WADC TECHNICAL REPORT 54-190
PART 3

DEVELOPMENT OF HIGH-TEMPERATURE OIL-RESISTANT RUBBER

WILLIAM J. MUELLER
LOUIS E. NOVY
RICHARD A. CLARK
RANDALL G. HEILIGMANN

BATTELLE MEMORIAL INSTITUTE

DECEMBER 1955

MATERIALS LABORATORY
CONTRACT AF 33(616)-476
PROJECT No. 7340
TASK NUMBER 73405

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield, O.
500 - April 1956

FOREWORD

This report was prepared by Battelle Memorial Institute under Supplemental Agreement No. 54-(55-935) to USAF Contract No. AF 33(616)-476. This contract was initiated under Project No. 7340, "Rubber, Plastic and Composite Materials", Task No. 73405, "Compounding of Elastomers", formerly RDO No. 617-12, "Compounding of Elastomers", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Mr. F. G. Kitts acting as project engineer.

This report covers work completed between January 1, 1955, and August 31, 1955.

ABSTRACT

This report describes research to develop two types of rubber composition. These were (1) a composition that will withstand 500 to 1000 hours of immersion in diester-type lubricating oil (Turbo Oil-15) at 350 to 400 F, and (2) a composition that will withstand immersion for the same time period in silicate ester-type hydraulic fluids (OS-45 or MLO-8200) at 400 F.

The best compositions for use in hydraulic fluids for an aging time of 168 hours at 400 F were prepared from Neoprene WRT. For this time period, these compositions met nearly all of the WADC minimum target specifications. For longer aging periods, stocks made with Acrylon BA-12 and with Philprene VP-A appeared to be the most promising, although only limited work has been done with these polymers. Hycar 1014 and Philprene VP-25 were less promising polymers than Neoprene WRT, and Hycar 1072 and butyl rubber were completely unsuitable.

Compositions to be used in Turbo Oil-15 were evaluated at both 350 F and 400 F. At 350 F, poly-FBA compositions were able to meet all of the minimum target specifications of this project, and at 400 F they failed only because of low tensile strength after aging (300 to 350 psi, compared with a minimum target of 800 psi). At 350 F, Hycar 4021 stocks missed the minimum target requirements because they swelled about 6 per cent above the 30 per cent maximum. At 400 F, Hycar 4021 stocks had about 25 per cent excessive swell, fell down in stress-strain properties, and cracked after 500 hours of aging. Further efforts to overcome the tendency of Acrylon EA-5 stocks to crack, even when aged at 350 F, were not successful.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER

M. R. Whitmore
Technical Director
Materials Laboratory
Directorate of Research

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES
(Continued)

DEVELOPMENT OF HIGH-TEMPERATURE OIL-RESISTANT RUBBER

by

W. J. Mueller, L. E. Novy, R. A. Clark,
and R. G. Heiligmann

INTRODUCTION

This is the final progress report on the "Development of High-Temperature Oil-Resistant Rubber", and covers work completed between January 1, 1955, and August 31, 1955. Previous progress on this same problem appears in WADC Technical Reports 54-190, Parts 1 and 2, dated January, 1955, and April, 1955, respectively. The work described in the present report emphasizes the development of a rubber for use in synthetic hydraulic fluids, whereas previous reports emphasized the development of a rubber for use in diester-type lubricants, such as Turbo Oil-15. A limited amount of research with the latter fluid was carried over into the present studies.

A description of the scope of the program, rubber properties desired, and suggested approaches to the problem appears in Exhibit "C", shown in Appendix A. Although the aging-temperature requirement for both lubricants and hydraulic fluids is now 400 F, the previous temperature requirement for lubricants (e.g., Turbo Oil-15) was 350 F. As a result, a portion of the hot-oil aging of rubber in Turbo Oil-15 that appears in this report was conducted at the lower temperature. All of the results for aging rubber in hydraulic fluids were obtained at 400 F.

For the purpose of clarity in this report, the results for aging rubber in these two general types of fluid (i.e., lubricants and hydraulic fluids) will be discussed separately.

