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SPACE ENVIRONMENTAL EFFECTS ON EXPANDABLE STRUCTURES MATERIALS

R. E. Southerlan

ARO, Inc.

April 1967

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NOTICES

SPACE ENVIRONMENTAL EFFECTS ON EXPANDABLE STRUCTURES MATERIALS

R. E. Southerlan

ARO, Inc.

FOREWORD

This report presents results of vacuum and solar exposure tests on fiber glass materials. The Air Force Aero Propulsion Laboratory, AFAPL, Air Force Systems Command (AFSC) was the sponsoring organization. The investigation was conducted under Program Element 62405214, Project 8170.

The results of tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Arnold Air Force Station, Tennessee, under Contract AF 40(600)-1200. The tests were conducted from September 26 to December 28, 1966, under ARO Project No. SA0618, and the manuscript was submitted for publication on March 3, 1967.

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Director of Test

ABSTRACT

This report presents data showing the effects of vacuum and combined vacuum and solar environments on fiber glass materials. Tensile and bending properties of these materials were determined after vacuum exposure periods of 5 and 60 days and the combined effects of vacuum and solar irradiation simulating a 200-nautical-mile orbit. Material density, elongation, thermal and optical properties were also determined.

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SECTION I
INTRODUCTION

The application of expandable structure technology is expected to increase as the requirements for large space shelters and containers develop (Ref. 1). For example, structures including a crew transfer tunnel, an aerospace shelter, and several shelter scale models have been deployed and rigidized in recent tests in the Aerospace Environmental Facility at the Arnold Engineering Development Center (AEDC) (Refs. 2 and 3).

Many of these structures will be subjected to low pressure and to the combined environments of low pressure and solar radiation. To determine the effects of these factors, rigidized fiber glass samples from Hughes Aircraft Company, Archer Daniels Midland Company (ADM), and National Cash Register Company (NCR) were tested in the Aerospace Research Chamber (7V).

The test included a 60-day vacuum exposure at mid-10^{-8} torr with solar irradiation 56.9 min per 90 min, simulating a 200-nautical-mile orbit. Test materials were exposed to the vacuum and the combined vacuum and solar environments. Tensile and flexural properties were determined for the two cases and compared with the results obtained after a five-day vacuum drying period. Effects on density, thermal expansion, dimensional stability, surface reflectance, and light transmission were also determined. This report presents the results of these tests.

SECTION II
APPARATUS

Vacuum and thermal environments were provided in the Aerospace Research Chamber (7V) (Fig. 1). A liquid-nitrogen (LN_2)-cooled liner completely encloses the test area, providing a radiation heat sink and a pump for 77°K condensables. Two 32-in. oil diffusion pumps backed with 6-in. oil diffusion and mechanical pumps provide the basic vacuum pumping.

Low temperature gaseous helium is available from two 1-kw sources, and either can be used with a liquifier to produce 60 liter/hr of liquid helium. A new liner is under construction that can be cooled with either gaseous or liquid helium. This will be used to provide low radiation backgrounds and a highly efficient molecular sink.

Solar environments were provided by a Genarco® carbon arc unit (Fig. 1). The unit produces one solar constant over a 36-in.-diam area. Radiometers located in the test plane monitored the radiation level throughout the 60-day test period (Fig. 2).

Two tensile test assemblies were fabricated: one installed in the solar beam and one shielded from the radiation (Figs. 1, 2, and 3). A drive assembly and load cell located outside the chamber provided tensile load and its measurement. The load was transmitted into the chamber through a flexible bellows seal, thus allowing a determination of tensile properties without exposing the test samples to atmospheric conditions.

SECTION III
PROCEDURE

Flexural and tensile specimens were cut with the warp direction lengthwise (Fig. 4). Samples were cut from 8- x 10-in. fiber glass laminates supplied by the test sponsor. Twenty samples of each shape were exposed to mid-10^{-8} torr vacuum for 108 hr to dry (LN_2 liner was cooled during the vacuum soak). These samples were then tested and the results used as a basis of comparison for later results. One flexural sample from each supplier was mounted for optical observation. Thermocouples were attached to smaller pieces to determine sample temperature before pulling.

Eighteen tensile samples were mounted in each test assembly for the 60-day test phase. Nineteen flexural samples were exposed to combined solar irradiation and vacuum, eighteen samples to vacuum only. After the 5- and 60-day exposure periods, the chamber was repressurized with dry nitrogen and the flexural samples were removed for testing. Several small samples were instrumented with thermocouples to measure the temperature variation during the 90-min simulated orbital period and to measure temperature differences across the samples.

Tensile tests were made under vacuum using a strain rate of 0.055 in./in.-min. Samples mounted in the solar beam slipped in the tester clamps, and only six were tested initially. After a nitrogen pressurization and removal of the flexural samples, additional clamping was added to the tensile tester (Fig. 3). The tensile samples were again vacuum soaked for two days, and six more were successfully tested. The remaining samples were removed and tested outside the chamber for ultimate tensile strength only.

The ASTM standard method of test for flexural properties of plastics (Ref 4) was used as a guide for the bending tests. The samples were supported on 0.25-in.-diam supports 1 in. apart. This gave a span-to-depth ratio of about 32 to 1. The mid-span deflection rate used was 0.037 in./min.

Reflectance and transmittance measurements were made a week after the samples were removed from the chamber. These measurements were made on a ratio recording spectrophotometer using magnesium oxide as a reference.

Throughout the 60-day phase the radiometer and thermocouple readings were recorded every 10 min. Two-minute time-lapse photography was provided from two outside locations. Optical measurements were made at various times during the 60-day test phase. On these separate 90-min periods, monitoring was made to observe the temperature response to solar heating.

A statistical distribution of solar intensity during the 60-day vacuum and solar exposure test is given in Fig. 5.

SECTION IV
RESULTS

A summary of the mechanical properties is shown in Table I. In general, an increase in strength was measured after exposure to solar irradiation and vacuum. No proportional limit was indicated by the tensile load versus deflection data (Fig. 6). The density values measured after environmental exposure up to the combined vacuum and solar effects were 10 percent higher than those values measured before any environmental exposure. Little change was noted after vacuum exposure only.

Slight, optically measured changes were noted in the dimensional properties. An elongation of 0.01 mms/in. was measured during the solar period. A slight curl in the NCR sample mounted for optical observation (Fig. 3) was noted during the "off" cycle. This amounted to a 2-mms displacement at the bottom. No other movement of the other two samples was detected by photography.

Temperature differences of 4°F between the illuminated and non-illuminated sides were measured throughout the test even though the samples darkened as the test progressed. During the solar exposure, maximum temperature varied with samples and the duration of the test period from 20 to 85°F, averaging near 60°F throughout the test period. In the "off" cycle, temperature drops ranged from 90 to 100°F. A typical temperature response is shown in Fig. 7.

SECTION V
DISCUSSION

5.1 GENERAL APPEARANCE OF MATERIALS

The sample sheets were constructed of interwoven and laminated fiber glass impregnated and rigidized with resin. No information was provided as to how the laminates were made or as to the composition of the resin. Samples supplied by NCR had the appearance of being pressed at some point during fabrication. Figures 8 and 9 show comparisons of surface texture and warpage before the test samples were cut.

5.2 TENSILE TESTS

A comparison of tensile failures and cross sections of nonfailed areas of these samples under 10X magnification is shown in Figs. 10 and 11. Most failures occurred at the minimum cross section on the Hughes and NCR samples. The light spot on the NCR sample is a partially failed area. A much larger area of resin failure was noted in the Hughes samples. One of these samples was tested at -200°F, and the resin separated from the fibers over the entire length of the 2-in. test section. The ultimate tensile strength of this sample was 43,500 psi, and a modulus of elasticity near 825,000 psi was measured. Many of the ADM samples failed at the face of the holding clamp, indicating a high notch sensitivity. Some of these samples were retested, and they failed in the minimum cross section at ultimate values near those previously obtained.

No set pattern of change in tensile strength or modules of elasticity was established for the three materials tested. After vacuum exposure the Hughes samples decreased in strength, and after the combined exposure the ADM samples weakened. There was no correlation between the ultimate strength and the modulus of elasticity. In all cases the modulus of elasticity decreased after 60 days of vacuum exposure and increased under the effects of combined exposure. Typical tensile data are shown in Fig. 6.

5.3 BENDING TESTS

The flexural test data gave additional indications of the environmental effects. The average failure load (Table I) increased after the 60-day exposure to vacuum. Further increases were measured on samples exposed to both vacuum and solar irradiation when flexed with the solar exposed side in compression. This was most apparent with the Hughes samples as a 45-percent decrease in strength and a 41-percent decrease in flexibility were measured with the side not directly exposed to the solar (back) in compression. Comparative runs are shown in Fig. 12. On more than half of these flexural samples, failure occurred on the back side, irrespective of the bending direction. This indicated a definite increase in resin strength under full solar exposure. Photographs of failed specimens and unfailed cross sections of the same samples are shown in Figs. 13 and 14.

5.4 DENSITY, DIMENSIONAL, AND THERMAL PROPERTIES

The mechanical properties of the fiber glass samples proved desirable for several reasons. No changes in length greater than 0.01 mms were measured after any of the test conditions. A coefficient of thermal expansion of 4.0×10^{-6} in./in. °F was measured from the solar "off" to "on" cycle.

Some indication of the heat conduction properties was made by temperature measurements on each side of samples exposed to the solar beam. Thermocouples were cemented to both sides of several samples, and temperature differentials of 4°F were measured. Many factors affect the accuracy of this measurement. and it is considered only an indicator of thermal conductivity. Spectrophotometer studies gave further experimental measurements of thermal properties. Reflectance and transmittance were determined on samples subjected to vacuum exposure and compared to similar samples exposed to the combined vacuum and solar irradiation. The transmittance was measured in the wavelength band from 0.35 to 2.5 microns and the reflectance from 0.27 to 2.5 microns. Changes in reflectance near 100 percent for the wavelength band from 0.35 to 0.6 microns were measured on two Hughes samples (Fig. 15). Maximum reflectance for the ADM and NCR samples was 50 percent measured near 1.0 micron

Transmittance curves for the Hughes sample and a NCR sample are shown in Figs. 16 and 17. Maximum transmittance was less than 30 percent for all samples. It is concluded that long-term solar exposure does increase the energy absorption in the 0.3- to 0.6-micron wavelength band.

