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RUBBER COMPOSITIONS

FOR

HYDRAZINE SERVICE

PSI PROJECT NO. 7034000
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FINAL REPORT

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ABSTRACT

Forty-three compounds were formulated and tested for hydrazine compatibility at 160°F. Variables introduced included silicon dioxide filler loading level and particle size. Both butyl and ethylene-propylene rubbers were employed as well as various vulcanization systems. Compatibilities averaged approximately 175 days as compared to a range of 159 to 239 days for the controls. The data showed that compounds containing butyl and butyl blended with ethylene propylene could not be distinguished from ethylene propylene alone as far as physical properties were concerned. A trend noted was that a filler level with higher silicon dioxide loading exhibited better hydrazine compatibility. Particle size variation did not show any consistent trends. Any of the vulcanization systems employed appeared to be satisfactory. A refined technique for dissolving aluminum cores from EPT-10 bladders was also perfected.

CONTENTS

SUMMARY

Forty-three rubber compounds, consisting of ethylene-propylene, butyl, and blends of both were prepared for hydrazine compatibility testing in this experimental investigation. The intent was to develop compounds suitable for bladders to be used for hydrazine expulsion on spacecraft.

The program was divided into the following five areas of investigation: (1) variable filler loading effects on the compound EPT-10, (2) variation of filler type and particle size effects, (3) properties of butyl and butyl-ethylene-propylene blends, (4) vulcanization systems, and (5) refinement of procedures for dissolving aluminum cores from hydrazine bladders during manufacture.

Hydrazine compatibility testing of the compounds was conducted at 160°F. Pressure rises to 50 psia, however, required as long as 223 days (175 days average) with control samples ranging from 158 to 239 days.

A slight trend was noted favoring higher silicon dioxide filler loading in ethylene propylene compounds, but no trend was apparent as far as particle size was concerned.

Butyl and butyl blends with ethylene propylene exhibited hydrazine compatibilities indistinguishable from those exhibited by ethylene propylene alone.

Compounds containing butyl rubber had higher surface tackiness than ethylene propylene compounds. This characteristic is desirable for some types of fabrication.

A study of vulcanization systems produced five compounds having properties suitable for diaphragm and bladder applications. These compounds were either butyl or butyl blends with ethylene propylene.

A procedure for the dissolution of aluminum cores from EPT-10 bladder was successfully carried out.

The program, as originally conceived, was not completed. Only pressure-rise data from hydrazine immersion of the test compounds were obtained. Weight-change determinations were not made, although the samples have been stored to permit this whenever desired.

Future studies should limit hydrazine exposure of test rubber compounds to one month or less, after which physical properties can be determined. It may be expedient to subject only the most promising compounds to this short-duration testing.

INTRODUCTION

The effect of hydrazine on rubber materials has been a source of concern for many years. Rubber compounds normally contain some chemicals which either catalyze hydrazine, causing decomposition, or react with hydrazine directly. A major portion of a rubber compound normally consists of the filler, and the concentration of other various ingredients in the material is largely dependent upon its nature.

In an earlier program (Ref. 1), it was shown that employment of rubber materials containing silicone dioxide or calcium silicate fillers reduced hydrazine decomposition rates drastically when compared to compounds containing carbon black fillers. The initial effort in the present program was directed toward establishing the compatibility of fillers with hydrazine.

The compatibility and weight-change data were expected to give some indication of the mechanism of hydrazine absorption. The structure of hydrazine is similar to that of water. As the filler Silene D is hygroscopic, it was suspected that this filler has a greater affinity for hydrazine than for water, because hydrazine is anhydrous and also very hygroscopic.

In a continued effort to discover a trend of hydrazine absorption by rubber materials, an attempt was made to correlate the compatibility of rubber compounds with hydrazine with the particle size of the fillers used in these compounds. Implicit in this approach is a relationship between compatibility and compound surface area.

In the past, butyl rubber compounds have been used with hydrazine. Butyl bladders were used for hydrazine expulsion in zero-gravity environment on all of the Ranger spacecraft as well as on the Mariner 4 and 7 spacecraft. Butyls have the added advantage of being characteristically tacky, thus facilitating lay-up fabrication. The main difficulty with butyl rubbers, however, is achieving suitable vulcanization in the presence of fillers other than carbon black. Studies of butyls and vulcanization systems are therefore closely linked.

