EFFECT OF PROTECTIVE COATINGS ON THE STRESS-CORROSION PROPERTIES OF SUPERSONIC-TRANSPORT SKIN MATERIALS

TENTH QUARTERLY STATUS REPORT
to
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
For the Period Between 1 March, 1965 and 31 May, 1965
Contract No. NASr-117

SOUTHERN RESEARCH INSTITUTE
2000 9th Avenue S. Birmingham 5, Alabama

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Southern Research Institute
Birmingham, Alabama 35205
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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

REPORT ON

EFFECT OF PROTECTIVE COATINGS ON THE STRESS-CORROSION PROPERTIES OF SUPERSONIC-TRANSPORT SKIN MATERIALS

INTRODUCTION

This report summarizes the progress made during the fourth quarter of a project being performed by Southern Research Institute under Contract No. NASr-117. This quarter consists of the period between 1 March, 1965, and 31 May, 1965.

The purpose of this research project is to determine whether selected coatings will protect metal substrates from stress-corrosion. These data will provide needed additional information on the feasibility of using commercially available protective coatings to prevent corrosion of the skins of supersonic-transport aircraft (SST). The coatings and substrates to be evaluated were chosen from the results of earlier work on this contract (1, 2)[1].

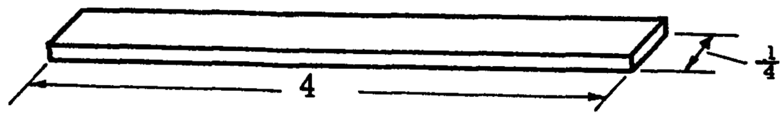
Pertinent background information and a detailed description of the specimen preparation and environmental exposures, along with the general evaluation procedure, were presented in earlier progress reports and will not be repeated here. Described briefly, the program consists of various stress-corrosion exposures applied to self-loading type specimens constructed as shown in Figure 1. The substrates, coatings, exposure conditions and evaluation methods are charted in Figure 2.

WORK PERFORMED

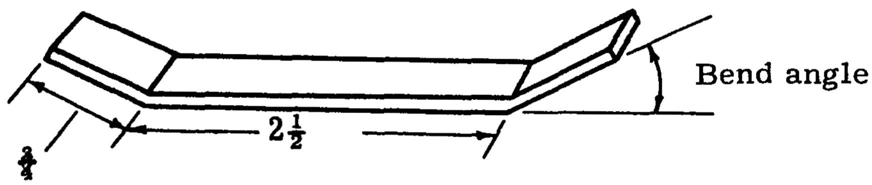
While the stress-corrosion specimens were undergoing exposures to the dry 550° F and the humid 95° F atmospheres, we constructed a fixture capable of supporting the exposed specimens for bend-ductility evaluations. After 1,000 hours, the first group of exposed specimens was removed from the exposure atmospheres, visually examined, rinsed, and subjected to compressive loading for bend-ductility evaluations.

The fixture consisted of two clamping members fitted vertically in a manually operated hydraulic press. Both clamping members were mechanically secured to the press, the top clamp to the upper, stationary crosshead of the

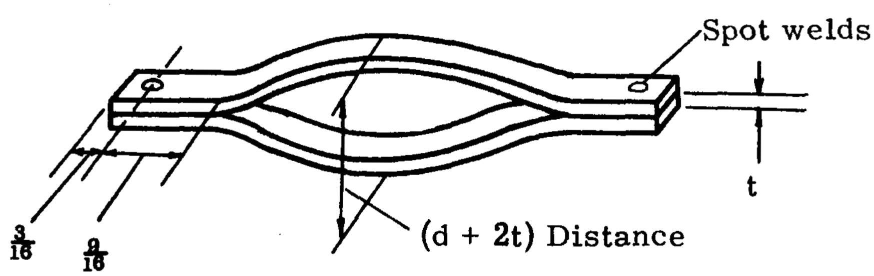
[1] The numbers in parentheses refer to the bibliography at the end of the report.



(a) Machined strip.

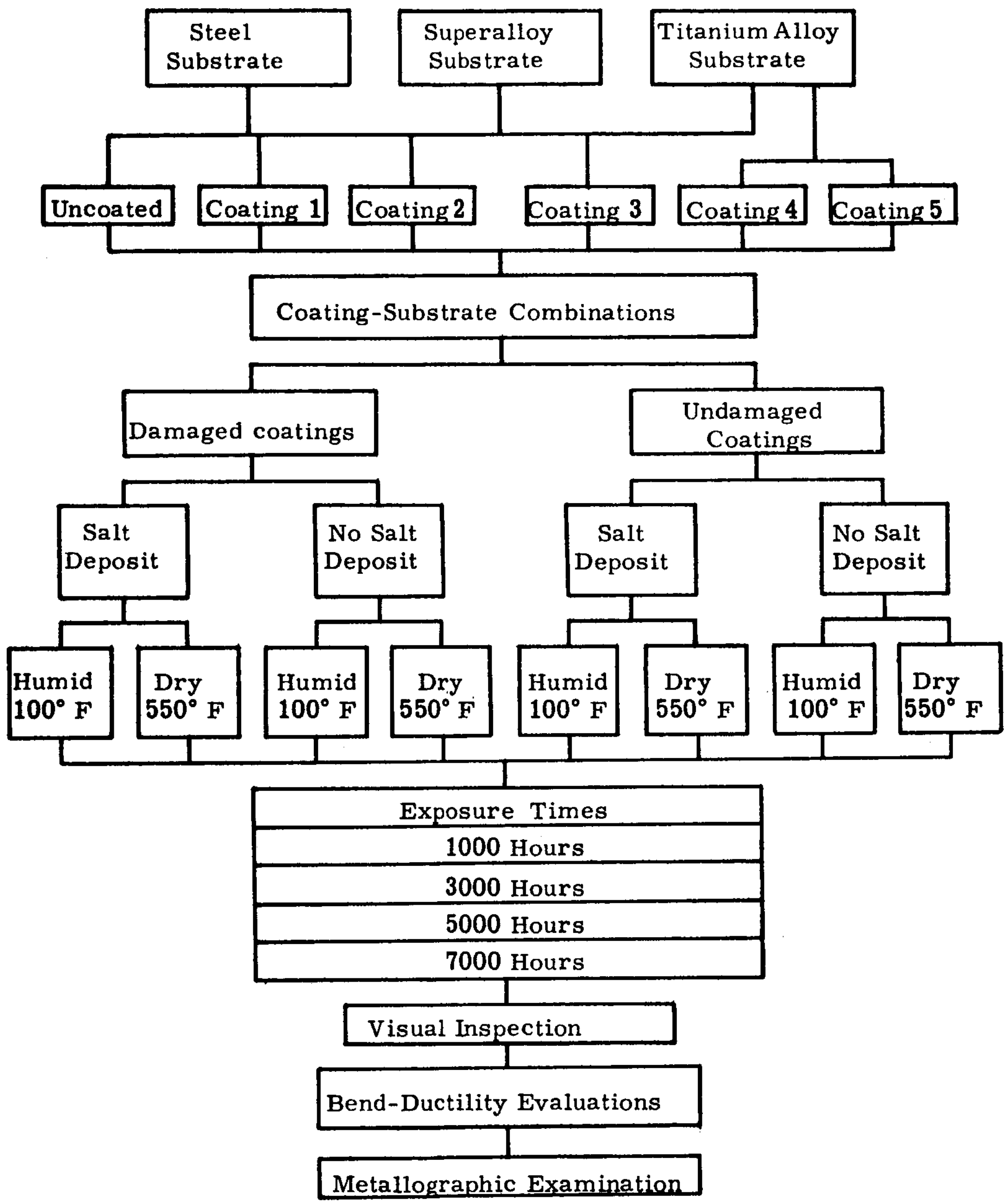


(b) Strip with ends bent.



