A Reproduced Copy

OF

N68-27526

Reproduced for NASA

by the

NASA Scientific and Technical Information Facility

FFNo 672 Aug 65

FLEXIBLE REINFORCED COMPOSITE WINDOW MATERIAL

By Jerry G. Williams

ABSTRACT

This paper presents the results of an investigation to determine the feasibility of reinforcing a flexible transparent matrix with high-strength filaments in a rectangular grid pattern to form a flexible window for use in a manned expandable space structure. Experimental results of the effect of the space environment on optical and mechanical properties of the candidate matrix, reinforcement, and composite materials are given. Two concepts for attaching the window as an integral part of an expandable structure are presented.

FLEXIBLE REINFORCED COMPOSITE WINDOW MATERIAL

By Jerry G. Williams*

INTRODUCTION

To date, all spacecraft for manned space flight have contained windows. These windows have proven extremely useful in conducting photographic-type experiments and in providing the capability for visual horizon and relative spacecraft referencing. Advanced applications of expandable space structures such as those shown in figure 1 also find it extremely desirable to provide windows for visual observations. A flexible window in the expandable lunar shelter(1) would allow observation of shelter support equipment and lunar experiments and would take advantage of external illumination for lighting. A window in a large expandable experiment module would be useful in viewing external phenomena. A window in the expandable airlock(2) would permit observation of space experiments located externally without requiring extravehicular activity (EVA) and would provide the means for initial orientation and referencing for EVA. Also the psychological aspects of a window in a manned space structure should not be overlooked. The purpose of this investigation was to determine if a flexible window compatible with the space environment could be developed for such applications.

Existing flexible transparent polymeric materials do not possess sufficient strength to resist the pressure loads developed in a manned spacecraft structure. The approach taken to meet this high-strength structural requirement for the flexible window is illustrated in figure 2. Basically a rectangular grid network of girth and axial filaments was embedded in a flexible transparent matrix, thus forming a flexible biaxially high-strength composite material. Rectangular space areas between filament groups were required to permit light transmission and viewing, as in a common window screen. The girth-to-axial-strength ratio was taken to be 2:1; the stress ratio developed in a pressure-loaded cylinder. Guidelines for the window were that it be capable of carrying a load of 840 lb/in. (147,000 N/m) in the girth direction and that the window display good optical properties under a 7-psi (48,300 N/m^2) pressure differential. In addition, the matrix was required to be capable of carrying the pressure loading within each grid without "blowout" up to a pressure differential of 35 psi (241,000 N/m^2).

The investigation approach taken was, first, to screen (including simulated space environment testing) available transparent polymers and reinforcement materials for suitable materials; second, to parametrically evaluate the reinforcement pattern; third, to develop an end attachment concept; and, last, to test the resulting composite materials and attachments. The results of this investigation will now be described.

---

*Aerospace Engineer, NASA Langley Research Center.

MATERIALS INVESTIGATION

Matrix

Following a survey of available transparent materials,(3) the optical and mechanical properties of four generically different types of flexible transparent polymers were evaluated. These included: (1) ethylenepropylene, (2) polyurethane, (3) silicone, and (4) polyisoprene. These materials were either cast or molded in sheets against ferro-type plates (1/2 rms finish) in thicknesses of approximately 0.030 inch (0.0762 cm), 0.060 inch (0.152 cm), and 0.120 inch (0.305 cm). Transparency and strength data for samples of each of the four polymers are given in table 1. The ethylene-propylene copolymer and polyisoprene materials were both considered to be unsatisfactory for the application due to their initiation of crazing, embrittlement, and reduced transparency after heat exposure of 100° C for 7 days. Heat exposure also darkened the polyester urethane and very slight crazing was noticed after 10 days of ultraviolet radiation exposure in a fadometer (ASTM procedure D-750-55T) with output strength of 3.15 watts/m^2 of wavelength below 4000 Å. The silicone polymer exhibited excellent resistance to both heat and ultraviolet exposure. The strength at 100-percent elongation and at break both before and after heat, vacuum, or ultraviolet exposure is also shown in table 1. Since these tests were of an exploratory nature, insufficient numbers of tests were conducted to give statistical significance to the differences noted. Apparently, however, the strength of the polyester urethane and silicone polymers was not appreciably changed by the environmental test conditions considered.

Figure 3 presents data for the percent of incident light transmitted by samples of dimethyl RTV silicone and polyester urethane corresponding to wavelengths ranging from 2400 Å to 150,000 Å. Thicknessess for the silicone and urethane were 0.111 inch (0.282 cm) and 0.075 inch (0.190 cm), respectively. Of particular interest is the visible spectrum ranging from 4000 Å to 7000 Å. It is noted that the silicone transmitted approximately 93 percent of the incident light throughout this range while the urethane was essentially opaque at 4000 Å and increased to approximately 88 percent at 7000 Å. Window anomalies are noted in the ultraviolet and infrared regions.

Additional information generated in the study showed the effect of thickness on the percent light transmission through the visible spectrum for the silicone to be negligible for the range of thicknesses tested (0.037 inch (0.094 cm) to 0.171 inch (0.435 cm)). This was not true, however, for the urethane which, for example, at a wavelength of 5750 Å showed a decrease from 84-percent to 71-percent transmission corresponding to an increase in thickness from 0.048 inch (0.122 cm) to 0.133 inch (0.338 cm).

The effect of heat exposure (100° C for 7 days) on the percent incident light transmitted by the silicone through the visible spectrum was found to be insignificant. Heat exposure, however, exhibited a notable effect on this property for the polyurethane, with a more pronounced effect occurring at the blue end of the spectrum than at the red. For example, a 0.133-inch- (0.338 cm) thick sample of urethane transmitted 35 percent of the incident light of 4240 Å before heat exposure and only 1 percent after exposure. At 7000 Å, 85 percent was transmitted before and 79 percent after heat exposure. The effect of the ultraviolet radiation exposure (previously described) on the percent incident light transmitted in the visible spectrum was determined to be insignificant for both the silicone and the urethane.

It should be pointed out that the optical clarity one obtains in looking through a window is not only dependent on the amount of light which is transmitted, but is also influenced by the degree of resolution provided by the window. The preceding discussion has dealt only with the amount of light transmitted by the matrix material. The second consideration, resolution, will be taken up in a later discussion involving human factors evaluations of reinforced pressure-loaded windows.

The ability of the matrix material to resist bending and repeated folding during packaging is of extreme importance for a flexible window concept. To determine the ability of the matrix materials to meet this requirement, a flexometer instrument, the essential elements of which are described in table 2, was used. Both the polyester urethane and the dimethyl RTV silicone successfully completed 349,000 flex cycles without failure. It should be pointed out, however, that one disadvantage of using silicone for the window application is its notch sensitivity and corresponding low tear resistance. Urethane, on the other hand, is quite tough and resistant to tear propagation. Study is currently under way to investigate the possibility of laminating the two materials in order to combine the desirable properties of both materials.

Reinforcement Material

Three different candidate window reinforcement materials were evaluated including glass, steel, and polyester filaments. Each reinforcement material was embedded in silicone test samples 1 inch (2.54 cm) wide as uniformly spaced uniaxial strands. The test samples were 5 inches (12.7 cm) long and were prepared so that the center 3 inches (7.63 cm) of the sample filaments were embedded in dimethyl RTV silicone while 1 inch (2.54 cm) at each end was "plotted" into an epoxy impregnated glass cloth. The tensile strength of the candidate reinforcement materials was then measured before and after heat exposure (100° C for 7 days) using the above-described test specimen in a constant strain rate test machine with a crosshead separation rate of 2 inches (5.08 cm) per minute. Results of these tests are shown in table 3.