In the cited earlier program (Ref. 1), the compound that was found to exhibit the best overall balance of properties for use in bladder fabrication was EPT-10. This compound however has characteristics considered less than optimum, including a relatively high absorption of hydrazine and a lack of tackiness which made lay-up construction difficult. EPT-10 is molded into bladders on an aluminum core. The common procedure for extracting this aluminum core from the bladder has not been completely satisfactory. Principally, EPT-10 was found to be sensitive to the caustic solution used in core dissolution. Development of a coating that would protect the rubber and the perfection of a technique for applying this coating over the exterior and interior surfaces of a bladder while still on the aluminum core were part of the present program.

TECHNICAL DISCUSSION

A. GENERAL

This program was divided into several areas of investigation:

(1) Effects of variable filler loading on EPT-10

(2) Effects of variation of filler type and particle size

(3) Butyl and butyl-ethylene-propylene blends

(4) Vulcanization systems

(5) Refinement of aluminum core dissolution procedures.

Rubber compounds were numbered beginning with compound 10. The numbering system was derived from the earlier program (Ref. 1). The numbering is consecutive except for compound 10A which was basically the same as compound 10 except for the cure system. Compounds 26 through 33 (except 29) were mill mixed for radiation studies which will be evaluated under another program and therefore have not been included in this report.

The compounds were immersed in hydrazine at a temperature of 160°F — a test temperature common in numerous specifications. It was hoped that this temperature would expedite the program by decreasing the time of rise to 50 psia. Many of the samples, however, exceeded 200 days of test duration.

Evaluation of the compounds was limited to pressure rise data during hydrazine immersion. As this is only a partial evaluation of the compounds, samples are presently being kept in storage so that they can be evaluated as to weight gain and hydrazine contamination should such a follow-on procedure be desired.

The pressure-rise data were plotted, and all curves were found to be linear after the first three or four days of immersion and until termination at 50 psia.

Variability of data was reduced considerably by preconditioning the samples as well as the test capsules in hydrazine for two days at ambient conditions. Nonetheless, there still remained a rather wide dispersion which made conclusions somewhat difficult to derive. There is some justification, however, for considering data obtained from longer exposures of samples to hydrazine as having greater validity because leaky capsules were readily

detectable. Short test durations are likely the result of contaminated capsules and/or test samples. It is interesting to note that the test duration of control samples varied from a low of 158 days to a high of 239 days. In this instance, data were very much better than expected. Samples from compound AFE-332-11, which was developed for hydrazine service by TRW also fared well as far as test duration was concerned, with two samples reaching 182 days and a third 156 days.

The mill processing characteristics of most of the compounds which were prepared under the program were satisfactory. As expected, the addition of butyl rubber to ethylene propylene invariably improved the handling characteristics.

All but one of the compounds were extruded through a 100-mesh screen. An attempt was made to extrude compound 51, but the virgin teflon clogged the screen. A companion compound, number 52, which contained ground, fused teflon, passed through the screen without difficulty. This process was an attempt to improve the tear strength which was accomplished with the virgin teflon (compound 51) having a tear strength of 265 lbs/in. as compared with 195 lbs/in. for compound 52. It appears that the virgin teflon reinforces the compound by simulating a fibrous structure. This can be seen visually in tensile strength and tear samples as they are stressed.

In addition, the compounds were X-rayed, and the test swatches were molded from areas which were free of particles approximately 0.005 in. or larger in cross section.

The core dissolution procedure for bladders from an earlier program was not completely satisfactory. The caustic solution which was employed in dissolving the aluminum core caused a degradation of the EPT-10 bladder material. The main effort in this investigation was directed toward the application of a protective coating over the rubber.

B. EFFECTS OF VARIABLE FILLER LOADING ON EPT-10

Compounds 10 through 14, as shown in Table 1, show considerable overlapping of data with respect to pressure rise, and a clear conclusion concerning filler loading is not obvious. There is some justification, however, for placing a greater degree of confidence in the higher figure of the two samples, because

it is inferred from experience that the presence of contamination will tend to mask the actual behavior of the test sample. Leakage also can be readily detected as pressure either stabilizes or decreases under this condition.