(c) Completed specimen.

Figure 1. Construction of the self-stressed specimen. (All dimensions are in inches).



Coating 1 - Aluminum-Modified Silicone
Coating 2 - Catalytically Cured Silicone
Coating 3 - Zinc in Silicate vehicle
Coating 4 - Electrophoretically Deposited Aluminum
Coating 5 - Flame-Sprayed Aluminum

Figure 2. Flow Sheet of Experimental Conditions

press by means of a threaded stud, and the bottom clamp to a steel supporting block that was "C" clamped to the lower, movable platen. A dial gage calibrated in 0.001-in. increments was mounted on a ring stand adjacent to the press. The height of the dial gage was adjustable on the ring stand and could be positioned so that the stem could bear against the movable platen of the press.

The configuration of the clamping members is shown in Figure 3. The members consisted of two 3-in. long, 1.25-in.-diameter round steel bars. Both members contained a 1-in.-deep, 0.100-in.-wide slot into which the specimen tab ends could be inserted. The edges of each slot were rounded to insure against breakage of the specimen at that point where the specimen deflected and bore against an edge of the slots. In order to insure that lateral alignment of the specimen tab ends could be repeated from specimen to specimen, we inserted two dial-pin locators across each slot. Four set screws were used in conjunction with each slot for the purpose of anchoring the specimens' tab ends. The set screws were arranged in pairs, with each pair extending through the sides on opposite sides of the slot.

PROCEDURES

Following the visual examination of the exposed specimens and the removal of salt from appropriate specimens by water rinsing, we loaded each specimen into the clamping members with its (D + 2t) distance (refer to Figure 1c) extending horizontally. The lower movable platen of the press was raised to a position where the full 3/4-in. length of the specimen tab ends would extend into the slots of both clamping members. Once inside the slots, the tab ends were positioned against the dial-pin locator stops and also against a common slot side in both clamping members. The specimen was then locked into position by tightening the set screws against the flat face of the tab ends.

After positioning and securing the specimen in the fixture, we placed the dial gage in contact with the lower movable platen and set it to the zero position. The specimen was then compressed by raising the lower platen with the hydraulic pump. Specimen compression was continued until fracture occurred, or until complete compression (maximum specimen shortening with contact between the tab ends) was attained. The dial gage, activated by the upward movement of the lower platen, provided a reading of the bend-ductility or shortening that occurred in the specimen.

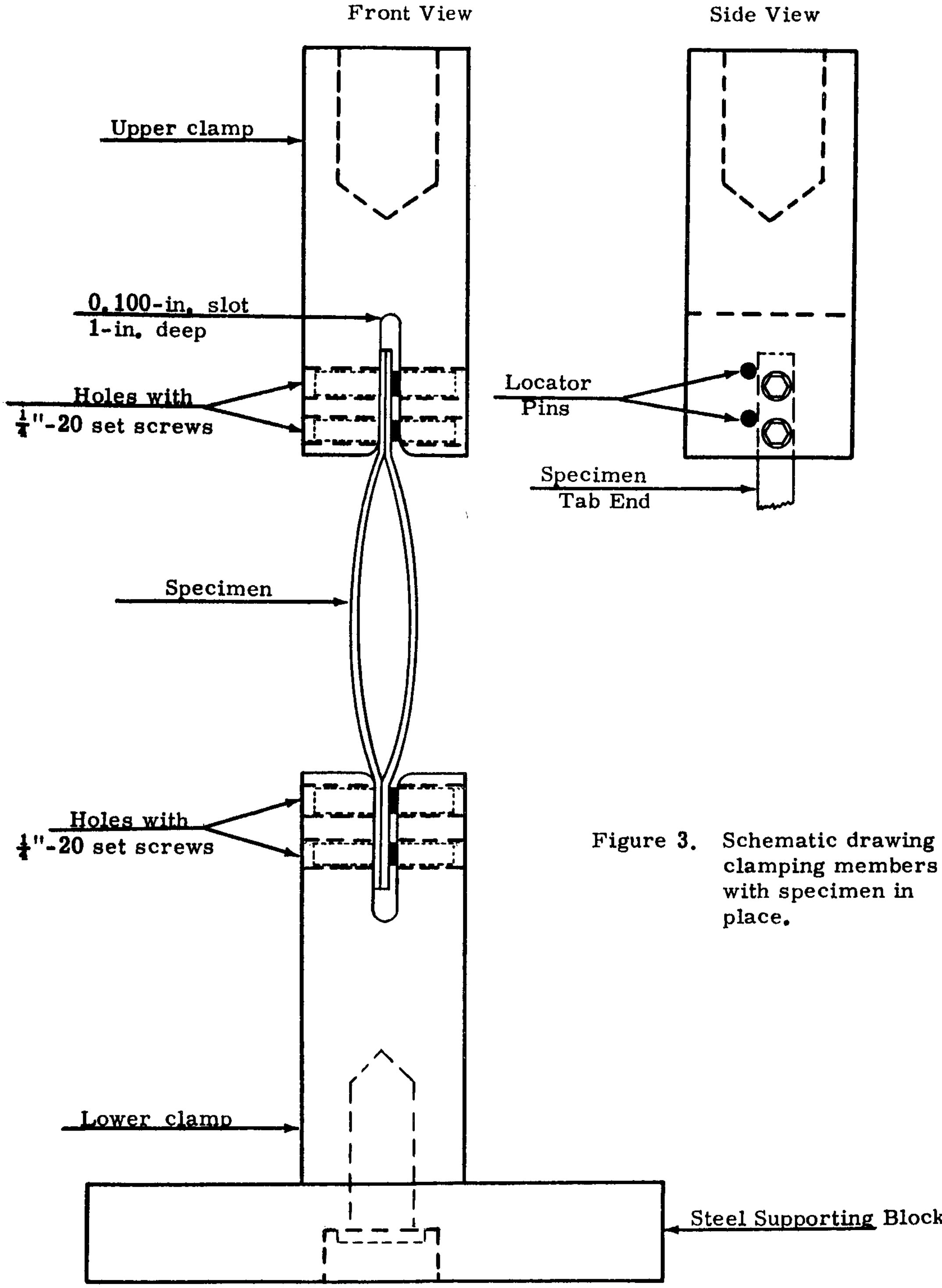


Figure 3. Schematic drawing of clamping members with specimen in place.

RESULTS AND DISCUSSION

Visual Examination

The results of the visual examinations of the exposed specimens are listed in Table I. This table lists general observations on the appearance of each substrate-coating combination after exposure to the dry 500° F or humid 95° F atmosphere.

The dry 550° F atmosphere caused the bare substrate of AM 350 and titanium to discolor but caused no discoloration of the bare Rene 41 substrate. The exposure to the humid 95° F atmosphere caused no visual changes in any of the bare substrates with the exception of a few rust spots on the bare, salt-deposited AM 350 alloy. Except for the occurrence of a few salt stains on salt-deposited specimens in the humid 95° F atmosphere, the appearance of the specimens coated with Aluminum-Modified Silicone was not changed by either exposure. The Catalytically-Cured-Silicone-coated specimens showed no visual change during the humid 95° F exposure. However, in the dry 550°F exposure, the Catalytically-Cured-Silicone coating shredded and spalled completely from all specimens of each substrate. Each specimen coated with Zinc-in-Silicate-Vehicle contained areas of grayish-white discoloration after exposure to the humid 95° F atmosphere. The dry 550° F atmosphere caused grayish-white discolorations to appear only on those zinc-coated specimens that had been subjected to salt deposits. These discolorations appeared only at the immediate areas where the salt was in contact with the coating.