SECTION VI
CONCLUSIONS

Rigidized fiber glass materials of the type tested were not adversely affected by the combined environmental effects of vacuum and solar irradiation for the simulated 60-day orbital period. Increases in the tensile strength of the Hughes and NCR samples and the average bending strength of all samples were measured after this period. The materials are dimensionally stable under these environments, but small density changes can be expected. The absorptivity of the materials increased between 0.3 and 0.6 microns. A closer investigation of these changes will be necessary before the long-term effects of solar exposure can be assessed.

REFERENCES

1. Aerospace Expandable Structures Conference Transactions. Air Force Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio, AFAPL-TR-65-108.

2. Nelms, F. W. "Vacuum Deployment Test of a Large Expandable Aerospace Shelter." AEDC-TR-66-123 (AD487116), August 1966.

3. Latture, N. C. "Vacuum Deployment Tests on an Expandable Crew Transfer Tunnel." AEDC-TR-66-66 (AD635106), July 1966.

4. American Society for Testing and Materials. 1966 Book of ASTM Standards, Part 27. June 1966.

APPENDIXES

I. ILLUSTRATIONS

II. TABLE

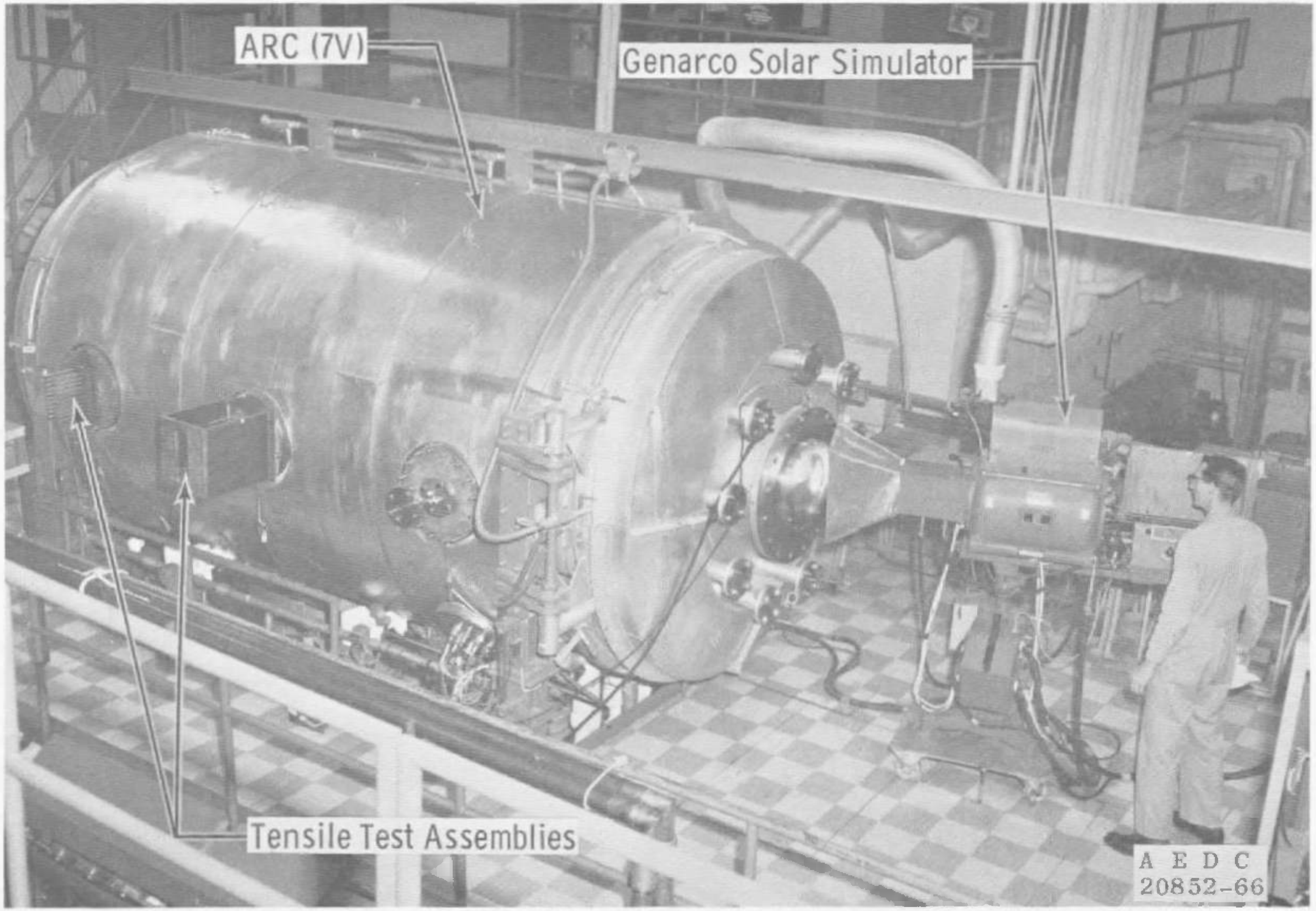

Fig. 1 Aerospace Research Chamber with Solar Simulator

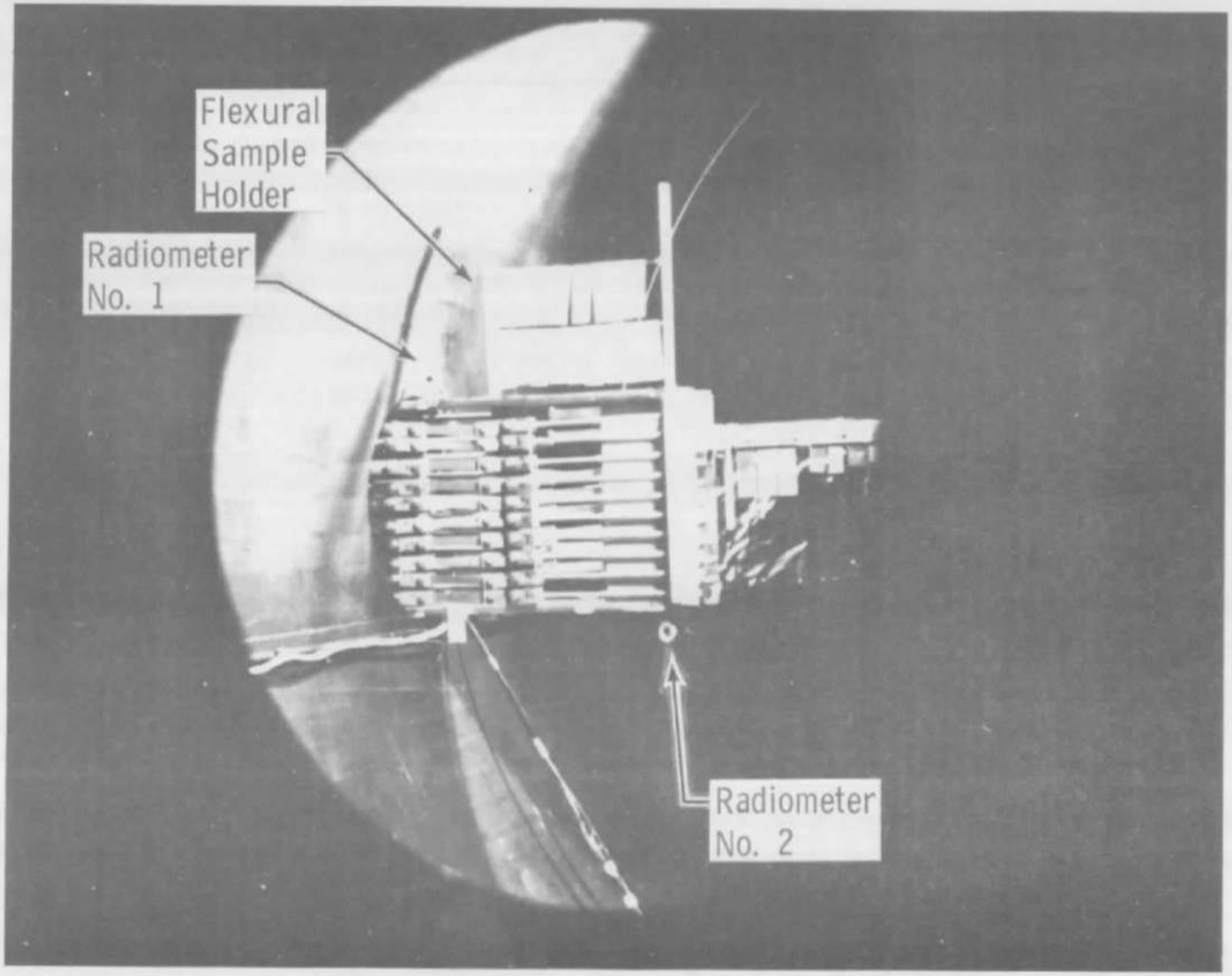

Fig. 2 View of Test Assembly through Solar Port

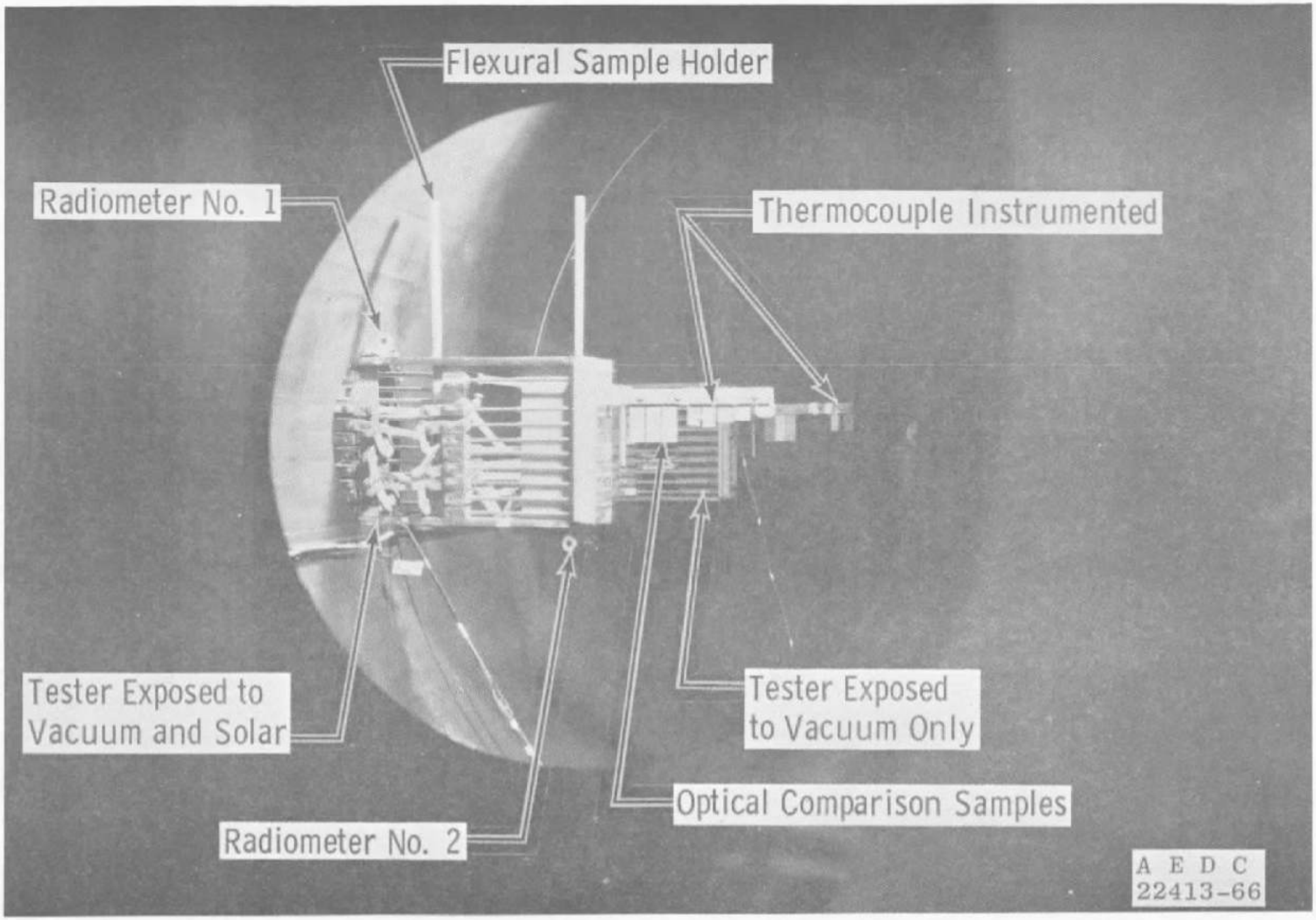

Fig. 3 60-Day Vacuum and Solar Test Installation

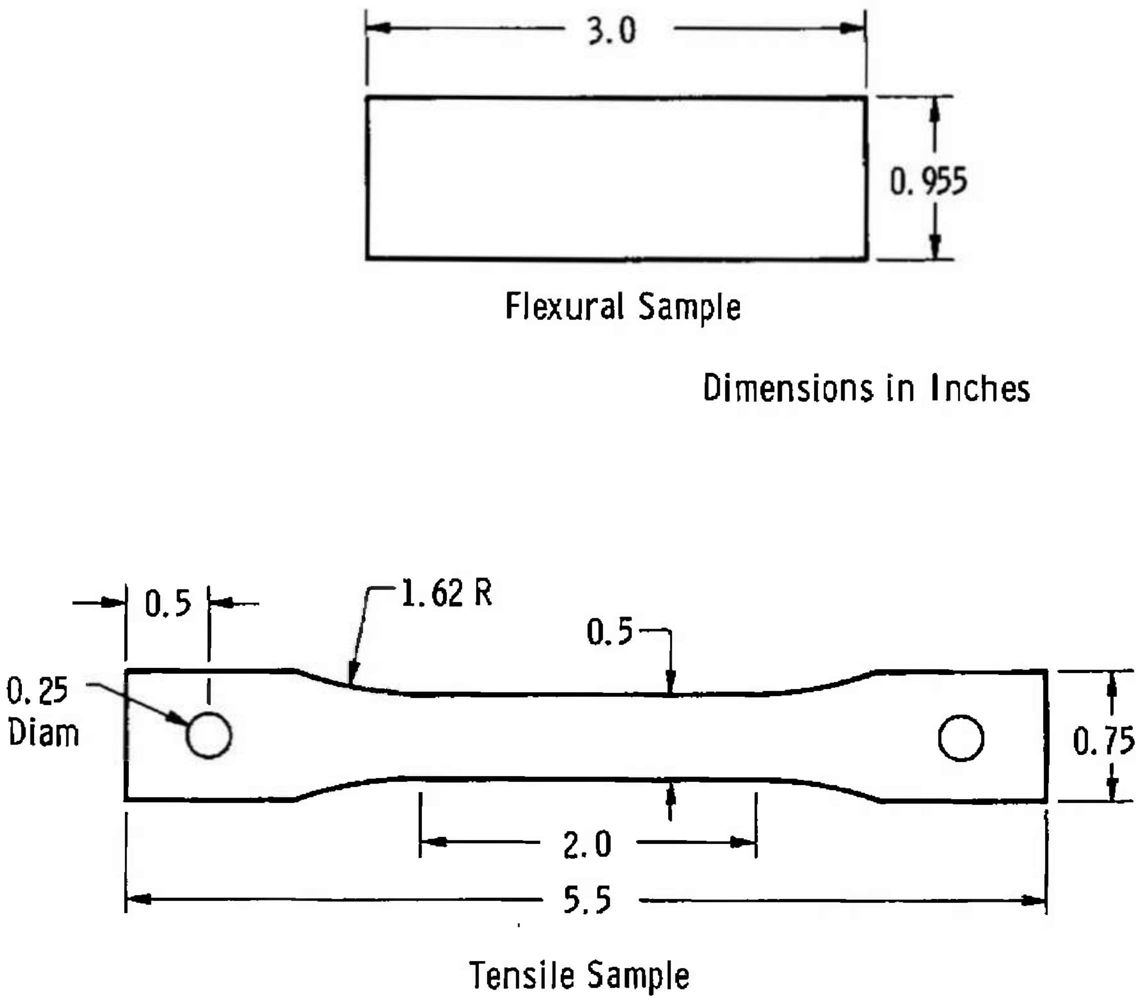

Fig. 4 Flexural and Tensile Shapes

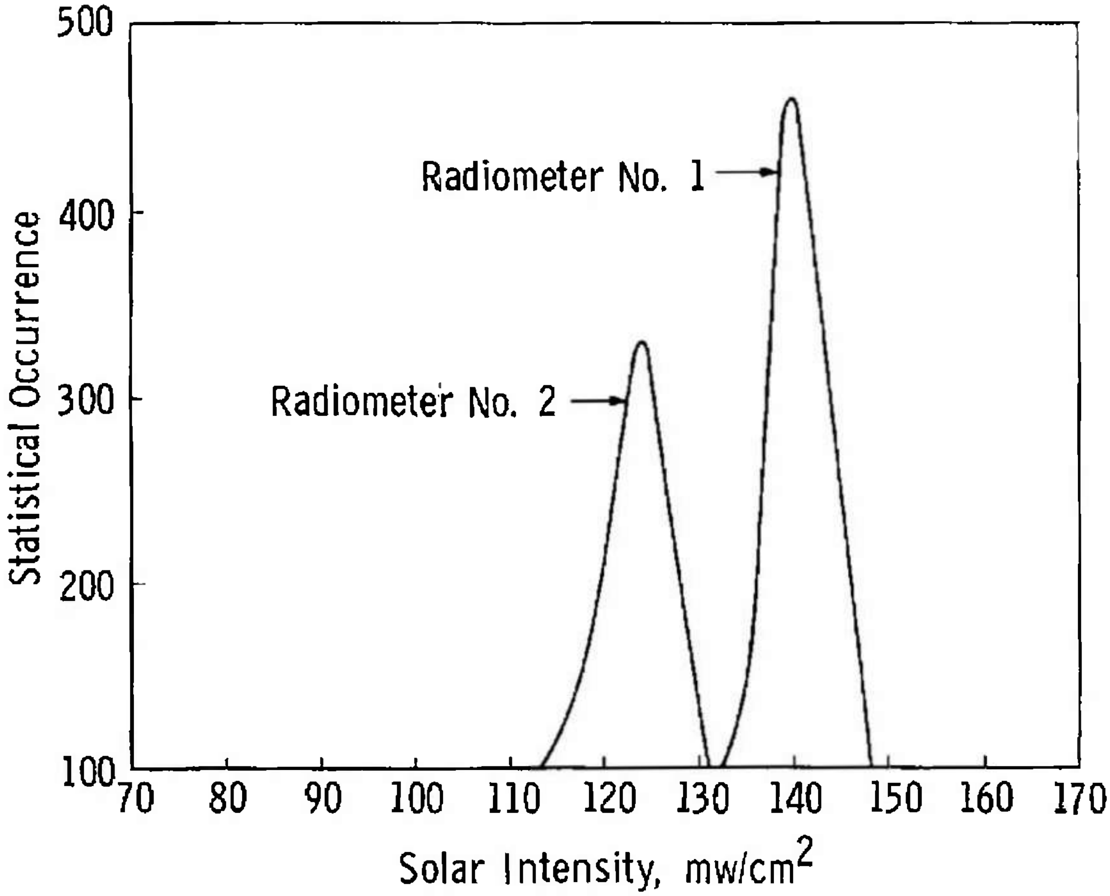

Fig. 5 Statistical Distribution of Solar Intensity during the 60-Day Vacuum and Solar Exposure