Of the fiberglass materials evaluated, the S-901 glass (S-glass with HTS finish) gave the highest ultimate tensile strength (5.3 lb (23.6 N) per end). The 0.010-inch- (0.0254 cm) diameter polyester filament gave a tensile strength of 6.9 lb (31.7 N) per filament and the 0.004-inch- (0.0102 cm) diameter steel wire gave a tensile strength of 6.3 lb (28.0 N) per wire. The effect of heat exposure (100° C for 7 days) is noted in the right-hand column of table 3. As expected, significant differences in tensile strength from unexposed samples were not obtained for the glass reinforcement. However, polyester reinforced test samples distorted and wrinkled badly after heat exposure due to shrinkage of the reinforcement. It was also found necessary, using the polyester, to fill almost the entire window viewing field with filaments in order to get the required design strength (840 lb/in. (147,000 N/m) in the girth direction). For these reasons, polyester reinforcement was considered unsatisfactory for the application.

Both the steel wire and S-901 fiberglass filaments appeared to be satisfactory for the window reinforcement material and were both used in the remainder of the study. One problem area, however, which was uncovered during the study and is particularly acute for the steel wire, was the poor adhesion developed between the matrix and reinforcement materials. Improvement in the compatibility of the finish used on the filament or wire with the matrix material should improve this property.

For design purposes, the reinforcement material was considered to carry all the girth and axial loads. However, as noted earlier, the matrix was required to resist blowout within the reinforcement grid. For calculation purposes, the design strength of the S-901 fiberglass and steel wire was considered to be 6.0 lb (26.7 N) per end (wire). This then required 140 filaments (wires) per inch (2.54 cm) to meet the 840-lb/in. (147,000 N/m) strength requirement in the girth direction and 70 filaments (wires) per inch (2.54 cm) to meet the 420-lb/in. (73,500 N/m) strength requirement in the axial direction.

REINFORCEMENT PATTERN

Various spacings of filaments were evaluated in this study to determine the effect of spacing on optical resolution both for a nonstressed and pressure-loaded condition. Reinforcement pattern properties for 15 different panels are shown in table 4. These panels included specimens whose reinforcement filaments were uniformly spaced as in panel number 1 where, for example, a bundle of 40 ends was spaced every 0.25-inch (0.635 cm) in the girth direction; and panels such as number 3 whose bulk of filaments was bundled in one uniformly spaced group with additional filaments uniformly spaced in between.

Thicknesses and weights for some of these panels are also given in table 4. It is believed that these thicknesses and weights can be reduced, although it appears that a thickness of approximately 0.120 inch (0.304 cm) is necessary in order to insure complete coverage of the reinforcement filaments by the transparent matrix material. If filaments are cast too close to the surface, local stress-induced surface straining seriously affects resolution characteristics.

To measure the optical clarity obtainable with nonloaded reinforced panels, photographs were taken of a test chart with the test panel located between the camera and the test chart. The test panel was located 1 foot (0.305 m) from the camera lens and 5 feet (1.27 m) from the 28-inch (0.711 m) × 36-inch (0.91 m) test panel. Some of the photographs resulting from this experiment are shown in figure 4. Lighting and development conditions were identical for all photographs. Test panels are shown below the corresponding photograph. For reference, the photograph in the upper left-hand corner was taken without any intervening test sample. The middle two photographs of the top row were taken with unreinforced dimethyl RTV silicone and polyester urethane, respectively, as the test panels. All the reinforced specimens shown are composed of fiberglass reinforcement embedded in a silicone matrix with the exception of the panel in the upper right-hand corner which uses steel reinforcement rather than glass.

The data from light transmission tests conducted on the reinforced panels revealed that the presence of the filaments reduced the percent of incident light transmitted by approximately the percent of projected area taken up by the filaments (from 10 to 30 percent depending on the pattern and wavelength). It should be pointed out that the optical resolution obtained by human viewing is normally superior to that obtainable in photographs. This, of course, is because of the superiority of the human eye and because of unconscious body movements which allow one to shift viewing angles slightly to compensate for view blockage caused by the filament pattern.

To measure the resolution obtainable under loaded conditions, the test panels were pressure loaded to 7 psi (48,300 N/m^2) and a human factors evaluation made. The individual making the evaluation viewed the test chart, located 6 feet (1.52 m) beyond the window, through the pressure-loaded test panel and made a comparative judgment based on the criteria set forth in table 5. Results for the first five panels shown in table 4 are given in table 6. For comparison, a rating of 1.0 was obtained for the three main points (blurriness, ability to focus, and readability) for a test conducted without intervening panel. The smallest legible print size which is readable looking through the panels is also given. Of these five panels, number 4 gave the best results.

ATTACHMENT DESIGN

The window geometry chosen for the attachment study was an ellipse whose major and minor axes were 11.4 inches (0.289 m) and 8.0 inches (0.203 m), respectively. Two systems were developed for attaching the flexible window element to a flexible expandable structure. The essence of these two concepts (adhesive bonding and mechanical clamping) is shown in a cross-sectional drawing in figure 5.

Since the reinforcement filaments carry the principal stresses, the attachment approach involved anchoring the filaments around the periphery of the window to meet the "pull-out" strength requirement, thereby transferring the window stresses into the flexible structure. Tests conducted on fiberglass rovings embedded in a silicone matrix showed the silicone to possess insufficient strength for this purpose. It was thus found necessary to terminate the reinforcement filaments in a stronger, higher modulus material. A nitrile polymer anchor flange approximately 2 inches (5.08 cm) wide was found satisfactory for this purpose. Two fiberglass doilies, wound to the elliptical shape of the nitrile flange, were adhered to both faces of the nitrile anchor flange for reinforcement.

The silicone-nitrile flange butt joint was found to form an inadequate joint for gas sealing purposes. Therefore, a seal consisting of a 0.015-inch (0.038 cm) nitrile sheet was bonded to both sides of the attachment in the joint interface region. It was found necessary, however, to provide an unbonded region on the nitrile seal at the silicone-nitrile flange interface in order to prevent stress concentration induced failures in the silicone. This condition was insured by the incorporation of an unbonded Mylar ring in this region.

Silicone polymer bonds poorly to most adhesives other than those with silicone base. Experimental investigations showed a combination of silicone adhesive A-4000 and an epoxy-based adhesive 943 to be satisfactory for bonding the silicone matrix to the nitrile rubber.

For the adhesively attached window, the attachment to the flexible structure was achieved by a nitrile cement bond between the anchor flange and the flexible structure. For the mechanical attachment, it was developed by a pair of rigid metal rings contoured to the cylindrical curvature of the window and fastened together by a uniformly spaced array of bolts.

The processes involved in fabricating a window and its attachment are shown in figure 6. First, the fiberglass filaments are laid up in a predetermined pattern on a frame-mold tooling fixture and a nitrile flange is placed beneath the fiberglass reinforcement. The glass rovings are then coated with nitrile cement in the flange region. The top half of the nitrile flange is then placed over the fiberglass and the entire system including fixture is placed in a press and cured at 154° C for 1 hour at a pressure of 100 psi (689,000 N/m^2). After the system is removed from the press, the silicone matrix is slowly cast in the elliptical section of the window and allowed to cure at room temperature for 12 hours. The nitrile flange is then trimmed and the glass rovings cut from the frame. The fiberglass ends are then tied in knots and brush coated in place with a nitrile cement. The Mylar ring is placed in the areas where nonadhesion is desired (not shown) and the nitrile seal is bonded into place.

TEST RESULTS

Permeability

Since the flexible window will be used as a pressure retainer, the permeability of the composite materials is of interest. Permeability data for five silicone fiberglass reinforced panels and for unreinforced silicone and polyurethane are shown in table 7. The permeability of the nonreinforced silicone and fiberglass reinforced silicone panels is of the same magnitude, indicating that the reinforcement had negligible effect on permeability. Heat exposure (100° C for 7 days) it will be noted did not apparently affect the permeability of the two polymers. For comparative purposes, Mylar, one of the better low-permeability materials, has a permeability to pure helium of 0.0722 cc(STP)/cm^2-mm-day-atmosphere.[4] This is two orders of magnitude lower than the silicone. Even so, however, the silicone permeability would probably be tolerable for space window application. However, if the composite material were used for large sections of a spacecraft with a long-duration mission, a composite with lower permeability would be desirable. A reinforced window with a laminated matrix using constituent materials such as silicone and Mylar would probably reduce the permeability.

