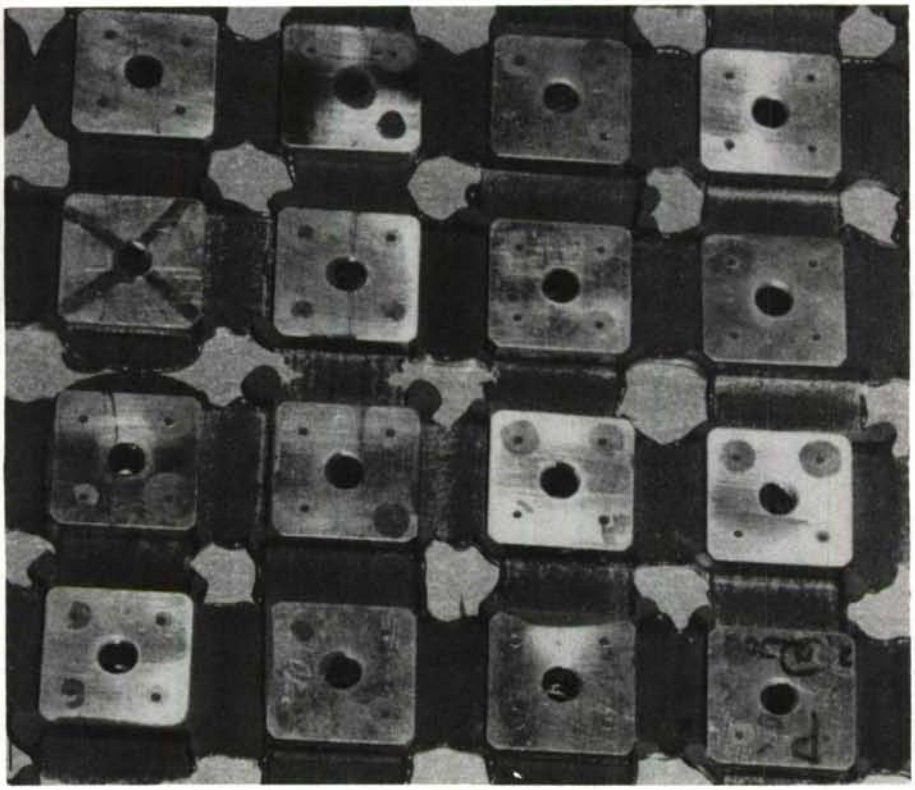


*Figure 31. RTV Silicone Bonded Tension Patch Test Plates After Vacuum Pressure Application.*

## Conclusions

From this series of tests the combination of GE RTV 60, 1/2 percent by weight of T-773 catalyst, and XS 4004 primer gave satisfactory heat stability and physical properties up to 600°F (Figure 26).

The mixture of RTV silicone and catalyst must be mixed throughly and accurately.

The primer gives consistent results on metals only when spray-coated to the proper uniform thickness with an airbrush sprayer.

This desired thickness can be determined by experience with the density of the fluorescent color.

Sandblasting or light sanding does not afford good bonding and should be avoided as a general practice.

An optimum RTV silicone tension patch cure was not necessarily obtained in these tests for best heat and load stability above 350° F. Proper cleaning of non-silicone materials is essential to obtain consistent bond techniques. This is done by washing with trichlorethylene and acetone, and scouring followed with a distilled water rinse.

Transient heat load tests were conducted using 2 x 2 - inch by 3/8-inch aluminum patch plates bonded to .062 titanium sheet. Test runs were made to 500° F, 1000° F, and 2000° F, at rates up to 50° F per second with a 50 psi patch load (Figures 27, 28 and 29). The adhesive breakdown point varies with rise rate and maximum skin temperature. Patch loads will be limited by this consideration. No breakdown or burning was experienced up to 2000° F. The effect of the colder patch area should have little effect on thermal shock or ultimate panel strength at temperature. It would be pure conjecture to say this would help or precipitate local panel buckling. More experience and knowledge is needed for this application of RTV silicone bonded load patches. (For straight transient heat-load conditions, without dwell periods at temperature, this should provide a useful test method for an interim period in the state-of-the-art.) Temperatures under the patch can be regulated with material and thickness combinations of the patch plate for various temperature maximums.

# Section III

## Structural Test Simulation Techniques at Elevated Temperatures

### Introduction

The use of tension patches to apply flight vehicle mechanical loads with thermal simulation is discussed. Also discussed is temperature distributions under thermal simulation on the skin structure. No internal temperature distribution is discussed.

It is difficult to apply distributed test loads to simulate air loads that are imposed by the flight operations of aircraft. The best acknowledged method of load simulation is tension patches bonded to the structure. The need for load simulation at elevated temperatures made the materials in use obsolete. They could not withstand the high temperature and were too bulky to allow simulation of aerodynamic heating.

Data is presented showing temperature simulation and its effect by using RTV silicone bonded tension patches described in Sections I and II. A comparison of heat simulation is made between this method and 2-inch diameter (cone frustrum) ground quartz compression load blocks.

Thermal simulation of aerodynamic heating to aircraft structures is possible by using radiant, conduction and induction heating systems.

Consideration is given only to radiant heat simulation in this treatise, the method used most in government and industry.

A test condition for programmed load and heat with the external skin temperature distributions is discussed.

A series of test panels with and without RTV silicone bonded tension patches were run at several constant power levels to determine the effect of heat sinks to the control point temperature. It is assumed that the third series of tests is analagous to a built-up structure with spar, rib, frame, etc., heat sinks. This data is presented in support of the hypothesis that hot spots, or thermal jumps, occur under radiant heat simulation in certain areas of this type construction. This is caused by the proximity of the heat sink and its effect on the external heat flows. Two adjoining control areas where one is on an open panel and one on a spar have an overlapping effect in skin heat flows. This area may be receiving thermal energy resulting in rise rates higher than either control area. Another probable cause is the capacity of the section to conduct into an internal heat sink. It is assumed that this is a direct effect of thermal simulation with radiant energy. At the present time there is no flight temperature data for comparison to simulated heating techniques.

Thermal simulation using RTV silicone tension patches under steady state (equilibrium) conditions is very good. In transient heating conditions the temperature under the patch lags the open panel test temperature. Considerable flexibility exists such that the lag time may be reduced or increased through the patch plate design.

Present temperature limits are 550° F to 600° F steady state, and up to 1700° F. with reduced load and time factors. The possibility exists with future adhesive for improving the present working limitations.

#### *Factual Data*

It is necessary to simulate the environments associated with high speed flight under controlled laboratory conditions to provide comprehensive structural evaluation of complete airframes. The laboratory simulation depends on items that can effectively be eliminated without compromising the overall test program. One airframe structural test program cannot simulate the true operating strength or life. The ultimate aim is to ascertain within reasonable accuracy the basic strength for only load, temperature, pressure, internal fuel, etc. Other environmental conditions such as metal oxidation, fatigue life, reduced atmosphere effects, cosmic radiation, and the like must be determined in other studies and test programs.

The structural test program must satisfy the basic requirements for safety of flight. The thermal gradients, equilibrium temperatures, and thermal shock must be duplicated (as accurately as the state of the art will permit) with structural loads, either static and/or dynamic.

Theoretical and analytical thermal analysis is good for simple structure and basic materials. The unknowns in thermal flow for complex structures make difficult the correlation of the simulated and analytical data when using radiant heat methods. Programming flux density versus time to obtain the desired heat simulation is theoretically possible. Variations between the programmed output and the desired input flux density is dependent on a transfer efficiency factor, or material property. The transfer efficiency is a function of source temperature, material absorption, surface emissivity, system reflectivity, irradiation, etc. The material property is a misnomer when applied to built-up structure. It is a function of mass weight per unit area and specific heat times some constant for the particular type construction. Other factors in thermal flow seem to influence the effective flux density at each point in the same control area.

Opaque materials react through molecular excitation to radiant energy and exhibit different physical properties. These materials vary from opaque to non-opaque, or transparent. For structural test applications, reflection and absorbtivity are varying factors that must be considered. A non-uniform emissivity will not cause a drastic change in heating but reflectivity will. Since energy is reflected, radiated and conducted away from a test article a 100 per cent efficiency is impossible to obtain as a real number. The maximum efficiency of radiant energy in the system used at WADD will approach 60 per cent, but for average black bodies it will be approximately 40 per cent. General Electric T-3 infra-red quartz tube lamps are used with several different reflector units and materials. In complex structure thermal resistances vary in each structural member and joint. The joint resistance or conductivity can only be determined experimentally. It appears that consistency could be obtained only with bonded, brazed, or welded joints.

These differences appear small, but in thermal simulation they present major obstacles. Power requirements are based on the basic skin materials in simulating the aerodynamic energy, but a control heat zone should cover an area that is compatible with the power controller. For example, a 500 KVA unit to heat an area of 10 $ft^2$ should have a maximum demand of 50 KVA per square ft., or a 50 KVA unit under the same conditions would heat only 1 square foot. This latter example would result in good heat control; the first example would not. It is therefore desirable to have a number of smaller control zones. This increases the complexity of the simulating facility by additional power and temperature controllers and regulators. Without full power controller capability it essentially de-rates the system capacity for that particular test. A large number of power regulators, or controllers, in a facility is more practical than a smaller number of large power controllers. The engineer then can program such that good simulation can be achieved using many small control areas. Problem areas can be isolated and treated individually for good temperature simulation.

This approach will not completely eliminate the problems that are encountered in rib, spar, longeron and frame to skin attachments. More work should be done to define the problem and the solution for good thermal simulation. This might require a bonding process for all contact joints in the structural test article. Some effects of this phenomena will be discussed in this report.

The art of structural testing has reached such a high level of complexity that development of laboratory techniques has lagged behind testing requirements. It is a thing of the past where a structural evaluation program consisted of loading a wing-fuselage combination for one or two flight conditions by sand and shot bags. The task now requires tests for many conditions and to apply not just mechanical flight loads, but also the associated thermal environment.

The application of simulated loads to effect a comprehensive structural evaluation requires that the hardware be attached externally and internally on the basic test article. Representative of the required equipment are load fittings or tension patches, radiant heat lamp-reflector units, strain gages, thermocouples, deflection wires, induction heating work coils, fuel simulant plumbing, external cooling provisions, and many other miscellaneous items.

Many of these heat sinks, disruptions, shadings, and the like cannot be accounted for in a practical sense, and the most important are those used to apply the test loadings.

Every effort in thermal simulation should lean toward methods that simplify or decrease the complexity of the problem.

The method of RTV silicone bonded tension load patches exposes the problem where it may be given individual treatment for thermal simulation effects. Its effect cannot be eliminated, but by judicious use the effects can be minimized or used beneficially in some instances.

The present RTV silicone bonded tension patch techniques will satisfy most load and thermal simulation requirements for steady state (soak) temperature conditions up to 600° F. Transient heat simulation has been carried to 1700° F for a limited time. This method is useful in both thermal requirements when properly used.

## *Test Results and Data*

The original effort in thermal simulation, using room temperature vulcanizing (RTV) silicone tension load patches, was used for steady state conditions on the B-58 static test program. Temperature rise rates were not an important factor, and the primary problem was to obtain like temperature distributions in all control areas.

The plate sizes used were 2 x 2 inches, and 2 x 3 inches with 3/8-inch aluminum and 1/8-inch steel plates. These plates are also used for the subsequent transient temperature thermal simulation tests reported.

The effect of the plates on the heated structure was beneficial, and resulted in more uniform temperature distributions in the control areas. These areas were less effected by convection currents. Convection and conduction heating under radiant simulation is undesirable, however, it cannot be eliminated. It varies with structural orientation and the reflector design that is used. Some areas may be heated without radiant power by the judicious use and control of the convection currents from adjacent areas. This was done on the B-58 fin leading edge, and when the desired temperature was approached holding power was then applied.

All test data presented herein is with the radiant heat reflector units above the test specimens, with the exception of the titanium missile fin lower surface.

Steady state thermal simulations in test structures are generally more difficult to establish and maintain than transient temperatures. However, it is more difficult to monitor transient temperatures than the steady state temperatures. Conduction heat flow in the plane of the material is quite complex even when heating an area to the same maximum temperature under both steady state and transient conditions. Radiant, convection and conduction heating from adjacent control areas is usually undesirable but is impossible to eliminate. Baffles placed around each area will control radiation effectively, but will not control the convection currents, only changes them. The titanium missile fin had all areas baffled, on the second run, but not the first.

The first test survey presented was made on a titanium missile fin under transient heat and load to 860° F. The missile fin is shown in (Figure 32). Originally the test was to be conducted on the static test article using quartz block load washers; therefore, a comparison of quartz load washers and RTV silicone bonded tension patches was made. The test loads were applied on the static test article with RTV silicone bonded tension patches.

The titanium sheet test specimen temperature survey (Figure 33) was made with computer control using the Equation $Q_{i_1} = h \ (T_{aw} - T_s) = KEI$. Input functions of (h) convective heat transfer coefficient and $(T_{aw})$ adiabatic wall temperature with time were supplied on computer drums, with $(T_s)$ skin temperature feedback from the control thermocouple. Power requirements were calculated for the KEI balance from the equation $Q_{i_2} = cwT\,(dT/dt)$, and pre-set into the computer to satisfy the equation $Q_{i_1}$. $(Q_{i_1} = Q_{i_2})$ Specific heat used was the average value for the temperature range.

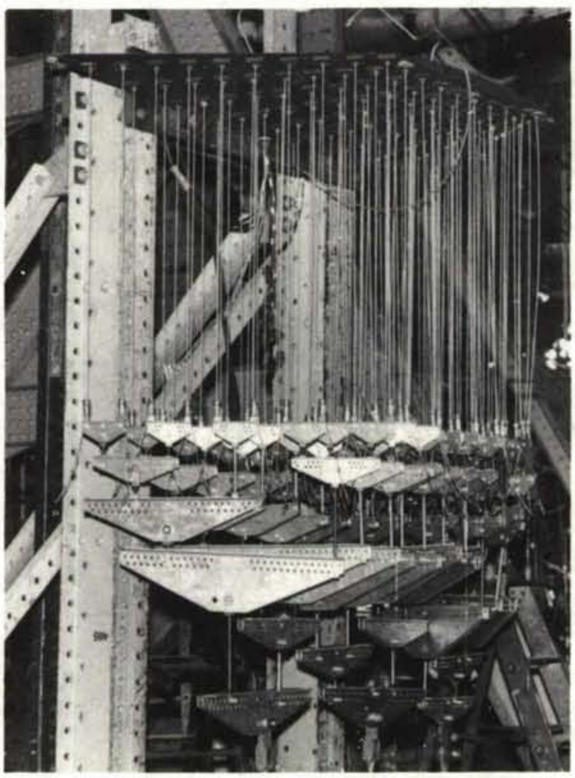


*Figure 32. Titanium Missile Fin Test Set-up Using RTV Silicone Bonded Tension Patches. (Radiant Heat Reflectors Not Installed.)*

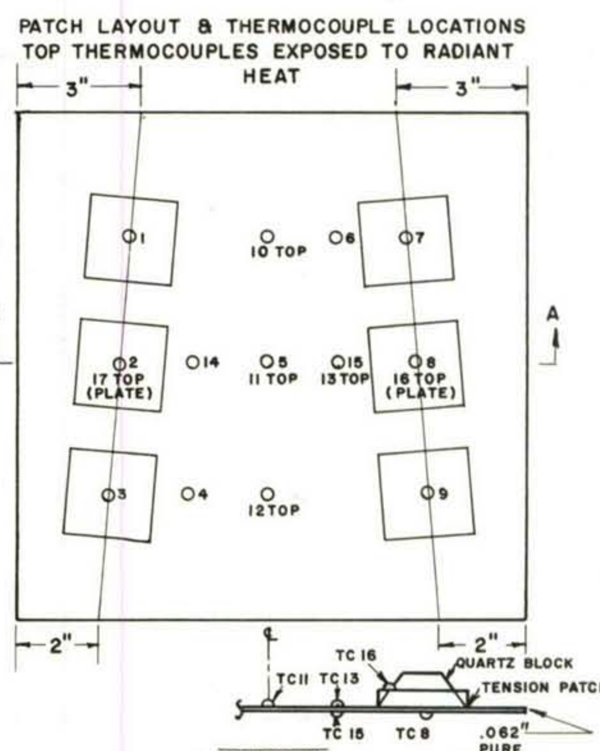



*Figure 33. Titanium Test Plate for Transient Thermal Simulation with RTV Silicone Bonded Tension Patches and/or Quartz Load Blocks.*

The efficiency of the system was calculated using constant power runs to the maximum calculated skin temperature at several temperature rise rates. All test specimens were sprayed with a graphite absorbfacient paint.

Test runs were made for a basic plate, basic plate with aluminum and also steel patches, and with quartz load blocks. Patch locations were the same as used in the actual test. Plate edge effects were not considered at the patch or quartz block locations, because the effects are essentially the same for all runs, except the plate without heat sinks. Of primary interest was the drawdown effect that was experienced at the control point. The temperature under the patch could never reach the open skin temperature, and the lower temperature would be a compromise in an area approximately 2 inches square. The computer is capable of making up a portion of the drawdown effect, but it cannot sense the change quickly enough as seen in (Figure 34). The tension patch plate temperature is shown in Figure 35. The quartz block was not instrumented.

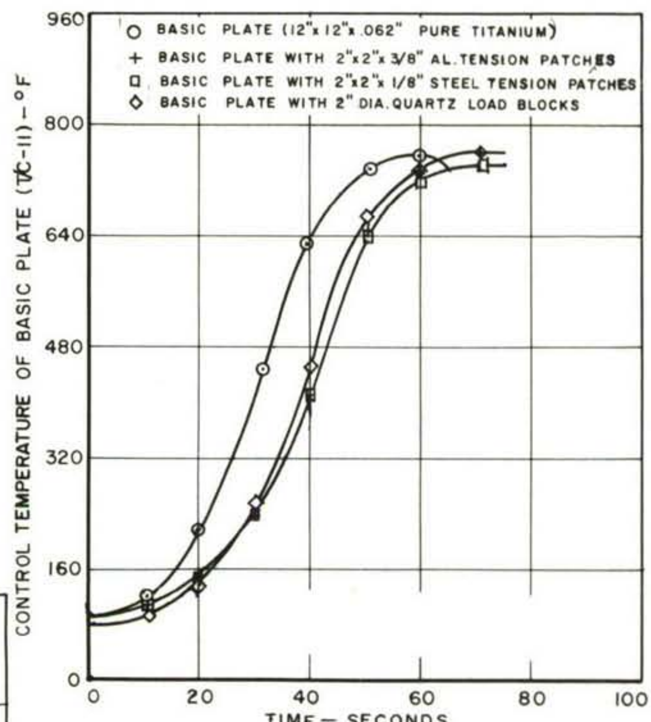



*Figure 34. Control Temperature Data for Transient Thermal Simulation on Titanium Test Plate. Thermocouple No. 11.*

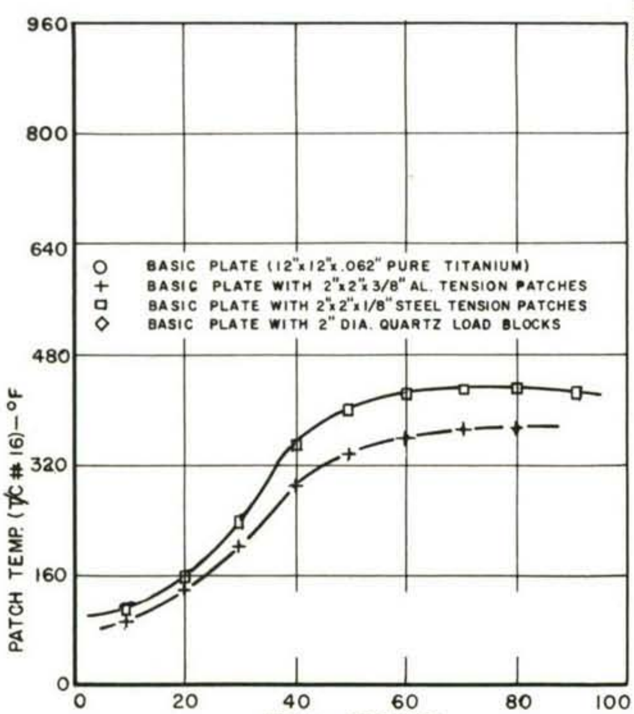



*Figure 35. Metal Backing Plate Temperatures for Transient Thermal Simulation on Titanium Test Plate. Thermocouple No. 16.*

The skin temperature at the center of the tension patch or quartz block is shown in (Figure 36). The quartz transmits most of the radiant energy and is heated in turn by conduction from the contact surface. Once the power is removed the skin temperature under the quartz block begins to drop while thermal inertia continues to increase the overall skin temperature. Power was decreased at 50 seconds in this test at which time heat conduction to the quartz actually started a drop in skin temperature underneath. The aluminum and steel tension patches have a greater lag time to conduct heat through and under the patch. The overall effect is a continued thermal drive after the radiant energy is decreased or removed. Temperatures under the patch are in phase with the basic skin temperature and eventually meet and cool at the same rate. Based on this data the logical approach is to design a tension patch backing plate which will have a very short lag time when bonded. This can be improved by different absorbtivity between the patch and skin. The limitation to the procedure is the adhesive strength at temperature or the adhesive breakdown temperature. The opposite approach may be followed by reversing this procedure and increasing the patch lag time. Any method chosen will be governed by the patch area coverage and their effect to the structural characteristics if known.