If the longer times are selected as representative of compound behavior, a general trend becomes apparent (compound 13 excepted) which appears to indicate that the dilution of the rubber with silicone dioxide filler tends to reduce the hydrazine decomposition rate.

Physical properties of the compounds indicate that compounds 10, 11 and 12 are entirely suitable for diaphragm and bladder applications, whereas compounds 13 and 14 have tensile strengths which are relatively low.

Table 1. Filler Level, Silene D

Characteristic	Compound				
	10	11	12	13	14
Parts per Hundred of Rubber, by Weight	65	50	35	20	0
Days to 50 psia in N_2H_4 at 160°F — Sample 1	210	172	160	182	141
Days to 50 psia in N_2H_4 at 160°F — Sample 2	125	164	139	170	102
Tensile Strength, psi	2030	1685	1400	810	280
Elongation, %	400	460	440	390	330
Hardness, Shore A	78	73	68	60	53

C. EFFECTS OF VARIATION OF FILLER TYPE AND PARTICLE SIZE

Early in this phase of the program, the amount of silicon dioxide added to compounds as a filler had to be reduced, as the particle size of this filler decreased until a level of 35 parts per hundred by weight of rubber was reached. This permitted a comparison of data from all of the silicon dioxide fillers.

The investigation was concentrated on obtaining data from silicon dioxide as there are very few non-carbon-black reinforcing fillers. The data shown in Table 2, however, indicate that the various particle sizes of silicon dioxide have no definite correlation with hydrazine compatibility. The range of 130 to 220 days of exposure appears to be the result of data scatter rather than tending to establish a trend.

Some other fillers employed in the investigation were Silene E F and Ice Cap KE clay, which are calcium silicate fillers. Compound 41 contained Ice Cap KE clay and had a hydrazine compatibility (196 days to 50 psia) which was within the time span of many of the compounds that contained silicon dioxide. This compound, as well as compound 23, with 210 days to 50 psia, indicates that calcium silicate is suitable as a reinforcing filler for hydrazine applications.

Compounds 51 and 52 each contained teflon powders. Compound 51 contained virgin teflon, while compound 52 was filled with the fused and ground material. The tear strength of compound 51 was 265 lbs/in. and of compound 52, 195 lbs/in. In order to increase tear strength, it is necessary to employ virgin teflon in filler material. No difficulties were encountered in mixing either compound, but compound 51 could not be extruded through the 100-mesh screen. Neither of these two compounds was subjected to compatibility tests; however, the two compounds should behave somewhat like compound 12.

All of the compounds processed more easily than EPT-10 during mixing, extruding, and molding (except for cited difficulties with compound 51 extrusion). The physical properties of the compounds discussed, however, were all within the range of workable expulsion devices.

Table 2. Filler Study, Types of Silicon Dioxide Particles

Characteristic	Compound*								
	12	18	19	20	21	22	23	24	25
Filler	Silene D	Cab-O-Sil EH5	Cab-O-Sil M-5	Cab-O-Sil H-5	Cab-O-Sil L5	Cab-O-Sil M7	Silene EF	Arcsilica 800	Hi-Sil 233
Particle Size, μ	0.03	0.005	0.012	0.007	0.05	0.012	0.03	0.005	0.022
Days to 50 psia in Hydrazine at 160°F — Sample 1	160	130	155	209	182	172	210	220	215
Days to 50 psia in Hydrazine at 160°F — Sample 2	139	---	---	186	145	137	145	181	154
Tensile Strength, psi	1400	2785	2590	2455	2425	3180	1390	1390	2735
Elongation, %	440	480	370	320	480	390	350	280	400
Hardness, Shore A	68	82	81	83	70	84	73	73	79

*Filler Level — 35 Parts per Hundred of Rubber by Weight

D. BUTYL AND BUTYL-ETHYLENE-PROPYLENE BLENDS

Often an approach is neglected because an apparent solution receives more attention. The ethylene propylene compounds have overshadowed the butyls for this reason during recent years. Yet butyl rubbers have several favorable characteristics. One of the most important is the resistance to crack growth during flexing, another is the low permeability to gases which should also be duplicated by a low permeability with hydrazine, and a third is the characteristic tackiness which enhances the prospects of lay-up-type fabrication.