Turbo Oil-15 Program

A brief review of the work that has been done to develop rubber compositions with improved resistance to this diester-type lubricant is in order. There are three general types of rubber that have received major attention: (1) butadiene-acrylonitrile copolymers (i.e., nitrile rubbers), such as Hycar 1001, (2) acrylate-type copolymers, such as Hycar 4021, and (3) poly-1,1-dihydroperfluorobutyl acrylate, also known as poly-FBA. Rubbers of the first class were susceptible to cracking when hot-oil aged; those of the second showed considerable promise, but swelled about 6 per cent more than the 30 per cent maximum desired; and those of the third class met all the target requirements at 350 F, although their physical properties were on the low side.

The earlier studies with nitrile rubber included investigations of fillers, curing systems, antioxidants, and plasticizers. Aging at 350 F in Turbo Oil-15 showed that (1) magnesia was a more effective reinforcing agent than carbon black or other nonblack pigments, (2) plasticizers contributed no beneficial effects, (3) choice of curatives had very little effect on aged properties, and (4) antioxidants were almost totally ineffective at this temperature. A brief study with a series of butadiene-acrylonitrile copolymers of varying acrylonitrile content revealed that copolymers with high acrylonitrile content (40 to 45 per cent) displayed the best aging properties.

Previous work with acrylate polymers centered around a study of fillers and vulcanizing systems, and a comparison of two acrylate copolymers, Hycar 4021 and Acrylon EA-5. In compounding studies with Hycar 4021, Hi-Sil and Silene EF were found to be the best fillers, both being somewhat better than carbon black. The optimum vulcanizing system contained triethylene tetramine and tetramethylthiuram disulfide, either with or without sulfur. Limited work with Acrylon EA-5 showed it to swell less than Hycar 4021, but it was susceptible to cracking.

Limited past studies with poly-FBA dealt with curing systems and fillers. Curing systems based on lead peroxide and magnesia were found to be too slow to be effective. The cure continued during aging and resulted in very poor aged properties. Cab-O-Sil (Aerosil), when used as a filler for poly-FBA, appeared to provide better retention of physical properties after aging than did carbon black fillers.

The work described in this report with Turbo Oil-15 deals with (1) attempts to reduce hot-oil cracking of nitrile rubber, (2) further work with fillers, polymer blends, and experimental polymers to lower the swell of acrylate polymers, and (3) additional work with fillers in poly-FBA, to improve its general physical properties.

Hydraulic-Fluid Program

The primary objective of the present research program was to develop rubber compositions suitable for use in silicate-ester-type fluids at 400 F. The fluids selected by WADC for this phase of the program were:

(1) OS-45 (Monsanto Chemical Company)

(2) MLO-8200 (Oronite Chemical Company)

(3) An 85/15 blend of MLO-8200 and Monoplex DOS [di-(2-ethylhexyl) sebacate, produced by Rohm and Haas Company].

Since WADC reported that Neoprene WRT showed promise for this application, a fairly extensive compounding study was carried out with this polymer. Nitrile rubber and several other butadiene-containing rubbers were included in the present investigation. Since air is excluded from hydraulic systems, the oxidation cracking of unsaturated polymers of this type was not expected to be as severe a problem as it is in lubrication systems, which contain large amounts of air. Cracking, however, proved to be a problem in both types of fluid.

EXPERIMENTAL SECTION

(Original data for this report appear in Battelle Laboratory Record Books:

(No. 8453, pages 42-48;
No. 10170, pages 1-22;
No. 10008, pages 1-96;
No. 10169, pages 1-100;
No. 9788, pages 27-44;
No. 10167, pages 1-100;
No. 10522, pages 1-8;
No. 10168, pages 1-100;
No. 10476, pages 1-40;
No. 10351, pages 1-7;
No. 9325, pages 87-100; and
No. 10477, pages 1-86.)

Equipment and Procedures

Turbo Oil-15 Program

Equipment. Aging of all samples was carried out in an aluminum-block heater drilled to fit 38 x 200-mm test tubes. Details of these heaters were given in Appendix II of WADC TR 54-190 and in Appendix IV of WADC TR 54-190 Part 2. The temperature of these heaters was controlled within 2 F at 350 and 400 F.