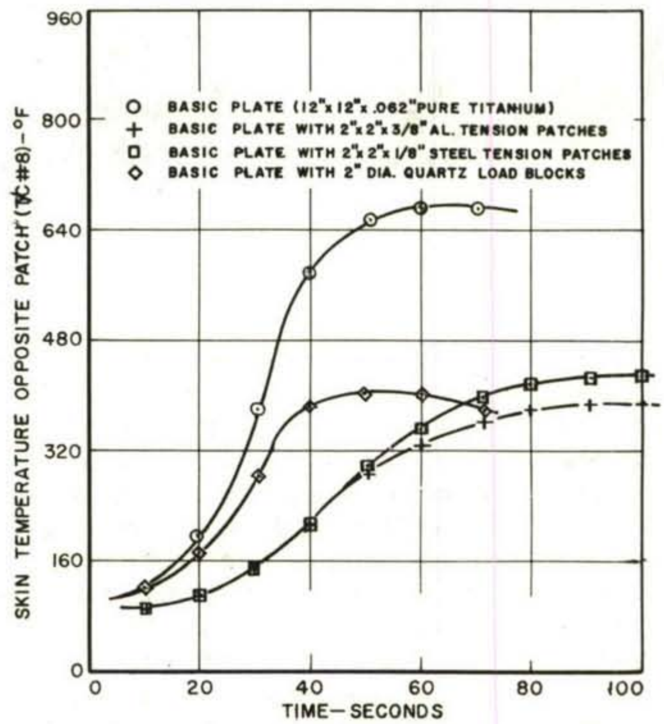



*Figure 36. Skin Temperature Under Load Medium for Transient Thermal Simulation on Titanium Test Plate. Thermocouple No. 8.*

On the actual test of the titanium missile fin an interesting phenomena occurred wherein "hot" spots occurred on the upper surface between the 20 per cent and 30 per cent chords. This surface was not patched. The fin was a conventional 2-spar and multi-rib design. At the forward side of the front spar and rib intersection, between control thermocouples, temperatures in excess of adiabatic wall were obtained, and even higher than the temperatures recorded at the 20 per cent chord. Programmed thermal energy was greater on the upper surface than the patched lower surface. (The designation upper surface is relative and in this report means the surface without applied load or tension patches.) Figure 37 shows the upper surface and Figure 38 the lower surface which was patched during test.

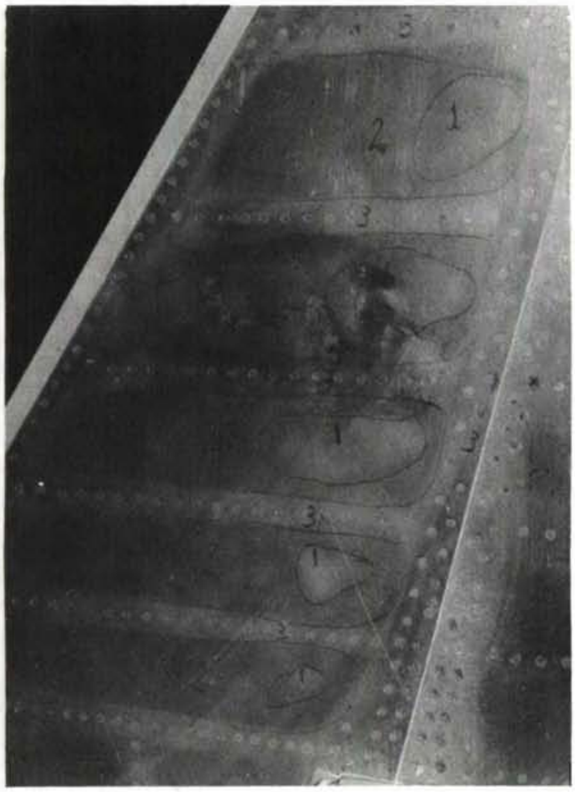


*Figure 37. Titanium Missile Fin Oxidation. Upper Surface Forward of 30 Per Cent Chord.*

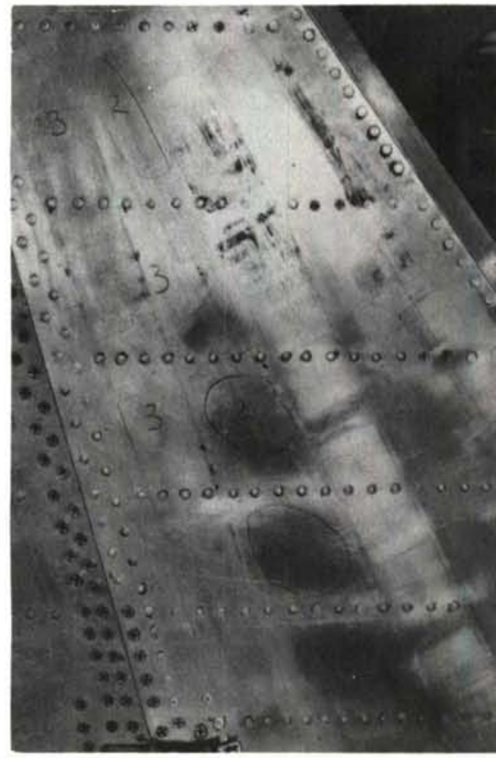


*Figure 38. Titanium Missile Fin Oxidation. Lower Surface Forward of 30 Per Cent Chord*

Area 1 is a bright blue color. Temperatures at this point are estimated to be in excess of 1000° F. Area 2 has a brown to light tan color with maximum temperature in this area estimated at 800° F. Area 3 is the normal fabricated titanium skin color. This oxidation occurred in the first run where a power runaway was evident in the control area just forward of the front spar and aft of the rear spar. These control thermocouples indicated a maximum temperature slightly above 1000° F. Power requirements were lower in 70 per cent chord area, and undoubtedly did not reach the same conditions as the forward area. On the second run additional thermocouples were added to these areas for control, and all indications are that the rear thermocouple in Run 1 was not indicating true surface temperatures. These thermocouples were replaced for control because instrumentation technicians covered the thermocouples with a polyamine epoxy protective coating. All indications later showed that these thermocouples were not giving the true skin temperature, and were being heated by radiant energy buildup. Regardless of which run the oxidation occurred it was very local in nature and undesirable, and was in excess of 1000° F in the area circled one (1). The temperatures are presented in Figure 39a and b for both runs, and if we assume that the lower surface thermocouple in Run 1 is correct, then the upper surface thermocouple is reading the temperature of the polyamine coating. Figure 40 gives chordwise temperature distribution at 120 seconds, but instrumentation was inadequate for a true presentation.

For this test the spar shear stresses and attachments bolt loads were measured. The first run was made allowing the applied shear to react directly into the attachment plate and supporting structure in a cantilever set-up (Figure 41). The second run was made with the shear reacted at the spar root attachments in front of the attachment plate. The applied shear values used at these spar root points were analytical values, and the resulting data is subject to a small error with respect to the actual shear. These curves are shown in Figures 42 and 43 for room and elevated temperature tests. Attachment bolt couple loads are presented in Figures 44 and 45. For the front and rear spar,

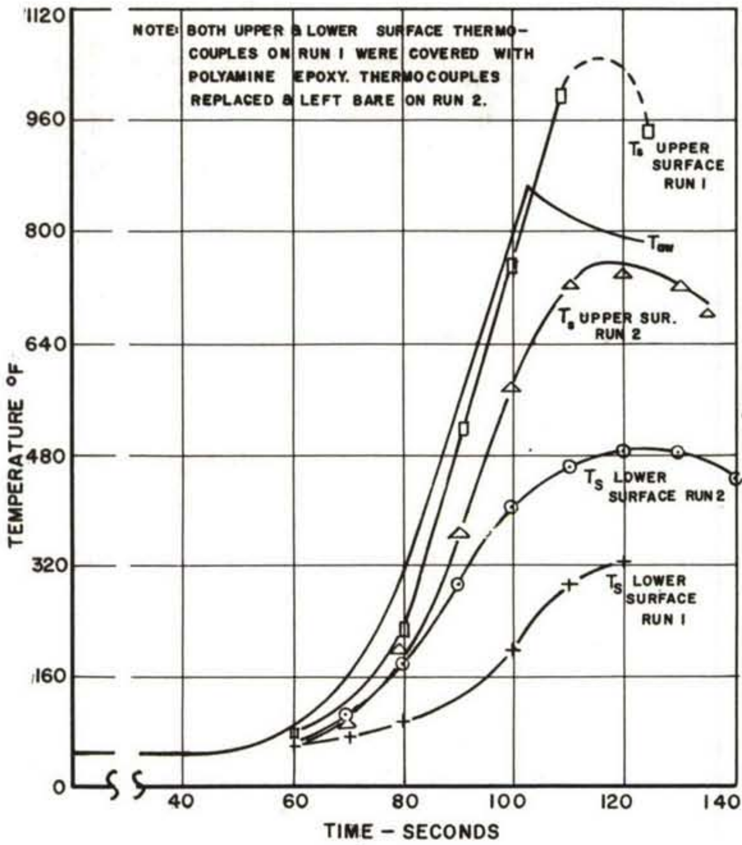
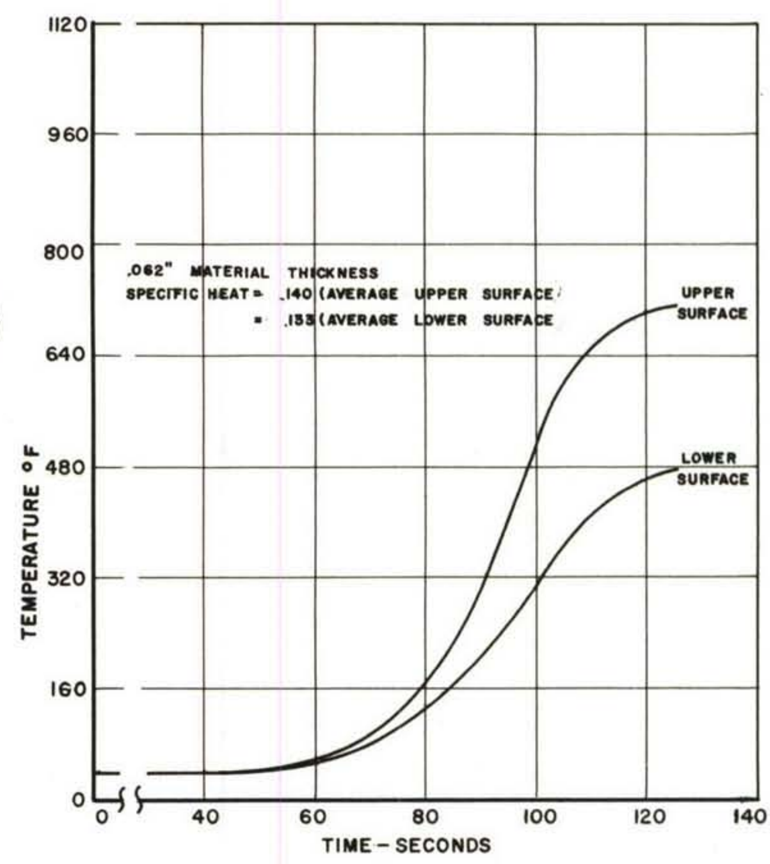



*Figure 39A. Titanium Missile Fin Aerodynamic Temperature Simulation at 20 Per Cent Chord and 50 Per Cent Span*

*Figure 39B. Titanium Missile Fin Calculated Skin Temperatures at 20 Per Cent Chord and 50 Per Cent Span*



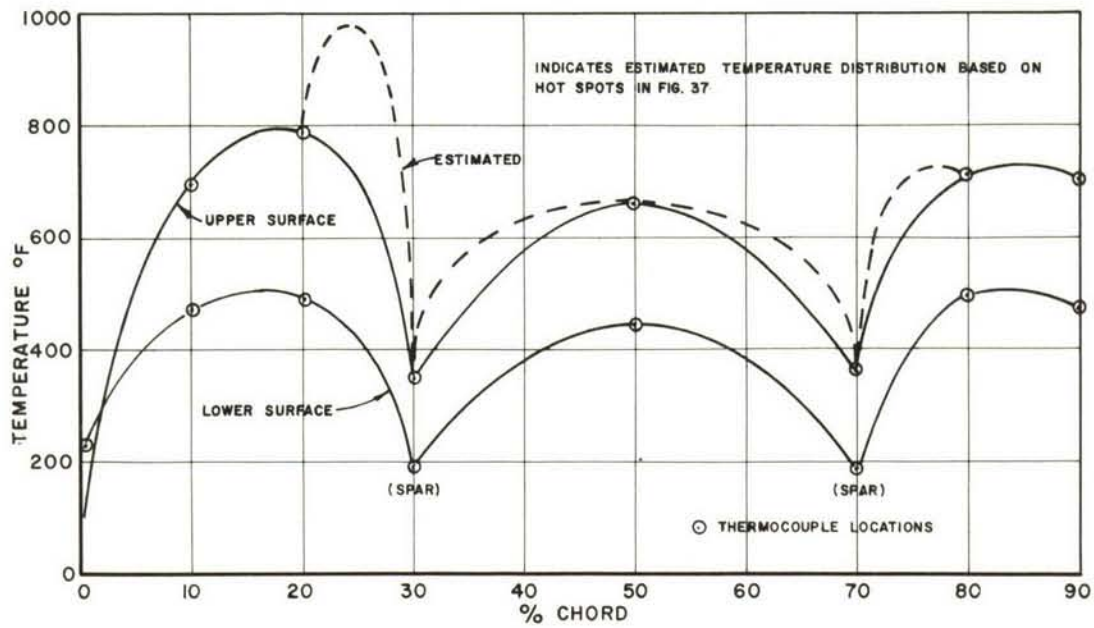



*Figure 40. Titanium Missile Fin Chordwise Temperature Distribution at 120 Seconds for 50 Per Cent Span*