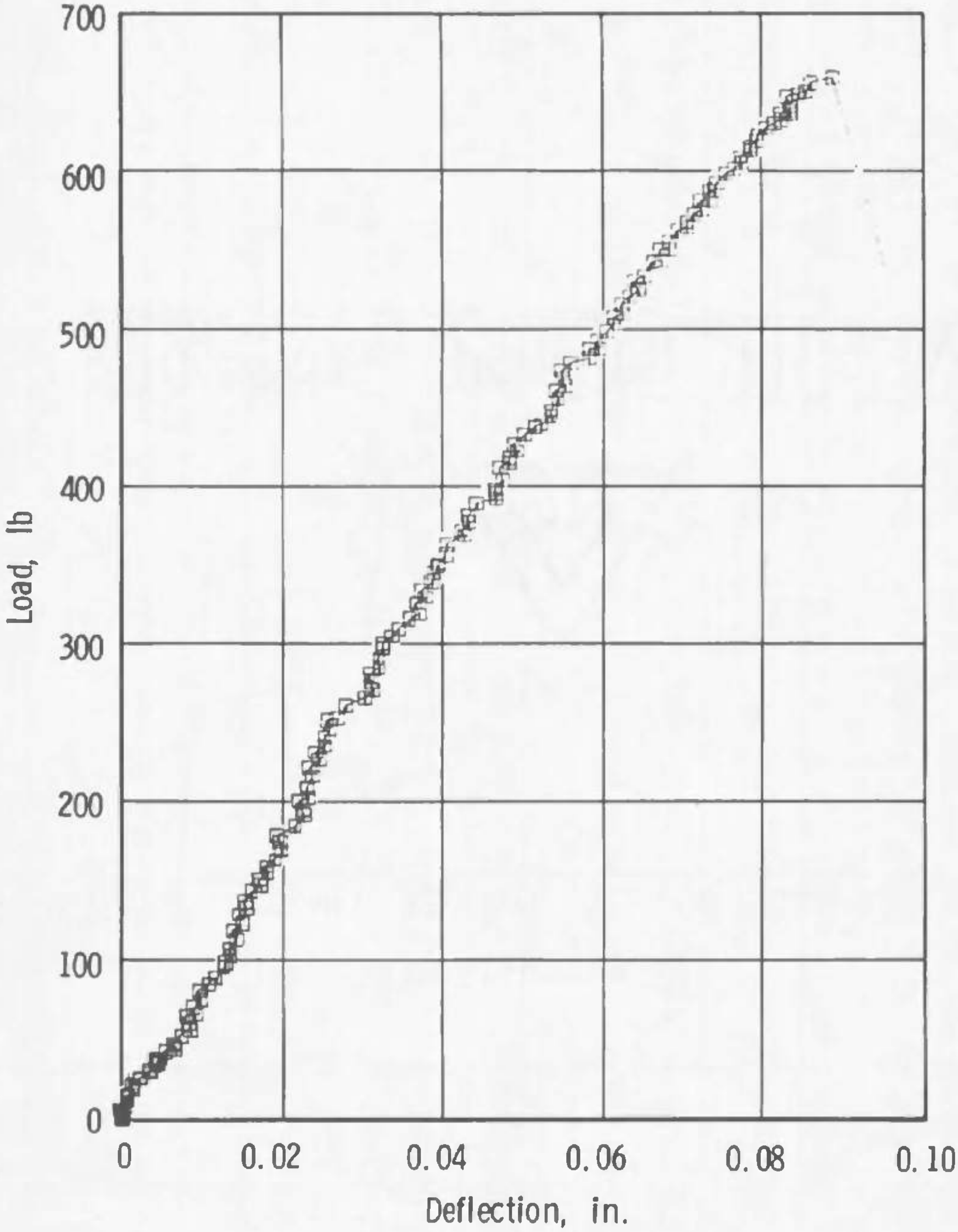

Fig. 6 Typical Tensile Data (Hughes Co. after Vacuum and Solar Exposure)

