a NASA facsimile reproduction

OF

N63-19852

N65-32925

REPRODUCED FROM MICROFICHE

by the

NASA Scientific and Technical Information Facility

53p

UNITED STATES RUBBER COMPANY

Research & Development Department

OTS PRICE

XEROX $ 5.60

MICROFILM $ 1.79

Research Center
Wayne, N. J.

FINAL REPORT

of

A RESEARCH STUDY TO INVESTIGATE THE APPLICATION OF FILAMENT WINDING FOR SECTIONS OF AN ERECTABLE SPACE STATION

under

CONTRACT NAS1-2317

by

M. W. Olson

for

THE UNITED STATES RUBBER COMPANY
Research Center
Wayne, New Jersey

April, 1963

FORWARD

The Research Center of the United States Rubber Company conducted a study into the application of filament winding as a technique for producing sections of an erectable space station. The investigation was sponsored by NASA under the Space Station Section of A M P D, Langley Research Center, Langley Station, Hampton, Virginia. Mr R. S. Osborne, Chief of the section, was the Project Officer for NASA. Mr. M. W. Olson acted as project leader for United States Rubber Company and Mr. R. H. Hugger was charged with administering the contract.

Credit for direct assistance and/or background information offered by various U. S. Rubber employees to further the subject study is acknowledged as follows:

Environmental Tests	-	Mr. E. P. Percarpio
Filament Winding Analyses	-	Dr. D. R. Elliott
Radiation Tests and Analyses	-	Dr. W. V. Smith Mr. B. E. Jacobs
Fiber Technology	-	Dr. E. M. McColm
Elastomer Technology	-	Dr. H. E. Haxo
Polymer Degradation Processes	-	Dr. E. M. Bevilacqua
Polyurethane Technology	-	Dr. J. R. Little Mr. D. H. Winslow
Processing Supervision	-	Mr. E. C. Uhlig Mr. E. Francois, Jr. Mr. E. P. Percarpio

TABLE OF CONTENTS

	Page
Abstract	1
Conclusion Summary	2
Introduction to Test Program	3
Sample Preparation and Testing Procedure	6
1. Hoop Wound Tensile Samples	6
2. Plate Wound Characterization Samples	12
3. Flexible Test Bottle	12
Test Results Discussion	18
1. Stress Element Properties	18
2. Binder Properties	23
3. Hoop Sample Test Results	26
4. Description of Composite Characterization Samples	30
5. Filament Wound Bottle Design and Efficiency	33
Bibliography	42
Appendix A - Recommended Avenues for Continued Studies	43
Appendix B - Summary of Binder Compounds and Properties	44
Appendix C - Description of Hoop Samples	49

LIST OF FIGURES AND ILLUSTRATIONS

	Page
Photograph A - Hoop Sample Assembly Drum	7
B - Hoop Sample Tensile Test Jaws	9
C - Hoop Sample Flexing Machine	10
D - Hoop Sample Pre-stressing Jig	11
E - 45-45-90 3-ply Lay-up Plate	13
F - 54-54 2-ply Lay-up Plate	14
G - Binder Impregnating Tape Assembly Drum	16
H - Filament Winding Machine	17
I - Completed Filament Wound Bottle	36
J - Partially Folded Filament Wound Bottle	37
K - Burst Filament Wound Bottle No. 1	38
L - Burst Filament Wound Bottle No. 2	39
Table 1 - Cord Tensile Properties	19
2 - Stress Element Characterization Study	22
3 - Properties of Elastomers and Flexible Plastics	24
4 - Elastomer Property Rating Summary	25
5 - Hoop Sample Test Results	27
6 - Properties of Characterization Samples	31
Figure 1 - Tensile-Temperature Relationship of Typical Fibers	20

ABSTRACT

19850

Recognizing that sections of an erectable, torroidal space station might conveniently be made of an inflatable-type construction, the Space Station Section at the Langley Research Center (NASA) sponsored a study into the application of filament winding for this purpose. The program consisted of screening available materials and establishing fabricating practices which would result in the most desirable filament-wound structure for the application. High strength to weight with flexibility was desired consistent with reliability and compatibility with the space environment.

Cords exhibiting considerable promise as the tensoidal element comprise a) encapsulated glass roving, and b) a high tenacity filament steel wire. Preferred binder material consisted of compounded natural rubber, polyurethane and ethylene propylene rubber. Materials best suited for elevated and depressed temperature environments are noted.

Three 18 x 24" bottles were fabricated of encapsulated glass filaments and a natural rubber binder combination. These were highly flexible but fell short of developing he design burst pressure as predicted by the measure strength of the individual cords which were applied in the bottle construction.

CONCLUSION SUMMARY

Conclusions to the study and test program can be summarized as follows:

1. Natural rubber is a preferred binder for a flexible filament wound wall construction of a space station because of its low initial modulus, high strength at elevated temperature, tendency to harden under radiation and resistance to degradation in the space environment. Polyurethane and ethylene-propylene rubber are close alternates.

2. Encapsulated glass roving is a leading contender for the stress element of the filament winding construction due to its high potential strength, excellent dimensional stability, resistance to radiation damage, suitable folding properties, strength at elevated temperature and non-magnetic properties. Steel wire represents a possible alternate choice.

3. Flexibility is enhanced by a thin wall construction, minimum binder, and minimum penetration of the cord by the binder.

4. Filament wound constructions are potentially stronger on an overall weight basis than unoriented aluminum and steel sheet material.

5. Based on individual measured cord strength, hoop samples made from encapsulated glass cord ranged from 54 to 81% efficient, tape to wind the bottles averaged 70% efficient and the bottles tested were 48 and 51% efficient respectively. Based on the tape strength, the bottles were 69 and 72% efficient.

INTRODUCTION TO THIS PROGRAM

The goal set for the proposed study called for the selection of the composite material best suited, both as to type and form, for filament-winding a section of an erectable manned space station. Several criteria were presented as a basis for this selection. In random order, these are as follows:

1. Material types must be resistant to the degrading effects of the space environment. For a one year period: they must function satisfactorily in a hard vacuum, on repeated thermal cycling between -50°F to +150°F and to electromagnetic and particle radiation in a 300 to 600 mile orbit.

2. The composite structure should incorporate maximum strength to weight properties consistent with suitable flexibility. A double helix-wound cylinder of 7 ft. diameter incorporating a hoop stress of 2900 lbs/inch will govern. Flexibility must be such as to permit folding into a small payload package for launch.

3. Folding to a 1/16 radius through 180° of arc as associated with normal handling procedures must not produce detrimental effects such as loss of strength of the composite structure. Prolonged folding should produce no ill effects.

Many other features which the composite structure should incorporate but which are not specifically considered in the current study include:

1. Low vapor pressure
2. Freedom from toxicity
3. Freedom from odor
4. Low oxygen, nitrogen and water vapor permeability
5. Resistance to penetration damage
6. Non-flammable (combustion resistant)
7. Resistance to launch vibrations and g loadings
8. Repairability
9. Compatibility to coatings and other layers in the space wall

In a space station wall, it is assumed that the filament-wound fabric will be lined internally with a non-permeable coating and self-sealant. It will further be protected externally with insulation, a meteoroid bumper and a passive thermal-controlling, reflective, outer surface. In this situation, exposure to environment extremes is effectively limited, damage through folding is minimized and a wide range of commonly used filament-winding materials present themselves as potential candidates. By giving some consideration as well to other applications for filament-wound structures in space and the varied conditions encountered by these, a wide range of commercially available materials were ultimately selected for the study herein reported. These are listed below:

Filaments (cords, yarns, rovings, etc.)

High Tensile steel	Fortisan
Glass (Encapsulated)	Polypropylene
Nylon	HT-1
High Tensile Boron	
Fortisan	

Binders (elastomers)

- Butyl rubber (std.)
- Butyl rubber (resin cured)
- Natural Rubber
- Neoprene rubber
- Silicone rubber
- Fluroelastomer (Viton B)
- Polybutadiene rubber
- Ethylene-Propylene rubber
- Paracril rubber
- Urethane elastomer (gum)
- Urethane thermoplastic (Estane)
- Urethane elastomer (liquid)
- Epoxy plastic (flexible)

A literature review was not specifically required under the contract. Pertinent publications, however, were evaluated and the general background and

Company experience was drawn upon to a considerable extent for arriving at the conclusions reached in this study. Of specific value was the results of a screening test conducted by the United States Rubber Company aimed at determining the affects of a hard vacuum on a large variety of materials at elevated temperatures.

No attempt is made in this report to review the nature of the space environment in the 300 to 600 mile orbiting range. Others[1][2][3] have thoroughly covered the subject. The test program, however, was designed with the full knowledge of the environment to be encountered and we believe supplies the necessary data for arriving at the conclusions which are made.

Also prepared and presented is a list of suggested future studies which would advance the background knowledge of flexible-inflatable structures for space use. This list was specifically requested by the RFP and has been included as Appendix A to this report. The importance of these suggested studies cannot be over emphasized considering that flexible structures offer:

1. Maximum solar flare shielding on a weight basis.[8]
2. Maximum strength to weight properties.
3. Maximum impact acceptance.
4. Maximum thermal insulation properties.
5. Maximum electric insulation properties.
6. Maximum sound and vibration deadening properties.
7. Minimum package payload volume.
8. Minimum electronics interference.
9. Maximum integrity and prefabrication potential.

SAMPLE PREPARATION AND TESTING PROCEDURES

Tests were conducted on filament-wound samples of three general descriptions:

1. 1" wide single ply hoop wound tensile samples
2. Plate wound multiple ply characterization samples
3. Flexible filament-wound 18 x 24 inch test bottles

In addition, tests were conducted on the individual filament package (cord, yarn, roving, etc.) and on each [illegible] every binder considered as a candidate in the current study.

1. Hoop-Wound Tensile Samples

These were prepared by assembling on a drum as shown by Photograph A. Generally, a solvent solution was prepared of the binder to be used and a thin coating was applied to the drum. On partial drying, the filament package (cord) with adhesive* pre-applied was spiraled on to the drum to the minimum lead found practical. It was necessary to allow a 4 to 5 mil space between the repeating element to prevent cross-overs. Flattening of the cord and flow of the base coat was involved. Additional binder solution was finally brushed on overall to build up to an amount sufficient to fill in the cord voids.