Attachment Study

The flexible window attached to a 3-feet- (1.02 m) square flexible fiberglass fabric using both adhesive and mechanical-type attachments was evaluated in the 4-foot- (1.02 m) diameter pressure chamber shown in figure 7. The flexible window withstood pressures up to 29 psi (200,000 N/m^2) using the adhesive attachment and up to 59 psi (406,000 N/m^2) using the mechanical clamp. All failures encountered were due to filaments "pulling out" of the nitrile flange, which resulted in breaking of the pressure seal and leakage. No reinforcement filament breakage was encountered and the strength of the silicone matrix to resist "blow out" between the reinforcement grid was concluded to be satisfactory for the test conditions considered.

Optical human factors tests were conducted on reinforcement pattern panels numbers 6, 9, and 13; previously described. The results of these tests are shown in table 6 for the panels pressure loaded at 7 psi (48,300 N/m^2).

Filament Wound Chamber

As a final test, conducted to evaluate the flexible window while focusing attention on more closely simulating the real structural application edge conditions, a flexible window was adhesively attached as an integral part of an 18-inch- (45.8 cm) diameter flexible fiberglass filament wound chamber. The chamber with an elliptical shaped, reinforced cut-out is shown in figure 8 along with an enlarged photograph of the window and flange.

The first flexible chamber and window constructed were pressurized to failure. Leakage developed at the window-flange interface at a pressure of 65 psi (448,000 N/m^2) which in an 18-inch- (45.8-cm) diamter cylinder is equivalent to a stress of 585 lb/in. (1025 N/cm) in the girth direction.

A folding test in which the window was bent to a radius of 1.5 inch (3.81 cm) is shown in figure 9. After 25 cycles of folding, the chamber was pressurized to 21 psi (145,000 N/m^2) without failure.

Figure 10 shows the flexible window and chamber while pressurized at 7 psi (48,300 N/m^2). The letters of the chart which reads "FLEXIBLE WINDOW STUDY" were 1 inch (2.54 cm) high and the chart was located inside the chamber approximately 18 inches (45.7 cm) from the window. The camera lens was located 5 feet (1.27 m) from the window. An internal light source was used to illuminate the test chart.

CONCLUDING REMARKS

The results of this investigation indicate that a flexible window is feasible for expandable structures application. A flexible window composed of a composite material of steel or fiberglass reinforcement embedded in a transparent silicone rubber matrix shows particular promise. Simulated space environment experiments conducted on flexible window elements have shown no serious degradation effects on the mechanical and optical properties of the composite, and good optical resolution was observed under a 7-psi- (48,300 N/m^2) pressure differential. Existing systems for attaching the flexible window into an expandable structure are insufficient to develop the full structural capability of the composite window material and improved attachment concepts should be developed.

REFERENCES

1. Tynan, C. I.: Lunar Stay Time Extension Module. Selected Papers on Environmental and Attitude Control of Manned Spacecraft. NASA TM X-1325, Dec. 1966.

2. Williams, J. G.: Development of an Expandable Airlock Utilizing the Elastic Recovery Principle. Second Aerospace Expandable Structures Conference, Minneapolis, Minn., May 25-27, 1965.

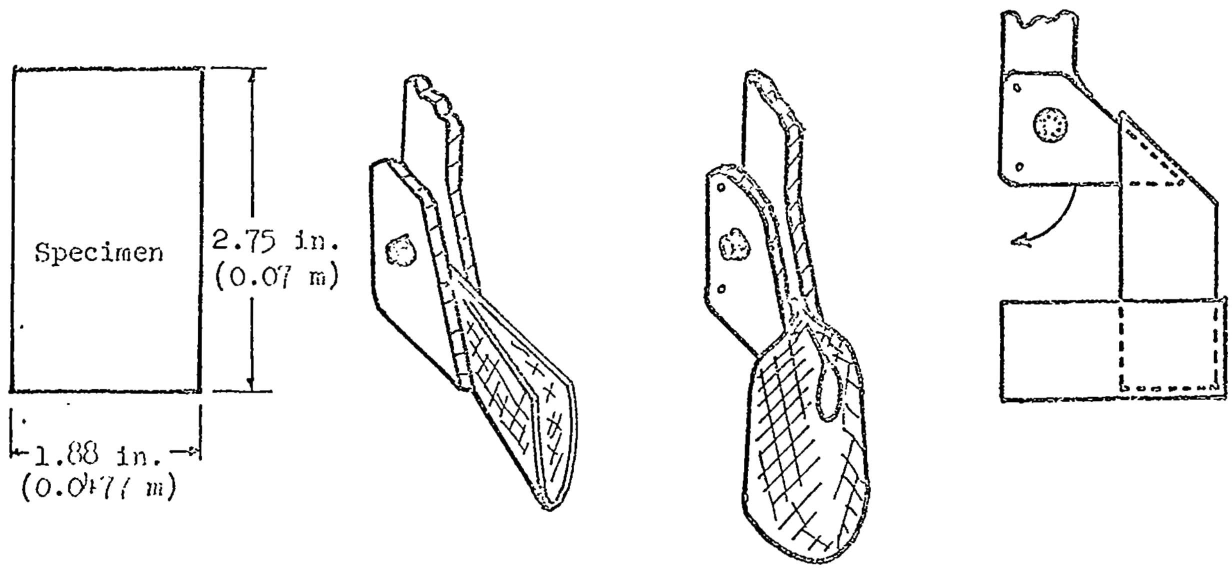
3. Kohrn, R. C.; Kelsheimer, G. E.; Uhlig, E. C.; and LaBelle, B. S.: Feasibility Study for Development of a Flexible Reinforced Window. Uniroyal, NASA CR 66299, March 1967.

4. Rogers, C. E.: Permeability and Chemical Resistance. From book entitled "Engineering Design for Plastics," edited by Eric Baer. Reinhold Publishing Corp., 1964.

TABLE 1.- FLEXIBLE TRANSPARENT POLYMER PROPERTIES

	Transparency		Strength, psi (N/m^2)				
			100 percent elongation			Break	
	Heat exposure 7 days - 100° C	Ultraviolet exposure 10 days	Original	Heat exposure 7 days - 100° C	Ultraviolet exposure 10 days	Original	Vacuum exposure 254 days ~ 3×10^{-8} torr
Ethylene propylene copolymer	unsatisfactory	unsatisfactory	270 (1.86×10^6)		320 (2.21×10^6)	1390 (9.59×10^6)	
Polyisoprene	unsatisfactory	unsatisfactory	140 (9.65×10^5)				
Polyester urethane	darkened	slight crazing	570 (3.93×10^6)	605 (4.17×10^6)	700 (4.83×10^6)	5780 (3.99×10^7)	
Dimethyl RTV silicone	satisfactory	satisfactory	615 (4.24×10^6)	625 (4.31×10^6)	560 (3.86×10^6)	744 (5.12×10^6)	877 (6.05×10^6)

TABLE 2.- FLEXIBILITY DATA



Unreinforced polymer	Thickness in. (cm)	Number of flex cycles
Polyester urethane	0.073 (0.185)	349,000 - test terminated
Dimethyl RTV silicone	0.066 (0.168)	349,000 - test terminated

TABLE 3.- REINFORCEMENT MATERIAL STRENGTH

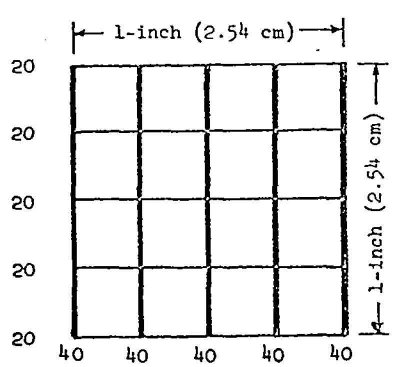
Reinforcement material, (finish and type glass)	Ultimate tensile strength, lb/end (N/end)	
	Original	Heat exposure, 7 days ~ 100° C
Glass(1) (901-S)	5.3 (23.6)	5.5 (24.5)
Glass (1014-S)	4.9 (21.8)	5.3 (23.6)
Glass (1026-E)	3.1 (13.8)	2.9 (12.9)
Glass (801-E)	3.0 (13.3)	3.4 (15.1)
Glass (902-E)	2.9 (12.9)	3.9 (17.4)
Glass (810-E)	2.3 (10.3)	2.5 (11.1)
Glass (711-E)	2.2 (9.8)	2.5 (11.1)
Glass (1033-E)	1.3 (5.8)	0.7 (3.1)
Polyester(2)	6.9 (30.7)	--
Steel(3)	6.3 (28.0)	--

(1) All glass filaments were G size (0.00038-inch (0.00097 cm) diameter).
(2) 0.010-inch (0.0254 cm) diameter filament.
(3) 0.004-inch (0.0102 cm) diameter wire.