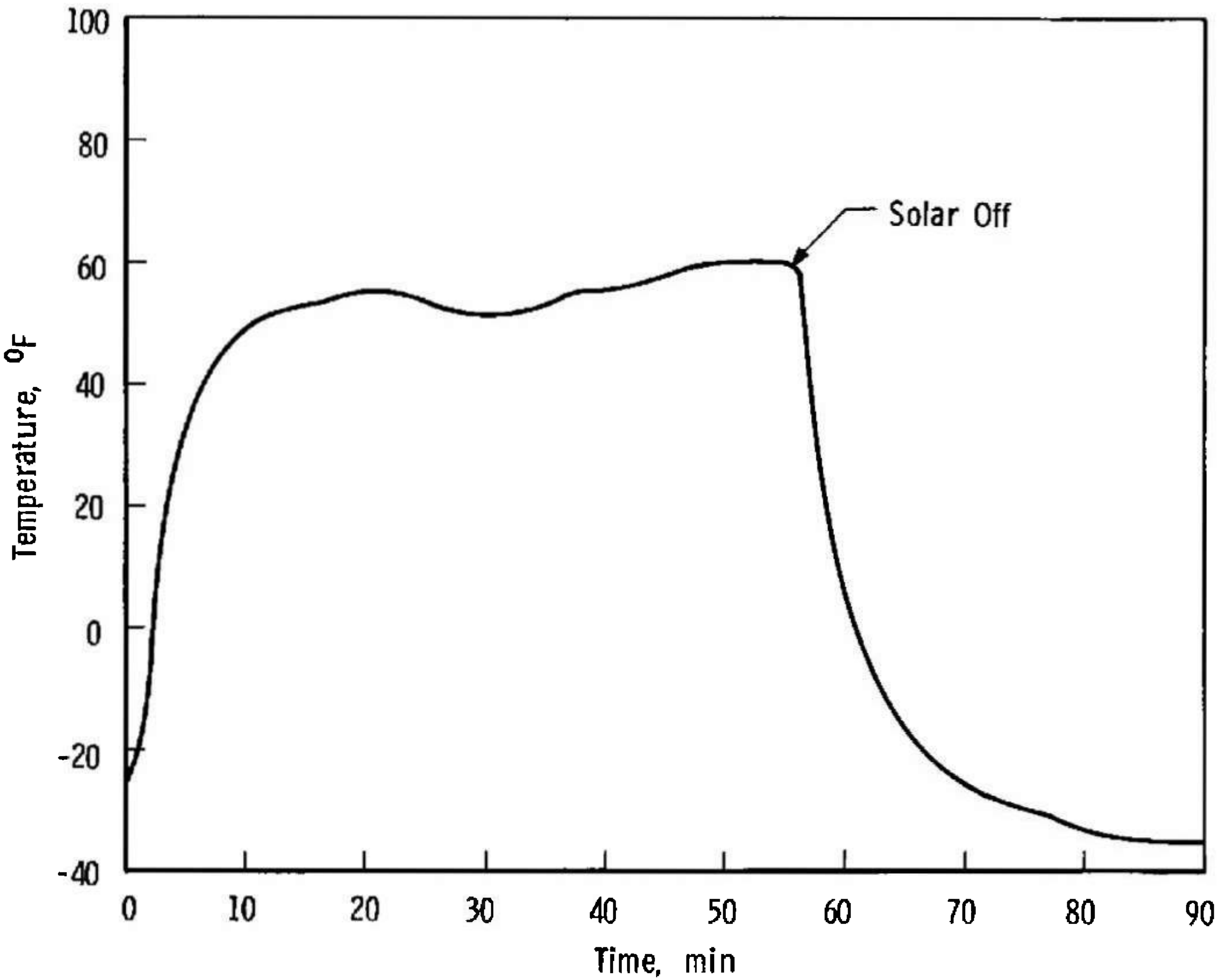

Fig. 7 Typical Temperature Response of Fiber Glass to Solar Radiation

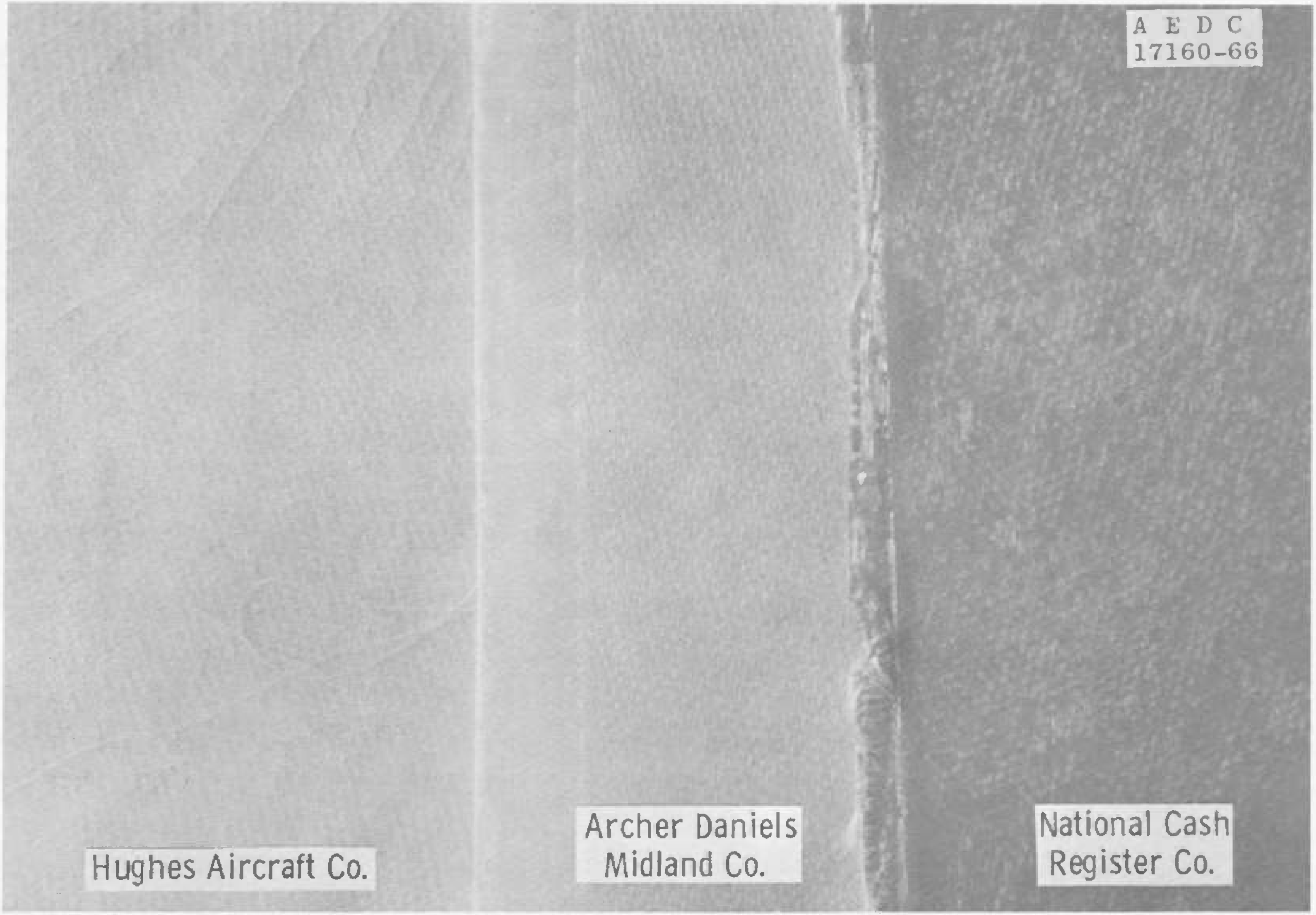

Fig. 8 Comparison of Samples before Testing

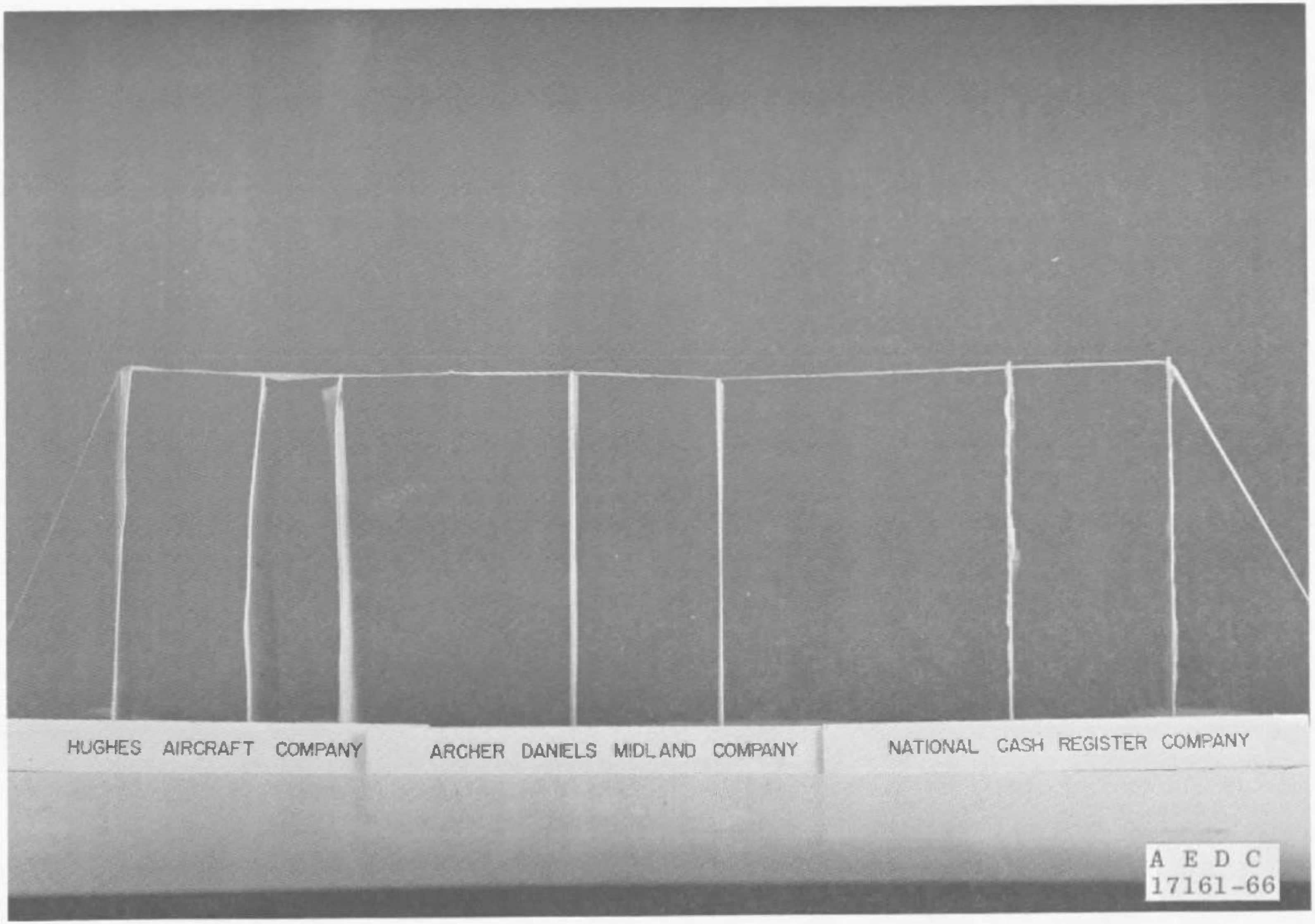

Fig. 9 Edge View Showing Warpage of Samples as Received