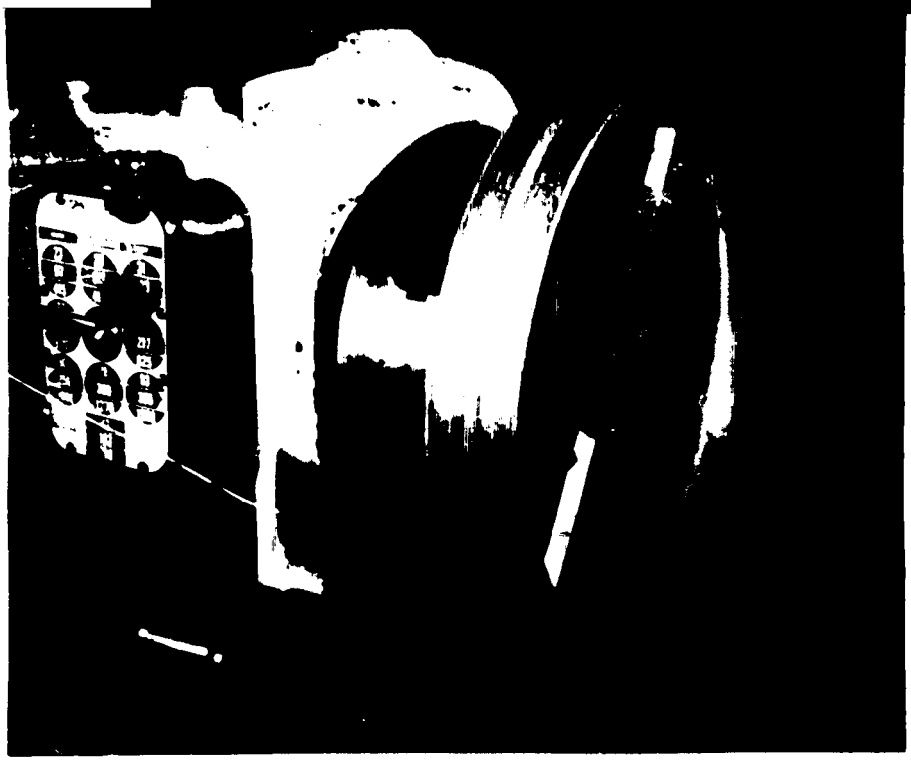
Solvent in the assembly was driven off by drying in a 125°F oven overnight (16 hrs.).

Samples with curable rubber binders were wrapped with fabric on the drum and vulcanized in a steam vulcanizer. Samples with plastic binders were fused or cured as required in an oven.

The physical description of all hoop-wound samples is summarized in Appendix C. The formulations of all binders used or investigated for possible use are tabulated in Appendix B.

---

* As referred to in this report, the adhesive is a very thin coating applied to the cord to insure a suitable bond between this element and the binder. The latter is used in sufficient quantity to tie the overall structure together.



PHOTOGRAPh A - Hoop Sample Assembly Drum

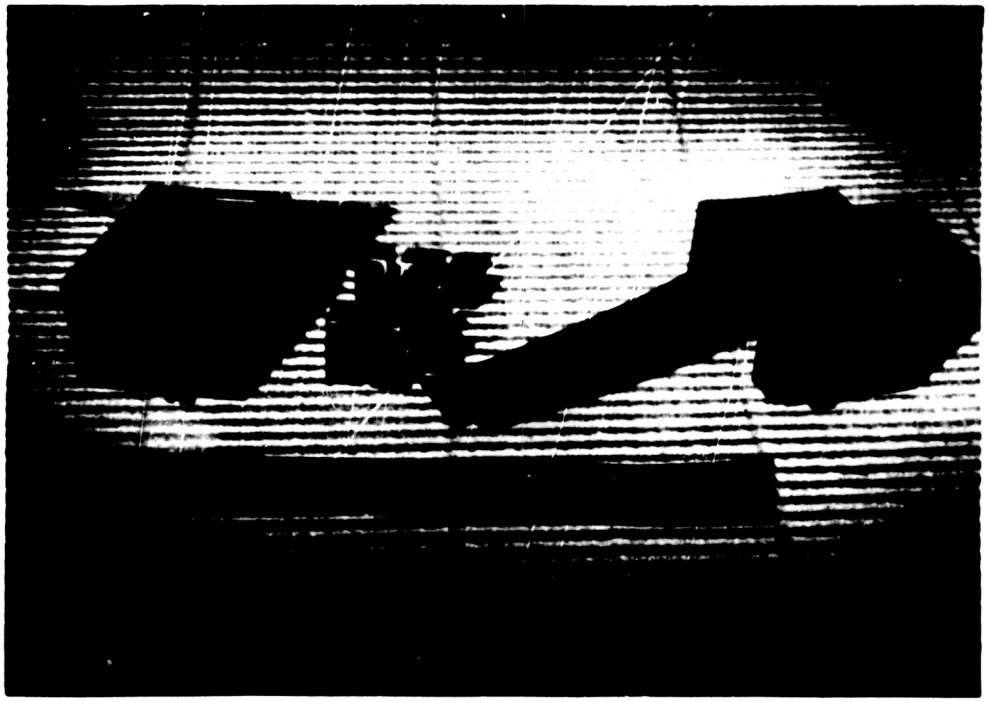
Tensile properties of the hoop-wound samples were measured with a typical Instron tensile testing machine. To prevent jaw slippage, special jaws were developed as shown by Photograph B. By wrapping over itself the sample is reinforced by surface friction where it contacts the gripping means and breakage generally occurred at its center. Stress-strain is automatically recorded.

Folding resistance was determined by flexing hoop samples a pre-selected number of times to a pre-selected radius (1/16 and 1/4" respectively) measured at the sample axis. This was accomplished in the U. S. Rubber Company designed machine shown by Photograph C. Following flexing, the respective samples were tensile tested as described previously. A series of samples were held folded on a 1/16" radius for eight weeks before testing.

To measure radiation damage, individual hoop samples were pre-stressed with a 1000 load, placed in a vacuum chamber consisting of a glass tube, pumped down and bombarded with electrons from a Van de Graaff accelerator. The pre-stressing fixture is shown by Photograph D. The pumping equipment and chamber were mounted on a portable rack making placement of the sample under the scanner a simple procedure. Pumping could also be continued and the vacuum maintained during the bombarding cycle.

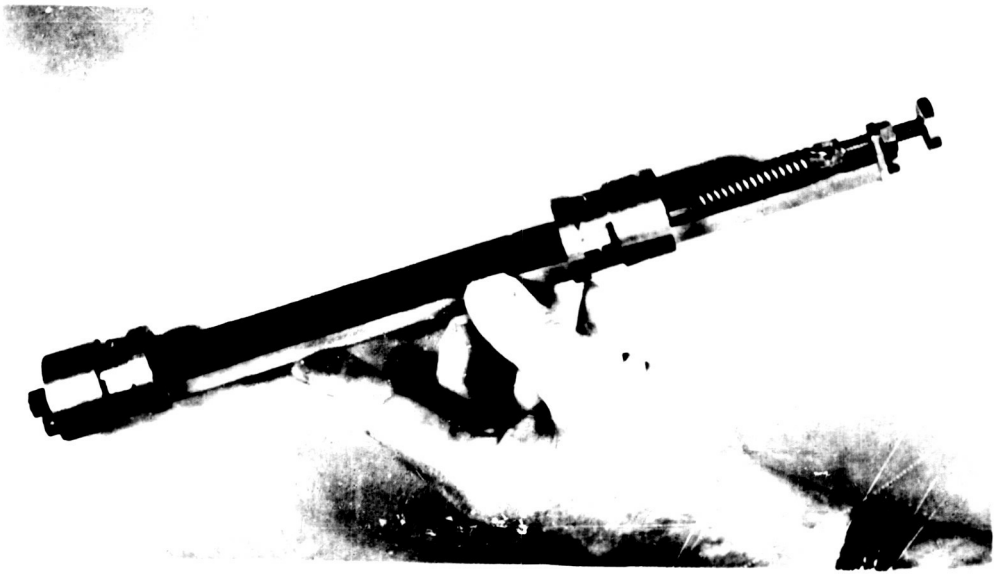
For the above test, each sample was pre-evacuated until outgassing slowed to an insignificant rate. This required a period of approximately one week's duration and the weight loss which occurred was recorded. While under bombardment, the outgassing rate is accelerated and this phenomenon was documented by noting the vacuum level which the pumping equipment was able to maintain during the 55 minute radiation cycle of each sample. The amount of creep and corresponding stress decay which occurred was measured and the tensile strength of the hoop-wound specimen was again measured 1) after exposure to vacuum for one week's duration, and 2) following exposure to the radiation treatment.

The stiffness of the various hoop-wound samples was compared by measuring the force in grams required to bend a one inch segment through a 45° angle.



PHOTOGRAPH B - Hoop Sample Tensile Test Jaws

PHOTOGRAPH C - Hoop Sample Flexing Machine



PHOTOGRAPH D - Hoop Sample Pre-stressing Jig

2. Plate-Wound Characterization Samples

Plates with their edges cut to specific angular relationships were used to simulate a triangulated pattern (45-45-90) and a double helical wound pattern (54-54). These represent two stress balanced patterns for filament winding a cylinder and are shown by Photographs E and F respectively.

Two ply, three ply and four ply filament wound fabric (characterization) samples were prepared on the above plates as follows:

a. Sheets of uncured rubber (simulated liner) are positioned on opposing faces of the winding plate.

b. Layers of cord are wound over the liner between parallel edges of the plate. Binder rubber in solution is applied to each layer (ply) by brushing on the amount calculated to fill the spaces between cords when fully dried. Like the hoop-wound samples, a minimum pitch was adopted in applying the cord.

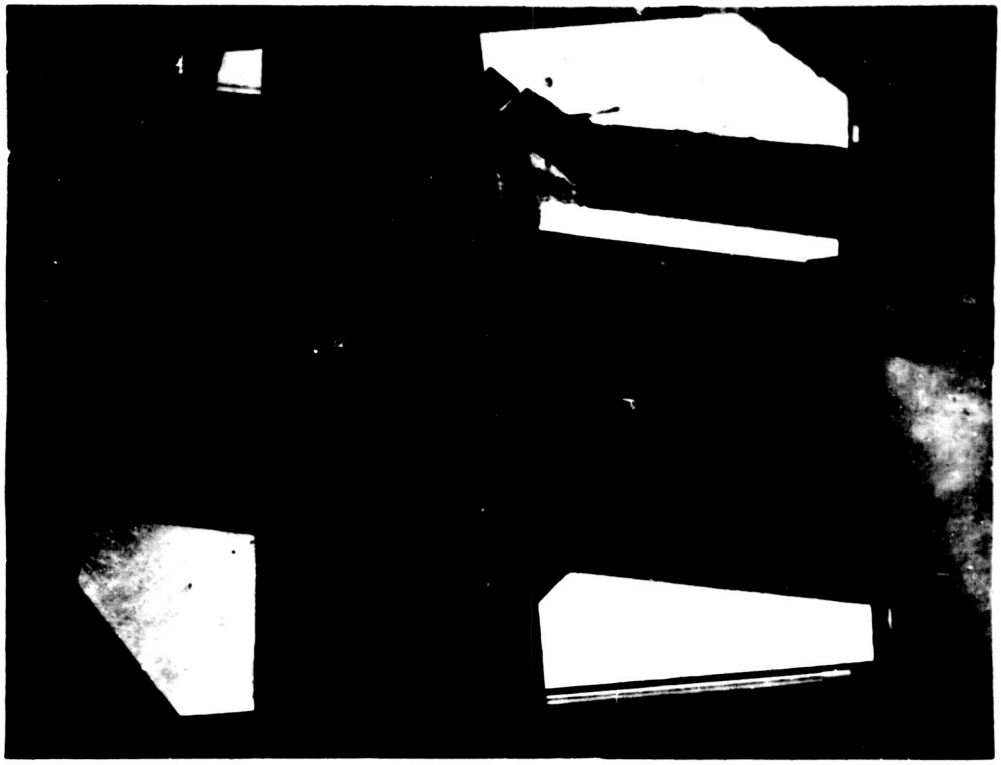
c. The solvent is dried out in a 125°F oven overnight (16 hours).

d. The samples (one each side of winding plate) are cured in a press with low hydraulic pressure applied. Shims were used to prevent squeeze-out from samples purposely made with excess binder material.