Bend-Ductility

The complete results of the bend-ductility evaluations on the 1,000-hour exposed specimens are listed in Tables II, III, and IV. The data from these tables are graphically illustrated in Figures 4, 5, and 6 (550° F exposure) and in Figures 7, 8, and 9 (95° F exposure). In each figure the bend-ductility or shortening data is presented in bar-chart form with each bar representing an average shortening value for two or more replicate specimens of a particular substrate-coating combination.

Four exposure conditions are indicated in each figure. These conditions are: undamaged, no salt; damaged, no salt; undamaged, with salt; and damaged, with salt. Grouped within each of the exposure conditions are separate bars that represent the average results from each substrate-coating combination. The bar for each substrate-coating combination is made with a different pattern so that particular combinations can be easily followed from one figure to the next. The dashed line in each figure represents the inherent shortening ductility of the substrate involved. The inherent ductility of a

Table I. Visual Examination of 1,000-Hr Exposed Specimens

Coating	Substrate	Exposure	Visual Observations after Exposure
Bare	AM 350	550° F	Brownish-bronze color over entire surface.
		95° F	Rust spots on specimen with salt.
Aluminum-Modified Silicone	AM 350	550° F	No change.
		95° F	Salt stains—otherwise no change.
Catalytically-Cured Silicone	AM 350	550° F	Coating spalled and shredded over entire surface within 48 hrs.
		95° F	No change.
Zinc in Silicate Vehicle	AM 350	550° F	Grayish-white oxide only on specimens with salt. No change in specimens with no salt.
		95° F	Spotted areas of brownish-gray discoloration on all specimens exposed.
Bare	Titanium	550° F	Yellowish-gold color over entire surface.
		95° F	No specimen exposed.
Aluminum-Modified Silicone	Titanium	550° F	No change.
		95° F	No change.
Catalytically-Cured Silicone	Titanium	550° F	Coating spalled and shredded over entire surface within 48 hrs.
		95° F	No change.
Zinc in Silicate Vehicle	Titanium	550° F	Grayish-white oxide only on specimens with salt. No change in specimens without salt.
		95° F	Only salt-coated specimens involved—grayish-white oxide layer.
Elphal	Titanium	550° F	No change.
		95° F	No specimen exposed.
Bare	René 41	550° F	No change.
		95° F	No change.
Aluminum-Modified Silicone	René 41	550° F	No change.
		95° F	Several salt stains only on salt-deposited specimens.
Catalytically-Cured Silicone	René 41	550° F	Coating spalled & shredded over entire surface within 48 hrs.
		95° F	No change.
Zinc in Silicate Vehicle	René 41	550° F	Grayish-white oxide only on specimens with sale. No change in specimens without salt.
		95° F	Grayish-white oxide layer on all specimens exposed.

Table II. AM 350 Bend-Ductility Data—1,000 Hours Exposure to Dry 550° F and Humid 95° F Atmospheres

Coating	Specimen Numbers[1] Undamaged No Salt	Specimen Numbers[1] Damaged No Salt	Specimen Numbers[1] Undamaged With Salt	Specimen Numbers[1] Damaged With Salt	Shortening in Inches Undamaged No Salt	Shortening in Inches Damaged No Salt	Shortening in Inches Undamaged With Salt	Shortening in Inches Damaged With Salt
AM 350 — 1,000 Hours, 550° F, Dry Atmosphere								
Bare	A0U1H1A	A0D1H1A	A0U2H1A	A0D2H1A	2.168	2.166	2.166	2.155
Bare	A0U1H1B	A0D1H1B	A0U2H1B	A0D2H1B	2.167	2.061	2.169	2.170
Aluminum-Modified Silicone	A1U1H1A	A1D1H1A	A1U2H1A	A1D2H1A	2.168	2.145	2.165	2.167
Aluminum-Modified Silicone	A1U1H1B	A1D1H1B	A1U2H1B	A1D2H1B	2.163	2.163	2.165	2.068
Aluminum-Modified Silicone			A1U2H1C				2.166	
Catalytically-Cured Silicone	A2U1H1A	A2D1H1A	A2U2H1A	A2D2H1A	2.161	2.075	2.163	2.165
Catalytically-Cured Silicone	A2U1H1B	A2D1H1B	A2U2H1B	A2D2H1B	2.168	1.964	2.160	2.161
Zinc in Silicate Vehicle	A3U1H1A	A3D1H1A	A3U2H1A	A3D2H1A	2.161	2.162	2.144	2.155
Zinc in Silicate Vehicle	A3U1H1B	A3D1H1B	A3U2H1B	A3D2H1B	2.159	2.163	2.145	2.123
AM 350 — 1,000 Hours, 95° F, 95% Humidity								
Bare	A0U1L1A	A0D1L1A	A0U2L1A	A0D2L1A	2.194	2.177	0[2]	0[2]
Bare	A0U1L1B	A0D1L1B	A0U2L1B	A0D2L1B	2.218	2.180	2.171	0[2]
Aluminum-Modified Silicone	A1U1L1A	A1D1L1A	A1U2L1A	A1D2L1A	2.155	2.170	2.174	2.170
Aluminum-Modified Silicone	A1U1L1B	A1U2L1B	A1U2L1B	A1D2L1B	2.163	2.167	2.165	2.165
Catalytically-Cured Silicone	A2U1L1A	A2D1L1A	A2U2L1A	A2D2L1A	2.165	2.167	2.159	1.975
Catalytically-Cured Silicone	A2U1L1B	A2D1L1B	A2U2L1B	A2D2L1B	2.164	2.110	2.165	2.161
Zinc in Silicate Vehicle	A3U1L1A	A3D1L1A	A3U2L1A	A3D2L1A	1.950	1.440	2.155	1.330
Zinc in Silicate Vehicle	A3U1L1B	A3D1L1B	A3U2L1B	A3D2L1B	1.360	1.705	1.965	1.000

[1] These specimen numbers relate to the shortening results that are located in the same relative positions.
[2] Fractured during exposure within 800 hours.

Table III. Rene' 41 Bend-Ductility Data—1,000 Hours Exposure to Dry 550° F and Humid 95° F Atmospheres