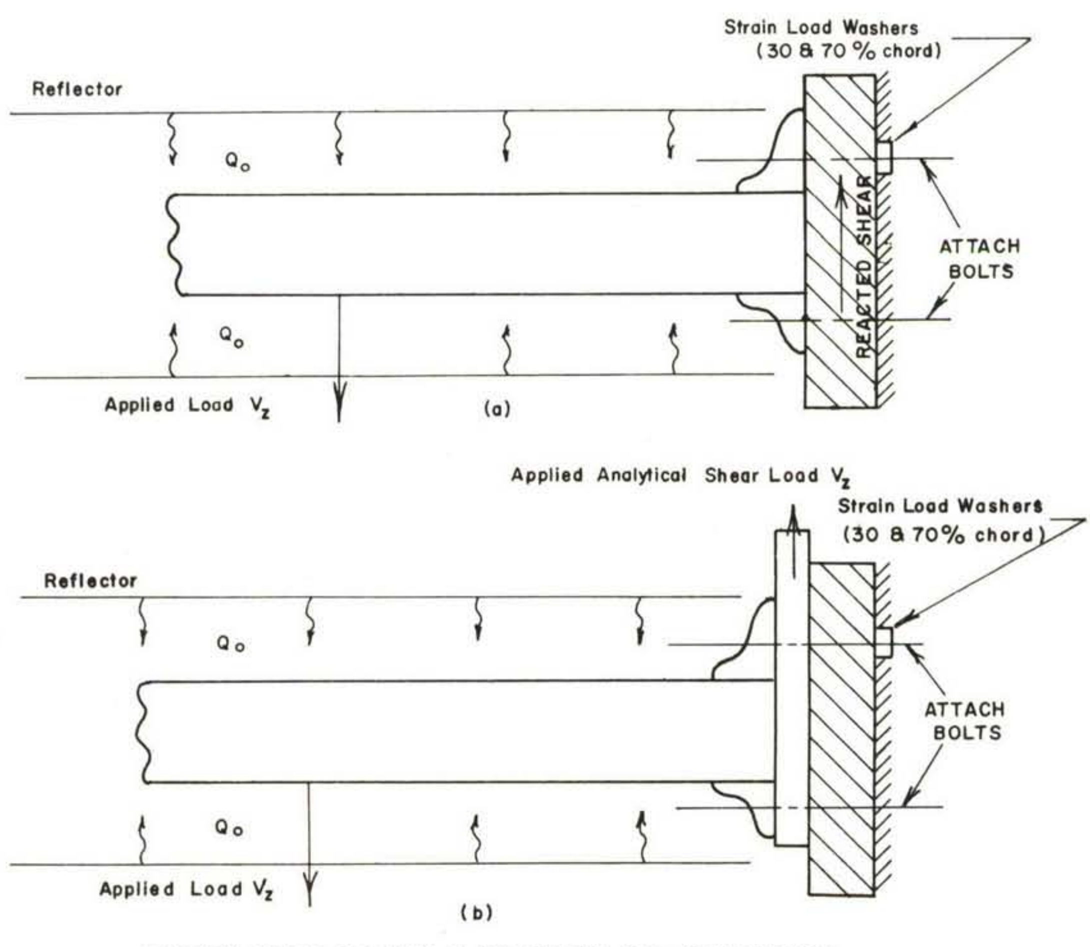



*Figure 41. Titanium Missile Fin Spar Sketch for Reacting Applied Test Loads*

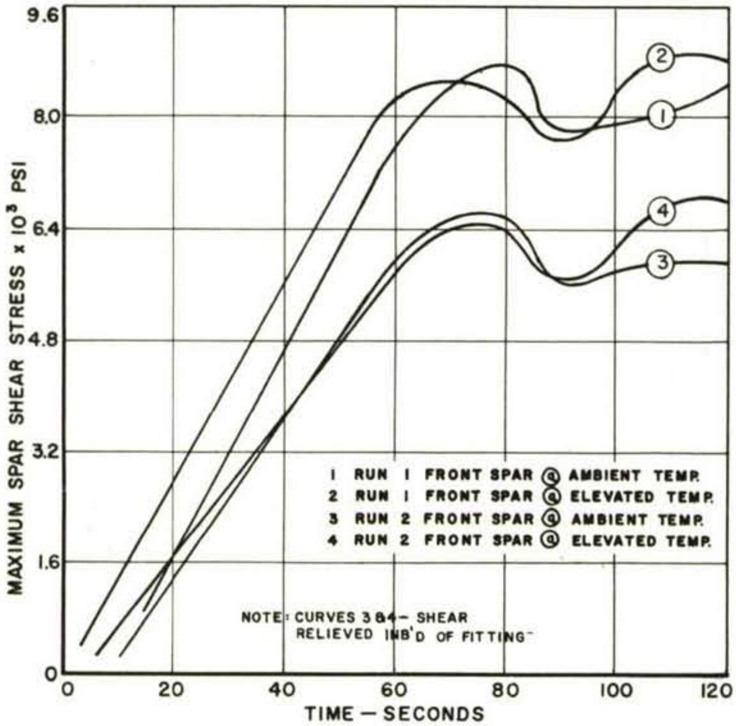



*Figure 42. Titanium Missile Fin Front Spar Root Shear Stress. (30% Chord)*

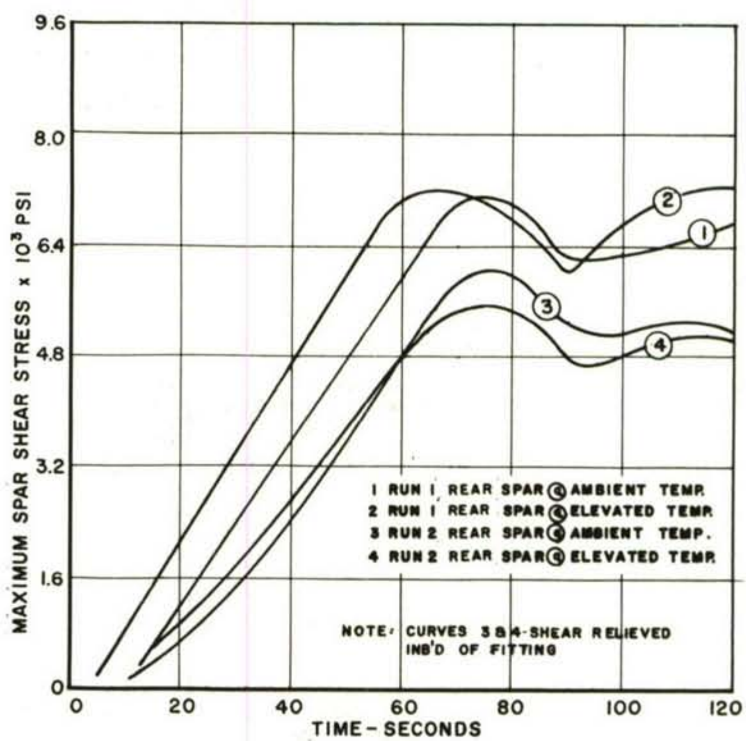
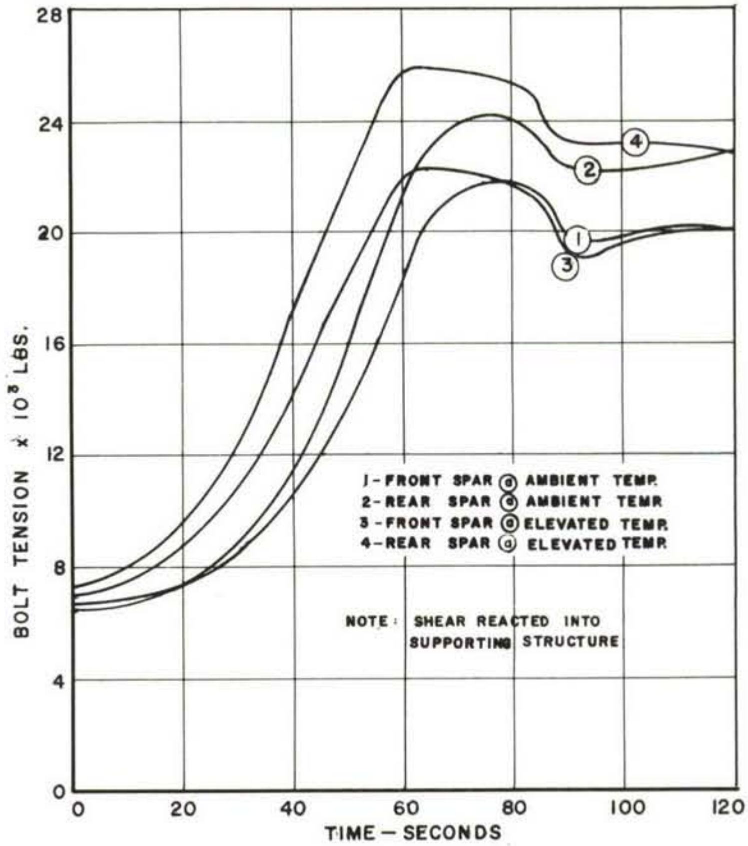



*Figure 43. Titanium Missile Fin Rear Spar Root Shear Stress. (70 Per Cent Chord.)*

*Figure 44. Titanium Missile Fin Attachment Bolt Tension Loads. Shear Reacted Into Supporting Structure.*



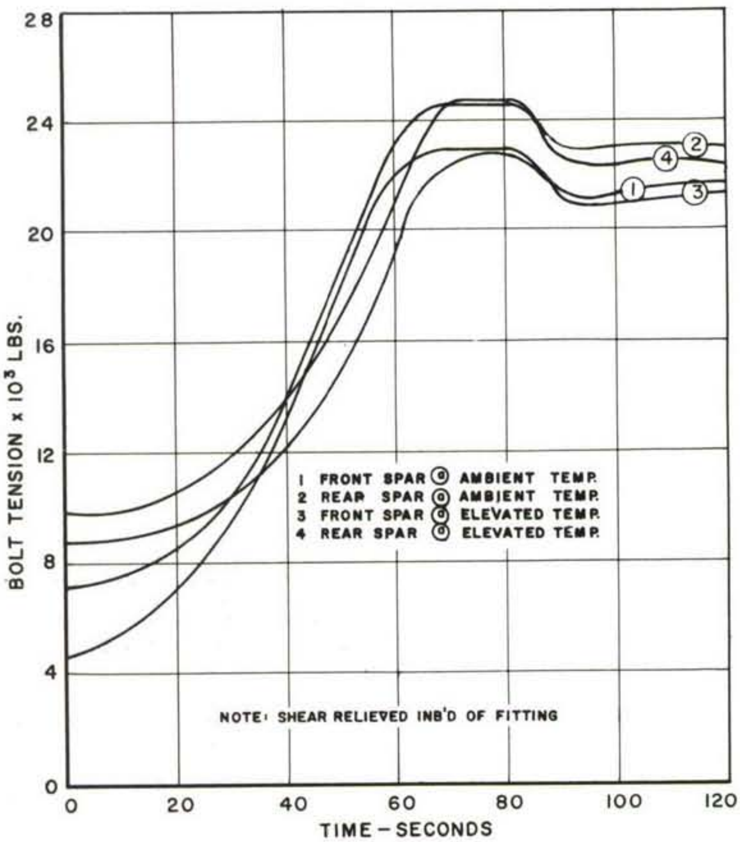




*Figure 45. Titanium Missile Fin Attachment Bolt Tension Loads. Shear Relieved at Spar Root*

the measured shear values were less when the analytical shear was applied at the spar root attachments. With the applied shear relief the rapid load portion of the curve shows good repeatability, and this is as expected since these stresses occur before temperature is applied and occurs after 60 seconds in the flight program.

This data indicates that test simulation must be considered for other effects in addition to the load methods such as tension patches. Jig effects as commonly known should not have been present in either Run 1 or Run 2 because the only variable involving differential displacement of the spars would have to be introduced by bolt yielding in tension, shear, or bending. Maximum applied load did not result in total normal force relief placed on the attachment by bolt torques. The only factor that was not applied was the relative deflection of the two spar fittings with load at the root. This could account for the variation between spar stresses in Run 1 and Run 2, but not for the difference in stresses in Run 1 at room and elevated temperature for the first 60 seconds. It is concluded that the tension patches used for loading had no overall or local structural effect. The only possible explanation is a time discrepancy with respect to the total applied load.

To better understand the heat flows, conduction, resistance and associated factors, a series of tests were made on titanium sheet material. Test simulation on the titanium missile fin indicated poor temperature distribution.

The test panels were painted with a black graphite absorbfacient paint. Since the specific heat (c) of titanium increases with temperature all data has been corrected to a constant value of 0.12 BTU/lb-°F. The efficiency of the radiant heat system varies with the absorbtivity of the specimen and filament temperature of the lamp. Other factors present are difficult to define and isolate, and everything present is included in the efficiency factors presented for these tests.

The control thermocouple was located in the center of the rectangular test panel and heated from above. General Electric T-3 infra-red quartz tube lamps were used with reflector material for heating. Figure 46 shows the results for this series using the flat sheet without tension patches. Data is plotted showing temperature rise rate versus per cent efficiency with temperature as the basic parameter. This data covers power levels required for heating rates up to 40 deg per second to 900° F. The parameters (BTU/ft$^2$-sec) for energy received by the material has not been included. This type data was used to check the accuracy of the WADC heat computer in the interim elevated temperature test facility.

The second series of tests were made on an identical sheet with two 2 x 2 x 3/8-inch aluminum RTV silicone bonded tension patches on centerline with a 1-inch space on the transverse centerline. Figure 47 presents this data for power applied to the patched surface.

The third series of tests were made on a test plate identical to the second, but with power applied on the side opposite the tension patches. Figure 48 presents this data.

Analysis of the data on test series 1 and 2 reveals that for the same rise rate a higher efficiency is obtained at the control point. This same simulation using computer control would result in a smaller power being received by the specimen over the programmed time in terms of final heat content in the specimen. Based on these findings a control thermocouple located in this position would not be satisfactory. The difference between Figure 46 and Figure 47 and 48 gives the influence efficiency effect.

A comparison between the data obtained between test series 2 and 3, Figures 47 and 48 shows a complete reversion of the curves, with "fictitious" efficiencies approaching 100 per cent. At 900° F the curve approaches an infinite efficiency for any power level. The result to the structure adjacent to such a heat sink would be a hot spot or thermal jump.

This data might help explain the "hot spots" that occurred on the titanium missile fin skin adjacent to the spar and rib intersections between the 20 per cent and 30 per cent chord lines. It should serve as a guide in considerations necessary to plan good heat simulation and location of control thermocouples. The only reliable method at this time is to make an experimental survey to determine the best method and control thermocouple location. This is the procedure for determining the efficiency of the lamp-reflector assembly for thermal simulation in each test set-up.

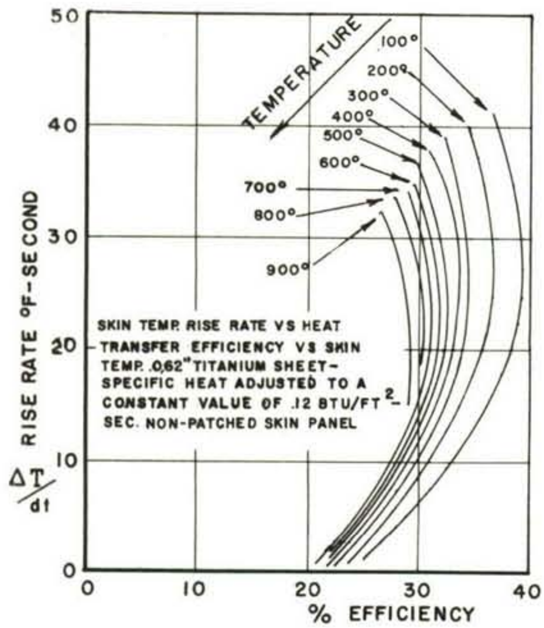



*Figure 46. Efficiency Curves for Radiant Heat Method of Thermal Simulation. Titanium Sheet.*

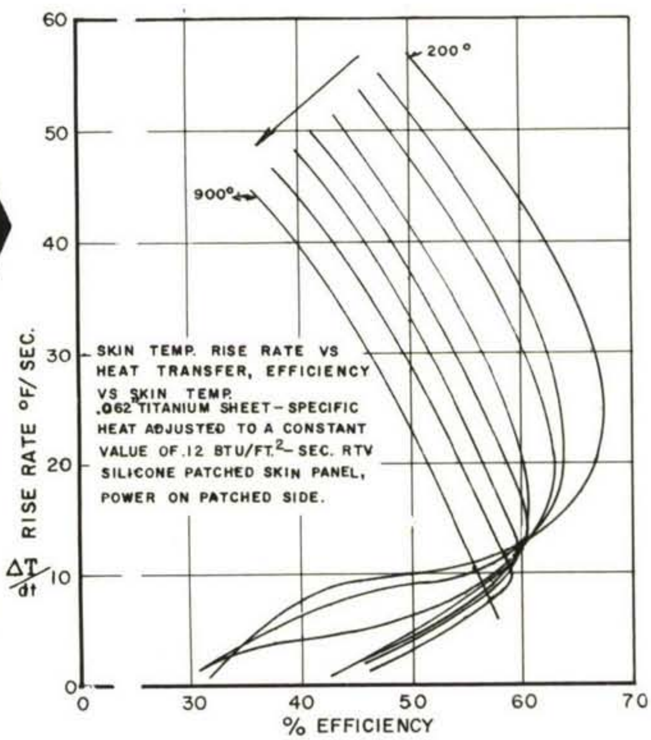



*Figure 47. Efficiency Curves for Radiant Heat Method of Thermal Simulation. Titanium Sheet with Tension Patch External Heat Sink.*

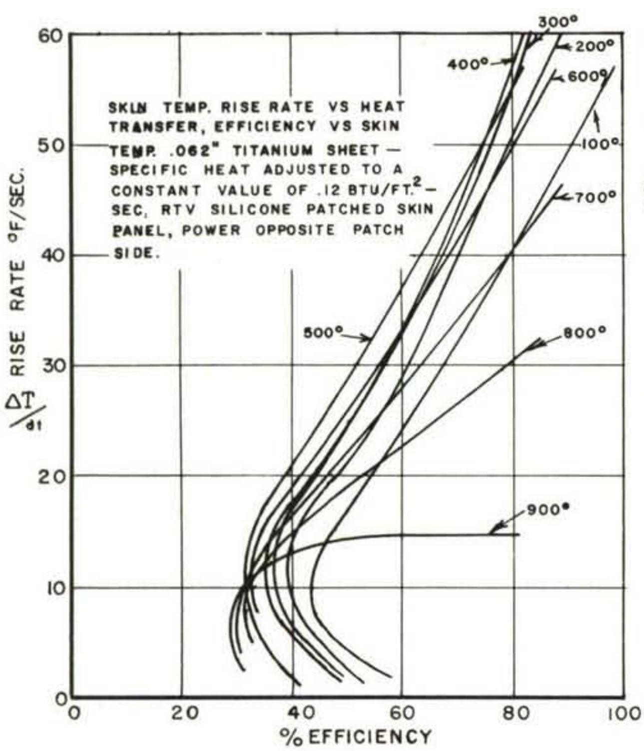



*Figure 48. Efficiency Curves for Radiant Heat Method of Thermal Simulation. Titanium Sheet with Tension Patch Internal Heat Sink.*

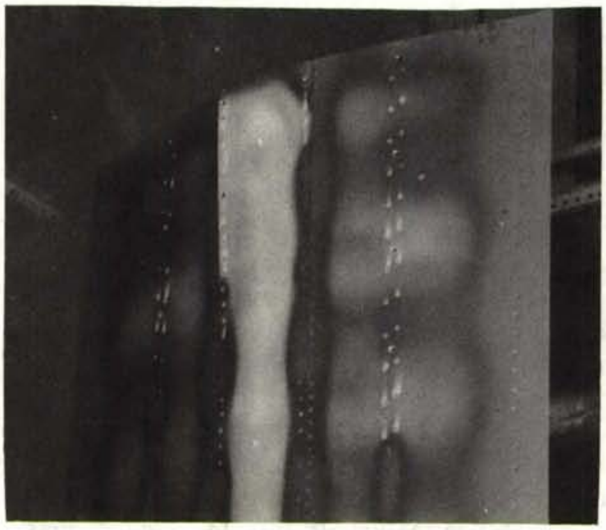


*Figure 49. Inconel Test Panel Oxidation Indicating Relative Temperature Distribution and Thermal Failure. Left Side.*

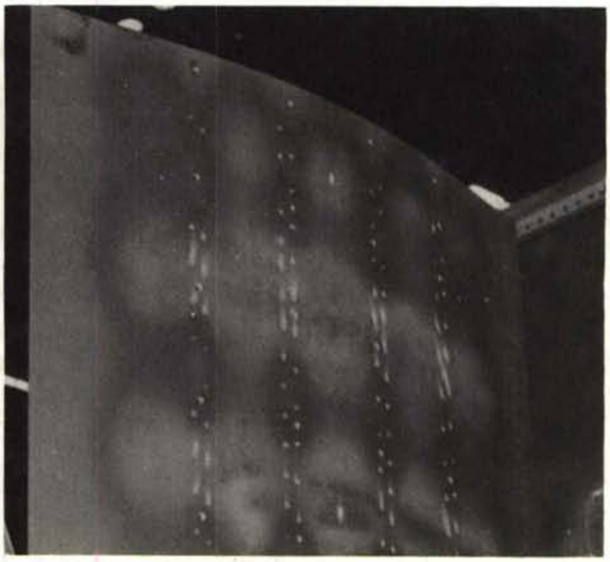


*Figure 50. Inconel Test Panel Oxidation Indicating Relative Temperature Distribution. Right Side.*

Figure 49 and 50 show the oxidation that occurred on one test during an efficiency check using constant power or flux density levels over the entire surface area. The center skin on Figure 49 is approximately five hundredths thinner than the skin on either side and the opposite side. Note the increased oxidation effect on the thinner skin area and construction difference. This inconel test panel was heated with nine control areas which were programmed to give identical flux densities and the resulting temperature was recorded.

Subsequent tests using the center chord thermocouple for control resulted in similar temperature distributions on an identical aluminum specimen, although the temperatures were not of the same magnitudes. This simulation is not satisfactory from either a spanwise or chordwise distribution of temperature. Using a single thermocouple for control it would require 198 individual control areas to insure good temperature simulation. This indicates that good thermal simulation methods must be developed.

The failure occurred from thermal edge stresses and thermal shock at a relatively high rise rate. (Approximately 50 deg per second. No external applied load). Using the parallel thermocouple method for mean temperature control a smaller number of control areas would be used. The optimum number will be determined by the maximum and minimum temperature relative to the mean.

Other materials were not investigated for the influence efficiency approach, but would exhibit the same general characteristics. Different surface conditions on the same materials will give variations or shifts in the basic system efficiency.

This type of efficiency data is satisfactory for use with computer control, or to calculate power requirements at each temperature using the KEI or YEI control functions. But on the derivative feedback (C .dT/dt) computer control, this effect must be related to some factor other than efficiency to modify the A x cwT term which is the constant C. The effect will vary at every point on the surface and will be dependent on the heat flow to the internal structure. This factor could be neglected if the thermocouple is properly located by the efficiency data.

The total heat content given to the specimen over the required time period in test simulation should agree with that received in flight and have the same effective distribution.

The simulation of heat flux in BTU/ft$^2$ -sec at the control point or area the size of the thermocouple junction for a large surface area is not valid. Methods and techniques must be developed and evaluated to effect a more rational simulation of the aerodynamic heating.

Based on this data a test simulation under past and present practice would result in lower overall specimen temperatures. The best solution at this stage of thermal simulation technology is to determine a mean control thermocouple location in each selected control area.

The most practical solution for obtaining a mean area temperature is to use several thermocouples connected in parallel. This method does increase the overall instrumentation for control. A sufficient amount of experimental work has been done at WADD to prove that this method gives the mean temperature for the area covered. Further work will be done to check this method with computer programmed input functions for the basic heating equation.

Any number of thermocouple junctions may be paralleled for the control thermocouple. At the present time only Type J (Iron & Constantan) junctions have been used for temperatures to 1000° F. This junction has been checked on aluminum, steel, stainless steel, and titanium materials. The Constantan is used for the basic parallel circuit with iron as the common ground. Other thermocouple materials should perform in a similar manner.

Several installation techniques for the ground circuit may be used. It may be a single point attachment, multiple, or a continuous ground attachment depending on the accuracy desired. Figures 51, 52 and 53, show the three suggested methods. The ground connection in Figure 51 may be located at any point in the control area, and gives accuracy within 2 per cent to 3 per cent for large temperature variations. This method gives a one to one effective thermocouple junction ratio. Two grounds may be used which will increase the accuracy and reliability.

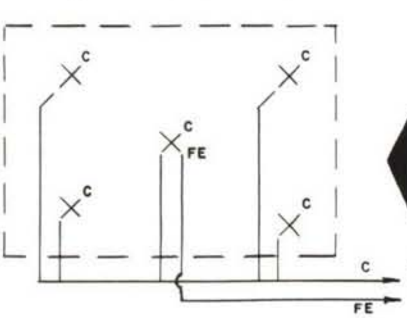



*Figure 51. Thermocouple Single Ground Parallel Circuit Diagram for Computer Control Feedback Signal.*

NOTE: THERMOCOUPLES MAY BE ARRANGED IN ANY GEOMETRIC PATTERN

C – CONSTANTAN JUNCTION

FE – IRON JUNCTION (GROUND)

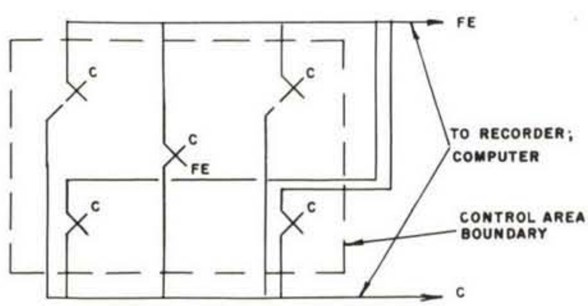



*Figure 52. Thermocouple Multiple Ground Parallel Circuit Diagram for Computer Feedback Signal.*

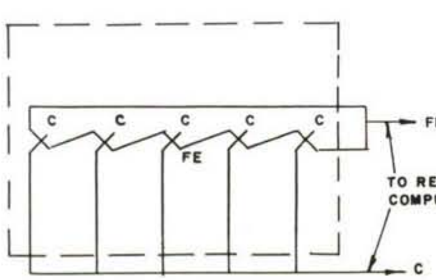



*Figure 53. Thermocouple Continuous Ground Parallel Circuit Diagram for Computer Feedback Signal.*

The thermocouples in Figure 52 are normal installations with all common material connected to form the parallel circuit. The error in this method is almost negligible. The effective number of thermoelectric junctions is the number connected in the circuit squared.