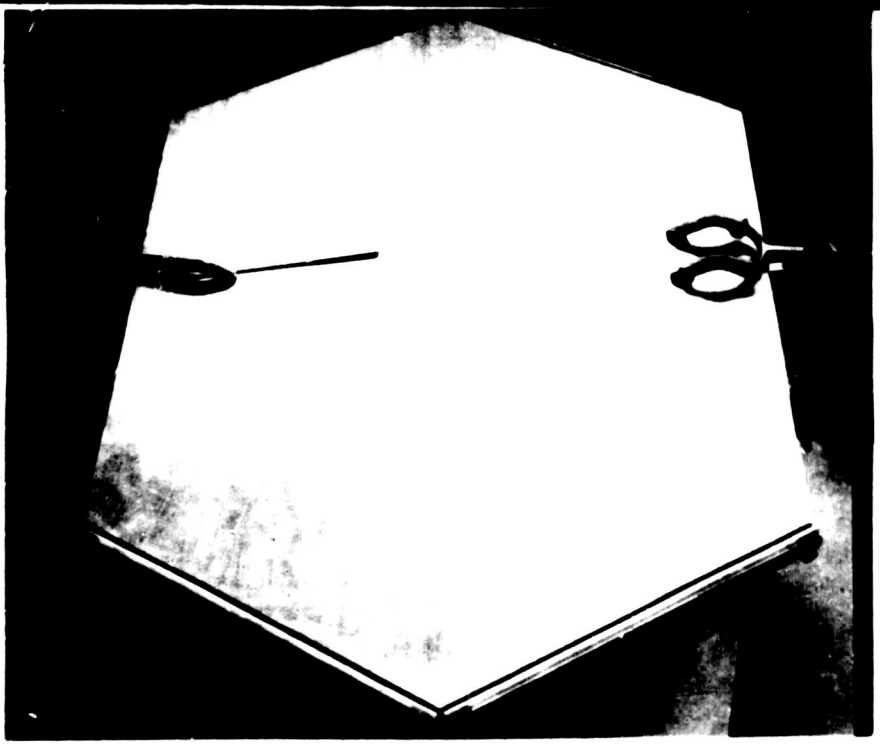
Characterization samples were made to insure flexibility in fabrics designed to serve in a space station wall. In this manner, the flexibility of fabrics made of many different materials and forms can be compared on an equal strength basis. Flexibility was measured in the same manner as it was measured in the hoop-wound tensile samples. Characterization samples make excellent visual props.

3. Flexible Test Bottle

The 18 x 24" test bottles were filament-wound in a routine manner. For applying binder material in the filament winding process, wet winding and pre-impregnating techniques both have been used successfully. In the current endeavor, we were confronted with applying a binder which exists normally as a solid, tacky, gum-like mass. Wet winding did not seem possible because the



PHOTOGRAPH E - 45-45-90 3-ply Layup Plate



PHOTOGRAPH F - 54-54 2-ply Layup Plate

pick-up of a 20% solids solution would probably be deficient as well as hazardous to personnel. Since in the filament-winding process it is normal to apply several parallel ends simultaneously, however, it was decided to prepare pre-impregnated tape to accomplish the desired result.

As shown by Photograph C, tape for winding the bottles was made by spiral-winding a pre-selected number of cord ends on to a large drum, impregnating the ends with the required weight of binder (as calender sheet or in solution) and spiral cutting to the width planned. To counter the extreme tacky nature of this product, however, a holland cloth liner was initially wrapped around the assembly drum. This liner was cut off with the tape and protected the latter until removed concurrently with winding the bottles.

As is usually the case, removable plaster mandrels were used as the building form. Each was covered with a 1/32" thick solid rubber cover which became an impermeable liner of the finished product. This liner was prevulcanized and coated with a fresh coat of rubber cement prior to winding. Photograph H shows the filament winding apparatus used to wind the current bottles.

The assembled bottles (binder) were cured, uncovered, in a steam vulcanizer and each mandrel was vented to prevent collapse during the pressure cycle. Following this, the mandrel was broken and removed.

The integrity of the bottle design was tested by subjecting two of the three fabricated bottles to a hydraulic burst test. Linear motion potentiometers were used to record axial and circumferential growth against internal pressure during one of these tests. The test consisted of filling the test bottle with water, connecting to a pressure source and increasing the pressure by 150 psi per minute until failure occurs. Photograph L following page 39 shows how the linear potentiometers were attached for testing bottle #2.

PHOTOGRAPH G - Binder Impregnating Tape Assembly Drum

PHOTOGRAPH H - Filament Winding Machine

TEST RESULTS DISCUSSION

Filament winding presents a means of achieving high strength design efficiencies and facilitates the use of certain material forms which cannot be readily made into woven fabrics. In addition, dimensional uniformity and stability is achieved since the cords are applied under constant tension and are designed to assume equal portions of the pressure-induced stresses.

The strength members (cords, yarns, etc.) are held in fixed relationship one to another by the use of a binder material. To achieve composite flexibility, the binder must incorporate a low tensile modulus and, perferrably, good elastic properties.

The strength of the binder does not enter into the design stress considerations except where stresses must be transferred from one winding pattern into another. This would occur wherever the stress members are cut to provide openings, etc., and reinforcements are added to assume the severed loads. Stress is also transferred by the binder where rupture of one or more elements in parallel accidentally occurs. Suitable adhesion of binder to cord obviously must be achieved for the binder to function satisfactorily in stress transfer situations. Contrary to the requirements for achieving flexibility, stress transfer is best served by a binder with high tensile modulus.

In studying composite filament-wound structures, the candidate stress elements and binders were initially analyzed independently of one another.

1. Stress Element Properties

The most important characteristic of a fiber for use as a stress carrying element is unquestionably its tensile strength and modulus (or elongation at break). These properties have been determined for several commercial cords both at ambient and elevated temperatures. The results are summarized in Table 1 and are plotted on Figure 1.

Cord Description	Initial[1] Pull in lbs. at Break @ RT	150°F	300°F	400°F
National Standard Co. 3 (.0030 dia.) filament High Tensile Steel Wire	21.0		20.1	
	20.6		20.1	
	20.6		20.0 (97)	
	20.6		20.2	
	20.5		20.0	
NCS 150 1/9, CO 13 Owens Corning Encapsulated Glass Yarn	28.5		13.2	
	33.0		16.8	
	31.8		13.0 (45)	
	31.7		13.9	
	33.5		14.4	
DuPont Type 68 High Tenacity Dacron 840/2	28.2		15.0	9.8
	28.5		15.2	10.8
	27.5		15.6 (55)	9.4 (36)
	27.5		16.1	10.2
	27.7		15.4	10.2
DuPont Type 51 Dacron 1100/2	27.0		19.5	17.0
	25.7		19.4 (73)	15.1 (60)
	26.2		18.9	15.5
DuPont Type 714 Nylon 840/2	29.6		13.3	8.1
	29.6		11.8	7.5
	30.0		13.2 (44)	8.7 (28)
	29.7		13.7	8.1
	30.1		12.8	9.6
Celanese Fortisan 1600/1	27.3		12.5	10.1
	25.8		12.3	10.6
	28.4		11.8 (46)	10.8 (37)
	25.1		13.4	3.8
	27.0		11.7	3.8
DuPont HT-1 Fiber 840/2	22.2		17.0	
	22.2		17.8	
	22.2		17.8 (79)	
	22.3		17.8	
	22.2		17.5	
Hercules Polypropylene Fiber 840/2	13.5	12.5	8.0	
	13.8	13.6	8.4	
	13.2	12.4 (88)	8.2 (61)	
	12.8	12.1	8.3	
	13.0	13.4	8.2	

(1) Numbers in parenthesis are % of RT pull from calculated averages.

(2) At 300°F and 1×10^{-7} torr for 75 hours.