In this program the main problems have centered around the physical properties of the butyls and butyl blends. This stems from the difficulty of obtaining satisfactory vulcanization in the presence of silicone dioxide fillers. Peroxides cannot be employed, as they will depolymerize the butyl polymers. Generally the sulfur or resin types offer the best possibilities. Both are also useable with ethylene-propylene terpolymers.

The data in Table 3 indicate that the hydrazine compatibility of butyl compounds and butyl-ethylene-propylene blends is comparable to that of ethylene propylene compounds. Therefore, it is necessary to look elsewhere for differences between these types of compounds. One of these areas is the processing characteristics. Butyl and butyl blends have better processing characteristics than ethylene propylene alone. The increase in surface tackiness would enhance the possibility of hand lay-up and vacuum-bagging type of construction. Elongations in the range of 500% and higher permit the removal of relatively large cores from butyl and butyl blend bladders by stretching the mouth openings sufficiently.

Table 3 summarizes the properties of several butyl compounds that show promise with hydrazine. The butyl bladders which were employed in Mariners 4, 6, and 7 were made from fargo rubber compound FR-6-60-26 which had a Shore-A hardness of 55, an elongation of 550%, and a tensile strength of 1200 psi. Two of the butyl compounds tested, namely 36 and 37, have physical properties similar to those of fargo rubber compound.

The test samples are in storage; weight-change determinations are not available at this time.

Table 3. Butyl Compounds

Item	Compound*				
	35	36	37	47	48
Rubber					
Butyl HT-1066	100		50	50	
Butyl 365		50			50
Royalene 301		50	50		
Nordel 1320				50	
Vistalon 2504					50
Vulcanizing Agent					
Sulfur	1.5	1.5	1.5		
Thionex	1.5	1.5	1.5		
MBT	0.5	0.5	0.5		
Sulfasan R				1.5	1.5
Ethyl Zimate				1.5	
Ledate					2.0
Characteristic					
Days to 50 psia in Hydrazine, Sample 1	198	182	203	223	178
Days to 50 psia in Hydrazine, Sample 2	190	157	148	170	166
Tensile Strength, psi	1915	1080	1245	1015	1335
Elongation, %	990	450	520	800	900
Hardness, Shore A	38	56	53	43	47

*Compounds are based on 100 parts of rubber by weight.

E. VULCANIZATION SYSTEMS

The study of vulcanization systems was directed toward several objectives. The elimination of sulfur was accomplished in compounds 10A (similar to EPT-10) and 41 with the utilization of a dicumyl peroxide cure. Both compounds had elongations which were below 200% and would therefore be somewhat marginal for expulsion bladders or diaphragms. As peroxide cores are not suitable for butyl-type elastomers, it was necessary to investigate other possibilities. Therefore compounds 42 through 50 served a double purpose by combining the study of butyls as well as of vulcanization systems.

Table 4 contains selected data showing the best properties of each basic vulcanization system. For compounds 42 through 45 a resin, ST 1055, was employed. The ultimate tensile strength was low, ranging from 595 to 775 psi. Compounds 47 and 48 employ Sulfasan R as the main agent with ethyl zimate and ledate, respectively, acting as activators. Both compounds show promise in hydrazine applications. With respect to compatibility, any of the vulcanization systems would appear to be satisfactory. Compound 41, which was cured with a peroxide, showed a duration of 196 days in the hydrazine test. This counterbalances the relatively poor results obtained with compound 10A.

F. REFINEMENT OF ALUMINUM CORE DISSOLUTION PROCEDURES

The process for extracting the aluminum core from a bladder in an earlier program was not completely satisfactory as there was an indication that compound EPT-10 was sensitive to caustic solutions. The data in Table 5 show why EPT-10 required isolation from caustic; a decrease in both the tensile strength and hardness are caused by EPT-10 in contact with caustic. It is also apparent from Table 5 that the oven post-cure phase of vulcanization for this compound should be performed after the caustic soak. As two EPT-10 bladders were still on cores, the problem was to arrive at a procedure for extracting the cores.