The circuit in Figure 53 is a variation of Figure 52, but requires the use of less thermocouple wire.

The problem associated with the parallel method is in determining the minimum number of junctions required to cover the area. Five thermocouple junctions appear to be the minimum number for use in controlling a rectangular area, and four for a triangular area, but this assumes the use of a relatively small area, and/or small temperature differentials. Each situation usually presents different problems or variations, and no definite rules or restrictions can be made.

The loss of any of the thermocouple junctions will decrease the effective number of thermocouples in the circuit. The effect on the mean will depend on that portion of area removed from the circuit. At least two ground junctions are desired for circuit reliability since the loss of a single ground will give an open circuit.

Multiple ground connections must be used on plastic or non-metallic materials. No data is available for this application.

The application of parallel thermocouple techniques will give more realistic values for the total efficiency of specimen, and lamp-reflector simulative setups, if properly applied. The presentation of influence efficiency data will show lower values. These effects related to the single control thermocouple efficiency presentation will not be as apparent.

It is feasible that adhesive technology used with good simulative techniques and procedures will permit the use of the tension patch methods presented for most thermostructural testing.

## *Conclusions*

The work outlined in this section describes the temperature simulation techniques used with RTV silicone bonded tension patches. From the comparison between the quartz compression loading blocks and RTV silicone bonded tension patches, the temperatures under each cannot meet open surface temperature requirements. The primary disadvantage in using quartz compression blocks is the necessity of drilling through the structure for installation and load application. Quartz compression load block breakage does occur during test and the contact surface must conform to the quartz block base to minimize this. Thermal buckling cannot be prevented and causes the most breakage. The Hawk missile elevated temperature test program was conducted using this method. The present cost is approximately $25.00 per quartz load block, which includes the flexible load cable. A number of factors will determine the maximum temperatures to which these blocks may be used. This will be determined only by experiment with the structure and under the conditions required for testing.

The transient data for the tension patches can be improved because the materials and thicknesses used were not optimum for maximum temperature under the patch. The biggest advantage in using this method is that the structure is not altered as it is with built-in load fittings or quartz compression blocks. Applied loading, patch distribution, and other changes can be made to suit any requirement. Additional transient temperature simulation data is presented in Section II.

The cost for using this method is approximately 5 cents per plate for the adhesive and 25 to 30 cents for the backing plate. The average installation time at WADD is approximately 5 patches per man hour. Comparing this cost to conventional room temperature neoprene rubber tension patches the RTV silicone patch costs about $2 less per equivalent patched area of 6 x 6 inches. This comparison is made using three 2 x 2-inch

RTV silicone patches for each 6 x 6-inch neoprene rubber patch. Based on cost figures the RTV silicone patch method should be used for all testing. The primary disadvantage of a larger number of load points has been offset at WADD with the change from the steel linkage to aluminum sheetmetal load beams designed by the author.

Tests made on the titanium missile fin and test panels indicate that methods and techniques must be developed to establish good laboratory load and temperature simulation. Other approaches should be made to verify the existence of this phenomena, and perhaps develop an analytical or empirical solution.

It is not known if this thermal jump effect is experienced in flight for the aerodynamic parameters simulated in the test laboratory using radiant heat methods. Less than 10° F per second temperature rise rate does not create a problem of any appreciable magnitude. Present service flight vehicles will not experience this temperature rate, but experimental aircraft or missiles do have this capability as evidenced in the missile fin data presented.

Efforts are being made by the government and industry to advance the adhesive technology for elastomer materials to higher temperature levels.

The elastomer adhesive bonded tension load patch method described is presently restricted by load and time at a given temperature level. New elastomer materials and techniques will extend their use for this application in the near future.

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# Appendix

Example Problem: Application of influence efficiency data for thermal simulation with computer control.

Assume that all basic calculations for power requirement, lamp reflector design, instrumentation, etc., are complete and the structure ready for testing. The last operation is to introduce the proper input functions and settings into the computer.

Before this can be done the combined efficiency ($\eta$) for the lamps, reflector and structure must be determined. The computer can set this function in as a constant. Supposedly then any deviation from this fixed value will be compensated by the computer based on the ($T_{aw} - T_s$) relationship during the programmed time period. Because of the extreme changes in efficiency between any one area and the surrounding areas, a true temperature simulation is not realized. The heat in the areas affect every other one by radiation, convection currents, and conduction. This is analagous to the load-deflection influence effects in redundant structures. The efficiency of each area for the entire time period of test must be determined.

The experimental method described in Section III, is used to determine these values. Test calculations are presented in Tables **16** through **19**. Conduct individual heating runs with manual power of a predetermined amount to all control areas. Record the actual power (same for all areas) and the control thermocouple temperature with time. Do not exceed the maximum rise rate for the adiabatic wall temperature ($T_{aw}$) curves, or maximum predicted skin temperatures in any area. (Fig. 54). The number of heat runs and the power output for each run should be related to the maximum power requirement. This may be obtained from the equation $Q_i = h\ (T_{aw} - T_s)$ when ($T_{aw} - T_s$) is maximum. A sufficient number of test runs should be made to produce the required data points. The change in specific heat (c) for the material with temperature increase or decrease may be included or separated in the data reduction process. The following procedure is recommended for data reduction:

1. Take temperature values after plotting test curves for uniform time intervals from the skin temperature ($T_s$) curve for each test run and control area.
2. Calculate ($T_s/dt$) temperature rise rate for each run at 100° F increments through the maximum range.
3. From the Equation $Q_i = cw\tau(T_s/dt)$ calculate the power input to the structure. Do this at each selected temperature increment.
4. Using the $Q_o$ values for each run in the Equation $= Q_i / Q_o$ calculate the efficiency values.
5. Plot temperature rise rate and efficiency at each selected temperature increment for all control areas. Reference Figure 55.
6. Use the temperature rise rate from the adiabatic wall temperature or calculated skin temperature curve at the selected temperature increments related to time. From the curve of item 5 find the efficiency value which corresponds to the rise rate and temperature parameters.
7. Using the time where the temperature rise rate at temperature value was selected take the values of h (Figure 56) from the convective heat transfer coefficient curve. (Basic curve)
8. Calculate new values for the equivalent convective heat transfer coefficient under radiant heat simulation. Since h is the heat transfer efficiency factor of the boundary layer its equivalent can be determined from the equation $h' = h/\eta$. Calculate values for $h'$ (equivalent convective heat transfer coefficient), plot these values versus time, and place on computer input drum.
9. Adjust settings in computer to be compatible to the new maximum "$h'$" value.

(An alternate method may be used by selecting a basic efficiency and adjusting the values

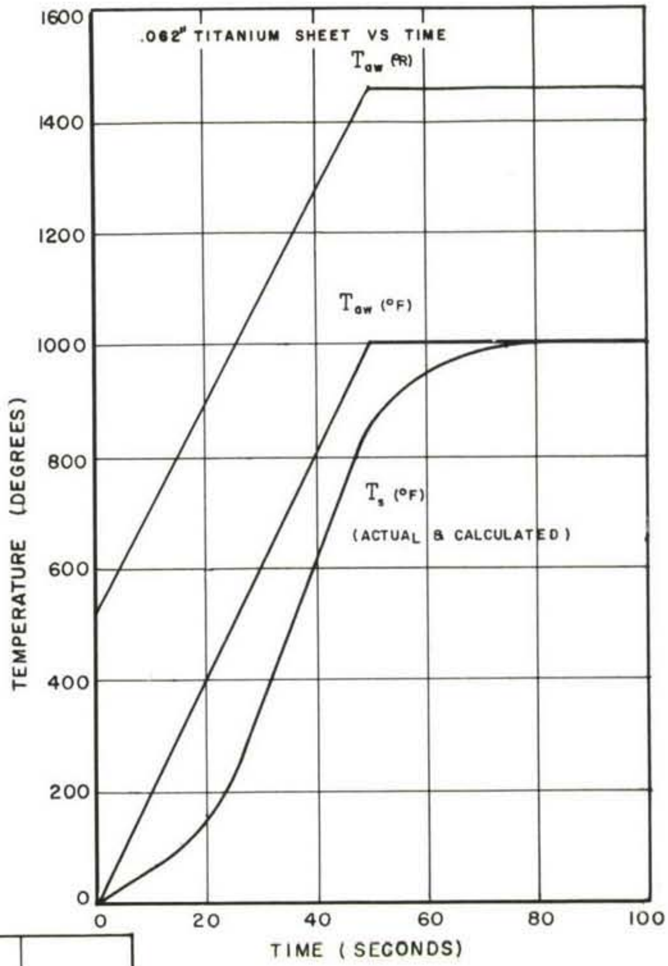


*Figure 54. Skin and Adiabatic Wall Temperature Curves for Sample Problem Presented in the Appendix.*

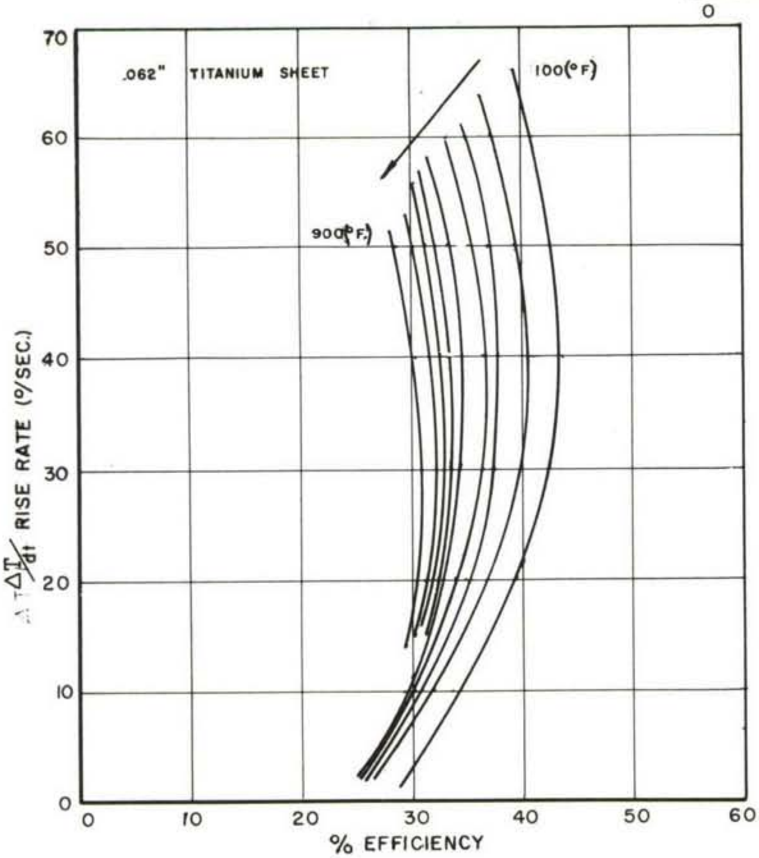


*Figure 55. Skin Temperature Rise Rate vs Radiant Heat Transfer Efficiency vs Skin Temperature for the Test Panel used in the Sample Problem Presented in the Appendix.*

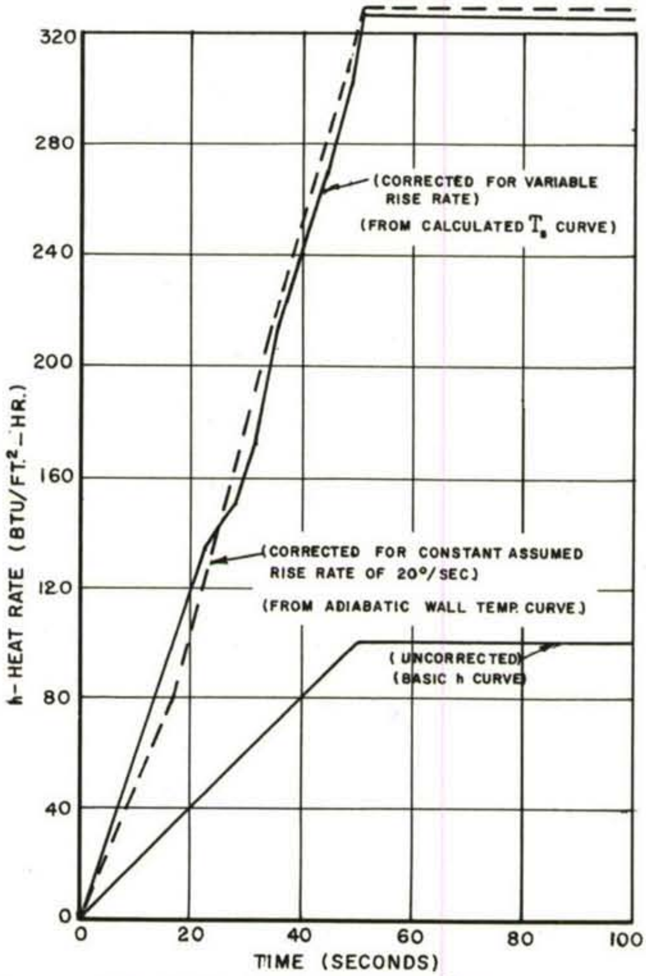


*Figure 56. Heat Rate Corrected for Radiant Heat Transfer Efficiency vs Time for the Test Panel Sample Problem Presented in the Appendix. (Note Relative Difference Between Figure 46 and Figure 56, where the Heated Area was Larger for Figure 56 Data with all Other Factors Relatively the Same.)*

of h for the difference between the basic efficiency and that for the total temperature range. The net signal is the same for either method.)

The experimental method presented gives efficiency in terms of the basic parameters temperature, time, and temperature rise rate, and included all the inherent structural heating characteristics, and the external factors that influence the basic heating problem.

It should be noted that actual control area efficiency curves for composite structures will be of the three types shown in Figure 46, 47, and 48, or any combination thereof.

The figures in this appendix show the results of this experimental method on a simple structure.

Figure 54 shows the skin temperature and adiabatic wall temperature time curves. The skin temperature curve is identical for calculated and actual test values.

Figure 56 is the heat rate or convective heat transfer coefficient - time curves. Two h' curves are presented. One is using the temperature rise rate from the adiabatic wall temperature curve, and the other is from the calculated skin temperature curve. The basic parameter h curve is labeled "uncorrected".

Figure 55 presents the experimental data derived from the constant power runs. This data is shown in terms of temperature rise rate, efficiency, and temperature, and is used to determine the equivalent convective heat transfer coefficient data (h').

Tables 20 and 21 present the tabulated data for correcting the convective heat transfer coefficient (h).

Table 2

| | |
|---|---|
| DATE TESTING BEGAN | 7 July 1959 |
| TEST NUMBER | 1 |
| TEMP. & HUMIDITY OF MIX | 81 & 36%, 86 & 35% |
| SILICONE | RTV 60 |
| CATALYST | T 773 |
| PRIMER | xs 4004 |

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | MAX. TEMP. RAISED TO | MAX. LOAD LOADED TO |
|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI |
| Room Temp. | 1/2 | R.T. | | 120 | 5 | | |
| | 1/2 | | | 125 | 10 | | |
| | 1 | | | 75 | 5 | | |
| | 1 | | | 100 | 15 | | |
| | 1 | | | 112 | 5 | | |
| | 1 | | | 87 | 5 | | |
| | 2 | | | 94 | 10 | | |
| | 2 | | | 112 | 15 | | |
| | 3 | | | 125 | 50 | | |
| | 3 | | | 137 | 60 | | |
| | 3 | | | 125 | 60 | | |
| | 3 | | | 112 | 30 | | |
| | 6 | | | 135 | 70 | | |
| | 6 | | | 150 | 95 | | |
| | 6 | | | 145 | 50 | | |
| | 7 | | | 182 | 95 | | |
| | 7 | | | 145 | 60 | | |
| | 8 | | | 145 | 90 | | |
| | 8 | | | 175 | 80 | | |
| | 9 | | | 130 | 70 | | |
| | 9 | | | 165 | 85 | | |
| | 10 | | | 150 | 60 | | |
| | 10 | | | 105 | 50 | | |
| | 13 | | | 145 | 60 | | |
| | 13 | | | 145 | 60 | | |
| | 16 | | | 200 | 95 | | |
| | 16 | | | 195 | 90 | | |
| | 21 | | | 165 | 80 | | |

Table 3

| | |
|---|---|
| DATE TESTING BEGAN | 7 July 1959 |
| TEST NUMBER | 1 |
| TEMP. & HUMIDITY OF MIX | 71°& 65%, 76°& 46% |
| SILICONE | RTV 60 |
| CATALYST | T 773 |
| PRIMER | 81822 |

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | MAX. TEMP. RAISED TO | MAX. LOAD LOADED TO |
|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI |
| Room Temp. | 1/2 | R.T. | | 65 | 0 | | |
| | 1/2 | | | 75 | 0 | | |
| | 1 | | | 62 | 0 | | |
| | 1 | | | 68 | 0 | | |
| | 1 | | | 65 | 0 | | |
| | 1 | | | 65 | 0 | | |
| | 2.8 | | | 65 | 0 | | |
| | 2.8 | | | 67 | 0 | | |
| | 3 | | | 75 | 0 | | |
| | 3 | | | 65 | 0 | | |
| | 3 | | | 85 | 0 | | |
| | 3 | | | 75 | 0 | | |
| | 4 | | | 70 | 0 | | |
| | 4 | | | 55 | 0 | | |
| | 4 | | | 80 | 5 | | |
| | 7 | | | 85 | 0 | | |
| | 7 | | | 90 | 0 | | |
| | 7 | | | 50 | 0 | | |
| | 8 | | | 100 | 0 | | |
| | 8 | | | 75 | 0 | | |
| | 8 | | | 95 | 20 | | |
| | 10 | | | 60 | 0 | | |
| | 10 | | | 75 | 0 | | |
| | 11 | | | 95 | 50 | | |
| | 14 | | | 105 | 25 | | |
| | 15 | | | 125 | 50 | | |
| | 16 | | | 125 | 25 | | |

Table 4

DATE TESTING BEGAN 13 July 1959
TEST NUMBER 2
TEMP. & HUMIDITY OF MIX 79 & 50%
SILICONE RTV 60
CATALYST T 773
PRIMER xs 4004

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | MAX. TEMP. RAISED TO | MAX. LOAD LOADED TO |
|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI |
| R.T. | 8 hrs | @ 250 | | | | | |
| R.T. | 6 days | @ R.T. | | 345 | 80 | | |
| R.T. | | | | 300 | 75 | | |
| 200 | | | | 90 | 10 | | |
| 200 | | | | 130 | 60 | | |
| 200 | | | | 120 | 70 | | |
| 200 | | | | 128 | 30 | | |
| 300 | | | | 102 | 15 | | |
| 300 | | | | 145 | 60 | | |
| 300 | | | | 122 | 5 | | |
| 300 | | | | 122 | 5 | | |
| 400 | | | | 125 | 25 | | |
| 400 | | | | 197 | 50 | | |
| 400 | | | | 158 | 40 | | |
| 400 | | | | 198 | 50 | | |
| 500 | | | | 130 | 99 | | |
| 500 | | | | 155 | 95 | | |
| 500 | | | | 143 | 100 | | |
| 500 | | | | 147 | 95 | | |
| 600 | | | | 0 | 100 | | |
| 600 | | | | ? | ? | | |
| 600 | | | | ? | ? | | |
| 600 | | | | 45 | 100 | | |
| 550 | | | | 72 | 100 | | |
| 550 | | | | 82 | 100 | | |
| 525 | | | | 100 | 100 | | |
| 525 | | | | 88 | 100 | | |
| 600 | | | | 80 | 100 | | |
| 600 | 7 days | @ R.T. | | | | | |
| 600 | 8 hrs. | @ 250 | | 0 | 100 | | |
| 600 | 7 days | R.T. | | | | | |
| 600 | 8 hrs. | 250 | | 0 | 100 | | |
| 530 | 7 days | R.T. | | | | Raised to 600 | |
| 530 | 8 hrs. | 250 | | 0 | ? | & tested @ 530 | |