Coating	Specimen Numbers[1]: Undamaged No Salt	Damaged No Salt	Undamaged With Salt	Damaged With Salt	Shortening in Inches: Undamaged No Salt	Damaged No Salt	Undamaged With Salt	Damaged With Salt
Rene' 41 — 1,000 Hours, 550° F, Dry Atmosphere								
Bare	R0U1H1A	R0D1H1A	R0D1H1A	R0D2H1A	0.485	1.264	1.284	0.795
Bare	R0U1H1B	R0D1H1B	R0U2H1B	R0D2H1B	0.319	1.620	0.400	1.155
Aluminum-Modified Silicone	R1U1H1A	R1D1H1A	R1U2H1A	R1D2H1A	1.014	0.980	1.750	0.645
Aluminum-Modified Silicone	R1U1H1B	R1D1H1B	R1U2H1B	R1D2H1B	0.970	0.858	0.738	0.904
Aluminum-Modified Silicone	R1U1H1C		R1U2H1C	R1D2H1C	0.445		0.715	0.755
Catalytically-Cured Silicone	R2U1H1A	R2D1H1A	R2U2H1A	R2D2H1A	1.030	1.232	1.784	1.035
Catalytically-Cured Silicone	R2U1H1B	R2D1H1B	R2U2H1B	R2D2H1B	0.824	0.800	1.148	0.745
Catalytically-Cured Silicone	R2U1H1C		R2U2H1C	R2D2H1C	1.000		1.400	0.769
Zinc in Silicate Vehicle	R3U1H1A		R3U2H1Z	R3D2H1A	0.640		0.558	0.540
Zinc in Silicate Vehicle	R3U1H1B	R3D1H1B	R3U2H1B	R3D2H1B	0.753	0.748	0.744	0.687
Zinc in Silicate Vehicle	R3U1H1C		R3U2H1C	R3D2H1C	0.875		0.670	0.660
Rene' 41 — 1,000 Hours, 95° F, 95% Humidity								
Bare	R0U1L1A	R0D1L1A	R0U2L1A	R0D2L1A	1.465	0.695	1.085	1.390
Bare	R0U1L1B	R0D1L1B	R0U2L1B	R0D2L1B	0.910	1.582	0.956	0.434
Aluminum-Modified Silicone	R1U1L1A	R1D1L1A	R1U2L1A	R1D2L1A	0.966	1.350	0.730	1.100
Aluminum-Modified Silicone	R1U1L1B	R1D1L1B	R1U2L1B	R1D2L1B	0.634	0.813	0.985	0.720
Aluminum-Modified Silicone	R1U1L1C		R1U2L1C	R1D2L1C	0.700		0.705	0.795
Catalytically-Cured Silicone	R2U1L1A	R2D1L1A	R2U2L1A	R2D2L1A	1.400	1.040	1.682	1.710
Catalytically-Cured Silicone	R2U1L1B	R2D1L1B	R2U2L1B	R2D2L1B	1.380	1.250	1.010	1.249
Catalytically-Cured Silicone	R2U1L1C		R2U2L1C	R2D2L1C	0.945		0.748	1.000
Zinc in Silicate Vehicle	R3U1L1A	R3D1L1A	R3U2L1A	R3D2L1A	0.490	0.355	0.651	0.550
Zinc in Silicate Vehicle	R3U1L1B	R3D1L1B	R3U2L1B	R3D2L1B	0.805	0.453	0.645	0.469
Zinc in Silicate Vehicle	R3U1L1C		R3U2L1C	R3D2L1C	0.735		0.440	0.423

[1] These specimen numbers relate to the shortening results that are located in the same relative positions.

Table IV. Ti-8Al-1Mo-1V Bend-Ductility Data—1,000 Hours Exposure to Dry 550° F and Humid 95° F Atmospheres

Coating	SPECIMEN NUMBERS[1] Undamaged No Salt	Damaged No Salt	Undamaged With Salt	Damaged With Salt	SHORTENING IN INCHES Undamaged No Salt	Damaged No Salt	Undamaged With Salt	Damaged With Salt
	Titanium — 1,000 Hours, 550° F, Dry Atmosphere							
Bare	T0U1H1A	T0D1H1A	T0U2H1A	T0D2H1A	1.484	1.450	0.315	0.236
Bare	T0U1H1B	T0D1H1B	T0U2H1B	ToD2H1B	1.765	0.955	0.530	0.305
Bare	T0U1H1C	T0D1H1C	T0U2H1C	T0D2H1C	1.885	1.345	0.334	0.230
Aluminum-Modified Silicone	T1U1H1A	T1D1H1A	T1U2H1A	T1D2H1A	1.819	1.561	1.810	1.348
Aluminum-Modified Silicone	T1U1H1B	T1D1H1B	T1U2H1B	T1D2H1B	1.285	1.254	1.405	1.167
Aluminum-Modified Silicone	T1U1H1C	T1D1H1C	T1U2H1C	T1D2H1C	1.828	1.214	1.790	1.230
Catalytically-Cured Silicone	T2U1H1A	T2D1H1A	T2U2H1A	T2D2H1A	1.790	1.365	1.700	1.444
Catalytically-Cured Silicone	T2U1H1B	T2D1H1B	T2U2H1B	T2D2H1B	1.794	1.152	1.450	1.442
Catalytically-Cured Silicone	T2U1H1C	T2D1H1C	T2U2H1C	T2D2H1C	1.730	1.510	1.815	1.469
Zinc in Silicate Vehicle	T3U1H1A	T3D1H1A	T3U2H1A	T3D2H1A	0.719	0.748	0.700	0.630
Zinc in Silicate Vehicle	T3U1H1B	T3D1H1B	T3U2H1B	T3D2H1B	0.748	0.750	0.720	0.815
Zinc in Silicate Vehicle	T3U1H1C	T3D1H1C	T3U2H1C	T3D2H1C	0.660	0.779	0.775	0.834
Elphal	T4U1H1A		T4U2H1A	T4D2H1A	0.554		0.320	0.470
Elphal	T4U1H1B		T4U2H1B	T4D2H1B	1.566		0.894	0.340
Elphal	T4U1H1C		T4U2H1C	T4D2H1C	0.780		0.480	1.480
	Titanium — 1,000 Hours, 95° F, 95% Humidity							
Aluminum-Modified Silicone			T1U2L1A				1.750	
Aluminum-Modified Silicone			T1U2L1B				1.838	
Aluminum-Modified Silicone			T1U2L1C				1.795	
Catalytically-Cured Silicone			T2U2L1A				1.500	
Catalytically-Cured Silicone			T2U2L1B				1.760	
Catalytically-Cured Silicone			T2U2L1C				1.925	
Zinc in Silicate Vehicle			T3U2L1A				1.100	
Zinc in Silicate Vehicle			T3U2L1B				1.225	
Zinc in Silicate Vehicle			T3U2L1C				1.162	

[1] These specimen numbers relate to the shortening results that are located in the same relative position.

substrate was determined by measuring the amount of shortening that occurred during compression of a bare, unexposed specimen of that substrate.

Because of the specimen and bending-fixture geometries, maximum shortening (maximum ductility) ranged between 2.0 and 2.2 in. All specimens with shortening values less than 2.0 in., including those used to measure inherent ductility, fractured in one or both bowed members. Some specimens with shortening values between 2.0 and 2.2 in. fractured also, but these fractures were considered to be insignificant because the shortening values were within the maximum ductility range.

Whether or not embrittlement has occurred is indicated by comparing the difference between the substrate's inherent ductility and its ductility after exposure. Because of the type of exposures involved, we assumed that any significant reduction in shortening was a result of stress corrosion. In our analysis of the results, ductility reductions of 0.2 in. or more were considered to be significant.

Figure 4, which presents the results from the AM 350 bare and coated specimens exposed to the dry 550° F environment, shows that there was no significant loss in ductility during the first 1,000 hours, either in salted or unsalted specimens. Therefore, it is indicated that AM 350 alloy is insensitive to hot-salt within 1,000 hours of exposure. If this insensitivity prevails throughout the long-duration exposures, protective coatings would not be necessary for AM 350 in this environment, but they would not be harmful if needed for protection in other environments.

The ductility results from Rene' 41 specimens exposed to the dry 550° F atmosphere are presented in Figure 5. These results are quite erratic for both bare and coated specimens. For example, the bare, damaged specimens exhibited greater ductility than the bare undamaged specimens, regardless of whether exposed to salt or not. In fact, the bare, undamaged, and unsalted specimens had the poorest ductility of all Rene' 41 specimens subjected to the dry 550° F environment.