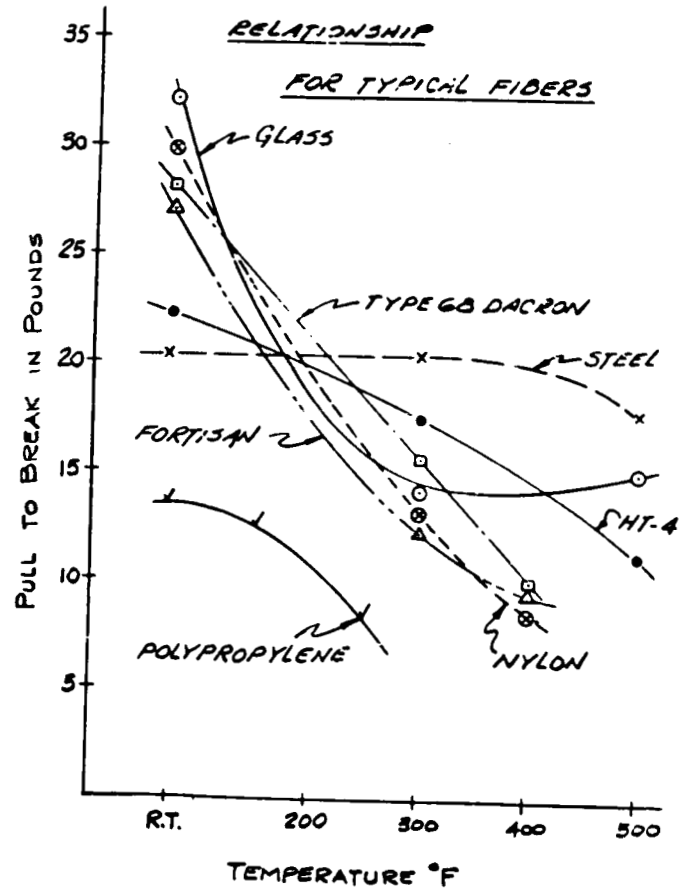
[illegible] TENSILE PROPERTIES

	Initial Elongation at Break in % @					Following Exposure(2) Full %		Elong. @	
500°F	R.T.	150°F	300°F	400°F	500°F	R.T.	300°F	R.T.	300°F
17.9	2.6		3.0		2.6	20.5		3.3	
17.9	2.2		2.4		3.1	20.5	15.0	3.0	2.1
17.9 (87)	2.6		2.9		3.1	20.5	13.2 (66)	3.2	1.9
17.9	2.6		2.6		2.7	19.6	11.9	3.1	[illegible]
17.8	2.3		2.5		3.1	20.3		3.0	
15.9	2.0		1.6		2.0	34.5	15.6	3.0	[illegible]
16.3	2.6		1.5		[illegible]	33.0	22.0	3.0	[illegible]
15.4 (45)	2.3		1.3		1.3	33.9	15.3 (51)	3.6	[illegible]
14.1	2.8		1.3		1.2	37.8	20.0	3.6	2.0
13.8	3.0		1.1		1.0	35.9	19.5	3.9	1.6
	18.0		16.0	15.0		27.2		30.0	
	18.8		16.2	19.5		24.0	14.8	26.4	23.5
	17.3		17.9	16.6		27.1	15.3 (52)	31.0	22.8
	17.2		20.0	17.0		26.7	11.1	29.2	20.5
	18.0		17.6	16.5		26.5		30.8	
						26.2	13.1	14.5	10.0
	11.3		12.7	19.0		28.5	16.2	16.6	13.0
	10.4		13.0	16.0		27.3	16.0 (51)	15.9	11.2
	11.6		13.0	14.0		27.5	11.1	16.1	9.5
						27.2	13.0	15.3	10.5
	21.3		16.6	15.1		28.7	20.2	31.0	29.3
	21.9		15.7	15.0		29.2	20.5	32.5	30.0
	23.3		17.0	20.0		29.2	20.7 (69)	33.0	30.4
	26.0		18.0	17.0		29.0	19.1	32.8	25.9
	23.7		15.6	16.5		28.6		33.5	
	5.3		3.0	2.5					
	5.3		3.5	4.8					
	5.9		3.9	6.8					
	5.3		3.3	2.5					
	5.5		2.4	2.5					
11.1	24.8		17.7		19.5				
11.2	24.7		23.0		19.9				
11.2 (51)	24.0		21.0		19.8				
11.2	23.9		21.3		19.0				
12.1	24.0		19.8		20.0				
	35.8	43.6	70.5						
	35.8	47.8	80.0						
	36.2	44.0	80.5						
	34.3	44.0	80.0						
	33.4	50.0	79.6						

TABLE 1

FIGURE 1

TENSILE - TEMPERATURE RELATIONSHIP FOR TYPICAL FIBERS



The effect on the tensile and elongation values from exposure to a 1×10^{-7} torr vacuum and 300°F temperature for a period of approximately three days is also summarized in Table 1.[6] The treatment did not seem to produce any permanent detrimental effects on the cords thus exposed.

Table 2 summarizes the most relevant features and characteristics of the cords as tested and used in the current study. It is well to remember that all the cords are commercial types and were twisted to achieve the desired flexibility and life in the varied dynamic product applications which they serve. Cords with lower twist will exhibit higher tensile strengths and lower elongations than are generally reported here.

Both the tenacity (grams/denier) and tensile strength (lbs./sq. in.) of the respective cords are indicative of the materials worth in a filament wound construction. Cords with high tensile properties require less binder on an equal strength basis.

National Standards' high tensile steel wire exhibits excellent properties for filament winding in spite of an inherent stiffness which makes it impractical to weave into a fabric. A number of metallic fibers[5] are being studied which exhibit improved flexibility and/or improved high temperature resistance but none incorporate the very high tensile properties of the National Standard material reported on here.

The physical properties of glass and Fortisan fibers are very similar with the former exhibiting the greater dimensional stability. It has lower elongation at break and does not change dimensionally with changes in humidity. On previously reported U. S. Rubber tests, the encapsulated glass cord exhibited almost equal flex life, as run on a 3/4" dia. pulley, with the Fortisan cord. We are unable to explain the loss in tensile strength of the encapsulated glass, however, between the temperatures of 70° and 300°F. As reported by others, a drop in tensile is not normally encountered below 600°F to 700°F.

A special glass which was recently developed (type S994) is reported to incorporate a filament strength of 700,000 lbs./sq. in. Used as impregnated roving in a rigid filament wound structure, a 280,000 lbs/sq. in. strength is achieved. Since the encapsulated E glass at only 157,000

STRESS ELONG

Fiber	Designation	Recovered Twist (4)	Specific Gravity Filament Material	Weight/1000 Ft. (5) Cord	Adhesive	Re
Steel	3 - .0030 dia. filament wire		8.3	.1288		1
Glass	BCC 150, 1/9, CO 13	4	2.55	.2300	.0290	(
Fortisan	1600/1	4.8	1 5	.1225	.0135	1 (1
Dacron	840/2 Type 68	14.79/13.78	1.38	.1404	.0099	1 (
NT-1	420/2/2	1.57/13.3/12.68	1.38	.1273	.0091	1 (1
Nylon	840/2 Type 1/14	14.4/13.2	1.14	.1386	.0143	1 (
	840 Type 300	13.8		.0675	.0068	(
	420 Type 300	13.4		.0314	.0025	(
	840 Type 300	0.5		.0604	.0087	(
Polypropylene	840/2	0.16/18.0	.92	.1670	.0286	(

(1) Number in parenthesis based on weight with adhesive applied

(2) Vinyl pyridine latex and resorcinol

(3) Lowest number indicates best resistance

(4) Turns per inch

(5) In pounds.

CHARACTERIZATION SUMMARY

		Room Temperature				300°F		
ier[1]	Adhesive Type	Strength in Lbs.	Tenacity Gr./Den.	Tensile Lbs/sq.in.	Elongation at Break in %	Strength in Lbs.	Elong. in %	Radiation[3] Resistance Rating
693	Brass	20.5	5.50	563,000	2.5 to 3.0	same		1
025 404)	Paracril (encapsulating material)	32	4.8	157,000	2.0 to 3.0	15	1.5	1
611 801)	Neoprene	27.0	7.59	145,500	5.5	12.5	3.3	3
881 015)	VPL + R[2]	28.0	6.75	119,000	18	15.5	17.5	2
707 827)	VPL + R	22.2	5.89	104,000	24	17.5	20.5	1 (strength increases)
857 049)	VPL + R	29.8	7.28	105,300	23	13	16.5	3
25.4 94.2)	VPL + R	14 9						
13.0 54.3)	VPL + R	7.5						
08.5 03.6)	VPL + R	14.9						
234 618)	VPL + R	13.3	2.7	31,800	35	8.2	78	4

TABLE 2

lbs./sq. in. compares favorably (Table 6) in a composite structure with the other materials studied, the potential of this glass fiber cannot be overlooked.

Nylon and polypropylene fibers are reported which have tenacities of 12 grams per denier but the elongation at break compared to glass and steel is still high. Of the organic fibers, Dacron appears to be most stable in the space environment[1] but it too incorporates the high elongation at break characteristic.

Boron or beryllium whiskers and other special fibers have not been developed to the point where they could be considered on a comparable basis in the current application study.

2. Binder Properties

Tensile strength, elongation at break, modulus, hardness and brittle point determinations for a variety of elastic and flexible plastic materials are summarized in Table 3. Also included are tensile and elongation measurements of these potential binder materials after oven ageing at various temperatures and after ageing in a high vacuum at elevated temperatures[6]. All of the elastomers compounded for and exposed to the vacuum environment avoided the use of volatile ingredients with the result that weight losses measured during the short period of exposure were practically negligible.

In addition to the above, a general comparison of the candidate binder materials is made in Table 4. These ratings were arrived at through many considerations and represents the composite thinking of several elastomer chemists on the Research Center staff.

The natural rubber compound retains its strength at elevated temperatures better than any of the other high strength flexible materials. And while quite subject to oxidation at elevated temperature, natural rubber is not seriously effected in vacuum. Tuex cured natural rubber compounds are expected to be stable up to 400°F in the absence of oxygen.

Ethylene propylene elastomer has many properties which make it interesting as a material for space applications. It is very resistant to

Elastomer	Code (7)	Modulus (Stress @ 100% Elong.)	Strength in Lbs/Sq.In.@ RT	200°F	300°F	400°F	Elong @ Break @ RT	200°F	300°F	Shore A Hardness	Britt Poin Temp
Natural Rubber	(5)		4300			325					
	(6)		3920	2965	1805		500	610	730	62	-54
	NWO-1	175	1350				357			54	
Butyl	NWO-2	150	1287				457			52	
Chlorobutyl	(5)		2400			650					
	(6)		2050	1190	830		380	340	350	65	-51
Resin Cured Butyl	(5)		2200			730					
	(6)		2125	810	555		480	250	270	58	-36
	NWO-4	170	1405				478			61	
Neoprene	(5)		3550			770					
	(6)		2765	1290	599		300	270	140	73	-39
	NWO-3	135	1450				520			51	
EPR	(5)		2580			510					
	(6)		3680	1460	807		570	110	330	66	<-70
EPRD	NWO-21	375	2495				472			59	
Cis 4 Br	(5)		2440			555					
	(6)		2240	1400	885		770	690	630	62	<-70
	NWO-23	250	1397				565			54	
Silicone Lq.	NWO-12		400				93			54	-95
Lq.	NWO-14	390	395				102			51	-95
Gum	(5)		1100			290					
Gum	(6)		782	568	480		220	240	230	65	<-70
Gum	NWO-19	75	688				492			47	
Epoxy	NWO-17		310		L		70			67	
	NWO-18		325		o		45			72	
	NWO-9	350	725		w		170			82	
Urethane Lq.	(6)		2890	340			790	1080		54.5	<-70
(6004) Lq.	NWO-8	115	5780	510	480 (8)		660	210	220 (8)	48	
(6006) Lq.		1800	7500	3400	2300		425	550	600	95	
(5004) Gum	(5)		4100			880					
	(6)		4865	1770	932		430	280	200	75	<-70
	NWO-7	350	2362				385			71	
Estane	NWO-15	160	1425				778			62	
Paracril	(5)		2500			230					
SBR	(5)		3600			545					
Viton A	(5)		1900								
B	(5)		2730								
	(6)		2065	985	572		190	170	100	84	-51
	NWO-5	260	1562				290		260	75	

(1) Oven aged 8 hrs. @ 400°F
(2) Oven aged 57 hrs. @ 200°F
(3) Aged in vacuum 78 hrs. @ 190°F
(4) Aged in vacuum 51 hrs. @ 290°F

...OMERS AND FLEXIBLE PLASTICS

	Tensiles After Aging @							Elongation After Aging @						Rating @ (8)			
(1) RT	(2) RT	(3) RT	(4) RT	(2) 200°F	(3) 200°F	(4) 300°F	(1) 400°F	(1) RT	(3) RT	(4) RT	(2) 200°F	(3) 200°F	(4) 300°F	RT Vac	200°F Vac	400°F Vac	RT Air
Low							Low										
	2950	3920	3220	1940	2965	1785		440	380	430	500	610	530	1	1	1	2
														2			
2000							670										
	1675	2050	1955	995	1190	709		440	380	360	350	340	250	2	2	2	1
1980							625										
	1930	1885	1725	930	810	425		350	330	310	300	250	180	2	2	3	1
Low							Low										
	2240	2650	2765	710	1290	590		430	350	300	260	270	140	2	2	3	3
1000							305										
		3680	3255		1460	748			370	530		110	300	1	2	2	3
	1735	1868	1365	748	867	584		340	350	270	250	250	180	2	4	4	3
														4	4	4	
1100							150										
	657	782	707	513	601	481		250	220	210	200	210	170	3	3	2	3
														4	4	4	
														2	4	4	
	7500			3400													
1650							375										
	3790	4865	3975	1675	1770	932		410	430	360	290	280	200	1	1	2	2
														3	4	4	
Low							Low							2			
Low							Low							1			
							200										
900	(70 hrs @ 550°F)																
	2145	2065	1810	836	985	463		210	190	160	200	170	90	2	2	3	2

(5) Reported in Literature
(6) Report in U. S. Rubber Vac. test report - Bibliography #6
(7) MMO series material tested on autographic stress-strain equip.
(8) Lowest number is best rating. Rating is for use of material at temperature noted and in atmosphere noted.