Table 5

| | |
|---|---|
| DATE TESTING BEGAN | 14 July 1959 |
| TEST NUMBER | 2 |
| TEMP. & HUMIDITY OF MIX | 82 & 36% |
| SILICONE | RTV 60 |
| CATALYST | T 773 |
| PRIMER | 81822 |

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | MAX. TEMP. RAISED TO | MAX. LOAD LOADED TO |
|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI |
| RT | 6 days | RT | | | | | |
| RT | 8 hrs. | 250 | | 375 | 100 | | |
| RT | 6 days | RT | | | | | |
| RT | 8 hrs. | 250 | | 387 | 100 | | |
| 200 | 6 days | RT | | | | | |
| 200 | 8 hrs. | 250 | | 285 | 95 | | |
| 200 | 6 days | RT | | | | | |
| 200 | 8 hrs. | 250 | | 222 | 100 | | |
| 200 | 6 days | RT | | | | | |
| 200 | 8 hrs. | 250 | | 227 | 100 | | |
| 300 | 6 days | RT | | | | | |
| 300 | 8 hrs. | 250 | | 215 | 100 | | |
| 300 | 6 days | RT | | | | | |
| 300 | 8 hrs. | 250 | | 230 | 100 | | |
| 300 | 6 days | RT | | | | | |
| 300 | 8 hrs. | 250 | | 187 | 100 | | |
| 400 | 6 days | RT | | | | | |
| 400 | 8 hrs. | 250 | | 192 | 100 | | |
| 400 | 6 days | RT | | | | | |
| 400 | 8 hrs. | 250 | | 220 | 95 | | |
| 400 | 6 days | RT | | | | | |
| 400 | 8 hrs. | 250 | | 215 | 100 | | |
| 500 | 6 days | RT | | | | | |
| 500 | 8 hrs. | 250 | | 100 | 99 | | |
| 500 | 6 days | RT | | | | | |
| 500 | 8 hrs. | 250 | | 152 | 100 | | |
| 500 | 6 days | RT | | | | | |
| 500 | 8 hrs. | 250 | | 118 | 100 | | |
| 600 | 6 days | RT | | | | | |
| 600 | 8 hrs. | 250 | | 0 | 15 | | |
| 600 | 6 days | RT | | | | | |
| 600 | 8 hrs. | 250 | | 0 | 30 | | |
| 530 | 6 days | RT | | | | | |
| 530 | 8 hrs. | 250 | | 130 | 100 | | |
| 530 | 6 days | RT | | | | | |
| 530 | 8 hrs. | 250 | | 90 | 80 | | |
| 200 | 7 days | RT | | | | | |
| 200 | 8 hrs. | 250 | | 240 | 90 | | |
| 300 | 7 days | RT | | | | | |
| 300 | 8 hrs. | 250 | | 190 | 80 | | |
| 400 | 7 days | RT | | | | | |
| 400 | 8 hrs. | 250 | | 275 | 100 | | |

Table 5 (Continued)

DATE TESTING BEGAN: 14 July 1959
TEST NUMBER: 2
TEMP. & HUMIDITY OF MIX: 82 & 36%
SILICONE: RTV 60
CATALYST: T 773
PRIMER: 81822

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | MAX. TEMP. RAISED TO | MAX. LOAD LOADED TO |
|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI |
| 530 | 7 days | RT | | | | | |
| 530 | 8 hrs. | 250 | | | | | |
| 530 | 1 hr. | 400 | | 40 | 20 | | |
| 530 | 7 days | RT | | | | | |
| 530 | 8 hrs. | 250 | | | | | |
| 530 | 1 hr. | 400 | | 48 | 85 | | |
| 530 | 7 days | RT | | | | | |
| 530 | 8 hrs. | 250 | | | | | |
| 530 | 1 hr. | 500 | | 0 | 90 | | |
| 530 | 7 days | RT | | | | | |
| 530 | 8 hrs. | 250 | | | | | |
| 530 | 1 hr. | 500 | | 50 | 5 | | |
| 500 | 7 days | RT | | | | | |
| 500 | 8 hrs. | 250 | | 117 | 100 | | |
| 600 | 7 days | RT | | | | | |
| 600 | 8 hrs. | 250 | | 0 | 20 | | |
| 575 | 7 days | RT | | | | | |
| 575 | 8 hrs. | 250 | | 35 | 0 | | |
| 550 | 7 days | R.T. | | | | | |
| 550 | 8 hrs. | 250 | | 60 | 100 | | |
| 525 | 7 days | R.T. | | | | | |
| 525 | 8 hrs. | 250 | | 105 | 100 | | |
| 530 | 7 days | R.T. | | | | | |
| 530 | 8 hrs. | 250 | | 87 | 80 | | |
| 530 | 3 hrs. | 400 | | | | | |
| 530 | 7 days | R.T. | | | | | |
| 530 | 8 hrs. | 250 | | 80 | 20 | | |
| 530 | 3 hrs. | 500 | | | | | |

Table 6

| | |
|---|---|
| DATE TESTING BEGAN | 8 July 1959 |
| TEST NUMBER | 3 |
| TEMP. & HUMIDITY OF MIX | 80 & 67% |
| SILICONE | RTV 60 |
| CATALYST | T 773 |
| PRIMER | XS 4004 |

*Failure

| TEST TEMP | CURE | | | STATIC TEST LOAD | COHESIVE | MAX. TEMP. RAISED TO | MAX. LOAD RAISED TO |
|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI |
| RT | 6 days | RT | | | | | |
| RT | 8 hrs. | 250 | | 115 | 80 | | |
| RT | 8 hrs. | 600 | | | | | |
| 600 | 6 days | RT | | | | | |
| 600 | 8 hrs. | 250 | | 68 | 100 | | |
| 600 | 8 hrs. | 600 | | | | | |
| 600 | 8 hrs. | 250 | | | | | |
| 600 | 24 hrs. | 300 | | | | | |
| 600 | 11 hrs. | 300 | 40 | | ? | 570 | 160 |
| 600 | 11 hrs. | 300 | 160* | | | | |
| 600 | 8 hrs. | 250 | | | | | |
| 600 | 24 hrs. | 300 | | | | | |
| 600 | 11 hrs. | 300 | 50 | | 98 | 5 50 | 200 |
| 600 | 4 hrs. | 300 | 200* | | | | |
| 600 | 8 hrs. | 250 | | | | | |
| 600 | 24 hrs. | 300 | | | | | |
| 600 | 15 hrs. | 300 | 100 | | 100 | 300 | 220 |
| 600 | 7 hrs. | 300 | 220* | | | | |
| 600 | 8 hrs. | 250 | | | | | |
| 600 | 24 hrs. | 300 | | | | | |
| 600 | 12 hrs. | 300 | 80 | | 100 | 300 | 240 |
| 600 | 6.8 hrs | 300 | 240* | | | | |
| 400 | 8 hrs. | 250 | | | | | |
| 400 | 24 hrs. | 400 | | 100 | 100 | | |
| 400 | 39 min. | 400 | 100* | | | | |
| 400 | 8 hrs. | 250 | | | | | |
| 400 | 24 hrs. | 400 | | 80 | 100 | | |
| 400 | 48 hrs. | 400 | 60 | | | | |
| 500 | 8 hrs. | 250 | | | | | |
| 500 | 24 hrs. | 500 | | 100 | 100 | | |
| 500 | 202 mins. | 500 | 100* | | | | |
| 500 | 8 hrs. | 250 | | | | | |
| 500 | 24 hrs. | 500 | * | 80 | 100 | 775 | |
| RT | 8 hrs. | 250 | | | 95 | | 420 |

Table 7

DATE TESTING BEGAN 16 July 1959
TEST NUMBER 3
TEMP. & HUMIDITY OF MIX 85 & 50%, 85 & 35%
SILICONE RTV 60
CATALYST T 773
PRIMER 81822

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | MAX. TEMP. RAISED TO | MAX. LOAD RAISED TO |
|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI |
| 110 | 8 hrs. | 250 | | | | | |
| 110 | 24 hrs. | 300 | | 174 | 100 | | |
| 110 | 6 days | RT | | | | | |
| 200 | 8 hrs. | 250 | | | | | |
| 200 | 24 hrs. | 300 | | 207 | 100 | | |
| 200 | 6 days | RT | | | | | |
| 300 | 8 hrs. | 250 | | | | | |
| 300 | 24 hrs. | 300 | | 155 | 100 | | |
| 300 | 6 days | RT | | | | | |
| 400 | 8 hrs. | 250 | | | | | |
| 400 | 24 hrs. | 300 | | 147 | 100 | | |
| 400 | 6 days | RT | | | | | |
| 500 | 8 hrs. | 250 | | | | | |
| 500 | 24 hrs. | 300 | | 140 | 95 | | |
| 500 | 6 days | RT | | | | | |
| 600 | 8 hrs. | 250 | | | | | |
| 600 | 24 hrs. | 300 | | 30 | 5 | | |
| 600 | 6 days | RT | | | | | |
| RT | 11 days | RT | | | | | |
| RT | 8 hrs. | 250 | | 150 | 75 | | |
| RT | 24 hrs. | 300 | | | | | |
| 300 | 11 days | RT | | | | | |
| 300 | 8 hrs. | 250 | | 100 | 95 | | |
| 300 | 24 hrs. | 300 | | | | | |
| 400 | 11 days | RT | | | | | |
| 400 | 8 hrs. | 250 | | 72 | 100 | | |
| 400 | 24 hrs. | 300 | | | | | |
| 500 | 11 days | RT | | | | | |
| 500 | 8 hrs. | 250 | | 0 | 95 | 420 | |
| 500 | 24 hrs | 300 | | | | | |
| RT | 13 days | RT | | | | | |
| RT | 8 hrs. | 250 | | 310 | 90 | | |
| RT | 5 days | RT | | | | | |
| RT | 8 hrs. | 250 | | 95 | 70 | | |
| RT | 8 hrs. | 600 | | | | | |

Table 8

| | |
|---|---|
| DATE TESTING BEGAN | 9 July 1959 |
| TEST NUMBER | 4 |
| TEMP. & HUMIDITY OF MIX | 85 & 35% |
| SILICONE | RTV 60 |
| CATALYST | T 773 |
| PRIMER | XS 4004 |

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | ELEVATED TO | | DURATION OF TEST | |
|---|---|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI | HOURS | MINS. |
| 300 | 8 days | RT | | 160 | 98 | | | | 42 |
| 300 | 8 hrs. | 250 | | | | | | | |
| 300 | 8 days | RT | | 140 | 85 | | | | 42 |
| 300 | 8 hrs. | 250 | | | | | | | |
| 530 | 8 days | RT | | | | | | | |
| 530 | 8 hrs. | 250 | | 120 | 80 | | | | 1 |
| 530 | 39 hrs. | 300 | 120 | | | | | | |
| 530 | 8 days | RT | | | | | | | |
| 530 | 8 hrs. | 250 | | 100 | 90 | | | | 5 |
| 530 | 40 hrs. | 300 | 100 | | | | | | |
| 530 | 8 days | RT | | | | | | | |
| 530 | 8 hrs. | 250 | | 80 | 95 | 610 | | | |
| 530 | 39 hrs. | 300 | 80 | | | | | | |
| 400 | 8 days | RT | | 160 | 95 | | | | 3 |
| 400 | 8 hrs. | 250 | | | | | | | |
| 400 | 8 days | RT | | 140 | 95 | | | | 31 |
| 400 | 8 hrs. | 250 | | | | | | | |
| 400 | 8 days | RT | | 120 | 98 | | | 1 | 33 |
| 400 | 8 hrs. | 250 | | | | | | | |
| 400 | 8 days | RT | | 100 | 95 | | | 2 | 6 |
| 400 | 8 hrs. | 250 | | | | | | | |
| 400 | 8 days | RT | | 80 | 95 | | | 3 | 37 |
| 400 | 8 hrs. | 250 | | | | | | | |
| 300 | 8 days | RT | | | | | | | |
| 300 | 8 hrs. | 250 | | 140 | ? | | | 3 | |
| 300 | 30 hrs. | 300 | 60 | 1 | | | | | |
| 530 | 8 days | RT | | | | | | | |
| 530 | 8 hrs. | 250 | | 60 | 100 | | | | 43 |
| 530 | ? | 400 | 60 | | | | | | |
| 500 | 8 days | RT | | | | | | | |
| 500 | 8 hrs. | 250 | | 160 | 90 | | | | .1 |
| 500 | 8 days | RT | | | | | | | |
| 500 | 8 hrs. | 250 | | 140 | 95 | | | | 1 |
| 500 | 8 days | RT | | 120 | 85 | | | | .5 |
| 500 | 8 hrs. | 250 | | | | | | | |
| 500 | 8 days | RT | | 100 | 98 | | | | 9 |
| 500 | 8 hrs. | 250 | | | | | | | |
| 500 | 8 days | RT | | 80 | 98 | | | | .5 |
| 500 | 8 hrs. | 250 | | | | | | | |
| 500 | 8 days | RT | | 60 | 100 | | | | 1 |
| 500 | 8 hrs. | 250 | | | | | | | |

Table 8 (Continued)

| | |
|---|---|
| DATE TESTING BEGAN | 9 July 1959 |
| TEST NUMBER | 4 |
| TEMP. & HUMIDITY OF MIX | 85 & 35% |
| SILICONE | RTV 60 |
| CATALYST | T 773 |
| PRIMER | XS 4004 |

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | ELEVATED TO | | DURATION OF TEST | |
|---|---|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI | HOURS | MINS. |
| RT | 13 days | RT | | | 85 | | 280 | | |
| RT | 8 hrs. | 250 | | | | | | | |
| RT | 13 days | RT | | | 90 | | 350 | | |
| RT | 8 hrs. | 250 | | | | | | | |
| 600 | 14 days | RT | | 0 | 85 | | | | |
| 600 | 8 hrs. | 250 | | | | | | | |
| 550 | 13 days | RT | | 100 | 95 | | | | 0 |
| 550 | 8 hrs. | 250 | | | | | | | |
| 550 | 13 days | RT | | 100 | 90 | | | | 0 |
| 550 | 8 hrs. | 250 | | | | | | | |
| 550 | 13 days | RT | | 80 | 100 | | | | .2 |
| 550 | 8 hrs. | 250 | | | | | | | |
| 550 | 13 days | RT | | 60 | 98 | | | | 0 |
| 550 | 8 hrs. | 250 | | | | | | | |
| 530 | 14 days | RT | | 100 | 95 | | | | 0 |
| 530 | 8 hrs. | 250 | | | | | | | |
| 530 | 14 days | RT | | 80 | 98 | | | | 0 |
| 530 | 8 hrs. | 250 | | | | | | | |
| 530 | 14 days | RT | | 60 | 95 | | | | .5 |
| 530 | 8 hrs. | 250 | | | | | | | |
| 530 | 14 days | RT | | 50 | 95 | | | | .2 |
| 530 | 8 hrs. | 250 | | | | | | | |
| 530 | 14 days | RT | | 40 | 95 | | | | .2 |
| 530 | 8 hrs. | 250 | | | | | | | |
| 530 | 14 days | RT | | 40 | 100 | | | | 11 |
| 530 | 8 hrs. | 250 | | | | | | | |
| 530 | 14 days | RT | | 35 | 99 | | | | 14 |
| 530 | 8 hrs | 250 | | | | | | | |

Table 9

| | |
|---|---|
| DATE TESTING BEGAN | 23 July 1959 |
| TEST NUMBER | 4 |
| TEMP. & HUMIDITY OF MIX | 88 & 70% |
| SILICONE | RTV 60 |
| CATALYST | T 773 |
| PRIMER | 81822 |

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | ELEVATED TO | | DURATION OF TEST | |
|---|---|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI | HOURS | MINS. |
| RT | 1 hr. | 250 | | | | | | | |
| RT | 4 hrs. | 275 | | | 99 | | 360 | | |
| RT | 15 hrs. | 300 | | | | | | | |
| RT | 1 hr. | 250 | | | | | | | |
| RT | 4 hrs. | 275 | | | 99 | | 370 | | |
| RT | 15 hrs. | 300 | | | | | | | |
| 200 | 1 hr. | 250 | | | | | | | |
| 200 | 4 hrs. | 275 | | | 100 | | 222 | | |
| 200 | 15 hrs. | 300 | | | | | | | |
| 300 | 1 hr. | 250 | | | | | | | |
| 300 | 4 hrs. | 275 | | | 100 | | 192 | | |
| 300 | 15 hrs. | 300 | | | | | | | |
| 300 | 1 hr. | 250 | | | | | | | |
| 300 | 4 hrs. | 275 | | | 100 | | 197 | | |
| 300 | 15 hrs. | 300 | | | | | | | |
| 400 | 1 hr. | 250 | | | | | | | |
| 400 | 4 hrs. | 275 | | | 100 | | 185 | | |
| 400 | 15 hrs. | 300 | | | | | | | |
| 500 | 1 hr. | 250 | | | | | | | |
| 500 | 4 hrs. | 275 | | | 100 | | 157 | | |
| 500 | 15 hrs. | 300 | | | | | | | |
| 550 | 1 hr. | 250 | | | | | | | |
| 550 | 4 hrs. | 275 | | | 100 | | 118 | | |
| 550 | 15 hrs. | 300 | | | | | | | |
| 600 | 1 hr. | 250 | | | | | | | |
| 600 | 4 hrs. | 275 | | | 100 | | 70 | | |
| 600 | 15 hrs. | 300 | | | | | | | |
| 600 | 1 hr. | 250 | | | | | | | |
| 600 | 4 hrs. | 275 | | | 100 | | 68 | | |
| 600 | 15 hrs. | 300 | | | | | | | |
| 530 | 1 hr. | 250 | | | | | | | |
| 530 | 4 hrs. | 275 | | 140 | 100 | | | | .2 |
| 530 | 15 hrs. | 300 | | | | | | | |
| 530 | 1 hr. | 250 | | | | | | | |
| 530 | 4 hrs. | 275 | | 130 | 100 | | | | .6 |
| 530 | 15 hrs. | 300 | | | | | | | |
| 530 | 1 hr. | 250 | | | | | | | |
| 530 | 4 hrs. | 275 | | 120 | 100 | | | | .4 |
| 530 | 15 hrs. | 300 | | | | | | | |
| 530 | 1 hr. | 250 | | | | | | | |
| 530 | 4 hrs. | 275 | | 100 | 100 | | | | 1.1 |
| 530 | 15 hrs. | 300 | | | | | | | |

Table 9 (Continued)

| | |
|---|---|
| DATE TESTING BEGAN | 23 July 1959 |
| TEST NUMBER | 4 |
| TEMP. & HUMIDITY OF MIX | 88 & 70% |
| SILICONE | RTV 60 |
| CATALYST | T 773 |
| PRIMER | 81822 |

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | ELEVATED TO | | DURATION OF TEST | |
|---|---|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI | HOURS | MINS. |
| 530 | 1 hr. | 250 | | | | | | | |
| 530 | 4 hrs. | 275 | | 90 | 100 | | | | 2.3 |
| 530 | 15 hrs. | 300 | | | | | | | |
| 530 | 1 hr. | 250 | | | | | | | |
| 530 | 4 hrs. | 275 | | 80 | 100 | | | | 3.1 |
| 530 | 15 hrs. | 300 | | | | | | | |
| 530 | 1 hr. | 250 | | | | | | | |
| 530 | 4 hrs. | 275 | | 80 | 100 | | | | 1 |
| 530 | 15 hrs. | 300 | | | | | | | |
| 530 | 1 hr. | 250 | | | | | | | |
| 530 | 4 hrs. | 275 | | 70 | 100 | | | | 6 |
| 530 | 15 hrs. | 300 | | | | | | | |
| 530 | 1 hr. | 250 | | | | | | | |
| 530 | 4 hrs. | 275 | | 60 | 100 | | | | 5.9 |
| 530 | 15 hrs. | 300 | | | | | | | |
| 530 | 1 hr. | 250 | | | | | | | |
| 530 | 4 hrs. | 275 | | 50 | 100 | | | | 7.5 |
| 530 | 15 hrs. | 300 | | | | | | | |
| 530 | 1 hr. | 250 | | | | | | | |
| 530 | 4 hrs. | 275 | | 40 | 100 | | | | 11.1 |
| 530 | 15 hrs. | 300 | | | | | | | |
| 530 | 1 hr. | 250 | | | | | | | |
| 530 | 4 hrs. | 275 | | 30 | 100 | | | | 13.5 |
| 530 | 15 hrs. | 300 | | | | | | | |
| 530 | 1 hr. | 250 | | | | | | | |
| 530 | 4 hrs. | 275 | | 20 | 100 | | | 1 | 8.3 |
| 530 | 15 hrs. | 300 | | | | | | | |
| 530 | 1 hr. | 250 | | | | | | | |
| 530 | 4 hrs. | 275 | | 10 | 100 | | | 1 | 1.3 |
| 530 | 15 hrs. | 300 | | | | | | | |