The Aluminum-Modified Silicone and Catalytically-Cured Silicone specimens showed similar erratic results in that neither salt nor prior mechanical damage affected the ductility results in any consistent pattern. The specimens coated with Zinc in Silicate Vehicle were the only ones that produced consistent results, and all of these had reduced ductility. This reduced ductility in the undamaged and unsalted specimens decreased slightly but steadily from the least severe condition to the most severe condition. Since the inherent ductility of the Rene' 41 substrate was apparently inconsistent, the effect of the coatings was obscured, with the possible exception that the zinc coating is detrimental both in the presence and absence of deposited salt.

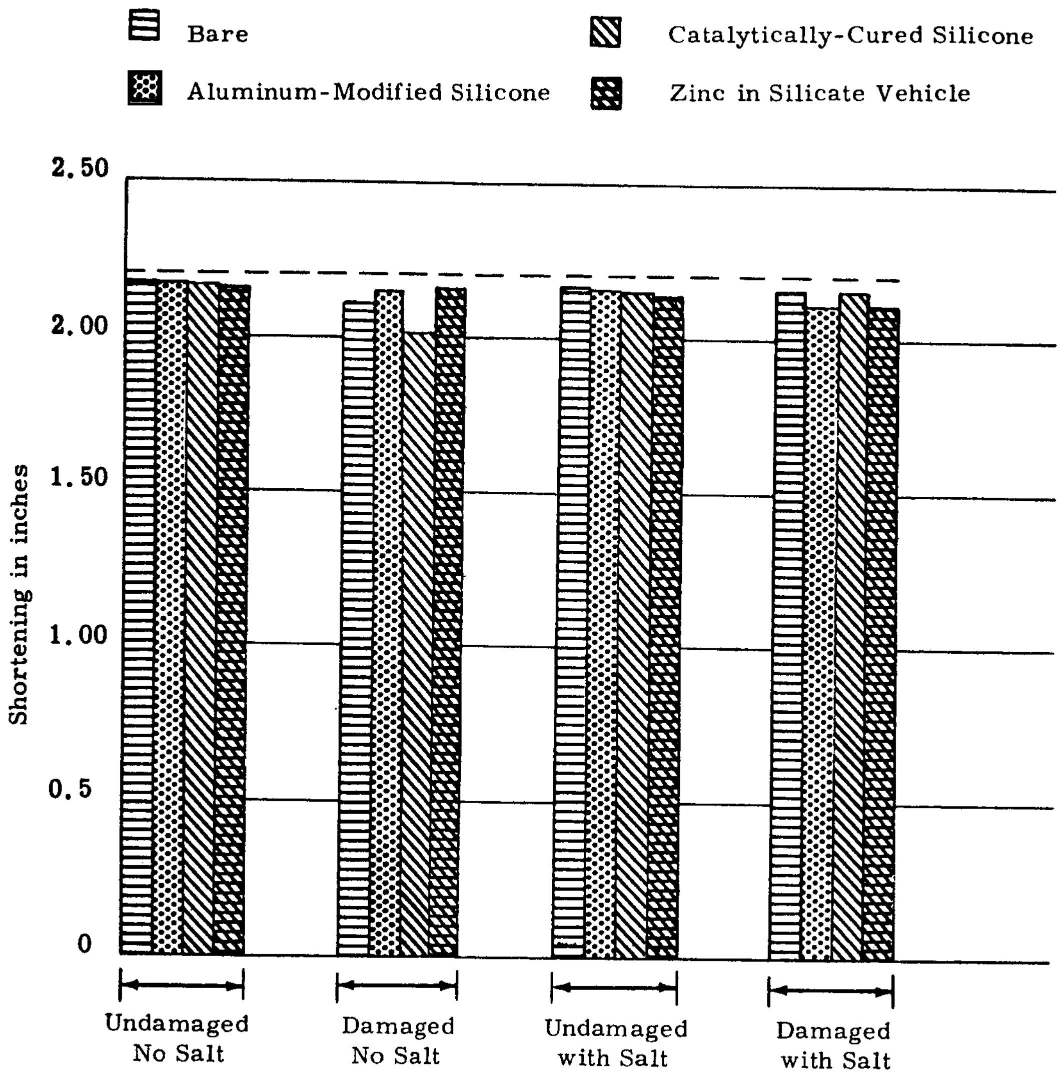
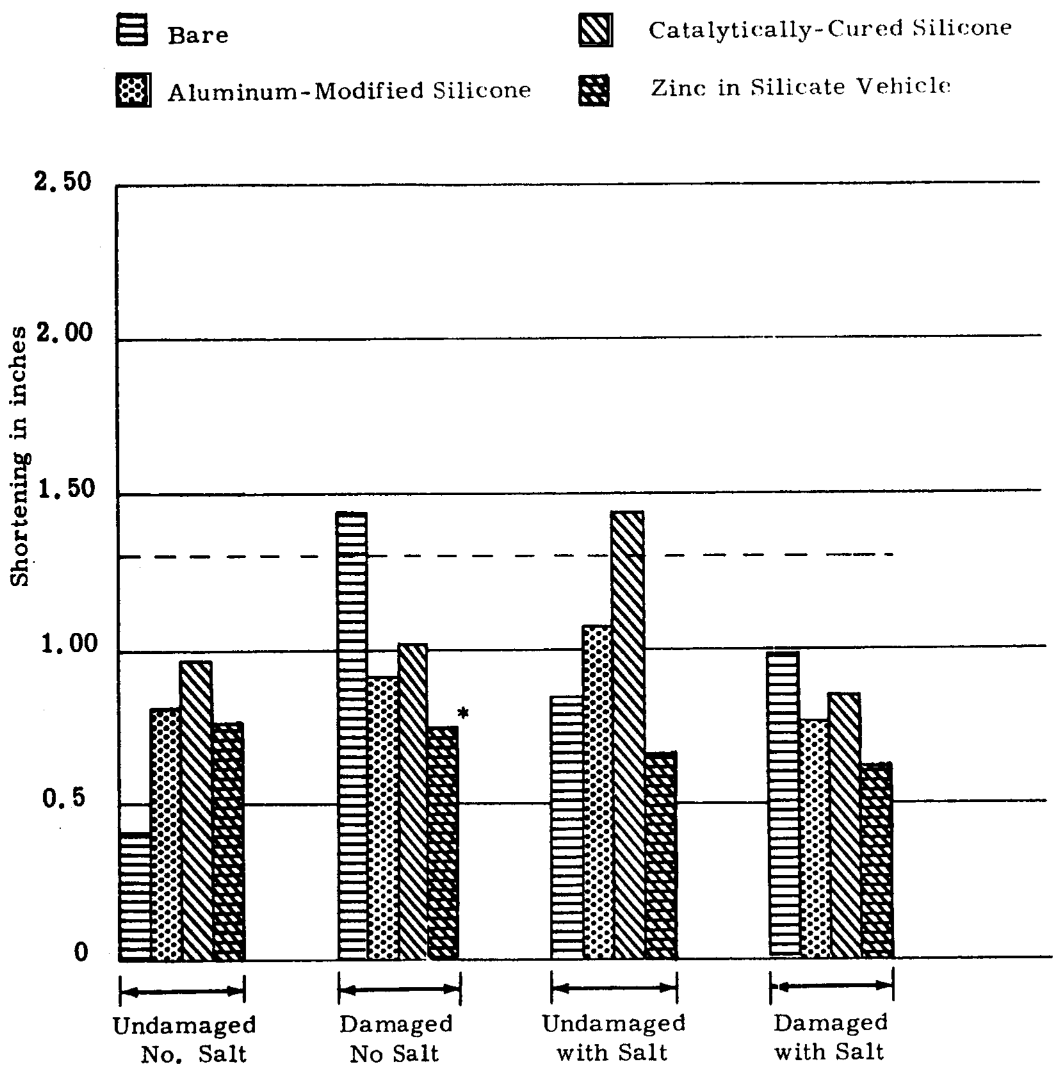


Figure 4. AM 350 Bend-Ductility Results after 1,000 Hours Exposure at 550° F



* One specimen only.