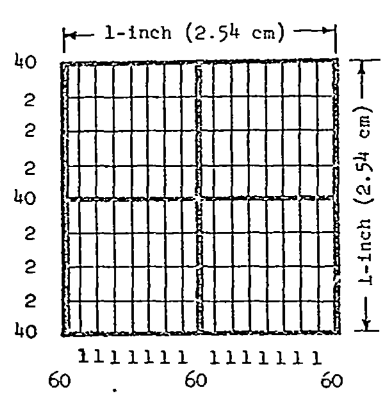
TABLE 4.- REINFORCEMENT PATTERN PROPERTIES

Panel No.	Matrix	Reinforcement	No. of groups of filaments per in. (No. per 2.54 cm)		No. of ends per group		No. of ends per in. (No. per 2.54 cm)		Thickness, in. (m)	Weight, lb/ft^2 (N/m^2)
			Girth	Axial	Girth	Axial	Girth	Axial		
1	Silicone	S-glass*	4	4	40	20	160	80	0.151	0.92
2	Silicone	S-glass	2	2	80	40	160	80	0.181	1.14
3	Silicone	S-glass	2 14	2 6	60 1	40 2	134	92	0.194	1.24
4	Silicone	S-glass	4 4	4 4	20 8	10 4	112	56	0.160	0.92
5	Silicone	S-glass	2 2	2 2	60 8	40 4	136	88	0.171	1.02
6	Silicone	S-glass	4 4	4 4	27 8	14 4	140	72		
7	Silicone	S-glass	16	16	9	5	144	80		
8	Silicone	S-glass	4 4	4 4	15 6	8 3	84	44		
9	Silicone	S-glass	16	16	6	3	96	48		
10	Polyurethane	S-glass	2 14	2 6	65 1	32 1	144	70		
11	Silicone	S-glass	2 14	2 6	65 1	32 1	144	70		
12	Silicone	S-glass	2 6	2 4	40 1	20 1	86	44		
13	Silicone	Steel**	2 2	2 2	60 8	40 4	136	88		
14	Silicone	S-glass	2	2	80	40	160	80		
15	Polyurethane	S-glass	4	4	35	18	140	72		

*S-901 glass filaments.
**0.004-in. (.01 cm) diameter steel wire.



Pattern Number 1



Pattern Number 3

TABLE 5.- HUMAN FACTORS OPTICAL TEST RATING

A. Blurriness (distortion)

1. No distortion
3. Blurred but still comfortable
5. Highly distorted, uncomfortable

B. Ability to Focus

1. Eyes focus immediately
3. Strands change focus but still comfortable
5. Strands interfere with focusing

C. Readability

1. Reading clear - minimum of magnification disturbance
3. Letters change magnification but still comfortable
5. Reading moves with eye movement (high degree of magnification change)

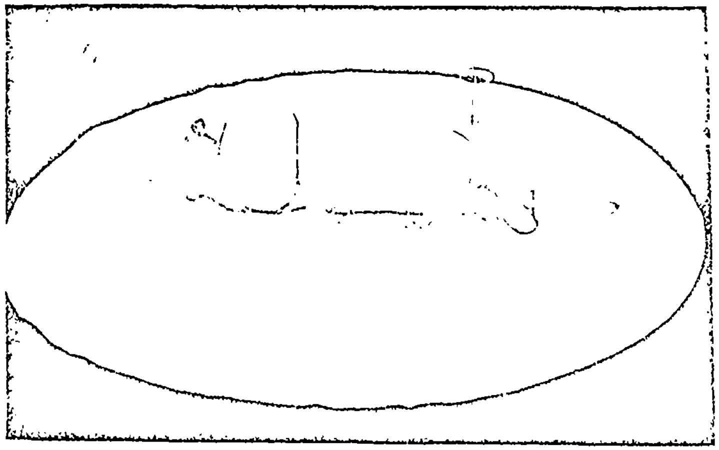
TABLE 6.- HUMAN FACTORS WINDOW EVALUATION

	Human factors optical test (pressurized 7 psi (46,300 N/m^2))			
Panel No.	Blurriness	Ability to focus	Readability	Smallest legible print size, in. (points)
1	3.0	3.5	3.5	0.30 (14)
2	3.7	4.0	3.8	0.156 (11)
3	3.2	3.0	3.6	0.156 (11)
4	2.0	2.0	2.0	0.0937 (6)
5	3.1	3.2	3.4	0.30 (14)
6	3.0	3.0	3.0	0.156 (11)
9	2.5	2.5	2.5	0.156 (11)
13	2.5	2.5	2.5	0.0937 (6)

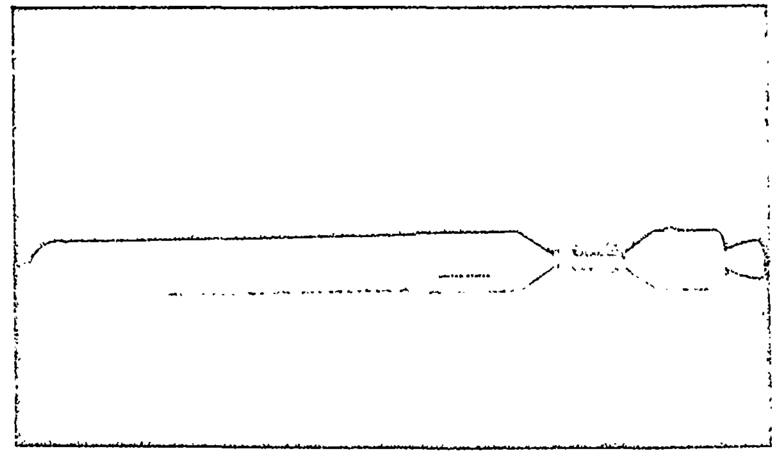
TABLE 7 .- PERMEABILITY DATA

Sample[1]	Permeability[2] cc(STP)/cm^2-mm-day-atmosphere	
	Original	Heat exposure, 7 days ~ 100° C
Dimethyl RTV silicone, unreinforced	10.7	10.4
Polyester urethane, unreinforced	0.23	0.29
Panel 1	6.4	
Panel 2	6.7	
Panel 3	14.2	
Panel 4	10.7	
Panel 5	4.5	

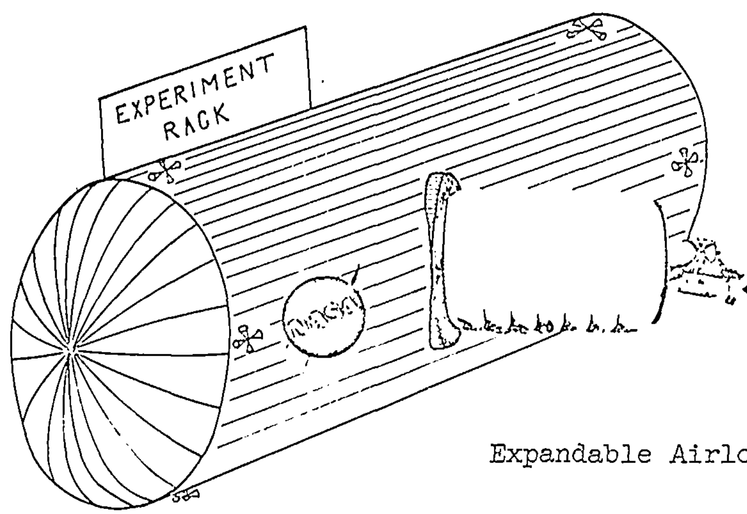
(1) For description of reinforced panels see table 4.
(2) Gas composed of 95 percent helium, 5 percent oxygen.