Procedures. Except for work with poly-FBA, ASTM Methods D15-52T and D412-51T were followed in the mixing, curing, and preparation of individual dumbbell-type specimens used for testing. For poly-FBA, mixing was carried out on a 2-1/2 x 7-inch mill fitted with adjustable guides. Curing was done in four-cavity molds, with individual cavities being 2 x 3 x 0.040 inch.

The aging procedure consisted of suspending the rubber samples in 38 x 200-mm test tubes, adding Turbo Oil-15, and placing the test tubes in the aluminum-block heater for the desired length of time. At the beginning of this work, glass hangers that overlapped the top of the test tubes were used. Because of excessive breakage, these were replaced with 304 stainless steel (0.0475-inch diameter) wire, which has proved much more satisfactory. For each sample to be tested, two test tubes were used. One contained three dumbbell specimens for the stress-strain and hardness tests, and the second contained two samples approximately 1 x 1 inch for swelling and cracking determinations. In evaluating poly-FBA, the dumbbell samples were used for all tests because of the limited amount of polymer. After the samples were suspended in the test tubes, 140 ml of Turbo Oil-15 was added and the tube covered with an inverted Petri dish. The cover fitted loosely and permitted the free entrance of air into the test tube. At the end of a given aging period, the tubes were removed from the aluminum block and allowed to cool for 1 hour. The rubber samples were then removed from the oil, dipped quickly in acetone to remove oil from the surface, and blotted dry before being tested.

The stress-strain properties of all rubber specimens except poly-FBA were determined with a Scott Tensile Tester, Model L6, run at 20 inches per minute. Dumbbell samples were cut with Die C, ASTM Method D412-51T. To conserve material, poly-FBA dumbbell specimens were cut with a midget die having an over-all length of 2 inches and a restricted section of 1/8 inch. This die is identical to a die currently in use at WADC. The loading required to test these small samples was below the range of the Scott Tester, so a Dillon Low-Range Tester was used at a speed of 20 inches per minute.

Hardness was determined by a Shore A2 Durometer, according to ASTM Method D314-52T.

Swelling was determined with a Kraus-Jolly balance. Per cent swelling was calculated by determining the relative volumes before and after aging.

The degree of cracking was rated by visual observation of 1 x 1-inch specimens flexed 180 degrees, using an arbitrary scale of (1) cracking, (2) crazing, and (3) no cracking.

Compression set was determined in both hot air and hot Turbo Oil-15. Set in hot air was determined according to ASTM Method D395-52T, Method B (Compression Set Under Constant Deflection). Details of the test method employed for determining compression set in Turbo Oil-15 at 350 F were given in pages 3 to 5 of WADC TR 54-190. In carrying out this test, one questionable feature developed. The test samples had a height of 0.225 inch (three plies from a standard 0.075-inch tensile sheet) and a diameter of 0.500 inch. Because of considerable swelling, it was found that the samples swelled around the spacers. To reduce this tendency, a smaller sample was investigated. Keeping the ratio of height to diameter constant, a sample of 0.150-inch height (two plies from a 0.075-inch tensile sheet) and 0.333-inch diameter was tried. Data are being accumulated on samples of both sizes, in order to decide which method should become standard. The test procedure employed is as follows:

(1) Disks are cut from 0.075-inch tensile sheet, either 0.333- or 0.500-inch diameter, and plied up, using either two or three disks. The total thickness of the sample is determined to the nearest 0.001 inch.

(2) The test specimens are placed between the plates of the compression device, along with spacers, and the assembly is tightened. The amount of initial compression on the sample depends upon the hardness, and is determined from the following table (from ASTM Method D395-52T):

Durometer Hardness	Deflection, per cent of original thickness
1 through 44	40
45 through 64	30
65 through 84	25
85 and over	20

(3) The assembly is then placed in a test tube. The tube is filled with Turbo Oil-15 and placed in the aluminum-block heater for the desired heating period.