Figure 5. Rene' 41 Bend-Ductility Results after 1,000 Hours Exposure at 550° F.

Figure 6 contains the ductility results from bare and coated Ti-8Al-1Mo-1V specimens after exposure to the dry 550° F atmosphere for 1,000 hours. The ductility of the bare specimens without salt was not significantly affected but, as expected, some decrease was caused by the mechanical damage. The ductility of the bare specimens with salt, however, was greatly decreased in the undamaged condition and further decreased in the damaged condition. Therefore, it is evident that coatings or some other form of protection will be needed for this substrate if it is to be subjected to this type of exposure in service.

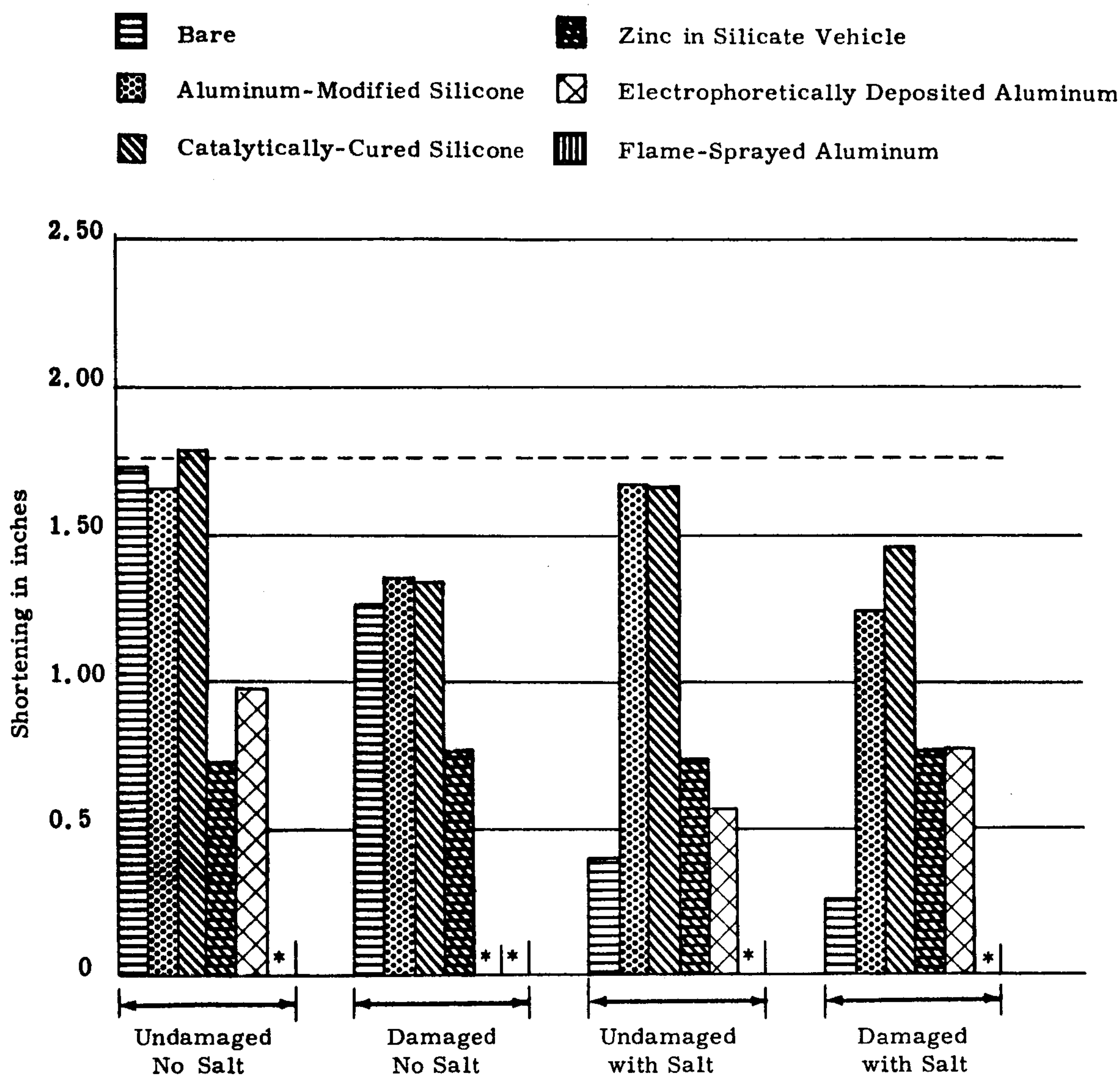
Specimens coated with Aluminum-Modified Silicone and Catalytically-Cured Silicone apparently provided the needed protection for 1,000 hours because the undamaged specimens exposed to salt had no significant decrease in ductility. Although the damaged specimens exhibited significant losses in ductility, the losses were no greater than those in the damaged but unsalted specimens, indicating that the losses were due to the previously inflicted damage. The apparent protection provided by Catalytically-Cured Silicone might be misleading because this coating shredded and spalled from the substrate very shortly after exposure to 550° F. It is probable that the salt deposit was removed along with the coating and allowed these specimens to retain the same ductilities as unsalted specimens.

The specimens coated with Zinc in Silicate Vehicle had much lower ductility than the inherent ductility of the substrate and the decreases were uniform regardless of the differences in exposure conditions. Since these ductilities were uniform under all conditions of exposure, the reductions in ductility must be attributed to the coating itself. The reasons for this behavior of the zinc coating have not yet been investigated.

The Elphal-coated specimens had low ductilities similar to those of the zinc-coated specimens. However, these specimens were from a different lot of material that had been retained from the previous program and that had undergone several rolling and heating treatments during experimental applications of the coating. The losses in ductility might be due to these treatments rather than to shortcomings in the coating. The characteristics of the coating itself should become more apparent when additional specimens from the longer exposures become available.