Initial efforts were performed on test swatches which were coated with several materials, namely, ethyl celulose, polyvinyl chloride plasticsol, and polyvinyl chloride dissolved in a mixture of ketones. Ethyl cellulose was heated to 350°F. Test samples were dipped and allowed to cool. The coating thickness could be controlled at will. The polyvinyl chloride plastisol was likewise dipped

Table 4. Basic Vulcanization System Properties

Item	Compound*					
	10A	22	45	46	47	48
Vulcanization System						
Dicup 40 c	7					
Vinyl Silante A-172	1					
Triallyl Cyanurate	1.5					
Sulfur		1.5				
Thionex		1.5				
MBT		0.5		0.5		
ST1055			12			
TMTDS				1.0		
TDEDC				1.0		
Sulfasan R				1.0	1.5	1.5
Ethyl Zimate					1.5	
Ledate						2.0
Characteristic						
Days to 50 psia in Hydrazine — Sample 1	137	172	190	180	223	178
Days to 50 psia in Hydrazine — Sample 2	127	137	164	147	170	166
Tensile Strength, psi	1645	3180	775	720	1015	1335
Elongation, %	170	390	620	780	800	900
Hardness, Shore A	73	84	47	50	43	47

*Compounds are based on parts per hundred of rubber by weight.

but had to be heated to 350°F in order to cause it to solidify. The third prospective coating, polyvinyl chloride dissolved in ketones, was dipped and then allowed to dry at room temperature. The first two of the enumerated coatings were not difficult to apply, but they would have been difficult to employ in the final process, where the interior of the bladder had to be coated with the plastisol. The polyvinyl chloride solution offered the most promise.

A small mold was constructed so that bladders could be molded on aluminum cores. The mold produced bladders which were approximately 5 in. in diameter. The cores were made from hydroformed aluminum hemispheres which were welded at the girth.

Table 5. Effects of Caustic Solution[1] on Compound 10

Sample Description	Physical Property		
	Tensile Strength, psi	Elongation, %	Hardness, Shore A
Control (not immersed)	2180	310	77
Postcured, Not Coated, Immersed	1390	340	62
Postcured, Coated with Ethyl Cellulose	1500	300	70
Not postcured, * Coated with Ethyl Cellulose	2025	280	74
Not postcured, * Coated with Polyvinyl Chloride Film	2300	300	77

*Postcured 4 hr at 350°F after completion of caustic soak; data obtained after final postcure.

[1] 2.5% sodium hydroxide solution by weight for one week at ambient temperature.

As had been encountered in the previous program, a release coating was required with EPT-10. Teflon and FEP coatings were tried. Both required high temperatures (700°F+) during application which could be harmful to the properties of aluminum components. No deformation was noted, however. The teflon coating peeled with the rubber after several molding attempts. Therefore it was replaced with an FEP coating which performed satisfactorily. The coating was applied employing the following procedure:

(1) Clean and grit blast surface to be coated, then bake at 705°F.
(2) Spray with Dupont 850-204 and fuse at 700°F.
(3) Spray with Dupont 856-204 and fuse at 610°F.
(4) Spray with Dupont 856-200 and fuse at 610°F.

Following the molding of suitable bladders, coating of the rubber was undertaken. The exterior caused no difficulty, but the interior required the insertion of stainless steel wires between the core and the bladder. The polyvinyl chloride solution would run to the bottom of the bladder along the channels paralleling the wires. The wires could then be moved about so that the entire inner surface was covered. Pinholes were encountered in the polyvinyl chloride coatings. Additional coats or entirely new coatings had to be applied to the exterior as pinholes would permit the caustic to come in contact with the rubber and cause localized discoloration.

Several cores were dissolved. The following procedure was developed for core dissolution:

(1) Prepare a 2.5% sodium hydroxide solution

Water	70.00 lbs
50% caustic solution	3.60 lbs

(2) Add to dissolving tank
(3) Insert pump outlet into aluminum core
(4) Start nitrogen gas bubbling (about one bubble per second)
(5) Start circulation pump
(6) Replace solution every 2-1/2 to 3 days.

The nitrogen gas bubbling was included in order to minimize formation of sodium carbonate.

NEW TECHNOLOGY

No reportable items of new technology have been identified.