TABLE 3

ELASTOMER PROPERTY RATING SUMMARY

Elastomer[1]	Tensile	Modulus	Tear	Abrasion	Impermeability	Hot Physicals	Cold Physicals	Heat Resistance	Oxidation Resistance	Ozone Resistance	Ultra-violet Resistance	Radiation Resistance	Flame Resistance	Bonding Property
Natural Rubber	1	1	1.5	2	3	1 (300) 3 (400)	2	1.5	2.5	4	3	1	3[2]	1
Butyl	2	1	2	2.5	1	2.5	2.5	2	1	2	2	4	3[2]	3
Chlorobutyl	2	1	2	2.5	1	2	2.5	1	1	2	2	4[3]		3
BC Butyl	2	1	2	2.5	1	2	2.5	1	1	2	2	4	3[2]	3
Neoprene	2	1	2	2	2	2	3	1.5	2	2.5	2	3[3]	1	1
EPR (D)	1	1	2	2	3	3	2	1	1	1	1	1	3[2]	4
Cis Br.	2	1	3	1	4	2	1	2	2	4	3	2	3[2]	2
Silicone (liquid)[4]	4	4	4	4	4	4		1	1	1				4
Silicone (gum)	3.5	2	4	4	4	4	1	1	1	1		2.5		4
Epoxy[5]	4	4				4		4					3	1
Urethane (liquid)[4]	1	1	1	1	1	4	2	3	1	1	1[6]	1	1	1
Urethane (gum)	1	3	1.5	1	1	2	2	2	1	1	1[6]	1	3[2]	1
Estane	1	1	1	1	1	5	3		1			1	1	1
S B R	1		3	1	3	3	4	1.5	2	4	3	2	3[2]	1
Viton B	2	3			2									
Viton A						4	4	1	1	1		3[3]	1	1
Paracril	2				1.5	4	3	2	3	1		2	4[2]	

(1) Normally requires solvents for solution coating, high temperature and pressure to cure
(2) Chlorowax and antimony oxide will flame resist
(3) Releases HCl
(4) RT cure, zero press, exists as natural liquid
(5) Solvent to thin required, oven cure OK
(6) Discolors

NOTE: Lowest number indicates best property or least degradation

TABLE 4

practically all forms of degradation including degradation from ultra-violet exposure. The strength at elevated temperatures and processing characteristics still require improvement, however.

Gum type urethane with carbon black filler retains good physicals at high temperature[7] with only a slight penalty in stiffness exhibited at room temperature. Both Viton and urethane elastomers are candidate binder materials for 400°F and higher applications.

For low temperature applications polybutadiene rubber (Cis Br) is outstanding. The overall physical properties and bonding capabilities of silicone elastomers are too low to consider them favorably as a filament winding binder material. Flexible epoxy compounds are hard and non-elastic. Estane is a suitable room temperature binder but does not retain good properties at elevated temperature.

Radiation exposure tends to harden natural rubber and to soften polyurethane[4]. In a space station the former tendency would be preferred while for air locks and other continually flexed applications a softening effect would probably be preferred.

3. Hoop Sample Test Results

These are summarized in Table 5.

Individual cord strength is not completely utilized in a hoop sample. This can be attributed to non-uniform winding tension, inaccurate insertion and uneven slippage in the tensile jaw. A few binders appeared to have effected filament strengths to some extent. In some instances, lack of adhesion between cord and binder voided the test completely.

The encapsulated glass hoop sample exhibits the greatest variation from test to test and compares least favorably with the single end test data. Its rubberized coating makes it a very special type of material to handle. Improvements in handling techniques should come with time and both higher and more consistent strength levels will probably follow.

Repeated folding or flexing, as described, did not effect the strength of any of the hoop wound samples. Holding in a folded condition for 60 days had no effect. It is logical to assume that no damage to

Sample No.	Description	Green Str. in Lbs.	Green Elong. in %	Flexed 50 cycle (½" R) Str.	Flexed 50 cycle (½" R) El.	Flexed 250 cycle (½" R) Str.	Flexed 250 cycle (½" R) El.	Flexed 50 cycle (1/16" R) Str.	Flexed 50 cycle (1/16" R) El.	Flexed 250 cycle (1/16" R) Str.	Flexed 250 cycle (1/16" R) El.
22	Dacron-Epoxy	1120 1070	16.0 15.0	1040	12.0	1020	11.3	1070	10.7	1040	12.0
11	Dacron-Natural Rubber	970 990	19.3 1[illegible].7							860	18.0
12	Dacron-Neoprene	720 1030	13.5 15.7							1020	16.7
16	Dacron-Urethane(gum)	990 1065 1065	17.0 17.3 16.3							970	14.7
28	Dacron-Urethane(Lq.)	970 1000(3)	20.0 18.0							640	16.7
18B	Dacron-Estane	630(3) 920	14.0 16.0							920	14.7
27	Dacron-EPRD	210(3) 460(3)								200(3)	
25	Dacron-Paracril	900 900	12.0 12.0							900	13.3
26	Dacron-Cis Br	380(3) 580(3)								380(3)	
5	Dacron-Butyl	1015 1020	17.0 17.3							990	17.6
4	Nylon-Butyl	1040 970	23.3 21.5							980	25.4
6	Fortisan Butyl	970 1000	6.7 7.3					1030	8.3	1010	8.7
17A	Polypropylene-Butyl	400 400	21.4 20.6							400	13.6
9A	Steel-Butyl	1380 1460	4.0 3.8	1430	6.0	1370	6.3	780(3)	2.7	1500	3.0
7	Glass-Butyl	1440 1590	4.7 4.7	1450	5.0	1440	4.7	1520 980	5.0 6.0	1380 970	5.0 5.3
14	Glass-RC Butyl	1250 1180	4.7 4.7	1300	4.0	1370	3.7	1130	6.4	1170	4.0
29	Glass-Natural Rubber	990 1100	4.7 3.0	880	4.0	850	4.0	930	5.3	900	4.7
19A	Glass-Viton B	410(4) 660(4)	2.0 2.3	840	3.7	800	2.3	770	1.7	610	2.0
8	HT-1-Butyl	940 920	17.3 19.0							880	20.0
20A	HT-1-Viton B	870 860	10.6 10.6							800	8.0
21	HT-1 Silicone	330(3) 660(3)		600(3)	10.0	400(3)	10.0	720(3)	14.0	500(3)	10.0

(See footnotes on next page)

PLE TEST RESULTS

Held /16 R. month		Exposed[1] Vacuum-1 week			Radiation Bombarded[2]						Green Strength Summary			Single End Test Strength (Table 2)	Band Strength (5
r.	El.	Str.	El.	W.L.	Dosage Watt Hours	Torr Vac. x 10^{-4}	Creep Inch.	Retained Load Lbs.	Subsequent Str.	Subsequent El.	No. of Cord Ends	Sample Str.	Cord Str.		
35	14.7	1140	16.3	0.40	9.9	12.0	1/64	92	1110	16.0	40	1080	27.0		90
90	16.7	1060	16.7	0.22	12.7	7.3	None	100	1040	17.0	40	960	24.0		8
20	15.3	1080	14.0	0.30	8.4	4.9	None	100	1030	14.4	40	1020	25.5		9
		1025	15.7	0.49	11.5	10.0	1/64	92	965	13.7	40	1000	25.0		
10[3]	15.3	1050	17.3	0.23	10.5	12.8	Slight	96	840	18.0	40	960	24.0		41.
10	16.7	1030	15.7	0.27	12.7	9.8	1/64	92	1040	17.7	40	920	23.0	28.0	10.
20[3]		170[3]		0.20	10.5	11.0	3.32[3]	50[3]	320[3]		40				12.
70	16.7	900	14.0	0.34	10 5	8.2	1/64	92	940	14.0	40	920	23.0		38.
40[3]		780[4]	10.7	0.18	10.5	4.2	None	100	470[3]		40				35.
20	16.7	1064	18.0	0.26	10.7	5.0	None	100	770[4] 750[4]	15.0 16.7	40	1000	25.0		2.
30	26.7	960	34.0	1.55	10.7	7.6	1/32	83	845	30.0	36	1000	27.8	29.8	5.
80	6.7	792	4.3	2.05	10.6	6.1	None	100	570	4.7	46	1050	22.8	27.0	10.
20	26.7	420	20.6	0.33	10.5	10.0	1/16	67	210	8.0	30	400	13.3	13.3	21.
40[3]	6.0	1640	3.3	0.12	11.1	5.5	None	100	1620	3.3	80	1500	18.75	20.5	47.
50	6.0	1380[4]	6.0	0.04 0.14	12.1	6.2 11.0	None	100	1100[4]	6.0	46	1000	21.7		67
40	4.7	1290[4]	4.0	0.08	11.6	6.5	None	100	1160[4]	4.0	46	1250	26.1		44.
40[4]	6.0	1300	4.0	0.01	10.5	6.8	None	100	1230	4.0	46	1100	23.9	32.0	77.4
50	2.5	1340	3.0	0.03	11.0	4.6	1/16[3]	67	1254[4]	3.0	46	800	17.3		234.
20	18.7	980	19.4	1.35	10.4	5.9	None	100	910	19.0	44	920	20.9		1.9
30	10.7	870	9.0	0.60	8.9	4.0	1/32	83	820	8.3	44	850	19.3	22.2	48.8
		680[3]		0.84	9.4	7.8	None	100	410[3]		44				17.4

TABLE 5

NOTES TO TABLE 5

(1) 1×10^{-5} torr, W. L. is weight loss in %.

(2) Bombarded for 55 minutes with Electron Accelerator. Vacuum is level sustained during bombarding cycle; creep is for 6" unsupported sample length all of which is bombarded. Retained loading is portion of 100# spring load applied to all samples at start of bombardment cycle. All Butyl samples were slightly tacky from exposure.