Table 10

| | |
|---|---|
| DATE TESTING BEGAN | 15 July 1959 |
| TEST NUMBER | 5 |
| TEMP. & HUMIDITY OF MIX | 80 & 67% |
| SILICONE | RTV 60 |
| CATALYST | T 773 |
| PRIMER | XS 4004 |

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | ELEVATED TO | | DURATION OF TEST | |
|---|---|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI | HOURS | MINS |
| RT | 6 days | RT | | | | | | | |
| RT | 8 hrs. | 250 | | | | | 175 | | |
| RT | 8 hrs. | 600 | | | 80 | | | | |
| 600 | 6 days | RT | | | | | | | |
| 600 | 8 hrs. | 250 | | 30 | ? | | | | 2.5 |
| 600 | 8 hrs. | 600 | | | | | | | |
| 600 | 8 hrs. | 250 | | | | | | | |
| 600 | 24 hrs. | 300 | | | 100 | 605 | 120 | | |
| 600 | 10 hrs. | 300 | 30 | | | | | | |
| 600 | 4 hrs. | 300 | 120 | | | | | | |
| 300 | 8 hrs. | 250 | | | | | | | |
| 300 | 24 hrs. | 300 | | | | | | | |
| 300 | 11.6 hrs. | 300 | 60 | | 100 | | 260 | | 1.8 |
| 300 | 11.8mins. | 300 | 260 | | | | | | |
| 400 | 12 days | RT | | | | | | | |
| 400 | 8 hrs. | 250 | | 120 | | | | | 1.5 |
| 400 | 24 hrs. | 400 | | | 100 | | | | |
| 400 | 12 days | RT | | | | | | | |
| 400 | 8 hrs. | 250 | | 60 | 100 | 690 | | | |
| 400 | 24 hrs. | 400 | | | | | | | |
| 400 | 48 hrs. | 400 | 60 | | | | | | |
| 500 | 12 days | RT | | | | | | | |
| 500 | 8 hrs. | 250 | | 120 | 100 | | | | .2 |
| 500 | 24 hrs. | 400 | | | | | | | |
| 500 | 12 days | RT | | | | | | | |
| 500 | 8 hrs. | 250 | | | | | | | |
| 500 | 24 hrs. | 400 | | | | 775 | | | |
| 500 | 45 hrs. | 500 | 60 | 60 | 100 | | | | |
| RT | 8 hrs. | 250 | | | 60 | | 390 | | |

Table 11

| | |
|---|---|
| DATE TESTING BEGAN | 15 July 1959 |
| TEST NUMBER | 5 |
| TEMP. & HUMIDITY OF MIX | 80 & 67% |
| SILICONE. | RTV 60 |
| CATALYST | T 773 |
| PRIMER | 81822 |

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | ELEVATED TO | | DURATION OF TEST | |
|---|---|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI | HOURS | MINS. |
| RT | 8 hrs. | 250 | | | | | | | |
| RT | 6 days | RT | | | 90 | | 125 | | |
| RT | 8 hrs. | 600 | | | | | | | |
| 530 | 6 days | RT | | 30 | ? | | | | .5 |
| 530 | 8 hrs. | 250 | | | | | | | |
| 500 | 6 days | RT | | | | | | | |
| 500 | 8 hrs. | 250 | | | 95 | | 140 | | |
| 500 | 24 hrs. | 300 | | | | | | | |
| 200 | 6 days | RT | | | | | | | |
| 200 | 8 hrs. | 250 | | | 100 | | 207 | | |
| 200 | 24 hrs. | 300 | | | | | | | |
| RT | 11 days | RT | | | | | | | |
| RT | 8 hrs. | 250 | | | 100 | | 160 | | ? |
| RT | 24 hrs. | 400 | | | | | | | |
| 300 | 11 days | RT | | | 100 | | 95 | | |
| 300 | 8 hrs. | 250 | | | | | | | |
| 400 | 8 hrs. | 250 | | | | | | | |
| 400 | 11 days | RT | | | 98 | | 72 | | |
| 400 | 24 hrs. | 500 | | | | | | | |
| 500 | 8 hrs. | 250 | | | | | | | |
| 500 | 11 days | RT | | | 80 | | 58 | | |
| 500 | 24 hrs. | 500 | | | | | | | |
| RT | 14 days | RT | | | 90 | | 287 | | |
| RT | 8 hrs. | 250 | | | | | | | |

Table 12

| | |
|---|---|
| DATE TESTING BEGAN | 21 July 1959 |
| TEST NUMBER | 3 |
| TEMP. & HUMIDITY OF MIX | 85 & 50% |
| SILICONE | RTV 60 |
| CATALYST | T 773 |
| PRIMER | 81822 |

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | ELEVATED TO | | DURATION OF TEST | |
|---|---|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI | HOURS | MINS. |
| 110 | 5 days | RT | | | | | | | |
| 110 | 8 hrs. | 250 | | | 100 | | 174 | | |
| 110 | 24 hrs. | 300 | | | | | | | |
| 200 | 5 days | RT | | | | | | | |
| 200 | 8 hrs. | 250 | | | 100 | | 207 | | |
| 200 | 24 hrs. | 300 | | | | | | | |
| 300 | 5 days | RT | | | | | | | |
| 300 | 8 hrs. | 250 | | | 100 | | 155 | | |
| 300 | 24 hrs. | 300 | | | | | | | |
| 400 | 5 days | RT | | | | | | | |
| 400 | 8 hrs. | 250 | | | 100 | | 147 | | |
| 400 | 24 hrs. | 300 | | | | | | | |
| 500 | 5 days | RT | | | | | | | |
| 500 | 8 hrs. | 250 | | | 100 | | 140 | | |
| 500 | 24 hrs. | 300 | | | | | | | |
| 600 | 5 days | RT | | | | | | | |
| 600 | 8 hrs. | 250 | | | 5 | | 30 | | |
| 600 | 24 hrs. | 300 | | | | | | | |
| RT | 11 days | RT | | | | | | | |
| RT | 8 hrs. | 250 | | | 100 | | 160 | | |
| RT | 24 hrs. | 400 | | | | | | | |
| 300 | 11 days | RT | | | | | | | |
| 300 | 8 hrs. | 250 | | | 100 | | 95 | | |
| 300 | 24 hrs. | 400 | | | | | | | |
| 400 | 11 days | RT | | | | | | | |
| 400 | 8 hrs. | 250 | | | 100 | | 72 | | |
| 400 | 24 hrs. | 400 | | | | | | | |
| 500 | 11 days | RT | | | | | | | |
| 500 | 8 hrs. | 250 | | | 95 | | 0 | | |
| 500 | 24 hrs. | 400 | | | | | | | |
| RT | 11 days | RT | | | | | | | |
| RT | 8 hrs. | 250 | | | 75 | | 150 | | |
| RT | 24 hrs. | 500 | | | | | | | |
| 300 | 11 days | RT | | | | | | | |
| 300 | 8 hrs. | 250 | | | 95 | | 100 | | |
| 300 | 24 hrs. | 500 | | | | | | | |
| 400 | 11 days | RT | | | | | | | |
| 400 | 8 hrs. | 250 | | | 98 | | 72 | | |
| 400 | 24 hrs. | 500 | | | | | | | |
| 500 | 11 days | RT | | | | | | | |
| 500 | 8 hrs. | 250 | | | 80 | | 58 | | |
| 500 | 24 hrs. | 500 | | | | | | | |

Table 13

| | |
|---|---|
| DATE TESTING BEGAN | 15 July 1959 |
| TEST NUMBER | 5 |
| TEMP. & HUMIDITY OF MIX | 80 & 67%, 85 & 35% |
| SILICONE | RTV 60 |
| CATALYST | T 773 |
| PRIMER | XS 4004 |

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | ELEVATED TO | | DURATION OF TEST | |
|---|---|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI | HOURS | MINS. |
| 300 | 6 days | RT | | | | | | | |
| 300 | 8 hrs. | 250 | | 40 for 11 hrs. | ? | | 160 | | |
| 300 | 24 hrs. | 300 | | | | | | | |
| 300 | 6 days | RT | | | | | | | |
| 300 | 8 hrs. | 250 | | 50 for 11 hrs. | 98 | 550 | | | |
| 300 | 24 hrs. | 300 | | | | | | | |
| 300 | 6 days | RT | | | | | | | |
| 300 | 8 hrs. | 250 | | 100 for 15 hrs. | 100 | | 220 | 7 | |
| 300 | 24 hrs. | 300 | | | | | | | |
| 300 | 6 days | RT | | | | | | | |
| 300 | 8 hrs. | 250 | | 30 for 10 hrs. | 100 | 605 | | | |
| 300 | 24 hrs. | 300 | | 120 for 4 hrs. | | | | | |
| 300 | 6 days | RT | | | | | | | |
| 300 | 8 hrs. | 250 | | 80 for 11.6 hrs. | 100 | | 240 | | 6.8 |
| 300 | 24 hrs. | 300 | | | | | | | |
| 300 | 6 days | RT | | | | | | | |
| 300 | 8 hrs. | 250 | | 60 for 11.7 hrs. | 100 | | 260 | | 1.8 |
| 300 | 24 hrs. | 300 | | | | | | | |
| 400 | 12 days | RT | | | | | | | |
| 400 | 8 hrs. | 250 | | 120 | 100 | | | | 1.5 |
| 400 | 24 hrs. | 400 | | | | | | | |
| 400 | 12 days | RT | | | | | | | |
| 400 | 8 hrs. | 250 | | 100 | 100 | | | | 39 |
| 400 | 24 hrs. | 400 | | | | | | | |
| 400 | 12 days | RT | | | | | | | |
| 400 | 8 hrs. | 250 | | 80 | 100 | | | 25 | 49 |
| 400 | 24 hrs. | 400 | | | | | | | |
| 400 | 12 days | RT | | | | | | | |
| 400 | 8 hrs. | 250 | | 60 | 100 | 690 | | | ? |
| 400 | 24 hrs. | 400 | | | | | | | |
| 500 | 12 days | RT | | | | | | | |

Table 13 (Continued)

DATE TESTING BEGAN 15 July 1959
TEST NUMBER 5
TEMP. & HUMIDITY OF MIX 80 & 67%, 85 & 35%
SILICONE RTV 60
CATALYST T 773
PRIMER XS 4004

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | ELEVATED TO | | DURATION OF TEST | |
|---|---|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI | HOURS | MINS |
| 500 | 8 hrs. | 250 | | 100 | 100 | | | 3 | 22 |
| 500 | 24 hrs. | 500 | | | | | | | |
| 500 | 12 days | RT | | | | | | | |
| 500 | 8 hrs. | 250 | | | | | | | |
| 500 | 24 hrs. | 500 | | | | 775 | | | |
| 500 | 48 hrs. | 500 | 80 | | 100 | | | | |
| 500 | 12 days | RT | | | | | | | |
| 500 | 8 hrs. | 250 | | | 100 | 775 | | | |
| 500 | 24 hrs. | 500 | | | | | | | |
| 500 | 48 hrs. | 500 | 60 | | | | | | |
| 500 | 12 days | RT | | | | | | | |
| 500 | 8 hrs. | 250 | | 120 | 100 | | | | .2 |
| 500 | 24 hrs. | 500 | | | | | | | |
| 500 | 48 hrs. | 500 | | | | | | | |

Table 14

DATE TESTING BEGAN — 23 July 1959
TEST NUMBER — 7
TEMP. & HUMIDITY OF MIX — 84 & 66%, 77 & 69%, 81 & 67%
SILICONE — RTV 60
CATALYST — T 773
PRIMER — XS 4004

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | ELEVATED TO | | DURATION OF TEST | |
|---|---|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI | HOURS | MINS. |
| RT | 2 days | RT | | | 50 | | 160 | | |
| RT | 3 days | RT | | | 50 | | 137 | | |
| RT | 6 days | RT | | | 99 | | 380 | | |
| RT | 6 days | RT | | | 30 | | 130 | | |
| RT | 6 days | RT | | | 98 | | 325 | | |
| RT | 7 days | RT | | | 99 | | 375 | | |
| RT | 10 days | RT | | | 99 | | 350 | | |
| RT | 10 days | RT | | | 99 | | 400 | | |
| RT | step | cure | | | | | | | |
| RT | 10 days | RT | | | 90 | | 390 | | |
| RT | step | cure | | | | | | | |
| RT | 10 days | RT | | | 90 | | 410 | | |
| 200 | step | cure | | | | | | | |
| 200 | 10 days | RT | | | 100 | | 292 | | |
| 200 | step | cure | | | | | | | |
| 200 | 10 days | RT | | | 100 | | 315 | | |
| 300 | step | cure | | | | | | | |
| 300 | 10 days | RT | | | 100 | | 292 | | |
| 400 | step | cure | | | | | | | |
| 400 | 10 days | RT | | | 95 | | 252 | | |

Table 15

DATE TESTING BEGAN 23 July 1959
TEST NUMBER 7
TEMP. & HUMIDITY OF MIX 84 & 66%, 77 & 69%, 81 & 67%
SILICONE RTV 60
CATALYST T 773
PRIMER XS 4004

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | ELEVATED TO | | DURATION OF TEST | |
|---|---|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI | HOURS | MINS |
| 500 | step | cure | | | 100 | | 198 | | |
| 500 | 10 days | RT | | | | | | | |
| 550 | step | cure | | | 100 | | 178 | | |
| 550 | 10 days | RT | | | | | | | |
| 600 | step | cure | | | 100 | | 130 | | |
| 600 | 10 days | RT | | | | | | | |
| 625 | step | cure | | | 100 | | 52 | | |
| 625 | 10 days | RT | | | | | | | |
| 400 | step | cure | | 240 | 95 | | | | .75 |
| 400 | 10 days | RT | | | | | | | |
| 400 | step | cure | | 220 | 100 | | | | 14.4 |
| 400 | 10 days | RT | | | | | | | |
| 400 | step | cure | | 200 | 100 | | | | 6.75 |
| 400 | 10 days | RT | | | | | | | |
| 400 | step | cure | | 180 | 100 | | | | 54.6 |
| 400 | 10 days | RT | | | | | | | |
| 400 | step | cure | | 140 | 100 | | | 15 | 35 |
| 400 | 10 days | RT | | | | | | | |
| 530 | step | cure | | 180 | 90 | | | | .6 |
| 530 | 10 days | RT | | | | | | | |
| 530 | step | cure | | 160 | 80 | | | | 2.5 |
| 530 | 10 days | RT | | | | | | | |
| 530 | step | cure | | 150 | 90 | | | | 2.0 |
| 530 | 10 days | RT | | | | | | | |
| 530 | step | cure | | 140 | 80 | | | | 1.5 |
| 530 | 10 days | RT | | | | | | | |
| 530 | step | cure | | 120 | 100 | | | | 2.3 |
| 530 | 10 days | RT | | | | | | | |

Table 15 (Continued)

DATE TESTING BEGAN 23 July 1959
TEST NUMBER 7
TEMP. & HUMIDITY OF MIX 84 & 66%, 77 & 69%, 81 & 67%
SILICONE RTV 60
CATALYST T 773
PRIMER XS 4004

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | ELEVATED TO | | DURATION OF TEST | |
|---|---|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI | HOURS | MINS. |
| 530 | step | cure | | | | | | | |
| 530 | 10 days | RT | | 100 | 100 | | | | 5.1 |
| 530 | step | cure | | | | | | | |
| 530 | 10 days | RT | | 80 | 100 | | | | 5.75 |
| 505 | step | cure | | | | | | | |
| 505 | 11 days | RT | | 120 | 100 | 505 | | | 36 |
| 505 | 1000 min. | 400 | | | | | | | |
| 505 | step | cure | | | | | | | |
| 505 | 11 days | RT | | 100 | 100 | 505 | | | 45 |
| 505 | 1000 min. | 400 | | | | | | | |
| 505 | step | cure | | | | | | | |
| 505 | 11 days | RT | | 80 | 100 | 505 | | | 38 |
| 505 | 1000 min. | 400 | | | | | | | |
| 505 | step | cure | | | | | | | |
| 505 | 11 days | RT | | 60 | 100 | 505 | | 4 | 7 |
| 505 | 1000 min. | 400 | | | | | | | |
| 400 | step | cure | | | | | | | |
| 400 | 11 days | RT | | 140 | 70 | | | | 0 |
| 400 | step | cure | | | | | | | |
| 400 | 11 days | RT | | 130 | 40 | | | | .1 |
| 400 | step | cure | | | | | | | |
| 400 | 11 days | RT | | 120 | 50 | | | | .1 |
| 400 | step | cure | | | | | | | |
| 400 | 11 days | RT | | 100 | 50 | | | | 0 |
| 400 | step | cure | | | | | | | |
| 400 | 11 days | RT | | 80 | 50 | | | | 0 |
| 500 | step | cure | | | | | | | |
| 500 | 11 days | RT | | 150 | 100 | | | | 3.75 |
| 500 | step | cure | | | | | | | |
| 500 | 11 days | RT | | 140 | 100 | | | | 3.75 |
| 500 | step | cure | | | | | | | |
| 500 | 11 days | RT | | 80 | 100 | | | | 2 |

Table 15 (Continued)

DATE TESTING BEGAN 23 July 1959
TEST NUMBER 7
TEMP. & HUMIDITY OF MIX. 84 & 66%, 77 & 69%, 81 & 67%
SILICONE RTV 60
CATALYST T 773
PRIMER XS 4004

| TEST TEMP. | CURE | | | STATIC TEST LOAD | COHESIVE | ELEVATED TO | | DURATION OF TEST | |
|---|---|---|---|---|---|---|---|---|---|
| °F | DAYS | °F | PSI | PSI | % | °F | PSI | HOURS | MINS. |
| 500 | step | cure | | | | | | | |
| 500 | 11 days | RT | | 80 | 100 | | | | 30 |
| 500 | step | cure | | | | | | | |
| 500 | 11 days | RT | | 60 | 100 | | | | 45 |
| 500 | step | cure | | | | | | | |
| 500 | 11 days | RT | | 40 | 100 | | | | 44 |
| 530 | step | cure | | | | | | | |
| 530 | 11 days | RT | | 40 | 100 | | | | 12 |
| 530 | step | cure | | | | | | | |
| 530 | 11 days | RT | | 30 | 100 | | | | 15 |
| 530 | step | cure | | | | | | | |
| 530 | 11 days | RT | | 30 | 100 | | | | 48 |
| 530 | step | cure | | | | | | | |
| 530 | 11 days | RT | | 20 | 100 | | | | 29 |

Table 16

Transient Heat Simulation
With
Elevated Temperature Loading Methods

| THERMO-COUPLE # | TIME SECONDS | BASIC PLATE °F | BASIC PLATE w/ Al. PATCHES °F | BASIC PLATE w/ STEEL PATCHES °F | BASIC PLATE w/ QUARTZ BLOCKS °F |
|---|---|---|---|---|---|
| 11 | 0 | - | 85 | 87 | - |
| | 10 | 105 | 100 | 100 | 85 |
| | 20 | 220 | 150 | 147 | 140 |
| | 30 | 440 | 250 | 247 | 260 |
| | 40 | 635 | 420 | 410 | 460 |
| | 50 | 735 | 645 | 635 | 680 |
| | 60 | 755 | 745 | 730 | 730 |
| | 70 | - | 749 | 745 | 740 |
| | 80 | - | - | - | - |
| | 90 | - | - | - | - |
| | 100 | - | - | - | - |
| 8 | 0 | - | 78 | 82 | - |
| | 10 | 120 | 88 | 90 | 120 |
| | 20 | 200 | 112 | 110 | 180 |
| | 30 | 380 | 154 | 150 | 270 |
| | 40 | 575 | 215 | 214 | 390 |
| | 50 | 650 | 281 | 290 | 400 |
| | 60 | 675 | 330 | 355 | 395 |
| | 70 | 675 | 363 | 399 | 385 |
| | 80 | - | 379 | 424 | - |
| | 90 | - | 385 | 433 | - |
| | 100 | - | 386 | 435 | - |
| 16 | 0 | - | 85 | 95 | - |
| | 10 | - | 103 | 116 | - |
| | 20 | - | 142 | 165 | - |
| | 30 | - | 208 | 245 | - |
| | 40 | - | 296 | 355 | - |
| | 50 | - | 340 | 400 | - |
| | 60 | - | 362 | 418 | - |
| | 70 | - | 370 | 424 | - |
| | 80 | - | 373 | 420 | - |
| | 90 | - | - | - | - |
| | 100 | - | - | - | - |