Lunar Shelter



Expandable Experiment Module



Expandable Airlock

Figure 1.- Expandable structures application for flexible window.

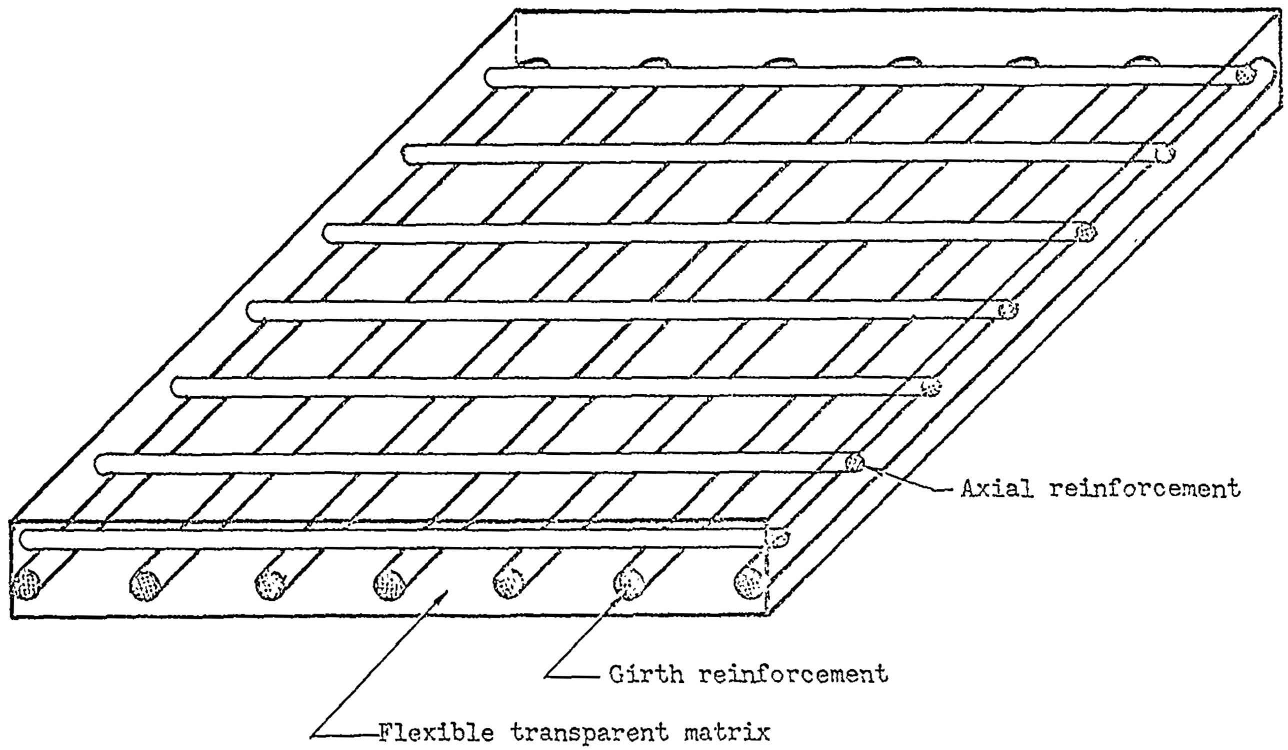


Figure 2.- Flexible window model.

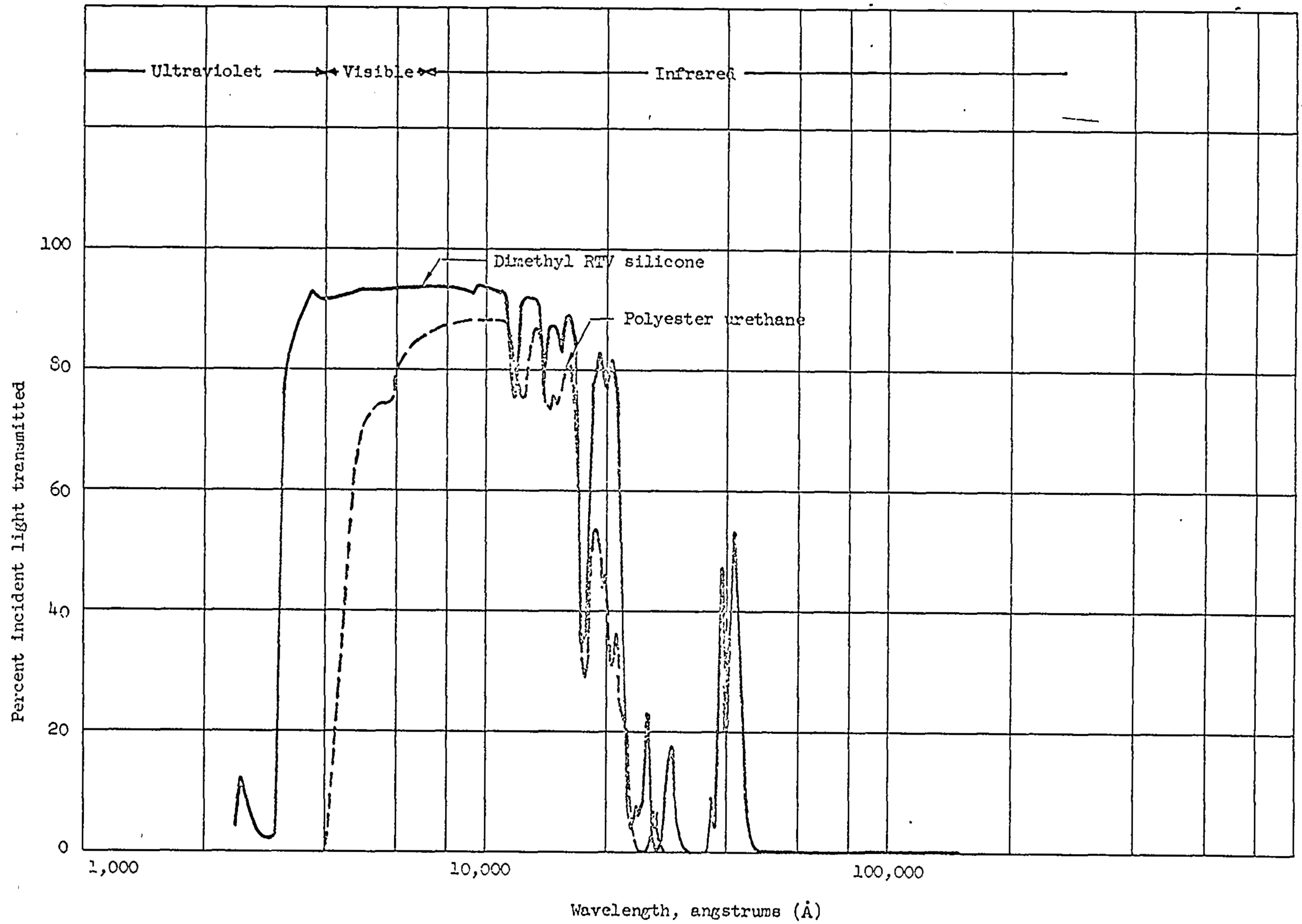


Figure 3.- Percent incident light transmission versus wavelength for polymeric specimen.