(3) Jaw slip

(4) Jaw break

(5) Weight in grams applied 1" from jaws required to bend sample 45°.

individual filaments will occur until the outer skin is elongated beyond the elongation-at-yield of the material in question. Assuming the value to be 3% (for glass) and that bending occurs around the neutral axis of the filament, the relationship can be expressed as follows:

length of outer skin = 103% of length at neutral axis

$$\text{or} \quad (r + \frac{t}{2}) \times \text{constant} = 1.03\, r \times \text{constant}$$

where r = radius of bend at neutral axis

t = thickness of section or diameter of filament

$$\therefore \quad r + \frac{t}{2} = 1.03\, r$$

$$\frac{t}{2} = .03\, r$$

$$\text{and} \quad 2\, r = d = \frac{t}{.03}$$

or d (bending diameter) = 33 t (33 times filament diameter)

From the above, it is readily seen how cementing the filaments into an interlocked cluster will decrease foldability and increase the section modulus.

Exposed to a vacuum only, the Fortisan-Butyl sample suffered the greatest weight loss with Nylon-Butyl, HT-1-Butyl and HT-1-Silicone following in the order listed. the cord member is suspected of controlling this alignment because other Butyl impregnated samples were relatively weight stable.

Electron bombardment with the samples stressed and in a vacuum produced varying effects on the following materials:

Fortisan	Butyl
Polypropylene	Flexible Epoxy
Nylon	Urethane
HT-1	Estane
Dacron	

Fortisan, polypropylene, nylon and Butyl seem to have been effected detrimentally. Tests conducted after the treatment was terminated only, would not have shown that nylon had been harmfully effected.

The glass cord with Viton B binder was notoriously stiff. The epoxy resin binder likewise exhibits an undesirable stiffening influence.

Elastomer coated steel wire broke in numerous places during vulcanization (of the coating) in open steam. This apparently is a stress corrosion phenomena as the difficulty was avoided by wrapping the assembly in a water impermeable liner for this processing step.

Further difficulties in the preparation of hoop samples involved:

a. a tendency for Viton to bond to aluminum

b. a tendency of the base coating to flow excessively out from under the tensioned cord.

By first roughening and then teflon coating the winding drum, limiting the thickness of the base coating and allowing the solvent sufficient time to escape, these problems were overcome. For liquid type binder material, time had to be allowed for the base coating to gel.

4. Description of Composite Characterization Samples

The characterization samples fabricated for the study are summarized in Table 6. The cord spacing for the several constructions studied was based on practical considerations as developed in winding the numerous hoop samples prepared. Quite obviously, this is the controlling factor in establishing the strength over weight rating achieved; and, changing the number of ends per inch in any of the samples described could easily change its relative rating with respect to any of the others. Changing slightly the amount of binder used in any sample would have the same effect.

Over a period of years, the techniques for achieving flexibility in fiber or cord reinforced elastomer based composite structures has been well established. To achieve this characteristic, the following are commonly employed:

PROPERTIES OF C

Sample Code(1)	Cord	Twist(9)	Ends/In. Per Ply	Lay-Up	No. of Wound Plies	Thickness With Liner
a	840/1 Nylon	13	54	54-54	2	.041
b	840/1 Nylon	1/2	54	54-54	2	.044
c(2)	840/1 Nylon	1/2	54	54-54	2	.040
i(3)	840/1 Nylon	13	54	54-54	2	.043
d	210/1 Nylon	13	108	54-54	4	.043
e	420/1 Nylon	13	72	45-45-90	3	.044
f(4)	840/1 Nylon	13	54	54-54	2	.057
g	3-.0038 Steel		108	54-54	2	.032
h	ECG 150 Glass	4	54	54-54	2	.049
j	840/2 Nylon	13/13	40	54-54	4	.094
	Aluminum					
	Steel					

(1) All incorporated .013" Butyl rubber liner on one face and a Butyl rubber binder.
(2) Binder diluted to 10% total solids concentration to better saturate cords.
(3) Incorporated gum urethane binder.
(4) .015 Butyl rubber spacer between plies.
(5) Based on individual cord strengths reported in Table 2.
(6) Based on 75,000 lbs./sq. in. strength.
(7) Based on 130,000 lbs./sq. in. strength.
(8) Weight in grams placed 1 1/2" from jaws required to bend 6" width through 45°.
(9) Turns per inch.

ACTERIZATION SAMPLES

in Inches		Weight in Lbs./Sq Ft.	Estimated Fabric Strength in Lbs./Inch(5)		Strength/ Weight Rating	Bending Strength(8)	
Without Liner	With Liner	Without Liner	Axial	Girth	Column 12÷10	Axial Direction	Hoop Direction
.028	.210	.148	530	1060	7160	42	52
.031	.239	.177	530	1060	5980	41	79
.027	.220	.158	530	1060	6700	40	93
.030	.234	172	530	1060	6160	27	39
.030	.234	.172	530	1060	6160	156	394
.031	.211	149	530	1060	7110	17	162
.044	.310	.243	530	1060	4275	59	86
.019	.445	.383	1500	3000	7330	104	231
.036	.392	.330	1150	2300	6970	69	210
.081	.454	.392	1600	3200	8160	410	940
.068		1	5000	5000	5000(6)		
.023		1	3040	3040	3040(7)		

except as noted.

TABLE 6

a) Incorporate moderate twist in cord construction.

b) Prevent saturation of cord.

c) Lubricate cord construction.

d) Reduce plies to a minimum.

e) Avoid triangulated winding pattern.

f) Use low modulus binder.

g) Limit binder usage.

The above criteria is again borne out. Sample "a" with twisted cord is more flexible than sample "b" with untwisted cord. The latter is more flexible than sample "c" in which the cord was purposely highly saturated. Sample "f" with excess binder was less flexible than sample "a". Sample "i" contrary to predictions was less stiff than sample "a". The higher modulus binder in sample "i" probably penetrated the cord to a lesser degree. Sample "d" made with four times the number of 1/4 strength cords was considerably stiffened. The triangulated wound sample was stiffer across the girth winding but surprisingly flexible in the opposite direction.

Samples g, h and j again show how a thin wall construction promotes flexibility. Even though made of the most flexible cord, the thickest wall (sample j) is the stiffest. Metallic and glass fibers or cords automatically become of interest for flexible applications because of this dominating factor.

All of the filament-wound sample constructions are stronger in tension (in the girth direction) than unoriented aluminum or steel. It would be interesting furthermore to contemplate the strength of closer packed windings or a glass fiber that developed the 280,000 lb./sq. in. stress of which it is actually currently capable of developing in rigid filament wound structures.

Filament wound walls are not normally impermeable. For this reason, liners are required in filament wound pressure vessels. These would be specifically designed to be impermeable and this property is not, therefore, a limiting factor in the selection of the cord binder material.

5. Filament Wound Bottle-Design and Efficiency

With agreement of the Project Officer, it was decided to construct sample flexible bottles of encapsulated glass cord and a natural rubber binder. These materials were selected for the reasons summarized below:

Encapsulated glass stress element:

1. High strength potential.
2. Excellent dimensional stability.
3. Unaffected by radiation.
4. Unaffected by space vacuum.
5. Unaffected by folding.
6. Suitably flexible.
7. Non-magnetic.

Natural rubber binder:

1. Good processing properties.
2. Good bonding characteristics.
3. Good resistance to radiation.
4. Resistant to space vacuum.
5. Low modulus with moderate strength.
6. Good strength retention at elevated temperatures.
7. Good thermal degradation resistance.
8. Low gravity.
9. Fair low temperature properties.

Encapsulated E glass cord with a paracril rubber coating is presently available in four sizes:

Designation	Cord Dia.	Weight #/1000'	* Twist or turns/inch	Tested Singles Strength	Calculated Strength in psi on glass content	Suggested Winding Ends/Inch	Suggested Winding Strength/Inch
G 150 1/3/9	.034	.729	2.5	91.6#	158,500	26	2380
G 150 1/9	.018	.259	4.0	32.0#	157,000	46	1380
G 150 1/3	.010	.082	3.3	10.9# (Est.)	169,000	80	870
G 150 1/0	.005	.027	2.2	4.6#	216,000	140	660

It was decided that the bottle would comprise a double (balanced) helical winding of 4.6# cord wound to the smallest practical winding angle (and port opening) and a girth winding to suit. The approximate strength in the axial direction of the cylindrical portion of the bottle would, therefore, be 1320 lbs./inch. This in turn called for a girth winding of approximately 2600 lbs/in. strength. A single ply of the 91.6# material was selected to insure maximum flexibility of the finished product combined with a moderate and desired strength advantage in the axial direction.

As described earlier, pre-impregnated tape incorporating the selected cord sizes was prepared for use in fabricating the 18 x 24 inch bottles. Problems in making the tape resulted from:

1. The non-uniform cross section characteristic of the individual encapsulated cord.
2. The "live" nature of the encapsulated cord.
3. The tendency of the tape to flatten under tension.
4. The tendency of binder to flow under compression.

The glass tape which was ultimately produced and used in winding the test bottles incorporated the following properties:

* Includes 11% by weight of encapsulating material.

Use	Construction	Tape Width	Strength Anticipated	Strength As Tested	Strength Efficiency Achieved
Axial Winding	36 ends of 4.6# cord	.260"	165#	113# @ ResCenter 117# @ Mishawaka 115# Average	70%
Girth Winding	7 ends of 91.6# Cord	.300"	641#	490# @ ResCenter 404# @ Mishawaka 447# Average	70%

The above tapes were laid side by side in the respective winding directions over a 1/32" thick natural rubber liner to produce the filament wound test bottles desired. Photograph I shows the completed bottle which was comprised of the following by weight:

		Average of 2 bottles
a.	fittings (2)	.495 lbs.
b.	Girth winding	1.495 lbs.
c.	Axial winding	1.920 lbs.
d.	Liner	2.655 lbs.
	Total	6.565 lbs.

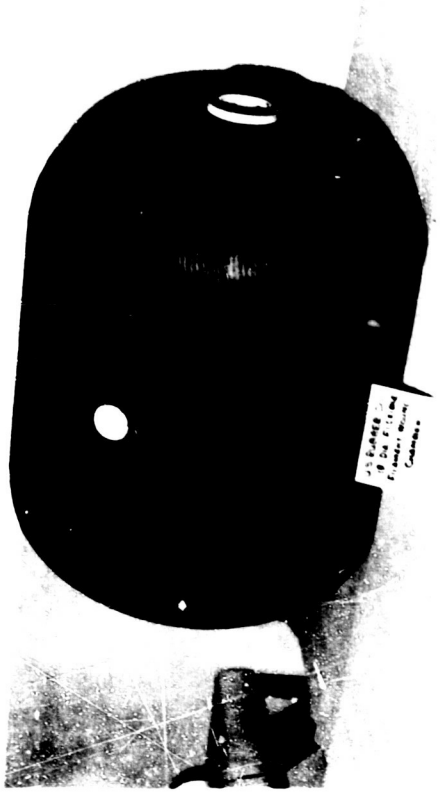
Its wall thickness in the cylindrical portion is:

a.	Axial Plies	0.013 in.
b.	Girth Ply	0.040 in.
c.	Liner	0.036 in.
	Total	0.089 in.