Table 17

Radiant Heat Thermal Simulation

.062" Titanium Sheet - Non Patched Skin Panel

| | ① | ② | ③ | ④ | ⑤ | ⑥ | ⑦ |
|---|---|---|---|---|---|---|---|
| TEMP. | RUN # 1 | RUN # 2 | RUN # 3 | RUN # 4 | RUN # 5 | RUN # 6 | SPECIFIC HEAT |
| °F | ΔT/dt | ΔT/dt | ΔT/dt | ΔT/dt | ΔT/dt | ΔT/dt | c |
| 100 | 3.5 | 24.2 | 40.2 | 71.7 | 3.5 | 23.1 | .120 |
| 200 | 3.2 | 23.1 | 39.3 | 69.3 | 3.2 | 22.2 | .129 |
| 300 | 3.0 | 22.1 | 38.2 | 66.9 | 2.8 | 21.3 | .136 |
| 400 | 2.7 | 21.0 | 37.2 | 64.6 | 2.4 | 20.5 | .140 |
| 500 | 2.5 | 20.0 | 36.3 | 62.2 | 2.1 | 19.6 | .145 |
| 600 | 2.3 | 18.9 | 35.3 | 59.9 | 1.7 | 18.8 | .148 |
| 700 | 2.0 | 17.8 | 34.4 | 57.5 | 1.5 | 17.8 | .150 |
| 800 | | 16.8 | 33.4 | 55.2 | | 17.0 | .154 |
| 900 | | 15.8 | 32.5 | 52.8 | | 16.2 | .159 |

| | ⑧ | ⑨ | ⑩ | ⑪ | ⑫ | ⑬ | ⑭ |
|---|---|---|---|---|---|---|---|
| TEMP. | $cw\tau$ | ①×[⑧$_n$−⑧$_{n-1}$] | ②×[⑧$_n$−⑧$_{n-1}$] | ③×[⑧$_n$−⑧$_{n-1}$] | ④×[⑧$_n$−⑧$_{n-1}$] | ⑤×[⑧$_n$−⑧$_{n-1}$] | ⑥×[⑧$_n$−⑧$_{n-1}$] |
| °F | $w\tau = 1.464$ | btu/ft$^2$. sec | btu/ft$^2$. sec | btu/ft$^2$. sec | btu/ft$^2$. sec | btu/ft.$^2$ sec | btu/ft$^2$. sec |
| 100 | .176 | .616 | 4.259 | 7.075 | 12.619 | .616 | 4.066 |
| 200 | .189 | .042 | .300 | .511 | .901 | .042 | .287 |
| 300 | .199 | .030 | .221 | .382 | .669 | .028 | .213 |
| 400 | .205 | .016 | .126 | .223 | .388 | .014 | .123 |
| 500 | .213 | .020 | .160 | .290 | .498 | .017 | .157 |
| 600 | .217 | .009 | .076 | .141 | .240 | .007 | .075 |
| 700 | .220 | .006 | .053 | .103 | .173 | .005 | .053 |
| 800 | .226 | | .101 | .200 | .331 | | .102 |
| 900 | .234 | | .126 | .260 | .422 | | .130 |

Table 17 (Continued)

Radiant Heat Thermal Simulation

.062" Titanium Sheet - Non Patched Skin Panel

| TEMP. | (15) | (16) | (17) | (18) | (19) | (20) |
|---|---|---|---|---|---|---|
| | (9)/$Q_o$ | (10)/$Q_o$ | (11)/$Q_o$ | (12)/$Q_o$ | (13)/$Q_o$ | (14)/$Q_o$ |
| | (9)/2.20 | (10)/10.72 | (11)/18.95 | (12)/30.42 | (13)/2.28 | (14)/10.12 |
| °F | % $\eta$ | % $\eta$ | % $\eta$ | % $\eta$ | % $\eta$ | % $\eta$ |
| 100 | 28.00 | 39.7 | 37.3 | 41.5 | 27.0 | 40.2 |
| 200 | 1.9 | 2.8 | 2.7 | 3.0 | 1.8 | 2.8 |
| 300 | 1.4 | 2.1 | 2.0 | 2.2 | 1.2 | 2.1 |
| 400 | 0.7 | 1.2 | 1.2 | 1.3 | 0.6 | 1.2 |
| 500 | 0.9 | 1.5 | 1.5 | 1.6 | 0.7 | 1.6 |
| 600 | 0.4 | 0.7 | 0.7 | 0.8 | 0.3 | 0.7 |
| 700 | 0.3 | 0.5 | 0.5 | 0.7 | 0.2 | 0.5 |
| 800 | | 0.9 | 1.1 | 1.1 | | 1.0 |
| 900 | | 1.2 | 1.4 | 1.4 | | 1.3 |

| TEMP. | (21) | (22) | (23) | (24) | (25) | (26) |
|---|---|---|---|---|---|---|
| | $(15)_n - \sum (15)_{n-1, n-2, \ldots}$ | $(16)_n - \sum (16)_{n-1, n-2, \ldots}$ | $(17)_n - \sum (17)_{n-1, n-2, \ldots}$ | $(18)_n - \sum (18)_{n-1, n-2, \ldots}$ | $(19)_n - \sum (19)_{n-1, n-2, \ldots}$ | $(20)_n - \sum (20)_{n-1, n-2, \ldots}$ |
| °F | % $\eta$ | % $\eta$ | % $\eta$ | % $\eta$ | % $\eta$ | % $\eta$ |
| 100 | 28.0 | 39.7 | 37.3 | 41.5 | 27.0 | 40.2 |
| 200 | 26.1 | 36.9 | 34.6 | 38.5 | 25.2 | 37.4 |
| 300 | 24.7 | 34.8 | 32.6 | 36.3 | 24.0 | 35.3 |
| 400 | 24.0 | 33.6 | 31.4 | 35.0 | 23.4 | 34.1 |
| 500 | 23.1 | 32.1 | 29.9 | 33.4 | 22.7 | 32.5 |
| 600 | 22.7 | 31.4 | 29.2 | 32.6 | 22.4 | 31.8 |
| 700 | 22.4 | 30.9 | 28.7 | 31.9 | 22.2 | 31.3 |
| 800 | | 30.0 | 27.6 | 30.8 | | 30.3 |
| 900 | | 28.8 | 26.2 | 29.4 | | 29.0 |

Table 18

Radiant Heat Thermal Simulation

.062" Titanium Sheet - RTV Silicone Patched Skin Panel - Power On Patch Side

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| TEMP. | RUN # 1 | RUN # 2 | RUN # 3 | RUN # 4 | RUN # 5 | RUN # 6 | RUN # 7 | RUN # 8 |
| °F | ΔT/dt | ΔT/dt | ΔT/dt | ΔT/dt | ΔT/dt | ΔT/dt | ΔT/dt | ΔT/dt |
| 200 | 2.9 | 4.4 | 9.1 | 11.5 | 25.3 | 35.9 | 52.5 | 25.7 |
| 300 | 2.3 | 2.8 | 8.0 | 9.0 | 21.5 | 33.7 | 50.7 | 21.1 |
| 400 | 1.5 | 2.9 | 4.5 | 6.9 | 17.9 | 31.4 | 48.6 | 18.1 |
| 500 | | | 0.7 | 5.6 | 14.9 | 28.9 | 46.2 | 15.7 |
| 600 | | | | 4.9 | 12.3 | 26.1 | 43.7 | 13.5 |
| 700 | | | | 4.0 | 10.7 | 22.7 | 40.9 | 12.2 |
| 800 | | | | 2.7 | 9.0 | 19.8 | 37.7 | 11.7 |
| 900 | | | | | 6.0 | 14.5 | 34.1 | 10.3 |

| | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) |
|---|---|---|---|---|---|---|---|---|
| TEMP. | SPECIFIC HEAT | CWτ | (1)× [(10)$_n$-(10)$_{n-1}$] | (2)× [(10)$_n$-(10)$_{n-1}$] | (3)× [(10)$_n$-(10)$_{n-1}$] | (4)× [(10)$_n$-(10)$_{n-1}$] | (5)× [(10)$_n$-(10)$_{n-1}$] | (6)× [(10)$_n$-(10)$_{n-1}$] |
| °F | c | wτ= 1.464 | btu/ft$^2$. sec. | btu/ft$^2$. sec. | btu/ft$^2$. sec. | btu/ft$^2$. sec. | btu/ft$^2$. sec. | btu/ft$^2$. sec. |
| 200 | .129 | .189 | .548 | .832 | 1.719 | 2.174 | 4.782 | 6.785 |
| 300 | .136 | .199 | .023 | .028 | .080 | .090 | .215 | .337 |
| 400 | .140 | .205 | .009 | .017 | .027 | .041 | .107 | .188 |
| 500 | .145 | .212 | | | .005 | .039 | .104 | .202 |
| 600 | .148 | .217 | | | | .025 | .062 | .131 |
| 700 | .150 | .220 | | | | .012 | .032 | .068 |
| 800 | .154 | .225 | | | | .014 | .045 | .094 |
| 900 | .159 | .233 | | | | | .048 | .116 |

Table 18 (Continued)

Radiant Heat Thermal Simulation

.062" Titanium Sheet - RTV Silicone Patched Skin Panel - Power On Patch Side

| TEMP. °F | (17) (7) x $[(10)_n - (10)_{n-1}]$ btu/ft$^2$. sec. | (18) (8) x $[(10)_n - (10)_{n-1}]$ btu/ft$^2$. sec. | (19) (11) / $Q_0$ (11)/1.61 % $\eta$ | (20) (12) / $Q_0$ (12)/2.36 % $\eta$ | (21) (13) / $Q_0$ (13)/3.74 % $\eta$ | (22) (14) / $Q_0$ (14)/3.87 % $\eta$ | (23) (15) / $Q_0$ (15)/7.11 % $\eta$ |
|---|---|---|---|---|---|---|---|
| 200 | 9.922 | 4.857 | 34.0 | 35.3 | 45.9 | 56.2 | 67.3 |
| 300 | .507 | .211 | 1.4 | 1.2 | 2.1 | 2.3 | 3.0 |
| 400 | .292 | .109 | 0.6 | 0.7 | 0.7 | 1.1 | 1.5 |
| 500 | .323 | .110 | | | 0.1 | 1.0 | 1.5 |
| 600 | .219 | .068 | | | | 0.6 | 0.9 |
| 700 | .123 | .037 | | | | 0.3 | 0.5 |
| 800 | .189 | .059 | | | | 0.4 | 0.6 |
| 900 | .273 | .082 | | | | | 0.7 |

| TEMP. °F | (24) (16) / $Q_0$ (16)/10.62 % $\eta$ | (25) (17) / $Q_0$ (17)/18.58 % $\eta$ | (26) (18) / $Q_0$ (18)/7.11 % $\eta$ | (27) $(19)_n - \Sigma(19)_{n-1, n-2, \ldots}$ % $\eta$ | (28) $(20)_n - \Sigma(20)_{n-1, n-2, \ldots}$ % $\eta$ | (29) $(21)_n - \Sigma(21)_{n-1, n-2, \ldots}$ % | (30) $(22)_n - \Sigma(22)_{n-1, n-2, \ldots}$ % |
|---|---|---|---|---|---|---|---|
| 200 | 63.9 | 53.4 | 68.3 | 34.0 | 35.3 | 45.9 | 56.2 |
| 300 | 3.2 | 2.7 | 3.0 | 32.6 | 34.1 | 43.8 | 53.9 |
| 400 | 1.8 | 1.6 | 1.5 | 32.0 | 33.4 | 43.1 | 52.8 |
| 500 | 1.9 | 1.7 | 1.5 | | | 43.0 | 51.8 |
| 600 | 1.2 | 1.2 | 1.0 | | | | 51.2 |
| 700 | 0.6 | 0.7 | 0.5 | | | | 50.9 |
| 800 | 0.9 | 1.0 | 0.8 | | | | 50.5 |
| 900 | 1.1 | 1.5 | 1.2 | | | | |

Table 18 (Continued)

Radiant Heat Thermal Simulation

.062" Titanium Sheet - RTV Silicone Patched Skin Panel - Power On Patch Side

| | (31) | (32) | (33) | (34) |
|---|---|---|---|---|
| TEMP. °F | $(23)_n - \sum (23)_{n-1, n-2, \ldots}$ % $\eta$ | $(24)_n - \sum (24)_{n-1, n-2, \ldots}$ % $\eta$ | $(25)_n - \sum (25)_{n-1, n-2, \ldots}$ % $\eta$ | $(26)_n - \sum (26)_{n-1, n-2, \ldots}$ % $\eta$ |
| 200 | 67.3 | 63.9 | 53.4 | 68.3 |
| 300 | 64.3 | 60.7 | 50.7 | 65.3 |
| 400 | 62.8 | 58.9 | 49.1 | 63.8 |
| 500 | 61.3 | 57.0 | 47.4 | 62.3 |
| 600 | 60.4 | 55.8 | 46.2 | 61.3 |
| 700 | 59.9 | 55.2 | 45.5 | 60.8 |
| 800 | 59.3 | 54.3 | 44.5 | 60.0 |
| 900 | 58.6 | 53.2 | 43.0 | 58.8 |

Table 19

Radiant Heat Thermal Simulation

.062" Titanium Sheet - RTV Silicone Patched Skin Panel - Power Opposite Patch Side

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| TEMP. °F | RUN # 1 $\Delta T/dt$ | RUN # 2 $\Delta T/dt$ | RUN # 3 $\Delta T/dt$ | RUN # 4 $\Delta T/dt$ | RUN # 5 $\Delta T/dt$ | RUN # 6 $\Delta T/dt$ | SPECIFIC HEAT c |
| 100 | 4.2 | 5.8 | 8.8 | 10.0 | 23.8 | 48.1 | .120 |
| 200 | 3.6 | 6.8 | 13.0 | 14.0 | 25.6 | 52.2 | .129 |
| 300 | 2.8 | 6.0 | 13.2 | 14.3 | 26.8 | 52.1 | .136 |
| 400 | 1.7 | 4.8 | 11.9 | 12.8 | 27.0 | 49.9 | .140 |
| 500 | | 2.6 | 9.0 | 11.1 | 26.1 | 45.9 | .145 |
| 600 | | | | 9.1 | 23.0 | 40.0 | .148 |
| 700 | | | | 7.0 | 19.0 | 32.6 | .150 |
| 800 | | | | 4.8 | 16.1 | 24.1 | .154 |
| 900 | | | | 2.4 | 13.5 | 13.9 | .159 |

| | (8) | (9) | (10) | (11) | (12) | (13) | (14) |
|---|---|---|---|---|---|---|---|
| TEMP. °F | $cw\tau$ $w\tau = 1.464$ | (1) × [(8)$_n$ - (8)$_{n-1}$] btu/ft$^2$. sec | (2) × [(8)$_n$ - (8)$_{n-1}$] btu/ft$^2$. sec | (3) × [(8)$_n$ - (8)$_{n-1}$] btu/ft$^2$. sec | (4) × [(8)$_n$ - (8)$_{n-1}$] btu/ft$^2$. sec | (5) × [(8)$_n$ - (8)$_{n-1}$] btu/ft$^2$. sec | (6) × [(8)$_n$ - (8)$_{n-1}$] btu/ft$^2$. sec |
| 100 | .176 | .739 | 1.021 | 1.549 | 1.760 | 4.189 | 8.466 |
| 200 | .189 | .047 | .088 | .169 | .182 | .333 | .679 |
| 300 | .199 | .028 | .060 | .132 | .142 | .268 | .521 |
| 400 | .205 | .010 | .029 | .071 | .077 | .162 | .299 |
| 500 | .213 | | .021 | .072 | .089 | .209 | .367 |
| 600 | .217 | | | | .036 | .092 | .160 |
| 700 | .220 | | | | .021 | .057 | .098 |
| 800 | .226 | | | | .029 | .097 | .145 |
| 900 | .234 | | | | .019 | .108 | .111 |

Table 19 (Continued)

Radiant Heat Thermal Simulation

.062" Titanium Sheet - RTV Silicone Skin Panel - Power Opposite Patch Side

| TEMP. °F | (15) (9)/Q₀ (9)/1.466 %η | (16) (10)/Q₀ (10)/2.169 %η | (17) (11)/Q₀ (11)/3.740 %η | (18) (12)/Q₀ (12)/3.766 %η | (19) (13)/Q₀ (13)/6.950 %η | (20) (14)/Q₀ (14)/9.478 %η |
|---|---|---|---|---|---|---|
| 100 | 50.4 | 47.1 | 41.4 | 46.7 | 60.3 | 89.3 |
| 200 | 3.2 | 4.1 | 4.5 | 4.8 | 4.8 | 7.2 |
| 300 | 1.9 | 2.8 | 3.5 | 3.8 | 3.9 | 5.5 |
| 400 | 0.7 | 1.3 | 1.9 | 2.0 | 2.3 | 3.2 |
| 500 | | 1.0 | 1.9 | 2.4 | 3.0 | 3.9 |
| 600 | | | | 1.0 | 1.3 | 1.7 |
| 700 | | | | 0.6 | 0.8 | 1.0 |
| 800 | | | | 0.8 | 1.4 | 1.5 |
| 900 | | | | 0.5 | 1.6 | 1.2 |

| TEMP. °F | (21) $(15)_n - \sum (15)_{n-1}$, n-2, ... %η | (22) $(16)_n - \sum (16)_{n-1}$, n-2, ... %η | (23) $(17)_n - \sum (17)_{n-1}$, n-2, ... %η | (24) $(18)_n - \sum (18)_{n-1}$, n-2, ... %η | (25) $(19)_n - \sum (19)_{n-1}$, n-2, ... %η | (26) $(20)_n - \sum (20)_{n-1}$, n-2, ... %η |
|---|---|---|---|---|---|---|
| 100 | 50.4 | 47.1 | 41.4 | 46.7 | 60.3 | 89.3 |
| 200 | 47.2 | 43.0 | 36.9 | 41.9 | 55.5 | 82.1 |
| 300 | 45.3 | 40.2 | 33.4 | 38.1 | 51.6 | 76.6 |
| 400 | 44.6 | 38.9 | 31.5 | 36.1 | 49.3 | 73.4 |
| 500 | | 37.9 | 29.6 | 33.7 | 46.3 | 69.5 |
| 600 | | | | 32.7 | 45.0 | 67.8 |
| 700 | | | | 32.1 | 44.2 | 66.8 |
| 800 | | | | 31.3 | 42.8 | 65.3 |
| 900 | | | | 30.8 | 41.2 | 64.1 |

Table 20

h (Corrected) Using Variable Rise Rates

| $T_s$ (°F) | Time (sec) | h (BTU/Ft$^2$-Hr) | ΔT/dt (°/sec) | η % | h/η (BTU/Ft$^2$-Hr) |
|---|---|---|---|---|---|
| 100 | 15.5 | 31.0 | 6.4 | 31.7 | 97.8 |
| 200 | 22.8 | 45.7 | 13.6 | 34.0 | 134.4 |
| 300 | 27.2 | 54.8 | 22.7 | 36.1 | 151.8 |
| 400 | 31.1 | 62.5 | 25.6 | 36.0 | 173.6 |
| 500 | 35.2 | 70.9 | 24.3 | 34.1 | 207.9 |
| 600 | 39.2 | 78.8 | 25.0 | 33.6 | 234.5 |
| 700 | 43.9 | 88.1 | 21.2 | 32.5 | 271.1 |
| 800 | 48.2 | 97.0 | 23.2 | 32.0 | 303.1 |
| 900 | 53.0 | 100.0 | 20.8 | 30.6 | 326.8 |

Table 21

h (Corrected) Assuming Constant Rise Rate of 20 °/sec

| | | | | | |
|---|---|---|---|---|---|
| 100 | 15.5 | 31.0 | 20.0 | 39.3 | 78.9 |
| 200 | 22.8 | 45.7 | 20.0 | 37.0 | 123.5 |
| 300 | 27.2 | 54.8 | 20.0 | 35.3 | 155.2 |
| 400 | 31.1 | 62.5 | 20.0 | 34.4 | 181.7 |
| 500 | 35.2 | 70.9 | 20.0 | 33.0 | 214.8 |
| 600 | 39.2 | 78.8 | 20.0 | 32.6 | 241.7 |
| 700 | 43.9 | 88.1 | 20.0 | 32.3 | 272.8 |
| 800 | 48.2 | 97.0 | 20.0 | 31.5 | 307.9 |
| 900 | 53.0 | 100.0 | 20.0 | 30.4 | 328.9 |

# Addendum

Elevated and room temperature fatigue tests were conducted at an approximate rate of 18 to 20 cycles per minute on 2 x 2 inch tension patches bonded with GE RTV-60 and DC 5302-5303 adhesives. Techniques of application of primer and adhesive were those recommended in Section II of this report. Heating was accomplished by using cylindrical radiant heat ovens (Fig. 16). Test results are presented in the following curves, Figures 57 through 61.