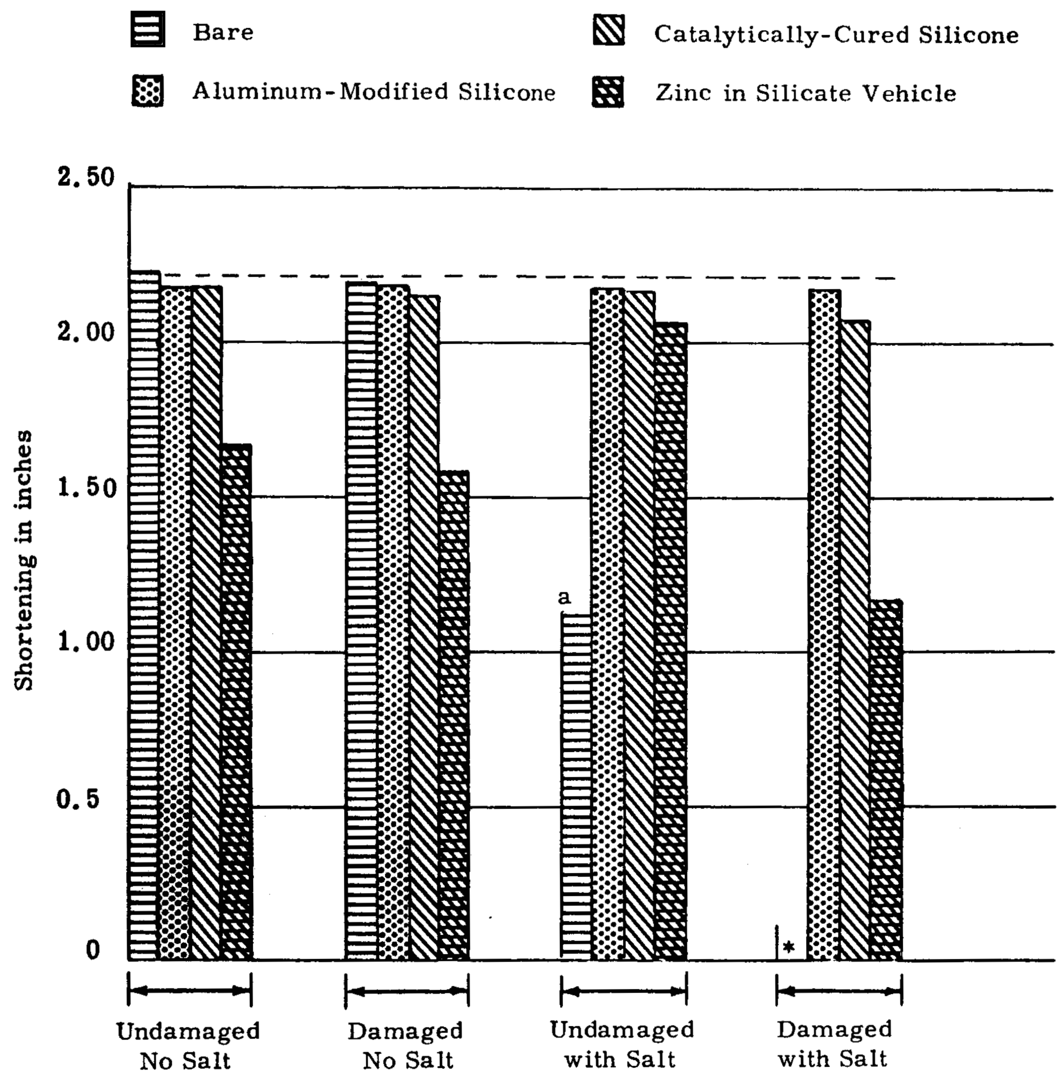
The Flame-Sprayed Aluminum coating could not be evaluated after 1,000 hours because the limited number of specimens available were assigned to the longer-duration exposures.

As shown by the results from the humid 95° F exposure on AM 350 specimens, Figure 7, the bare specimens without salt retained good ductility in both the damaged and undamaged conditions. The salted specimens, however, were rapidly attacked. Both damaged specimens fractured prematurely before the completion of the 1,000 hours, as did one of the undamaged specimens. The other undamaged specimen retained full ductility. Each of the



* No specimens available for this exposure.

Figure 6. Ti-8Al-1Mo-1V Bend-Ductility Results after 1,000 Hours Exposure at 550° F.



a Average between one specimen that had no significant change in ductility (2.171-in. shortening) and one specimen that fractured during exposure (zero shortening).

* Specimens fractured during exposure (zero shortening).

Figure 7. AM 350 Bend-Ductility Results after 1,000 Hours at 95% Humidity.

premature failures occurred near the end of the bowed specimens rather than at the center where the maximum stress and the scratches were located. Although one specimen retained full ductility for some unknown reason, these results indicate that salt and a humid atmosphere cause rapid stress corrosion to occur in bare AM 350, and that the attack may be most severe at a certain critical intermediate stress.

The ductility of all the coated AM 350 specimens with the exception of those coated with Zinc in Silicate Vehicle was essentially unchanged after the humid exposure, indicating that Aluminum-Modified Silicone and Catalytically-Cured Silicone provided adequate stress-corrosion protection. The zinc coating, on the other hand, apparently caused some ductility losses that bore no consistent relationship with the presence of salt or mechanical damage. The apparent lack of effects from salt on the zinc coated AM 350 is exemplified by the relatively high amount of ductility shown in undamaged specimens with salt as compared to the lower ductility in those undamaged and without salt.

The ductility results from bare and coated Rene' 41 specimens after exposure to the humid, 95° F atmosphere are presented in Figure 8. Contrary to the erratic ductilities after 550° F exposure (Figure 5), the bare substrate showed a steady ductility drop from the least severe to the most severe exposure condition, indicating that salt-laden humid environments might cause stress corrosion to occur in Rene' 41 material. However, specimens coated with Aluminum-Modified Silicone and Catalytically-Cured Silicone showed ductilities that were quite erratic in relation to the severity of the exposure conditions. For example, the Aluminum-Modified Silicone specimens were more ductile when damaged than when undamaged, either with or without the presence of salt, and the undamaged, unsalted specimens had less ductility than the others. On the other hand, the Catalytically-Cured Silicone specimens under the most severe condition (damaged, with salt) were more ductile than those under the less severe conditions. The specimens coated with Zinc in Silicate Vehicle exhibited low ductilities under all four exposure conditions.

The ductilities of titanium specimens exposed to the humid, 95° F atmosphere are presented in Figure 9. Because of a shortage of specimens, no bare specimens and only a few coated specimens (undamaged, with salt) were exposed in the 1,000-hour group. The results from these few specimens show that there was no ductility loss in the specimens coated with Aluminum-Modified Silicone and Catalytically-Cured Silicone. There was, however, a drop in the ductility of those specimens coated with Zinc in Silicate Vehicle.