Photograph J shows that the bottle is suitably flexible.

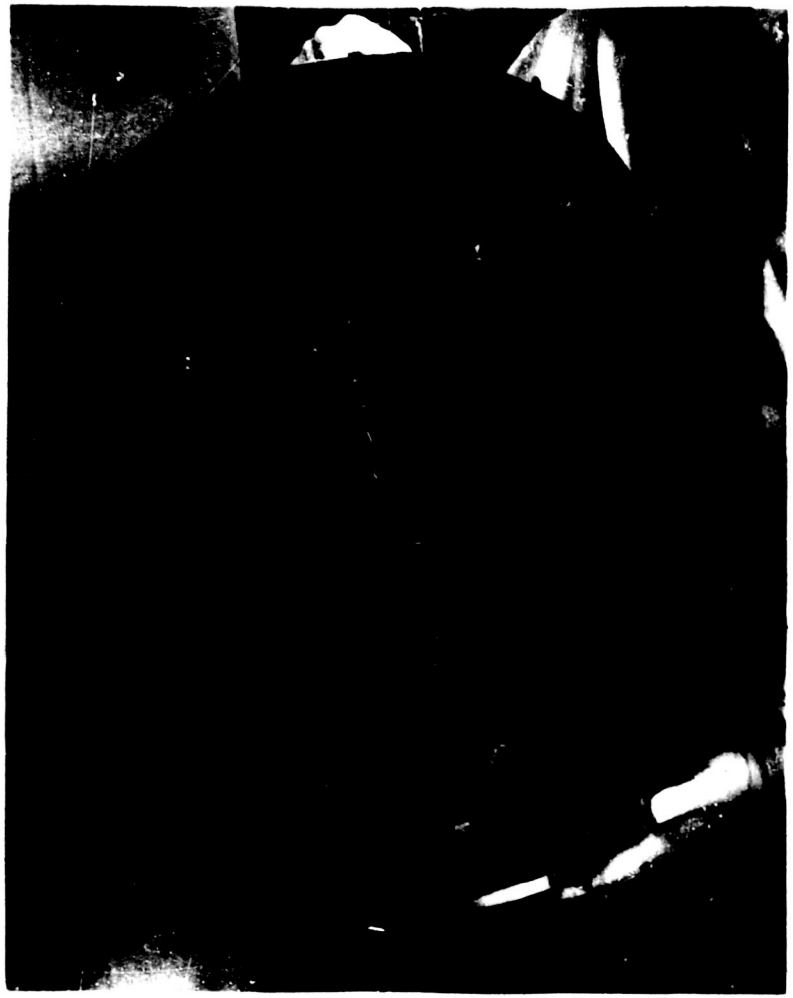
Photographs K and L show the results of two burst tests conducted on the filament wound test bottles. The actual burst pressures at which the respective bottles failed was:

For bottle No. 1 120 psi (Girth winding break)
For bottle No. 2 136 psi (Axial winding break)



PHOTOGRAPH I - Completed Filament-Wound Bottle

PHOTOGRAPH J - Partially Folded Filament-Wound Bottle



PHOTOGRAPH K - Burst Filament-Wound Bottle - Test No. 1

PHOTOGRAPH L - Burst Filament-Wound Bottle - Test No. 2

Linear motion gages were installed axially and circumferentially of the cylinder to record the increment growth of these two dimensions with pressure. The data is tabulated below:

Applied Pressure psi	Axial Length Inches	Cylinder Circumference Inches
0	25.600"	56.500"
25	25.620"	56.528"
50	25.640"	56.556"
75	25.660"	56.585"
100	25.680"	56.614"
120	25.696"	56.6357"
136# bust		

The glass filaments in bottles No. 1 and No. 2 broke at 80,200 psi and 104,000 psi respectively. This is brought out in the following analysis:

	Actual Ends/Inch	Singles Strength Pull to Break	Singles Strength psi*	Calculated Ply Strength in Lbs/Inch
Double ply Axial Winding	$\frac{36}{.260} = 138.5$	4.6	216,000	$138.5 \times 4.6 \times 2 = \underline{1274}$
Single ply Girth Winding	$\frac{7}{.300} = 23.3$	91.6	158,500	$23.3 \times 91.6 = \underline{2134}$

	Calculated Approximate Burst Pressure	Actual Burst	Stress Developed at Burst in psi
Axial Winding	$\frac{1274}{9/2} = 283$ psi	136 psi (bottle #2)	$\frac{136}{283} \times 216{,}000 = 104{,}000$ (bottle #2)
Girth Winding	$\frac{2134}{9} = 237$ psi	120 psi (bottle #1)	$\frac{120}{237} \times 158{,}500 = 80{,}200$ (bottle #1)

	Calculated Burst Pressure Based on 70% Efficient Tape	Bottle Efficiency Based on Burst Pressure Calculated From Tape Strength	Bottle Efficiency Based on Burst Pressure Calculated From Singles End Strength
Axial Winding	198 psi	68.6% (Bottle #2)	48.0% (Bottle #2)
Girth Winding	166 psi	72.3% (Bottle #1)	50.6% (Bottle #1)

* See footnote page 34

Obviously, considerably improved techniques must be developed to achieve higher design efficiencies with the materials selected. At the stress developed in rigid filament wound structures (280,000 psi), the burst pressure of the test bottles would have been 420 psi.

BIBLIOGRAPHY

1. J.P.L. Technical Report No. 32-510 on Behavior of Materials in Space Environments by L. D. Jaffee and J. B. Rittenhouse.

2. Goodyear Aircraft Technical Reports on High-Strength Materials for Expandable Structures by J. L. Blighton and D. P. Tannacht, Jr. under Contract AF33(616)-8473.

3. Northrup Space Laboratories Technical Report No. TDR-62-709 on Elastomeric and Compliant Materials by R. M. Heitz, R. W. Hunter and P. J. D'Anna under ASD Contract AF33(616)-8258.

4. Southwest Research Institute Report No. TR 61-234, Handbook of Design Data on Elastomeric Materials Used in Aerospace Systems by A. G. Pickett and M. M. Lemcoe under ASD Contract AF33(616)-7093.

5. Haskins Mfg. Co. Report TDR-62-727, Part I on Ultra-Fine High Temperature, High Strength Metallic Fibers under ASD Contract AF-8346.

6. U. S. Rubber Company Report on Effect of Vacuum at Elevated Temperatures on Elastomers, Plastics, Fibers and Foams by E. P. Percarpio.

7. U. S. Rubber Tire Company Technical Reports TR-57-913 on Study of Manufacturing Processes and Development of Manufacturing Methods to Provide High Temperature Tires by S. Van der Burg and J. G. Manchetti under ASD Contract No. AF33(600)-42970.

8. Article on "Protection Against the Solar Flare" by Herman J. Schaefer of U. S. Naval School of Aviation Medicine, Pensacola, Florida, published in August 1962 issue of Astronautics.

APPENDIX A

RECOMMENDED STUDIES TO ADVANCE PLANS TO USE FILAMENT WOUND STRUCTURES IN SPACE

1. Continue materials search and testing program in the following areas:
   a. Categorize new materials and configurations as they become available or semi-commercial.
   b. Conduct combined environmental exposure tests of composite samples to establish safe design stress levels at maximum and minimum use temperatures anticipated. Continue radiation creep tests.

2. Study means to improve encapsulated glass cord performance:
   a. Study improvements to cord construction by improving size uniformity and by adopting S994 type glass filament in the basic stress element. Eliminate strength loss @ 300°F.
   b. Determine the effect of the necessary filament winding processing steps on cord strength retention. Establish most effective tensioning means for handling.
   c. Develop consistent method for producing a high quality pre-impregnated encapsulated glass tape for filament winding operations.
   d. Determine best winding procedures and means of removing mandrel from finished product.

3. Study design capabilities of flexible constructions:
   a. Determine requirements to transfer stress
      1) into reinforcing of off axis ports
      2) from one configuration to another, and
      3) into a non-flexible member
   b. Construct and test a fully flexible multi-tube juncture.

4. Determine degree to which companion space wall elements will protect the filament wound stress ply:
   a. Define protection from meteoroids achieved by bumper and spacer construction.
   b. Determine limits of thermal exposure controlled by reflective surface and insulation layer.
   c. Select materials and forms best suited for these protective roles.

APPENDIX B

(Sheet 3)

BINDER COMPOUNDS - SOLUTIONS - PROPERTIES

Ingredients	MWO-11[3]	MWO-12[3]	MWO-13[3]	MWO-14[3]	MWO-15
RTV-11[1]	100				
RTV-60[1]		100			
Thermolite 12	0.5	0.5	0.5	0.5	
RTV-X511[1]			100		
RTV-X560[1]				100	
Estane 5740 X-2[2]					100
Description	Flows well	Flows poorly	Flows well		
Solvent Type					MEK
Solvent Concentration in parts on above					300
% Total Solids	100	100	100	100	25
Solution Specific Gravity	1.18	1.47	1.18	1.42	0.88
Sol. Wt. in Gr./Cu. In.	19.35	24.1	19.35	23.3	14.4
Cure Time	24 hr.	24 hr.	24 hr.	24 hr.	20 min.
Oven Temp. °F	Room temp.	Room temp.	Room temp.	Room temp.	350
Durometer Shore A	43	54	47	51	62
Tensile psi[4]	170 psi	400 psi	130 psi	395 psi	1425 psi
% Elongation at break[4]	105%	93%	112%	102%	778%
Modulus in psi at 300% elong.[4]	---	---	---	---	250 psi
Test Sample Gage in In.	.085	.072	.068	.080	.069

(1) General Electric room temperature vulcanization Silicone elastomer

(2) B. F. Goodrich thermoplastic polyurethane lot #11-21

(3) Deaerate after mixing. Pot life 1-2 hours.

(4) U. S. Rubber Autographic Stress Strain Test. Ring sample is continually rotated while stressed. Tensile normally lower than for Instron tensile test. Modulus is identical.

APPENDIX B

(Sheet 4)

BINDER COMPOUNDS - SOLUTIONS - PROPERTIES

Ingredients	MWO-16	MWO-17	MWO-18	MWO-19	MWO-20[4]
Epon 871[1]	85	100			
Epon 828[1]	15				
Epon Z	11.4				
Nadic Methyl Anhydride		44.8			
Benzyldimethyl Amine		1.0			
Epon 872X75[1]			133		
Epon U			6.1		
GE SE-555U[2]				100	
Cadox TS-50				1.3	
Liquid Vibrathane 6004[3]					100
MOCA					11.5
Solvent Type	Xylene	Xylene	Xylene	Xylene-Toluene	MEK
Solvent Concentration in parts on above	---	---	33	405.4	36.5
% Total Solids	100	100	75.6	20	75
Solution Specific Gravity	1.02	1.04	1.01	0.91	1.08
Sol. Wt. in Gr./Cu. In.	16.7	17.06	16.56	14.9	17.7
Cure Time	2 hr+3 hr	4 hr+4 hr	24 Hr+8 hr	1 hr + 8 hr	
Press Temp. °F				300	R.T.
Oven Temp. °F	175 & 300	250 & 300	RT & 150	375	
Durometer Shore A	88	67	72	47	77
Tensile psi[5]	575 psi	310 psi	325 psi	688 psi	1835 psi
% Elongation at break[5]	35	70	45	492	557
Modulus in psi at 300% elong.[5]	---	---	---	275 psi	495 psi
Test Sample Gage in In.	.076	.058	.082	.060	.063

(1) Product (epoxy) of Shell Chemical Co.