CONCLUSIONS

The program, as originally conceived, was not completed. Data from hydrazine immersion consisted of pressure rise only. Consequently, weight-change determinations will not be available until some future date, and the optimization of compounds could not be undertaken during the course of this program.

Although there is still a large spread in the data, this was considerably reduced by keeping samples and test apparatus for 48 hours at room temperature. The hydrazine compatibility test was conducted at 160 °F with the expectation that the time to reach 50 psia, when the tests were to be terminated, would be rather short. While control samples ranged from 159 to 239 days, however, test samples averaged approximately 175 days and went as long as 223 days.

The data have indicated a slight trend that implies that higher ratios of silicon dioxide promote compatibility with hydrazine. There is no evident trend as far as particle size is concerned.

Calcium silicate fillers can be employed successfully, but lower the physical properties of the rubber.

Butyl compounds and butyl ethylene-propylene blends compare favorably with ethylene-propylene alone, with respect to hydrazine compatibility. In addition, butyl enhances the property of surface tackiness of the raw compound. This characteristic is desirable where layups are required during the fabrication process.

The variations in vulcanization included peroxide, sulfur, sulfur substitution, and resin. Compounds which were suitably vulcanized so that they could be employed in diaphragms and bladders included peroxide, sulfur, and sulfur substitute formulations. None of the resin-cured compounds had adequate tensile strength properties (1000 psi or more).

The core dissolution procedure for bladder fabrication was refined so that EPT-10 could be used in the production of bladders. The basic element found necessary for successful core removal was the addition of a protective coating over both the interior and exterior surfaces of the bladder. The coating is a polyvinyl chloride solution in a mixture of ketones.

RECOMMENDATIONS

Samples remain from this program that still require evaluation with respect to weight change. The sample capsules contain the gaseous decomposition products as well as residues which are dissolved in the hydrazine so that no loss of material can occur.

As the compatibility tests ran for such an unexpected long duration, future studies should include a limited exposure, not to exceed one month, after which properties such as weight, ultimate tensile strengths, elongation changes, and other data can be obtained. It may be expedient to subject only the most promising compounds to short-duration testing.

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APPENDIX

TEST DATA

Test results are presented in tabular form in this appendix to substantiate the findings elaborated under "Technical Discussion" and "Conclusions."

Table A-1. Compatibility with Hydrazine, at 160°F, in psia

Compound	Days				
	50	100	150	200	To 50 psia
10	15	26	37	48	210
	22	40			125
10A	28	42			127
	24	39			137
11	20	33	46		164
	18	31	44		172
12	22	35	49		160
	22	37			139
13	20	32	45		179
	16	27	41		182
14	23	37			141
	30	49			102
15	17	28	40		184
16	19	29	41		190
	38				95
17	21	36	48		151
18	22	40			130
19	20	34	48		155
20	16	27	38	49	209
	17	29	40		186
21	17	28	42		182
	20	36			145
22	18	31	45		172
	20	38			137
23	23	38			145
	20	29	38	48	210
24	20	31	42		181
	17	27	38	48	220

Table A-1. Compatibility with Hydrazine, at 160°F, in psia (Cont'd)

Compound	Days				
	50	100	150	200	To 50 psia
25	16	25	36	47	215
	21	36	49		154
34	18	30	43		
	14				187
35	18	28			190
	17	27	38		198
36	19	31	48		157
	17	29	42		182
37	16	26	37	49	203
	20	35			148
38	18	31	40		198
	18	28			
39	18	33	48		155
	17	29	43		180
40	19	33			142
	19	31			169
41	15	26	39		196
	16	26	38		196
42	16	29	44		173
	16	30	43		175
43	16	25	36	48	220
	15	28	43		176
44	14	24	34	45	224
45	18	30	41		190
	17	30	46		164
46	23	37			147
	15	27	41		180
47	16	28	43		170
	13	22	33	45	223

Table A-1. Compatibility with Hydrazine, at 160 °F, in psia (Cont'd)

Compound	Days				
	50	100	150	200	To 50 psia
48	17	31	46		166
	16	29	42		178
AFE 332-11	17	30	41		182
	20	35	49		156
	18	30	42		182
Control	14	26	38	50	200
	14	23	32	42	236
	12	21	30	41	239
	20	33	44		172
	18	33	48		158