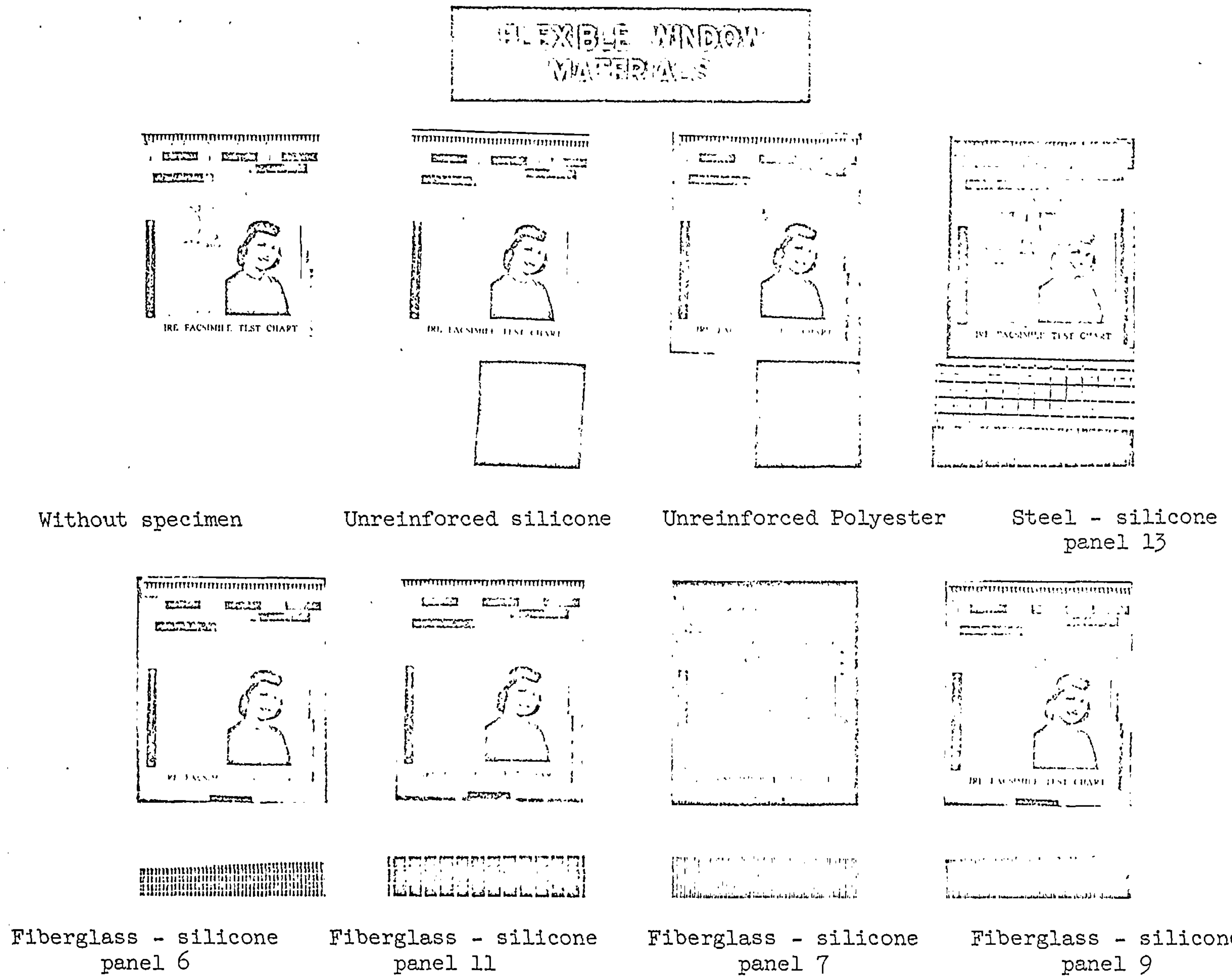


Figure 4.- Photographic test of materials and reinforcement patterns.

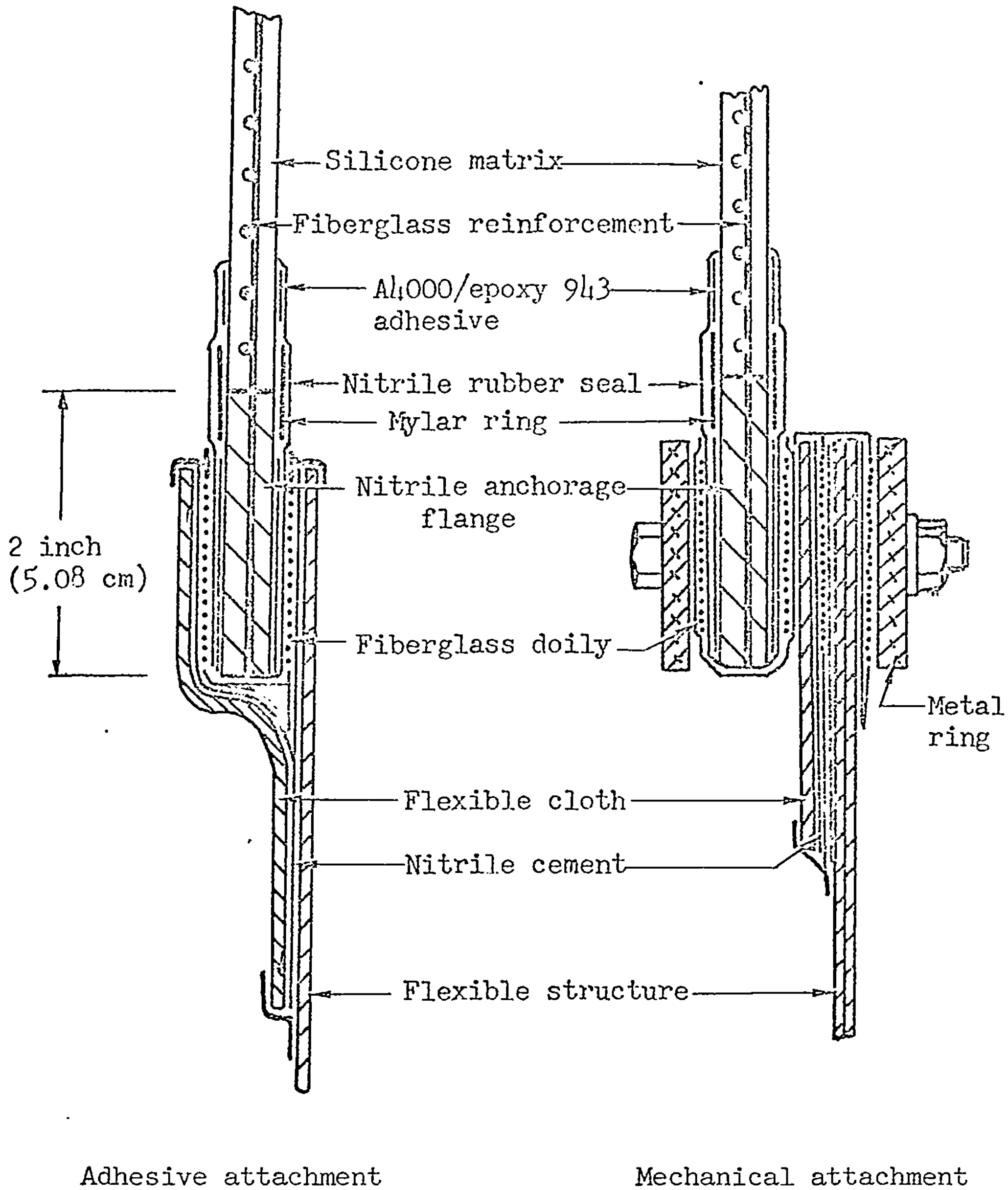


Figure 5.- Window attachment designs.