(2) Product (silicone gum) of General Electric Co.

(3) Product (Polyurethane) of Naugatuck Chemical Co.

(4) Dissolve MOCA in 11½ parts MEK
Dissolve RESIN in 25 parts MEK
Blend

(5) U. S. Rubber Autographic Stress Strain Test. Ring sample is continually rotated while stressed. Tensile normally lower than for Instron tensile test. Modulus is identical.

APPENDIX B

(Sheet 1)

BINDER COMPOUNDS - SOLUTIONS - PROPERTIES

Ingredients	MWO-1	MWO-2	MWO-3	MWO-4	MWO-5 (1)
SS #2	100				
Philblack 0	35				
Stearic acid	2	0.5	1		
Kadox	3				
Santocure	0.75				
Sulphur	2.25	1.5			
Butyl 325		100			
MPC black		35			
Zinc oxide		5	5	5	
Tellmac		1			
MBTS		1			
Neoprene WRT			100		
SRF black			35		
MgO			4		
IRR 218 (Butyl)				92.5	
HT 10-66				7.5	
Philblack A				30	20
Philblack E				25	
Laurex				3	
SB1001				1	
CRRA0803				8	
Viton B					100
Maglite D					5
Diak #3					3
Solvent Type	Skellysolve	Skellysolve	Toluene	Skellysolve	MEK
Solvent concentration in parts on above	572	576	435	688	304
% Total Solids	20	20	25	20	25
Solution Specific Gravity	0.74	0.75	0.96	0.74	0.92
Sol. Wt. in Gr./Cu. In.	12.1	12.3	15.7	12.1	15.1
Cure Time	45 min.	45 min.	45 min.	45 min.	45 min. (2)
Press Temp. °F	307	307	307	330	307 (2)
Durometer Shore A	54	52	51	61	75
Tensile psi (3)	1350	1287	1450	1405	1562
% Elongation at break (3)	357	457	520	478	290
Modulus in psi at 300% elong. (3)	1000	625	600	750	---
Test Sample Gage in In.	.076	.074	.078	.074	.076

(1) Shelf life 6 days

(2) Cure for MWO-5 - Following the press cure for 45 min. @ 307°F
Place in air oven for 1 hr. @ 250°F,
1 hr. @ 300,
1 hr. @ 350,
1 hr. @ 375, and for
16 hr. @ 400

(3) U. S. Rubber Autographic Stress Strain Test.
Ring sample is continually rotated while stressed. Tensile normally lower than for Instron tensile test. Modulus is identical.

APPENDIX B

(Sheet 2)

BINDER COMPOUNDS - SOLUTIONS - PROPERTIES

Ingredients	MWO-7	MWO-8	MWO-6	MWO-9 (3)	MWO-10 (3)
Gum Vibrathane 5004 (1)	100		100		
Philblack 0	22.5		22.5		
Stearic Acid	0.5		0.5		
DiCup 40C	4				
Liquid Vibrathane 6004 (1)		100			
Multrathane XA		7.9			
TMP		0.4			
DiCup 95C			4		
Maraset 636-A (2)				100	100
Maraset 636-B (2)				150	100
Maraset Hand. #30 (2)				10	10
Ferric Acetyl Acetonate		0.01			
Solvent Type	Acetone	Acetone	Acetone		
Solvent Concentration in parts on above	508	---	381		
% Total Solids	20	100	25		
Solution Specific Gravity	0.86	1.18	0.86	1.04	
Sol. Wt. in Gr./Cu. In.	14.1	19.35	14.1	17.05	
Cure Time	60 min.	24 hr.	60 min.	3 hr.	3 hr.
Press Temp. °F	302		302		
Oven Temp. °F		225		212	212
Durometer Shore A	71	48	63	82	
Tensile psi (4)	2362	780	2175	725	
% Elongation at break (4)	385	660	730	170	
Modulus in psi at 300% elong. (4)	1650	175	---	---	
Test Sample Gage in In.	.076	.083	.079	.077	

(1) Products (Polyurethane) of Naugatuck Chemical Co.

(2) Product (epoxy) of Marblette Corp.

(3) Blend A & B. Heat at 212°F. until mixture is clear. Add #30, mix. Pour into mold.

(4) U. S. Rubber Autographic Stress Strain Test. Ring sample is continually rotated while stressed. Tensile normally lower than for Instron tensile test. Modulus is identical.

APPENDIX B

(Sheet 5)

BINDER COMPOUNDS - SOLUTIONS - PROPERTIES

Ingredients	MWO-21	MWO-22	MWO-23
EPRD 62-8-16 (1)	100		
HAF	40		
ZNO	5	5	3
Stearic Acid	1	1	2
Monex	1.5		
MBTS	0.5	1	0.7
Sulfur	0.8	1.5	1.75
Paracril BJ (2)		100	
SRF		75	
Phillips Cis 4 (3)			100
Philblack O			40
Flexone 3C			1
Solvent Type	Cyclohexane	MEK	Toluene
Solvent concentration in parts on above	1711	730	170.8
% Total Solids	8	20	8
Solution Specific Gravity	0.77	0.88	0.89
Sol. Wt. in Gr./Cu. In.	12.6	14.4	14.6
Cur Time	30 min.	60 min.	45 min.
Press Time °F	320	287	292
Durometer Shore A	59	62	54
Tensile psi (4)	2495 psi	1765 psi	1397 psi
% Elongation at break (4)	472%	422%	565%
Modulus in psi at 300% elong. (4)	1000 psi	1350 psi	425 psi
Test Sample Gage in In.	.076	.075	.077

(1) Ethylene Propylene rubber by Naugatuck Chemical Co.

(2) Paracril rubber by Naugatuck Chemical Co.

(3) Butadiene rubber by Phillips Chemical Co.

(4) U. S. Rubber Autographic Stress Strain Test. Ring sample is continually rotated while stressed. Tensile normally lower than for Instron tensile test. Modulus is identical.

A	B	C	D	E	F	G	H
		Cord Description					
Sample No.	Cord (1)	Dia.	No./ Inch	Weight In Grs/Sq.In	Equiv. Thickness in Inches	Binder	Code No.
4	840/2 Nylon (714)	.023	36	.208	.015	Butyl	NAO-
5	840/2 Dacron (66)	.021	40	.223	.014	Butyl	NAO-
6	1600/1 Portfiber	.017	46	.254	.010	Butyl	NAO-
7	EGG 150 1/9 Glass	.017	46	.450	.010	Butyl	NAO-
8	420/2/2 HT-1	.019	44	.227	.012	Butyl	NAO-
9A	3-.0038 Steel	.009	80	.386	.003	Butyl	NAO-
11	840/2 Dacron (66)	.021	40	.228	.014	Nat. Rubber	NAO-
12	840/2 Dacron (66)	.021	40	.228	.014	Neoprene	NAO-
14	EGG 150 1/9 Glass	.017	46	.450	.010	R. C. Butyl	NAO-
16	840/2 Dacron (66)	.021	40	.228	.014	Urethane	NAO-
17A	840/2 Polypropylene	.023	30	.222	.019	Butyl	NAO-
18B	840/2 Dacron (66)	.021	40	.228	.014	Urethane	NAO-
19A	EGG 150 1/9 Glass	.017	46	.450	.010	Viton B	NAO-
20A	420/2/2 HT-1	.019	44	.227	.012	Viton B	NAO-
21	420/2/2 HT-1	.019	44	.227	.012	Silicone Rub.	NAO-
22	840/2 Dacron (66)	.021	40	.228	.014	Epoxy	NAO-
25	840/2 Dacron (66)	.021	40	.228	.014	Paracril	NAO-
26	840/2 Dacron (66)	.021	40	.228	.014	Butadiene	NAO-
27	840/2 Dacron (66)	.021	40	.223	.014	Royalene	NAO-
28	840/2 Dacron (66)	.021	40	.228	.014	Urethane	NAO-
29	EGG 150 1/9 Glass	.017	46	.450	.010	Nat. Rubber	NAO-

(1) Including adhesive (see Table 2, page 22)

(2) See Appendix B

(3) Plus oven cure: 1 hr. at 250°F
1 hr. at 300°F
1 hr. at 350°F
1 hr. at 375°F
16 hr. at 400°F

[illegible] C

[illegible]

(2)	I	J	K	L	M	N	O	P
		Amount Applied		Minimum Binder Req'd.		Skin Thickness		
	Density	Grams/ Sq.In.	Thickness in Inches	C - F Inches	Grams/ Sq.In.	in Inches (K-L)/2	% Binder (5)	Cure
2	1.0932	.272	.015	.008	.145	.004	41	45 min. in 60# steam
2	1.0932	.244	.014	.007	.122	.004	35	45 min. in 60# steam
2	1.0932	.216	.012	.007	.126	.003	36	45 min. in 60# steam
2	1.0932	.265	.015	.007	.124	.004	22	45 min. in 60# steam
2	1.0932	.261	.015	.007	.122	.004	35	45 min. in 60# steam
2	1.0932	.248	.014	.006	.106	.004	22	45 min. in 60# steam
1	1.0649	.268	.015	.007	.125	.004	35	45 min. in 60# steam
3	1.4231	.348	.015	.007	.162	.004	42	45 min. in 60# steam
4	1.1264	.198	.011	.007	.126	.002	22	60 min. in 80# steam
7	1.2869	.279	.013	.007	.150	.003	40	1 hr. in 55# steam
2	1.0932	.309	.017	.009	.164	.004	42	45 min. in 60# steam
15	1.1877	.264	.014	.007	.132	.004	37	20 min. in 350°F steam
5	1.8342	.222	.007	.007	.222	0	33	40 min. in 60# steam(3)
5	1.8342	.262	.009	.007	.204	.001	47	40 min. in 60# steam(3)
19	1.1788	.235	.012	.007	.137	.003	38	1 hr. in 300°F steam(4)
18	.987	.269	.017	.007	.111	.005	33	24 hr. at R.T. plus 8 hr. @ 15
22	1.2558	.293	.014	.007	.147	.004	39	60 min. in 287°F steam
23	1.0919	.304	.017	.007	.125	.005	35	45 min. in 45# steam
21	1.0550	.303	.017	.007	.125	.005	35	30 min. in 320°F steam
20	1.2342	279	.014	007	.140	.004	38	R. T.
1	1.0849	.234	.013	.007	.126	.003	22	45 min. in 60# steam

(4) Plus oven cure - 8 hr at 375°F

(5) % of total composite weight based on minimum binder required.