(4) At the end of the test period, the test tubes are removed from the aluminum block and the samples removed from the test assembly. They are allowed to cool in air for 30 minutes.

(5) Final thickness is determined to the nearest 0.001 inch, and the compression set is determined from the following formula:

$$\text{Per cent compression set} = \frac{t_o - t_1}{t_o - t_s} \times 100,$$

where

t_o = initial thickness

t_1 = final thickness after cooling for 30 minutes

t_s = thickness of the spacers.

Low-temperature retraction tests were made according to ASTM Method D1329-54T, using an initial stretch of 55 per cent of the breaking elongation.

Hydraulic-Fluid Program

Several changes were necessary for the hydraulic-fluid program because of the high cost and limited supply of the fluids prescribed. The revised methods used for hydraulic-fluid testing are described below.

Equipment. The aging of samples was carried out in 25 x 200-mm Pyrex culture tubes sealed with aluminum caps containing liners of poly-FBA. One change was necessary in the aluminum-block heater used for aging. The Transite cover was replaced with one containing smaller holes to accommodate the smaller diameter tubes.

Procedures. ASTM Methods D15-52T and D412-51T were followed where possible in the mixing, curing, and preparation of individual dumbbell-type specimens used for testing. Curing was done in four-cavity molds, with the individual cavities being 6 x 6 x 0.040 inch. The dumbbell length was reduced to 2 inches, this being the smallest convenient size that could be pulled on the Scott Tester.

The aging procedure consisted of suspending the rubber samples on wire hangers in 25 x 200-mm culture tubes, adding 50 ml of hydraulic fluid, sealing the tubes, and placing them in the aluminum-block heater for the desired length of time. At the end of a given aging period, the tubes were removed from the aluminum block and allowed to cool for 1 hour before the caps were removed. The rubber samples were then removed from the fluid, dipped quickly in acetone to remove fluid from the surface, and blotted dry before being tested. One tube containing three dumbbell specimens was used for each sample. These dumbbells were used for all tests, including swell and cracking.

The stress-strain properties of all rubber specimens were determined with a Scott Tensile Tester, Model L6, run at 20 inches per minute.

Hardness was determined by a Shore A2 Durometer, according to ASTM Method D314-52T.

Swelling was determined by a Kraus-Jolly balance. The per cent swell (volume change) was calculated by determining the relative volumes before and after aging.

The degree of cracking was rated by visual observation of dumbbell specimens flexed 180 degrees, using an arbitrary scale of (1) cracking, (2) crazing, and (3) no cracking.

Brittle temperatures were determined by a solenoid-actuated brittleness temperature tester according to ASTM Method D746-54T.

DISCUSSION OF RESULTS

Hydraulic-Fluid Program

Studies With Neoprene WRT

Work reported by the Materials Laboratory (WADC TR 54-458) indicated that the best compounds developed up to 1955 for silicate-ester fluid applications were made with Neoprene WRT. The best compound (WADC 453-26 C) survived only 72 hours' exposure at 400 F, however. One of the main objectives of this program, therefore, was to improve the service life of Neoprene WRT.

Preliminary Neoprene WRT Compounds. The results of aging several Neoprene WRT compounds are shown in Table 1. The first three compounds in this table were arbitrarily selected from the following sources:

N-2 - A general-purpose compound selected from Du Pont literature

N-3 - The composition developed at WADC, 453-26 C.

N-4 - A compound suggested by earlier work at Battelle.

Of these three compounds, the N-3 gave the best results, although it retained adequate physical properties for only 72 hours. In addition, its performance for this time period was adequate in only one of the three test fluids, the blend of MLO-8200 and Monoplex DOS. The other two fluids, in general, were more harmful to all of the neoprene compositions. Although the N-2 compound showed promise in one test fluid, it was unplasticized and probably would have failed the -65 F brittle-point requirement.

The remaining compositions in Table 1 were made to demonstrate possible effects of zinc oxide content on the aging of Neoprene WRT. No marked trend was apparent from these limited results. However, a more detailed treatment of zinc oxide concentration was undertaken subsequently, with results shown in the following section of this report.