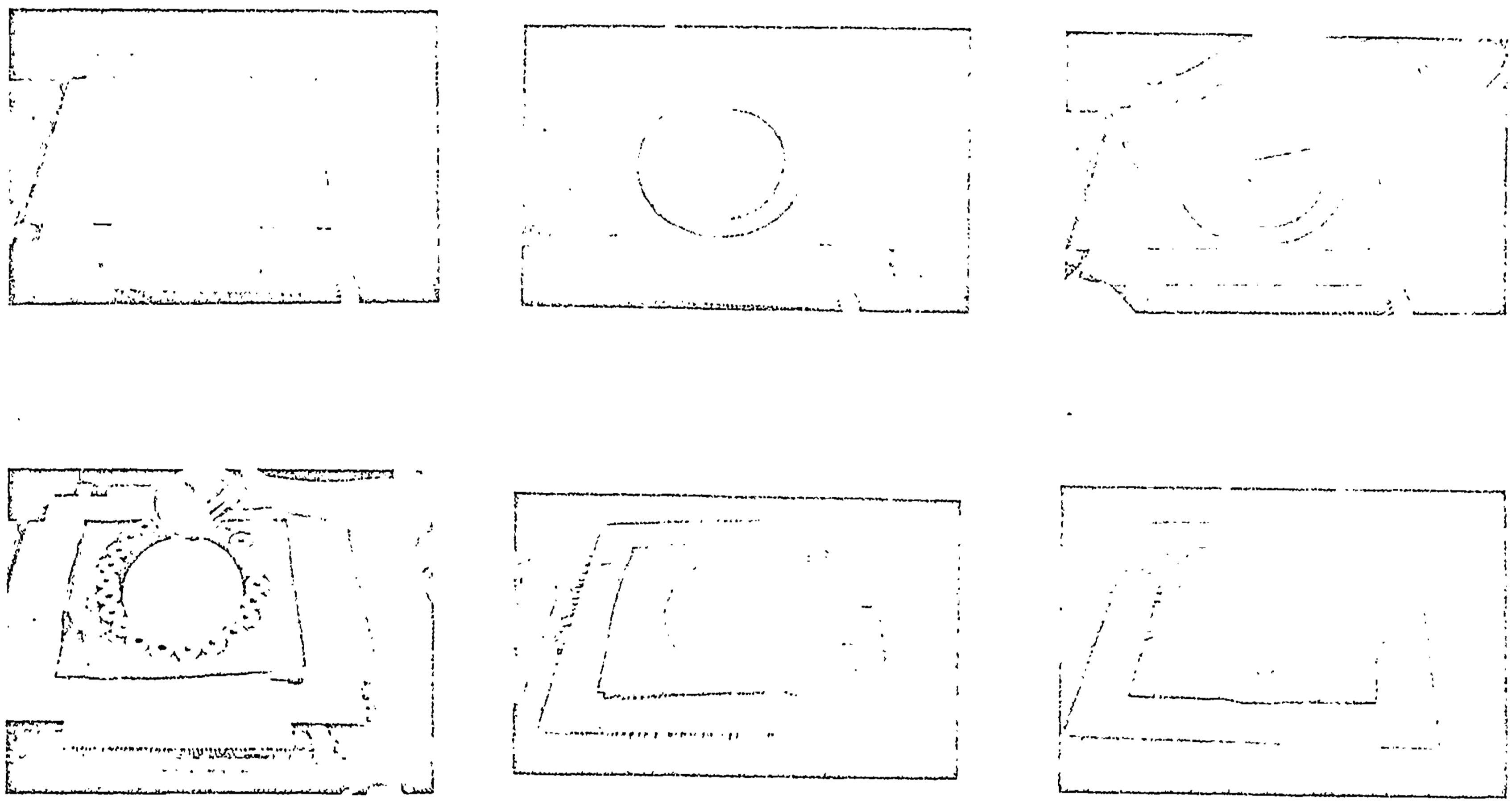
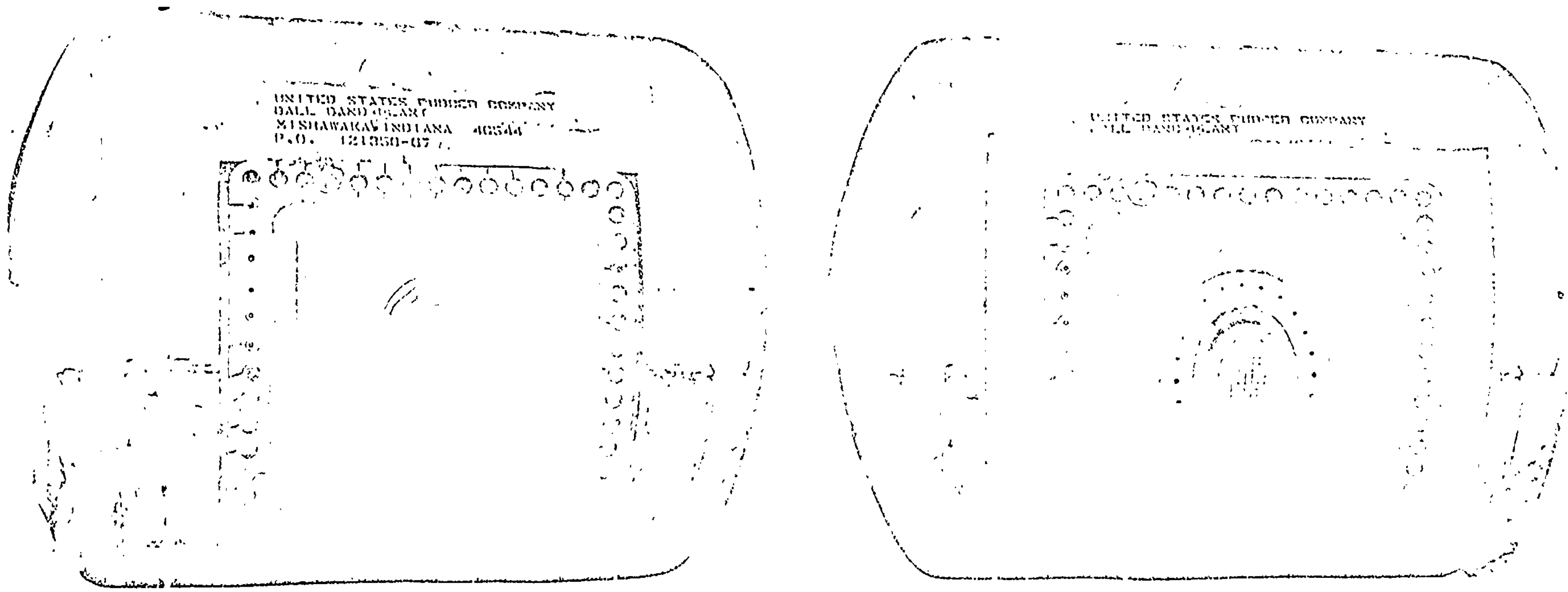
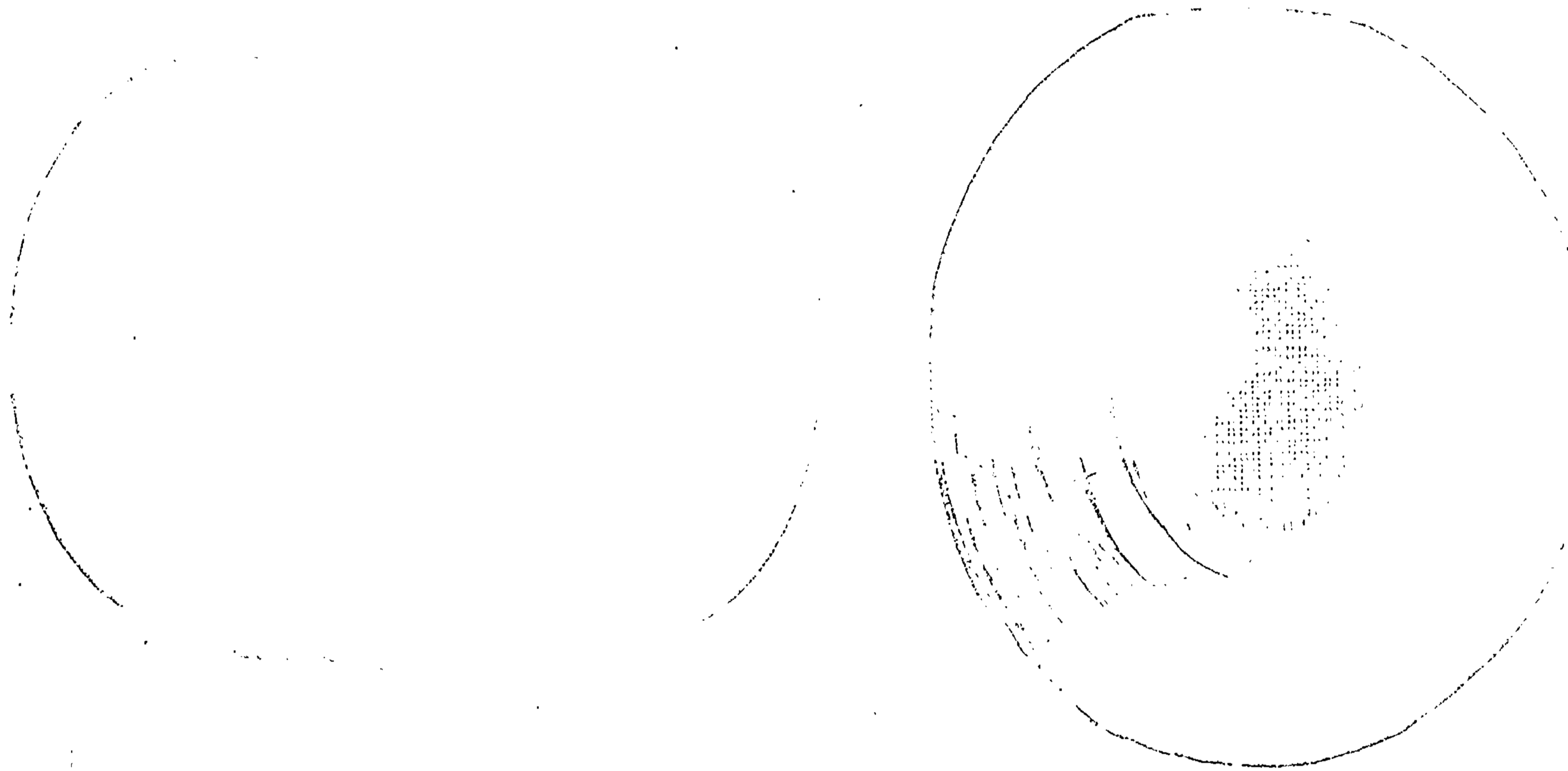