Table A-2. Effect of Silene D Loading[1]

Item	Compound*				
	10	11	12	13	14
Variable					
Silene-D	65	50	35	20	0
Constant					
Royalene 301	100	100	100	100	100
Zinc Oxide	5	5	5	5	5
Sulphur	1.5	1.5	1.5	1.5	1.5
Thionex	1.5	1.5	1.5	1.5	1.5
MST	0.5	0.5	0.5	0.5	0.5
Physical Property					
Tensile Strength, psi	2030	1685	1400	810	280
Elongation, %	400	460	440	390	330
Hardness, Shore A	78	73	68	60	53
Sp. Gr.	1.08	1.05	1.02	1.0	1.0

*Parts per hundred of rubber by weight.

[1]Press cured 1 hr at 320 °F and oven postcured 4 hr at 350 °F.

Table A-3. Composition of Compounds with Hystl*

Ingredient	Compound	
	49	50
Nordel 1440	--	75
Nordel 1320	25	--
Butyl HT-1066	75	25
Hystl B-200	10	10
Silene D	35	35
Zinc Oxide	5	5
Sulfur	1.5	--
Thionex	1.5	--
MBT	0.5	--
ST 1055	--	15

*Parts per hundred of rubber by weight; neither compound could be vulcanized satisfactorily.

Table A-4. Filler Study*

Item	Compound										
	15	16	17	18	19	20	21	22	23	24	25
Rubber											
Royalene 301	100	100	100	100	100	100	100	100	100	100	100
Filler											
Silene EF	50								35		
Arc Silica 800		50								35	
Hi Sil 233			50								35
Cab-O-Sil EH5				35							
Cab-O-Sil M-5					35						
Cab-O-Sil H-5						35					
Cab-O-Sil L-5							35				
Cab-O-Sil M-7								35			
Vulcanizing System											
Zinc Oxide	5	5	5	5	5	5	5	5	5	5	5
Sulfur	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
MBT	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Thionex	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Physical Property											
Tensile Strength, psi	1485	2485	2975	2785	2590	2455	2425	3180	1390	1390	2735
Elongation, %	380	500	440	480	370	320	480	390	350	280	400
Hardness, Shore A	77	78	88	82	81	83	70	84	73	73	79
Specific Gravity	1.08	1.10	1.10	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05

*Press cured, 1 hr at 320 °F, and oven cured, 4 hr at 350 °F.

Table A-5. Compounds with Fluorocarbon Filler*

Item	Compound		
	51	52	12
Rubber			
Royalene 301	100	100	100
Filler			
Silene D	35	35	35
Zinc Oxide	5	5	5
Teflon, TFE T-58	10	--	--
Teflon, TL-126	--	10	--
Sulphur	1.5	1.5	1.5
Thionex	1.5	1.5	1.5
MBT	0.5	0.5	0.5
Physical Properties			
Tensile Strength, psi	1330	1350	1330
Elongation, %	280	390	440
Hardness, Shore A	77	65	68
Tear Strength, lbs/inch	265	195	--

*Press cured 1 hr at 32 °F and oven postcured 4 hr at 350 °F.

Table A-6. Butyl Compounds and Blends*

Ingredient	Compound						
	34	35	36	37	38	39	40
Butyl 365	100		50		50		
Butyl HT-1066		100		50		50	100
Royalene 301			50	50			
Nordel 1440					50	50	
Silene D	35	35	35	35	35	35	
Zinc Oxide	5	5	5	5	5	5	5
Sulphur	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Thionex	1.5	1.5	1.5	1.5	1.5	1.5	1.5
MBT	0.5	0.5	0.5	0.5	0.5	0.5	0.5

*Parts per hundred of rubber by weight.

Table A-7. Vulcanization Systems, A*

Ingredient	Compound				
	42	43	44	45	46
Butyl 365	100		50		50
Butyl HT-1066		100		50	
Royalene 301			50	50	
Nordel 1440					50
Vistalon 2504					
Silene D	35	35	35	35	35
Zinc Oxide	5	5	5	5	5
ST 1055	12	12	12	12	
MBT					0.5
TMTDS					1.0
TDEDC					1.0
Sulfasan R					1.0

*Parts per hundred of rubber by weight.