Also shown in Table 1 are the results of experiments in which tubes containing hydraulic fluid were heated to expel air before rubber aging was started. The venting procedure consisted of placing the test tubes with the prescribed amount of hydraulic fluid in the aluminum-block heater for 1 hour before adding the rubber samples and sealing the tubes. This pretreatment of the fluid appeared to have no important effect on the aging of the rubber.

The Effects of Zinc Oxide Content on the Aging of Neoprene WRT. Work reported by WADC TR 54-458 indicated that zinc oxide was an important compounding variable in Neoprene WRT compositions aged in sealed systems at high temperatures. Their results suggested the optimum level of zinc oxide was 2.5 phr. Du Pont technical information and previous experience at Battelle indicated, however, that higher loadings of zinc oxide might improve the aging of neoprene, at least at temperatures up to 300 F. Therefore, an investigation of the zinc oxide concentration was considered essential. The results are shown in Table 2.

Improved compounds were obtained at zinc oxide loadings of 60 to 80 phr. The improvements were most pronounced in compounds containing reduced amounts of carbon black (recipes N-33 and N-34). One shortcoming of the high-zinc oxide compounds was their consistently poor aging in MLO-8200. They do, however, maintain good physical properties in the blended fluid and in OS-45. After 168 hours' aging in the blended fluid, the N-34 compound did not crack, although cracking did occur in the other two fluids.

The data in Table 3 show the results obtained by incorporating several types and amounts of carbon black into Neoprene WRT compositions containing 80 phr of zinc oxide. These compositions showed the same trends as those described above. High loadings of zinc oxide afforded improvements only when the carbon black level was reduced and the aging was carried out in either the OS-45 or the blended fluid.

The Effect of Magnesia Content on the Aging of Neoprene WRT. The data shown in Table 4 deal with the determination of the optimum magnesia content for curing Neoprene WRT. Two levels of zinc oxide were used, and the carbon black content was adjusted to maintain a reasonable total filler-loading level. At the higher zinc oxide concentration, variations in magnesia content had very little effect on either the original or the aged physical properties. At the lower zinc oxide concentration, however, at least 4 to 5 phr of magnesia are preferred, with larger amounts having very little effect. This indicates that, for vulcanization purposes, relatively large amounts of zinc oxide can be used to replace relatively small amounts of magnesium oxide. From an aging viewpoint, better polymer stability is apparently contributed by a large total oxide content.

The Effects of Accelerators Other Than NA-22 on the Aging of Neoprene WRT. Compounds that were accelerated with materials other than NA-22 are shown in Table 5. Although this evaluation was preliminary, no other material was found that approached the effectiveness of NA-22 in producing a neoprene composition having good retention of physical properties.

The Effect of Nonblack Fillers on the Aging of Neoprene WRT. The results obtained with nonblack-filled neoprene compounds are shown in Table 6. In several of the compositions, the accelerator level was raised from 1.0 to 1.5 phr in an attempt to improve tensile strength by tightening the cure. The minor gains in aged tensile strength provided by increasing the accelerator, however, were offset by significant losses in aged elongation.

Additional nonblack-filled compounds are shown in Table 7. Particular attention is directed to the greater freedom from cracking shown by the stocks containing nonblack fillers in comparison with those containing carbon black. As has been discussed in previous reports, cracking appears to be associated with excessive loss in elongation. Although the carbon black stocks were better at retaining tensile strength during aging, they also lost more elongation.

The Effects of Blending Black and Nonblack Fillers. An effort was made to combine the desirable properties contributed to Neoprene WRT by carbon black with those contributed by nonblack fillers. The results of a number of such combinations are shown in Table 8. In general, the serious loss in elongation of carbon black-type stocks is carried over into these blends, with no significant gain in other properties.