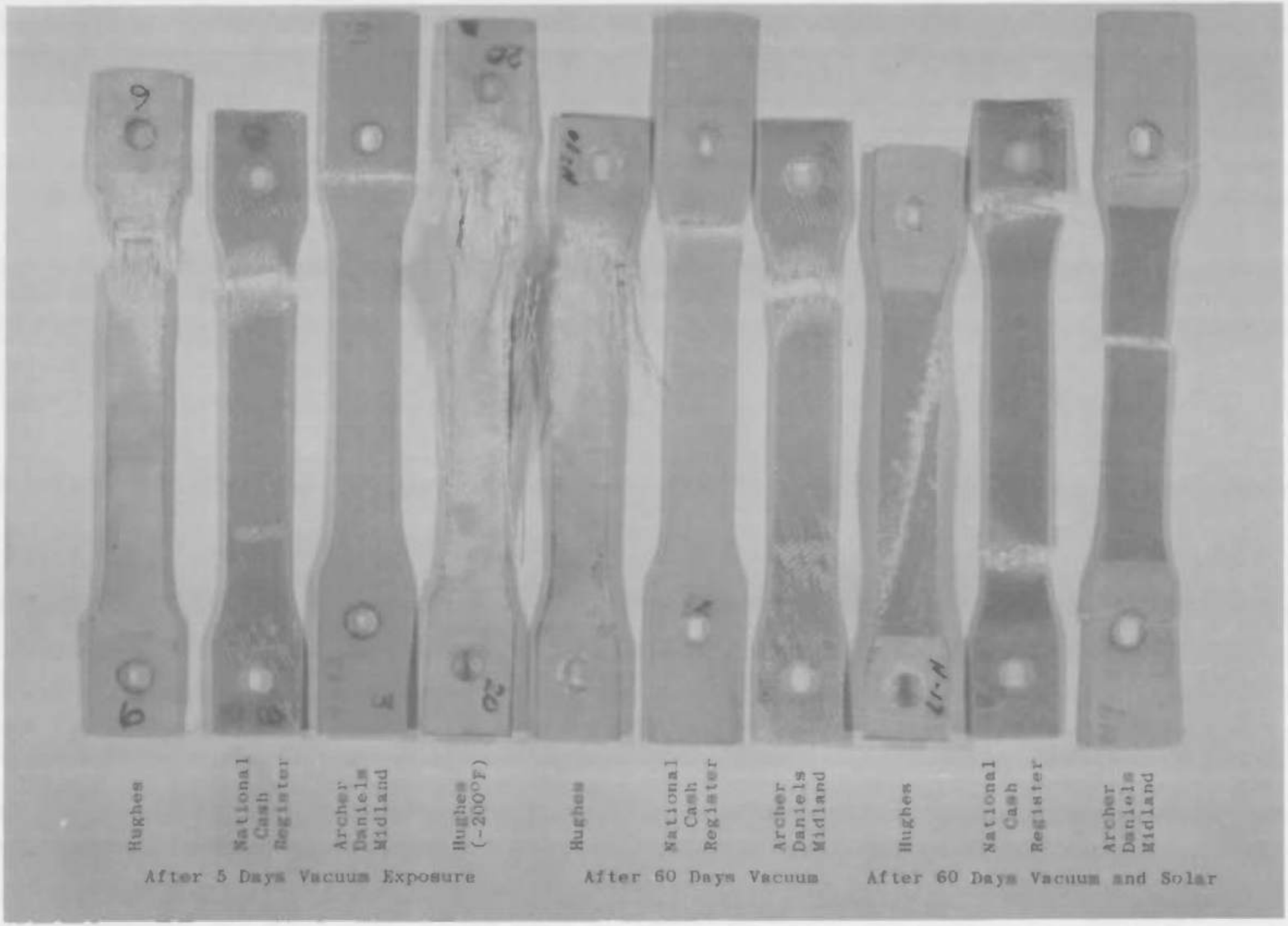

Fig. 10 Comparison of Samples that Failed in Tension

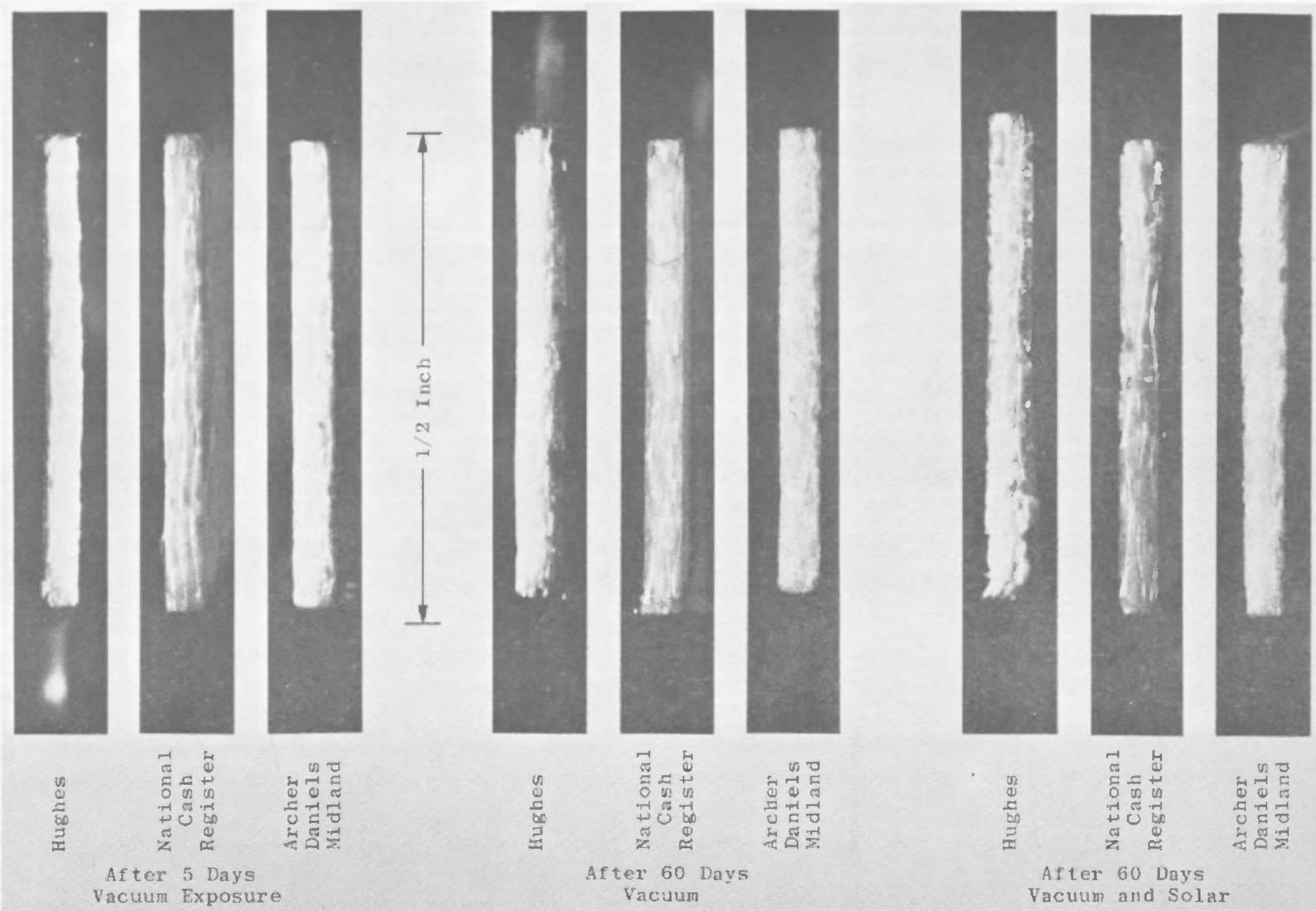

Fig. 11 Cross Sections of Samples that Failed in Tension

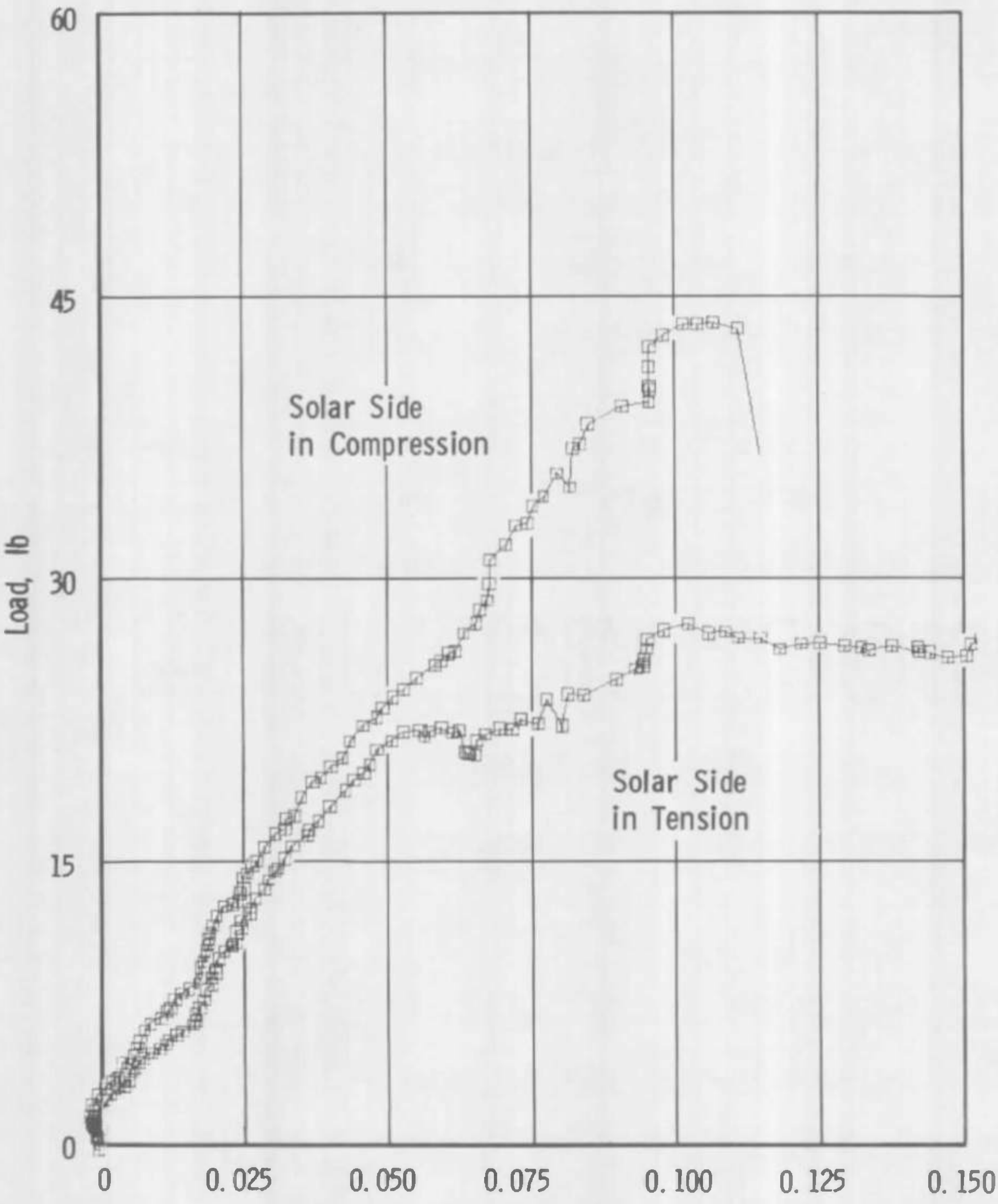

Fig. 12 Bending Data on Hughes Fiber Glass Material after the 60-Day Solar and Vacuum Exposure