Table A-8. Vulcanization System, B*

Ingredient	Compound			
	10A	41	47	48
Rubber				
Royalene 301	100	100	--	--
Butyl 365	--	--	--	50
Butyl HT-1066	--	--	50	--
Nordel 1320	--	--	50	--
Vistalon 2504	--	--	--	50
Filler				
Silene D	65	--	3.5	35
Ice Cap KE Clay	--	100	--	--
Dicup 40C	7	7	--	--
Vinyl Silene A-172	1	1	--	--
Tri Allyl Cyanurate	1.5	1.5	--	--
Vulcanizing System				
Zinc Oxide	--	--	5	5
Sulfasan R	--	--	1.5	1.5
Ethylzimate	--	--	1.5	--
Ledate	--	--	--	2.0

*Parts per hundred of rubber by weight.

Table A-9. Physical Properties

Compound	Press Cure, 320°F hr	Oven Cure, 350°F hr	Tensile Strength, 100%	Elongation, %	Modulus, 100%	Hardness, Shore A
10A	1	-	1645	170	940	73
34	1	4	375	1090	55	30
34	1.5	-	705	610	115	47
35	1	4	605	1090	60	27
35	1.5	-	1915	990	110	38
36	1	4	1080	450	160	56
37	1	4	1245	520	165	53
38	1	4	685	490	170	53
39	1	4	975	540	145	53
40	1	-	230	600	60	28
41	1	-	1835	140	1110	72
42	0.75	-	595	620	60	40
43	0.75	-	605	320	180	44
44	0.75	-	775	700	120	45
45	0.75	-	775	620	120	47
46	0.75	-	720	780	110	50
47	1	-	1015	800	115	43
48	1	-	1335	900	60	47

Table A-10. List of Ingredients

Ingredient	Description	Source
Polymers		
Butyl 365	Isobutylene-Isoprene	Enjay
Butyl HT-1066	Chlorinated Isobutylene-Isoprene	Enjay
Nordel 1320	Ethylene Propylene Terpolymer	Dupont
Nordel 1440	Ethylene Propylene Terpolymer	Dupont
Royalene 301	Ethylene Propylene Terpolymer	Uniroyal
Vistalon 2504	Ethylene Propylene Terpolymer	Enjay
Fillers		
Arc Silica 800	Silicone Dioxide	Pittsburgh Plate & Glass
Cab-O-Sil EH5	Silicone Dioxide	Cabot
Cab-O-Sil H-5	Silicone Dioxide	Cabot
Cab-O-Sil L-5	Silicone Dioxide	Cabot
Cab-O-Sil M-5	Silicone Dioxide	Cabot
Cab-O-Sil M-7	Silicone Dioxide	Cabot
Hi Sil 233	Silicone Dioxide	Pittsburgh Plate & Glass
Ice Kap KE Clay	Calcium Silicate	Burgess
Silene D	Calcium Silicate	Pittsburgh Plate & Glass
Silene EF	Calcium Silicate	Pittsburgh Plate & Glass
Teflon, TFE T-58	Tetrafluro Ethylene	Dupont
Activators and Vulcanizing Agents		
Dicup 40 C	Dicumyl Peroxide	Hercules
Ethyl Zimate	Zinc Dirthyl-Dithiocarbamate	R. T. Vanderbilt
Ledate	Lead Dimethyl-Dithiocarbamate	R. T. Vanderbilt
MBT	Mercapto Benzothiazole	R. T. Vanderbilt
TDEDC	Tellurium Dirthyl-Dithiocarbamate	R. T. Vanderbilt
Thionex	Tetramethyl Thiuram Monosulfide	Dupont

Table A-10. List of Ingredients (Cont'd)

Ingredient	Description	Source
Activators and Vulcanizing Agents (Cont'd)		
TMTDS	Tetramethyl Thiuram Disulfide	
Tri Allyl Cyanurate	---	American Cyanamid
ST-1055	Polyhalomethyl Phenol Resin	Schenectady Chemicals
Sulfasan R	4,4 Dithiodimorpholine	Monsanto
Sulfur	---	L. A. Chemical
Vinyl Silane A-172	---	Union Carbide
Zinc Oxide	---	New Jersey Zinc