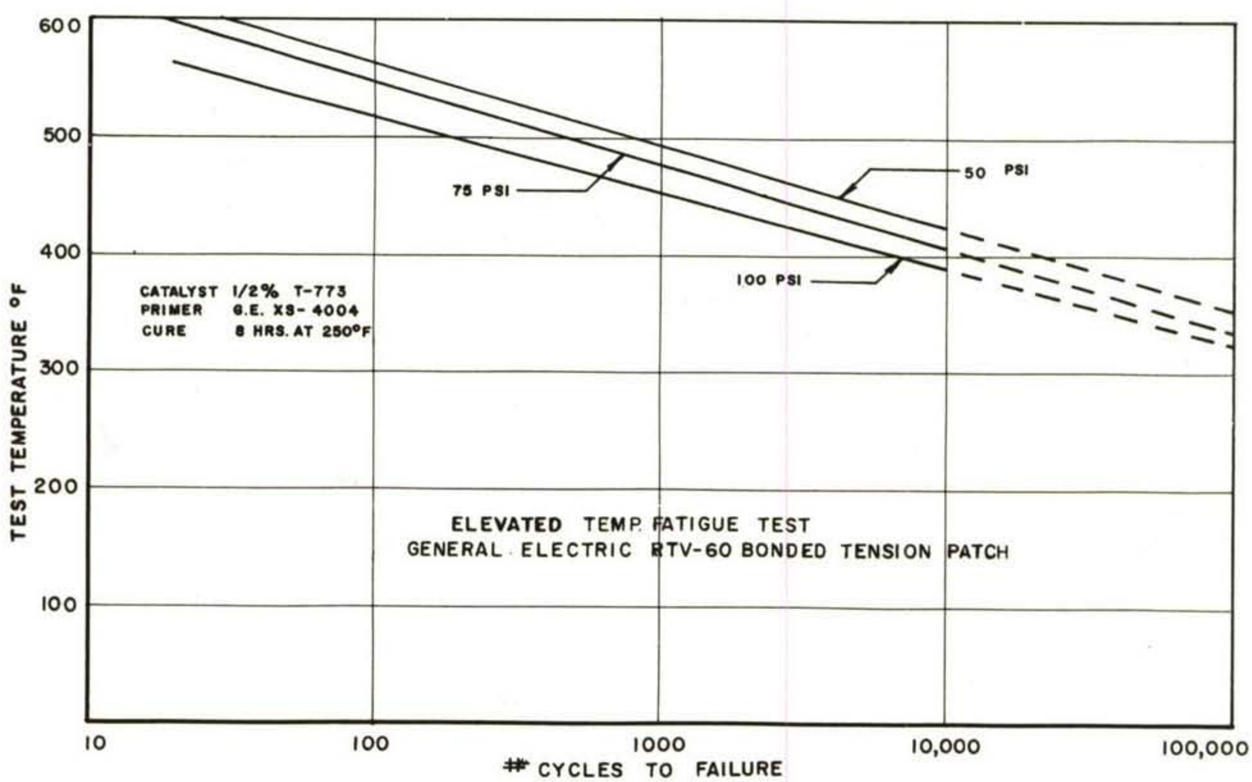


*Figure 57 G.E. RTV-60 Silicone Bonded Tension Patch Test Temperature vs Cycles to Failure for Various Patch Loadings.*

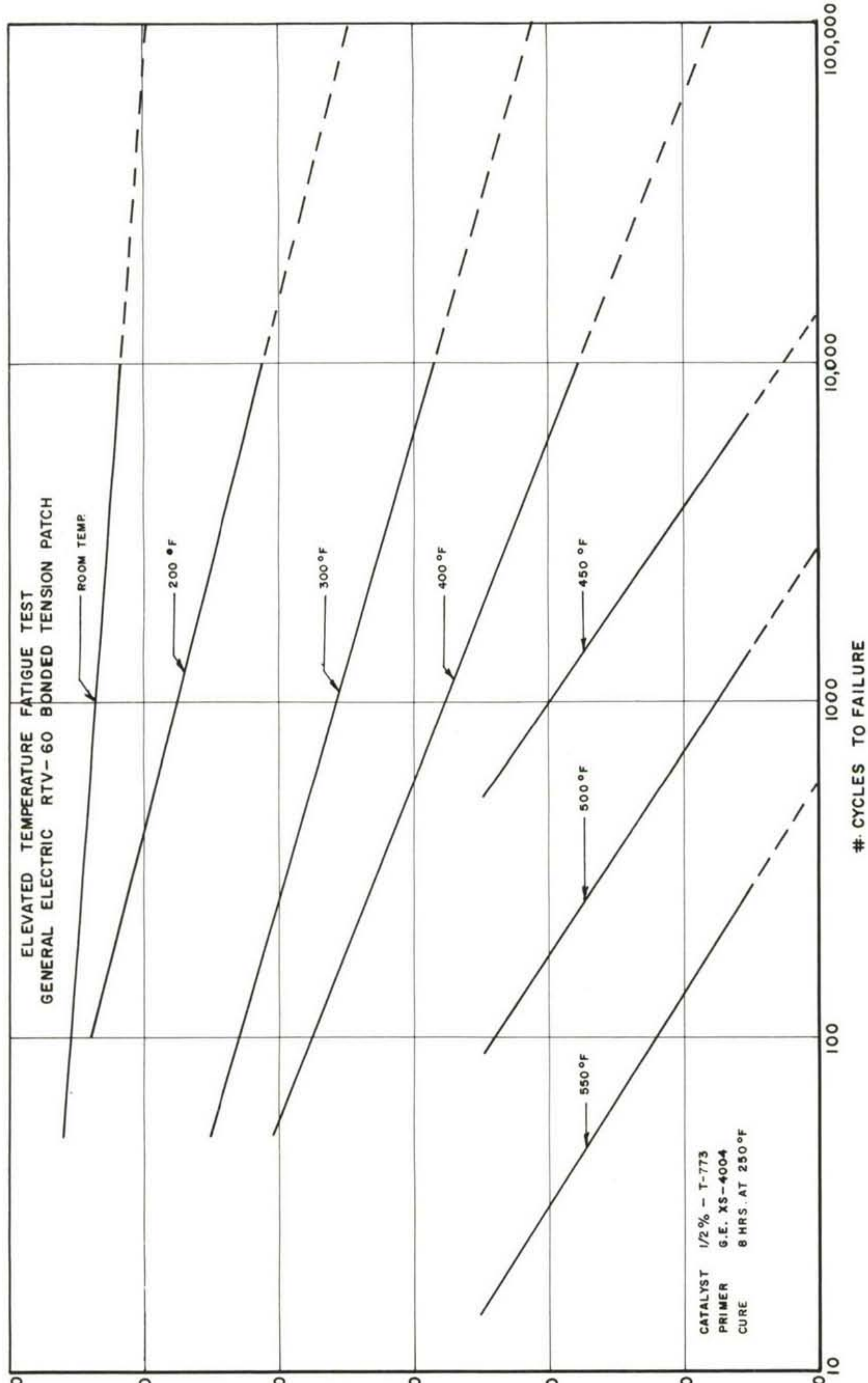


*Figure 58. G.E. RTV - 60 Silicone Bonded Tension Patch Failing Load vs Cycles To Failure for Various Test Temperatures.*

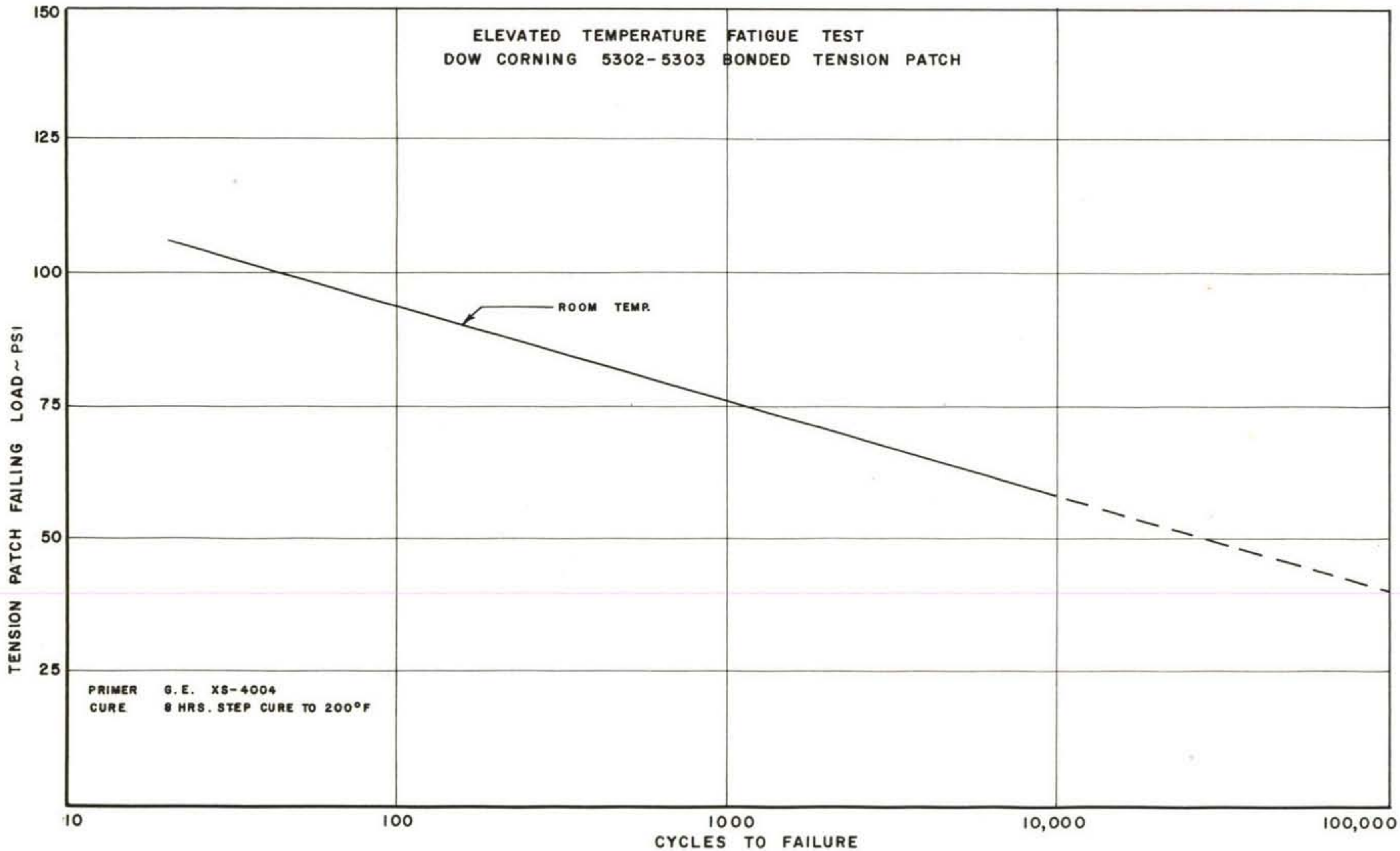


*Figure 59. DC 5302–5303 Silicone Bonded Tension Patch Failing Load vs Cycles to Failure At Room Temperature.*

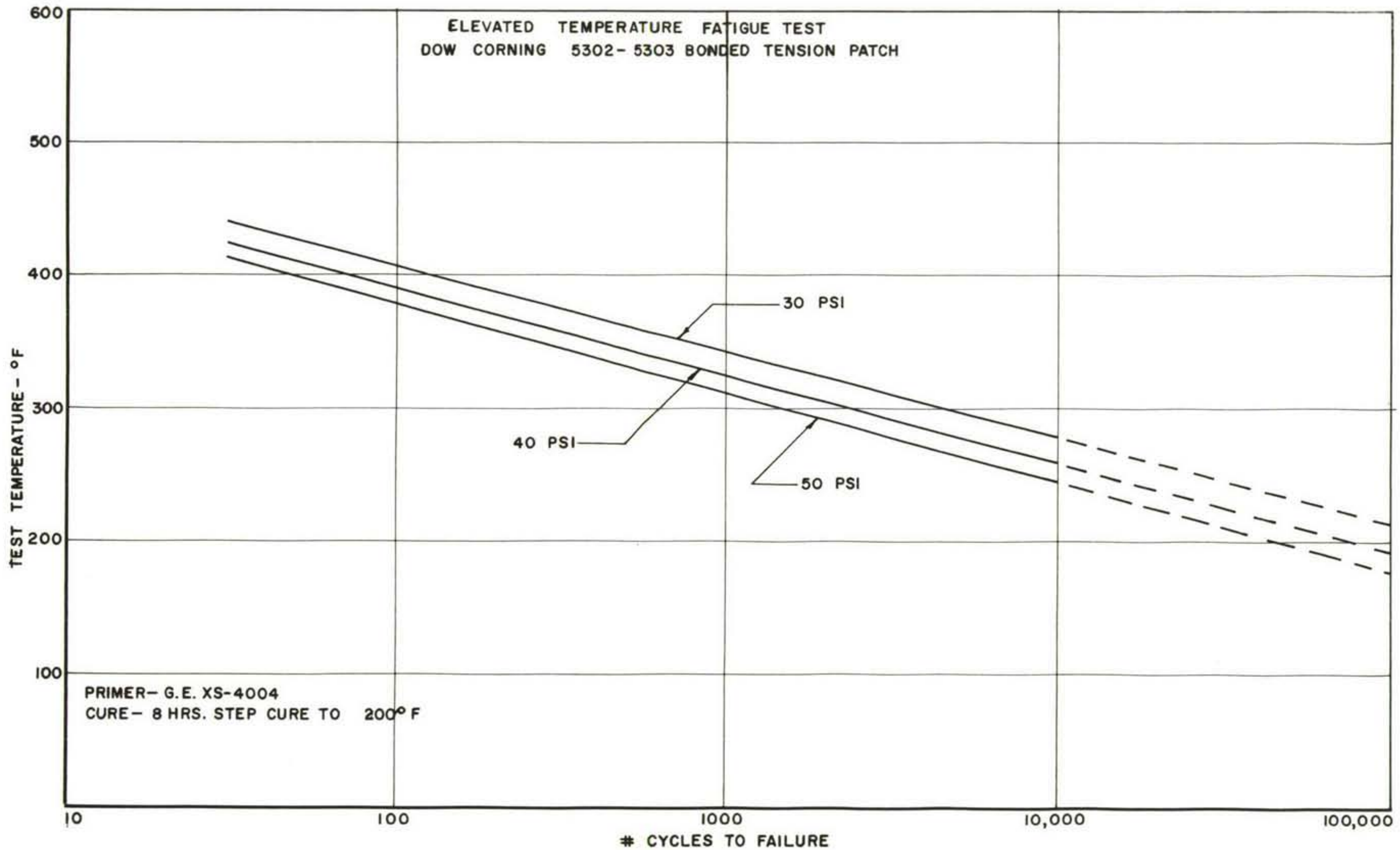


*Figure 60. DC 5302–5303 Silicone Bonded Tension Patch Test Temperature vs Cycles to Failure for Various Patch Loadings.*

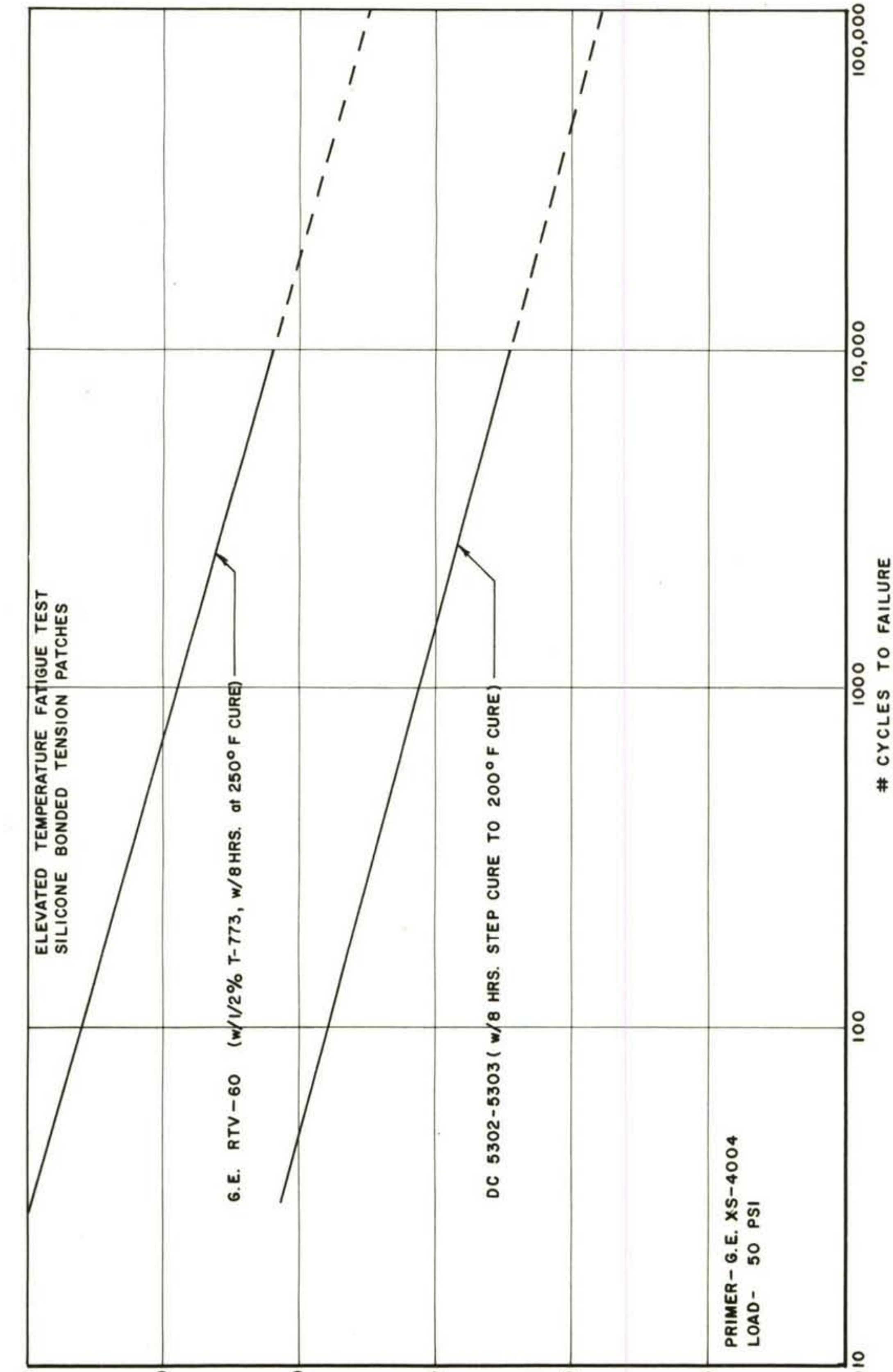


*Figure 61. G.E. RTV–60 And DC 5302–5303 Silicone Bonded Tension Patch Test Temperature vs Cycles to Failure for a 50 psi Patch Loading.*

Engineering Test Division, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio.
HIGH TEMPERATURE TENSION PATCH AND THERMAL SIMULATION METHODS FOR STRUCTURAL TESTING, by Bernard C. Boggs. July 1960, 88 p. incl illus. (Proj. 1347; Task 13730) (WADD-TR-60-235) Unclassified report.

The development of elevated temperature tension patches and shear loading straps using RTV (room temperature vulcanizing) silicone material as the bonding agent is

( over )

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described in Sections I and II. For tension patches, 2 x 2 inch backing plates are bonded directly to the surface for loading. The methods described resulted in tension patch applications which may be used satisfactorily to approximately 550°F under steady state temperature conditions. They may be used for transient heating to higher temperatures for short time duration. The current practice of installing built-in load fittings in the structure is costly and not representative.

Temperature and load simulation techniques are discussed in Section III.

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Engineering Test Division, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio.
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