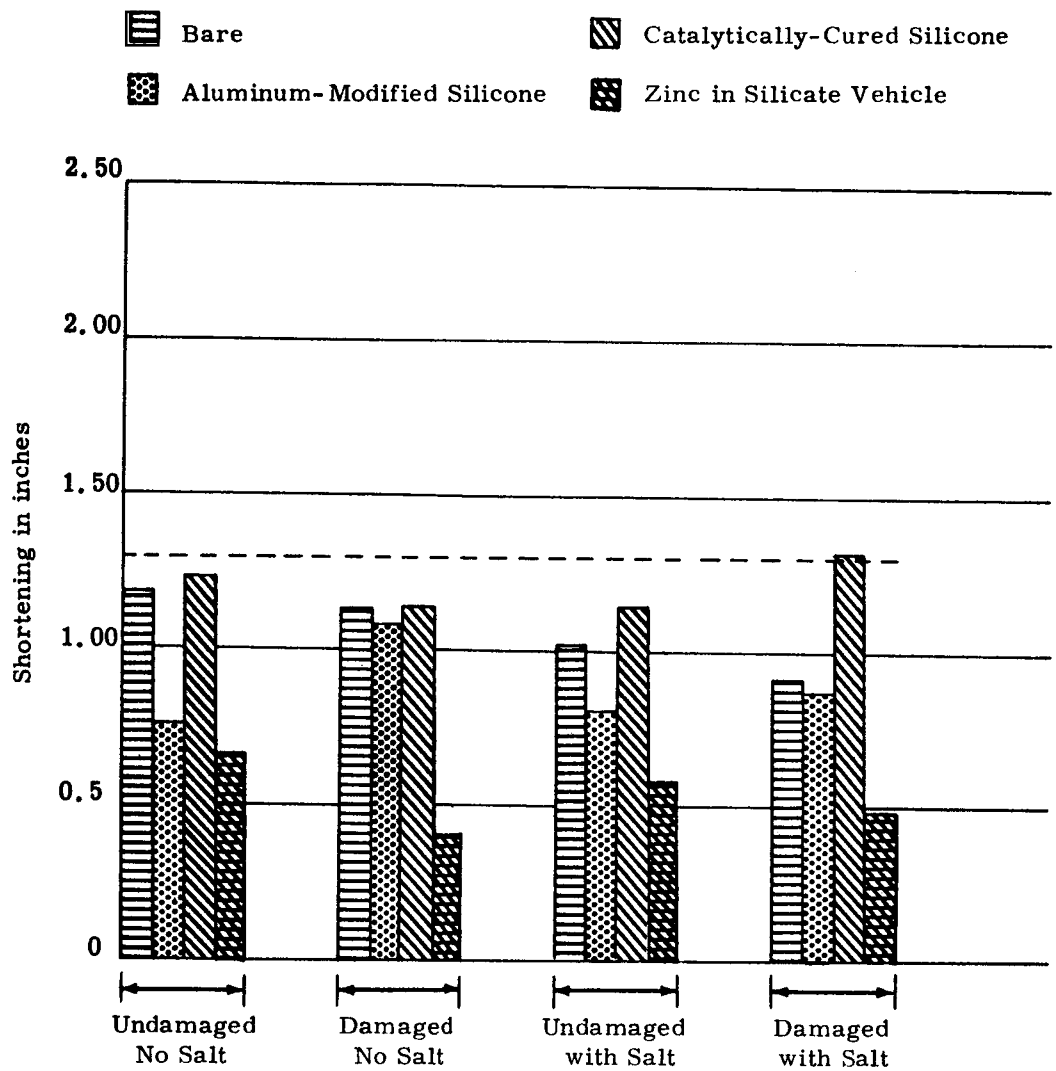
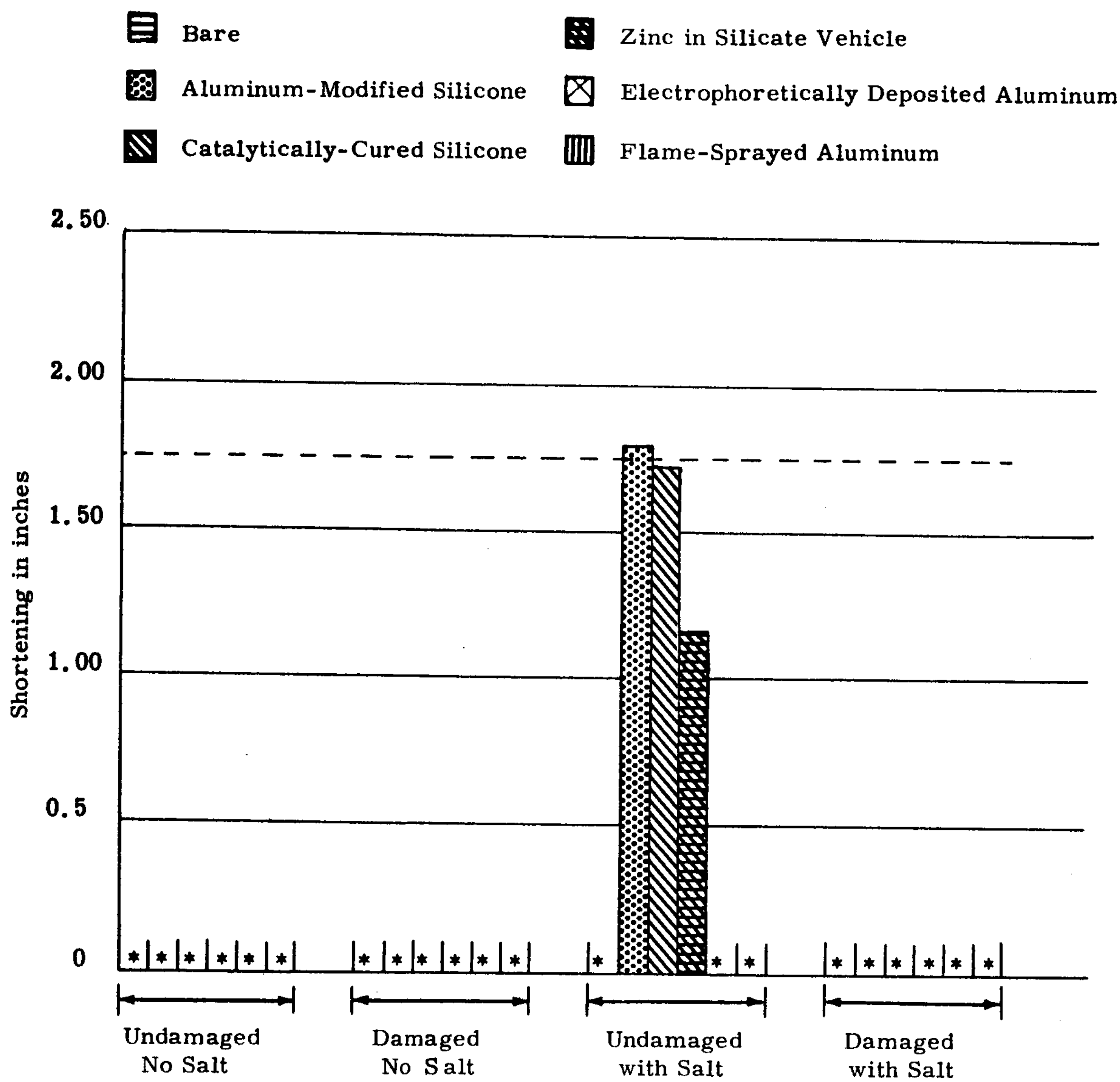


Figure 8. Rene' 41 Bend-Ductility Results after 1,000 Hours Exposure at 95% Humidity.



* No specimens available for exposure.

Figure 9. Ti-8Al-1Mo-1V Bend-Ductility Results after 1,000 Hours at 95% Humidity.

CONCLUSIONS

On the basis of the results from the 1000-hour exposures, we draw the following conclusions:

1. The AM 350 SCT stainless steel substrate will require protection from stress corrosion in salt-laden humid environments.

2. The inherent ductility of solution-treated and aged Rene' 41 is inconsistent to the point of obscuring its vulnerability to stress corrosion within 1,000 hours.

3. Duplex annealed Ti-8-1-1 alloy will require protection from stress corrosion when exposed to dry salt at 550° F. Its vulnerability to stress corrosion in salt-laden humid environments has not yet been determined in this program.

4. Aluminum-Modified Silicone on the AM 350 and Ti-8-1-1 substrates provides excellent protection against stress corrosion for 1,000 hours, either under dry 550° F conditions or humid 95° F conditions. It probably provides protection for Rene' 41 superalloy also, but its effects were obscured because of apparent inconsistencies in the inherent ductility of this substrate.

5. Catalytically-Cured Silicone provides excellent protection on all three substrates in the humid 95° F environment. Its protective qualities at 550°F are in doubt because it quickly shredded and peeled from all three substrates when exposed to the elevated temperature.

6. Zinc in Silicate Vehicle has a deleterious effect on the ductility of all three substrates after exposure to the humid 95° F environment. In the dry 550° F environment it has no deleterious effects on AM 350 SCT stainless steel, but is possibly deleterious on Rene' 41 and is definitely deleterious on Ti-8-1-1 alloy.

7. Insufficient specimens were available in the 1000-hour exposures for indicating the effects of Electrophoretically Deposited Aluminum and Flame-Sprayed Aluminum on the Ti-8-1-1 alloy, which was the only substrate to which these coatings were applied.

FUTURE WORK

During the next quarter, bend-ductility evaluations will be performed on specimens from the 3,000-hour exposure interval which ends on 22 June. When necessary for additional clarification of results, we shall make metallographic examinations of selected specimens from both the 1,000-hour and 3,000-hour exposures.

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15 June 1965
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