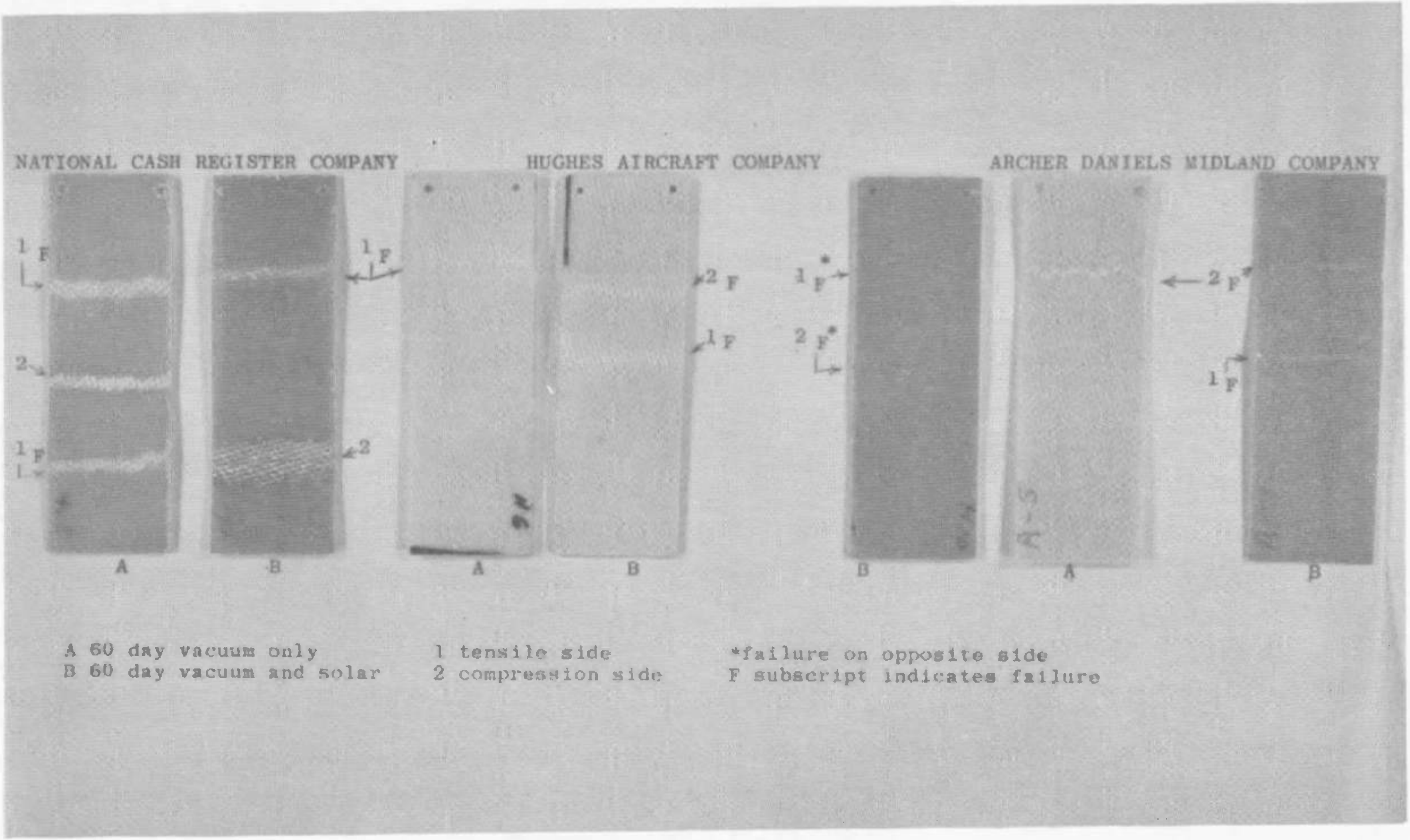

Fig. 13 Comparison of Flexed Samples

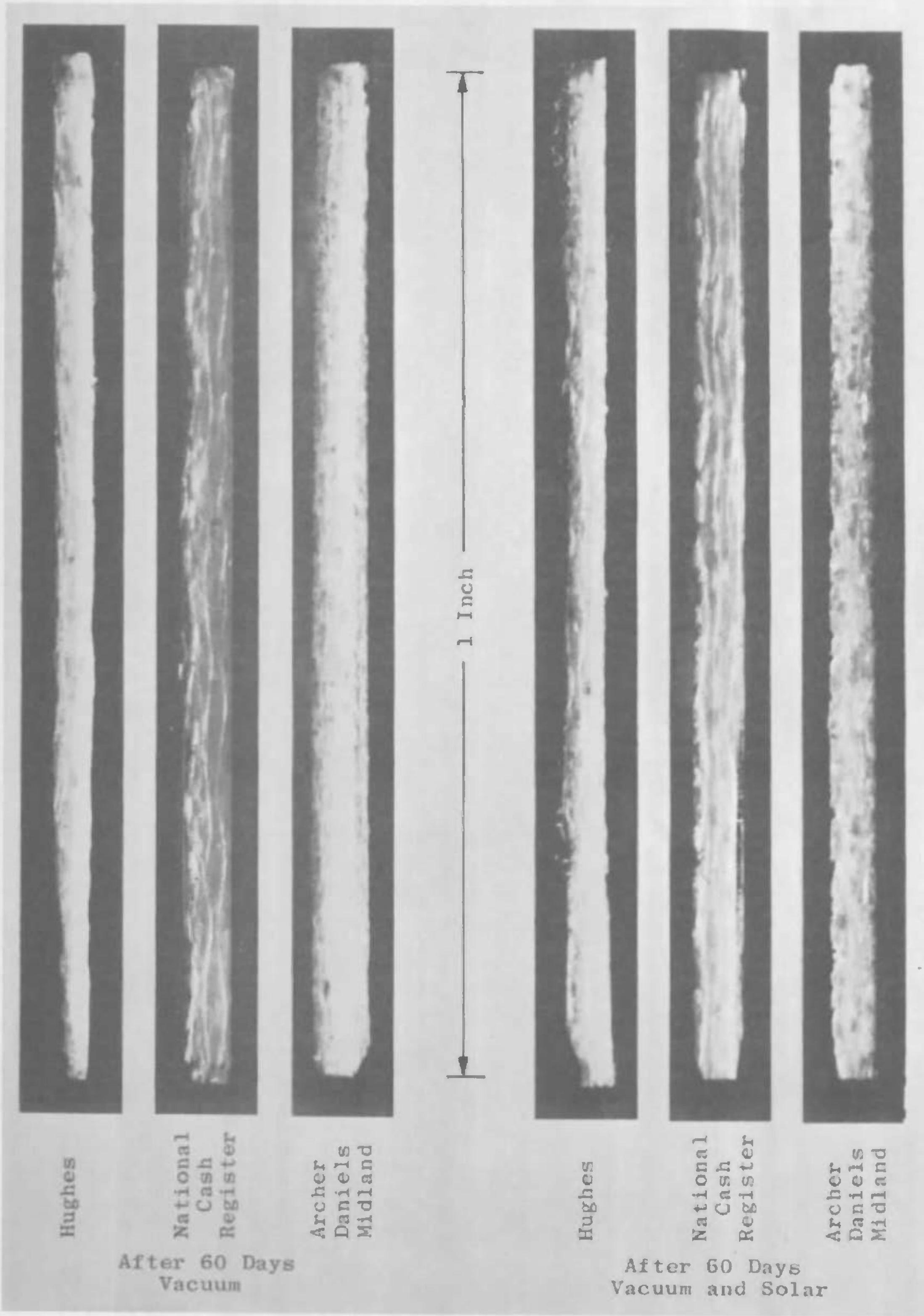

Fig. 14 Cross Section of Flexed Samples

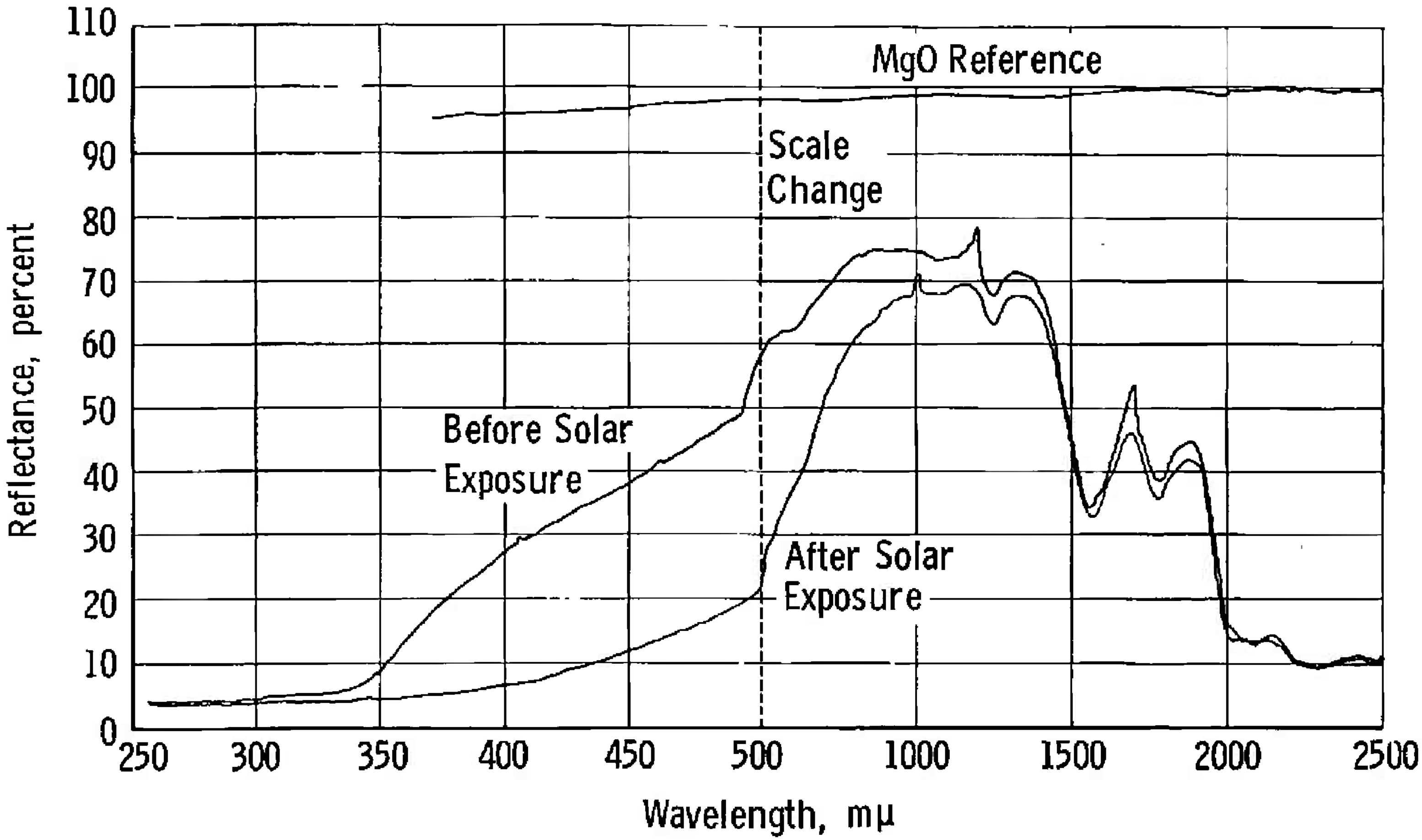

Fig. 15 Solar Effects on Reflectance of Hughes Fiber Glass Samples

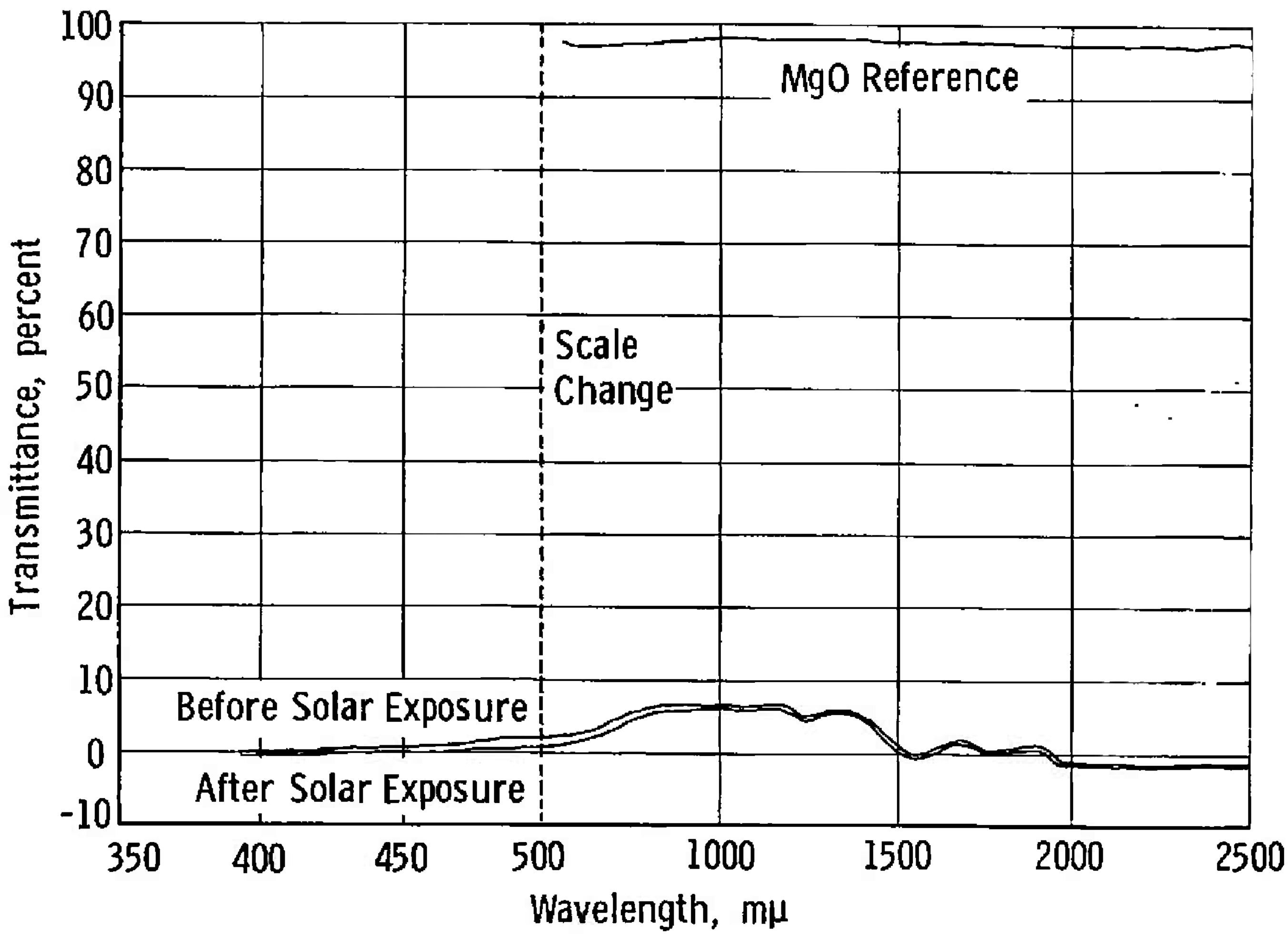

Fig. 16 Solar Effects on Transmittance of Hughes Aircraft Co. Fiber Glass Samples

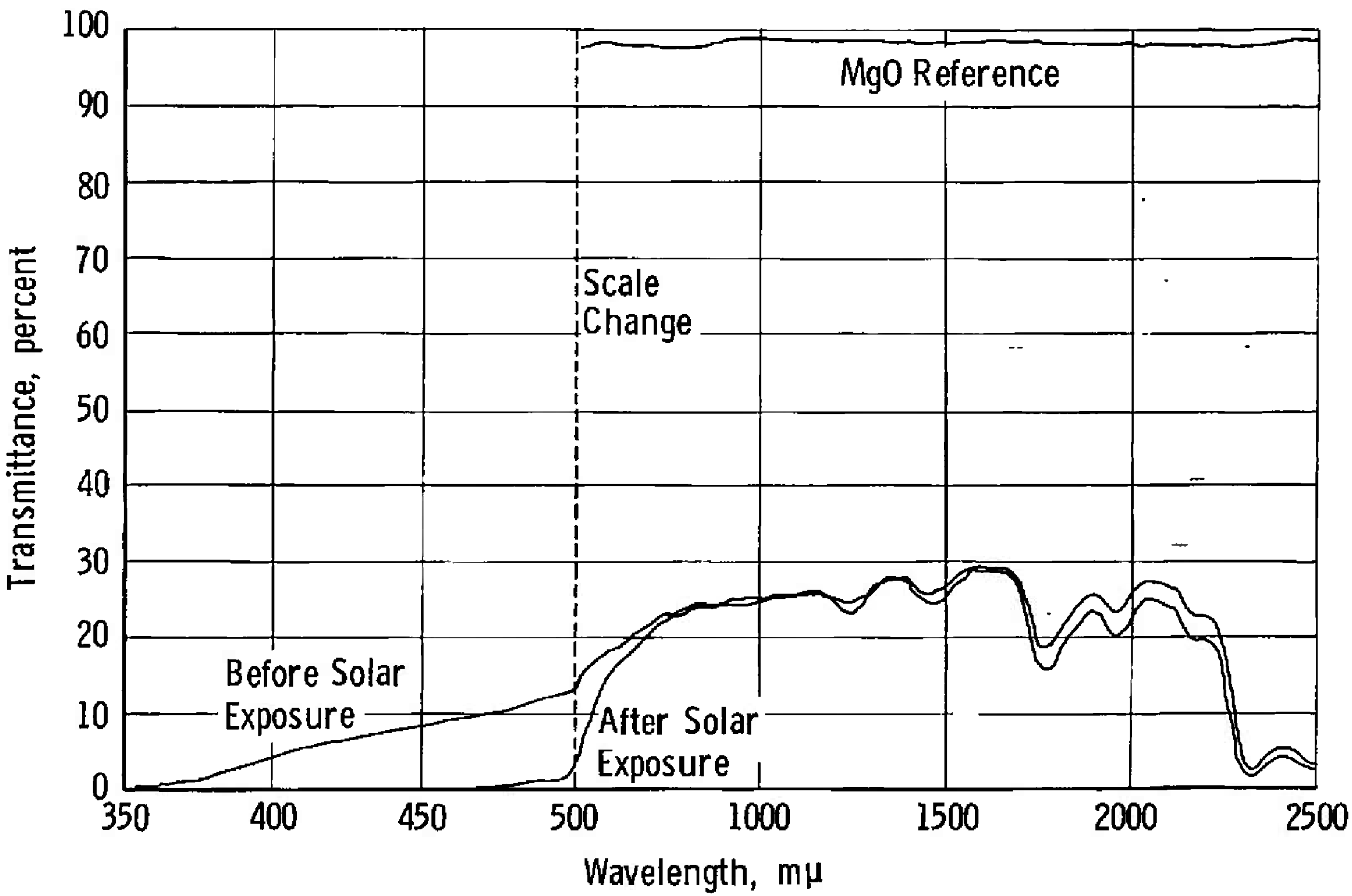

Fig. 17 Solar Effects on Transmittance of National Cash Register Co. Fiber Glass Samples

TABLE I
SUMMARY OF MECHANICAL PROPERTIES

TENSILE PROPERTIES

SUPPLIER	ULTIMATE VACUUM EXPOSURE, psi			MODULUS OF ELASTICITY VACUUM EXPOSURE, psi		
	5 Days	60 Days	60 Days and Solar	5 Days	60 Days	60 Days and Solar
Archer Daniels Midland Co.	28, 600	32, 200	27, 400	703, 000	627, 000	643, 000
Hughes Aircraft Co.	25, 500	24, 300	26, 900	619, 000	401, 000	540, 000
National Cash Register Co.	25, 600	26, 200	27, 800	656, 000	550, 000	673, 000

FLEXURAL PROPERTIES

	AVERAGE LOAD AT FAILURE, lb			DEFLECTION, in.		
Archer Daniels Midland Co.	55. 6	62. 0	63. 2* 62. 1	0. 100	0. 090	0. 089* 0. 089
Hughes Aircraft Co.	29. 0	39. 2	43. 6* 23. 9	0. 090	0. 109	0. 124* 0. 073
National Cash Register Co.	31. 8	38. 3	47. 2* 37. 6	0. 101	0. 103	0. 109* 0. 022

DENSITY, gm/cc

	0 Days	5 Days	60 Days	60 Days and Solar	Average Thickness, in.
Archer Daniels Midland Co.	1. 43	1. 56	1. 42	1. 55	0. 042
Hughes Aircraft Co.	1. 48	1. 50	1. 45	1. 61**	0. 050
National Cash Register Co.	1. 64	1. 66	1. 68	1. 81	0. 044

*Side exposed to solar in compression
**Sample density before 60-day period = 1. 56 gm/cc

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13 ABSTRACT

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
vacuum						
expandable structures						
fiber glass						
space environmental tests						
density						
elongation						
thermal properties						
optical properties						
tensile properties						
bending properties						
solar irradiation						

2 Fiber glass
3 "
10 16
Environmental effects
Space effects

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