Figure 6.- Photographs showing fabrication techniques for making window.



Adhesive attachment　　　　　　　　　　Mechanical attachment

Figure 7.- Four-foot- (1.22 m) diameter test fixture with adhesive and mechanical window attachments.



Flexible pressure vessel with reinforced opening

Flexible window

Figure 8.- Flexible filament wound pressure vessel and window.

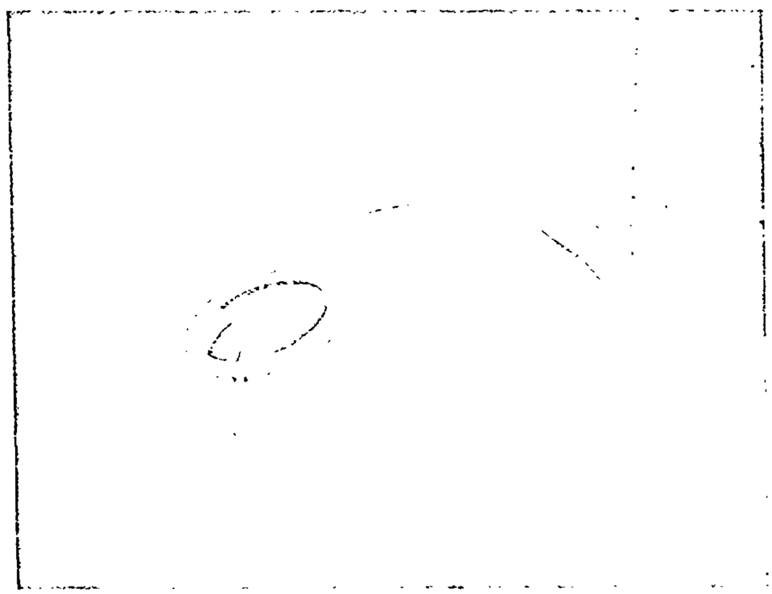


Figure 9.- Window folding demonstration.

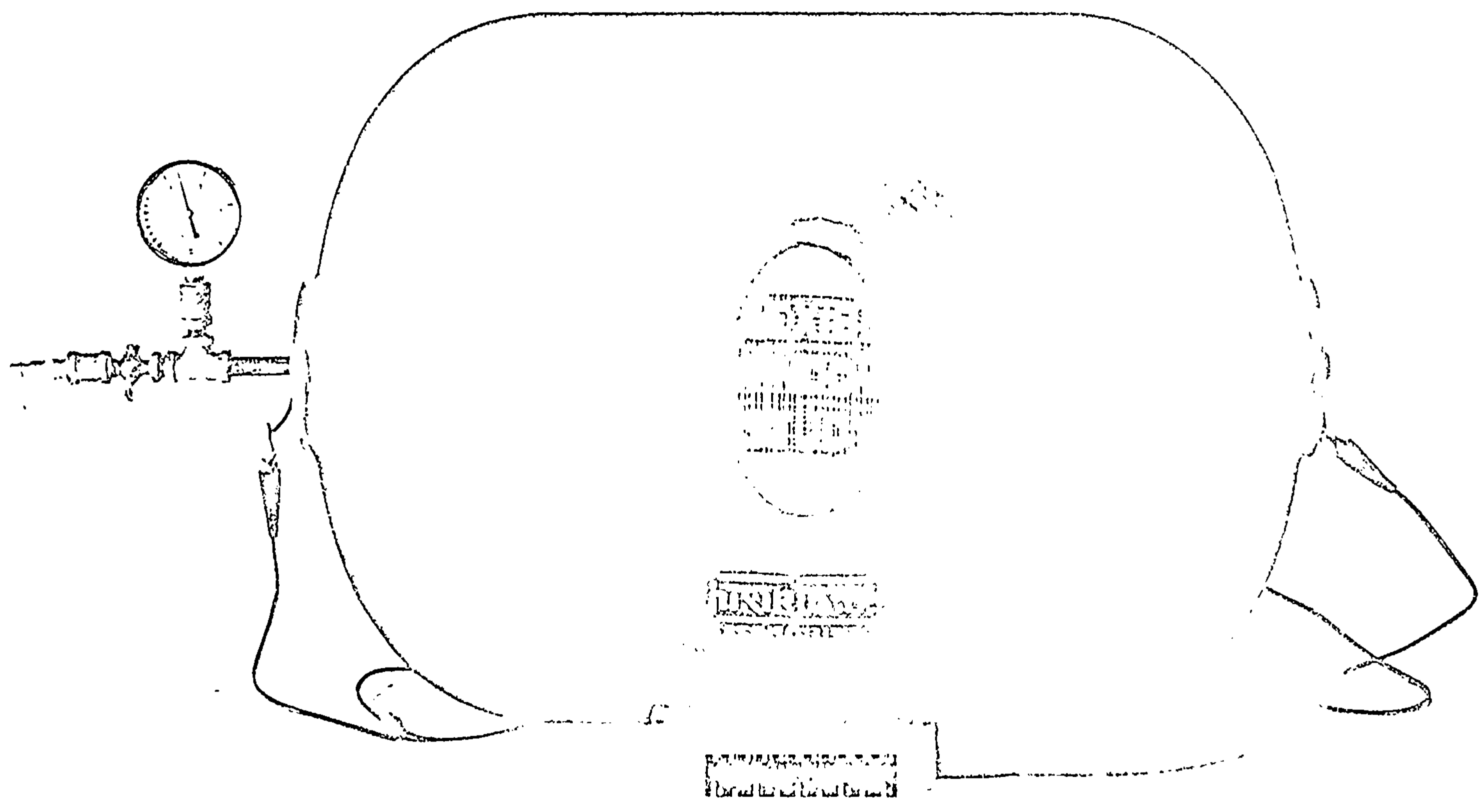


Figure 10.- Flexible window in flexible pressure vessel pressurized at 7 psi (48,300 N/m2).

NASA-Langley, 1967