The Effects of Varying Accelerator and Activator. Attempts also were made to improve the tensile strength of neoprene compounds by reducing the acceleration level and varying the activator. The results in Table 7 indicate that gains in certain physical properties are usually at the expense of other properties. An exception to this trend, however, is shown in the results for

Recipe N-101. This composition, containing 0.6 phr NA-22, displayed appreciably better results than a similar composition containing 1.0 phr NA-22 (Recipe N-13, Table 6).

The significance of the caps blowing off the tubes in some of the tests has not been established. Although the particular fluid and rubber combination may be critical, there are other factors that might be responsible. One of these is that the caps were reused many times and may have been damaged from previous use. Another is that a completely air-tight seal might not have been obtained initially, and this may have helped generate pressure within the tubes. Although new caps and liners gave more favorable results in some instances, such as in tests repeated for Recipe N-101 in two of the fluids, the data for new caps are too limited to be decisive. They do, however, indicate that further improvement in the aging of neoprene might be attained by further studies with filler and NA-22 content.

Control Runs With WADC 26-C Compound. The effects of milling procedure on the aging of a control compound (WADC 26-C) are shown in Table 9. The 26-C recipe was prepared according to WADC recommended procedure, and then repeated using the Du Pont recommended procedure. In the WADC procedure, zinc and magnesium oxides and NA-22 are mixed together before addition to the banded rubber. The blacks are mixed together and added next, and the plasticizer is added last. In the Du Pont procedure, the compounding ingredients are added separately to the rubber during milling in the following order: magnesia, SRF black, Thermax, plasticizer, zinc oxide, and NA-22.

Neither mixing procedure appeared to demonstrate any particular advantage over the other.

Brittle Points of Neoprene Compounds. Table 10 shows the brittle-point results for representative Neoprene WRT compositions before aging. The data show that 15 phr of butyl oleate reduced the brittle point to near -60 F. It is quite probable that only a small amount of additional plasticizer would reduce the brittle point to the required -65 F without appreciable damage to the strength properties of these compositions.

Compounding Studies With Hycar 1014

Nitrile rubber, evaluated on the Turbo Oil-15 program (WADC TR 54-190 Part 2), was found to be unsatisfactory because it cracked after aging. This failure was attributed to the presence of air (causing cross-linking and embrittlement). Consequently, in an air-free hydraulic-fluid system, this type of rubber was expected to make a better showing. Since flexibility at -65 F was desired, a low-nitrile copolymer, Hycar 1014, was selected for the first work. Preliminary tests were made using a modification of the A-23 composition in which Hycar 1014 was substituted for Hycar 1001. The original A-23 stock was filled with ELC magnesia and was the best nitrile-rubber stock tested in Turbo Oil-15. Recipe A-384 in Table 11 shows the effect of aging this modified stock in the three hydraulic fluids. The tensile strength of this stock started out rather low for a nitrile rubber (920 psi) and suffered a severe loss after 72 hours' aging, and then improved decidedly during longer aging periods. Swell was well below the maximum allowable 30 per cent, but some of the samples cracked after aging. As the aging period was increased to 336 hours, the tensile strength and hardness greatly increased, and elongation decreased. At all aging periods, the OS-45 was found to degrade the polymers more than did the other two fluids.

Thus, the preliminary tests on Hycar 1014 indicated two outstanding shortcomings: (1) a low tensile strength after aging 72 hours at 400 F, and (2) excessive cross-linking or hardening when this aging was continued to 336 hours. In order to eliminate one or both of these shortcomings, studies were made of fillers, vulcanizing systems, antioxidants, miscellaneous additives, and blends of Hycar 1014 with Philprene VP-25.

Fillers. Several fillers were tried in an effort to eliminate or reduce the low aged tensile strength found for the ELC magnesia-filled stocks. The most successful were the silica fillers, Hi-Sil and Cab-O-Sil, with properties shown in Table 12. Recipe A-385, containing 60 phr Hi-Sil, gave better results than any Hycar 1014 stock produced to date, having a somewhat better balance of properties than other silica-filled stocks.

Several additional stocks containing Philblack A, Silene EF, Calcene NC, and dixie clay were evaluated (Table 11), but none of these fillers gave the balance of properties found when using Hi-Sil.

Ratio of Stearic Acid-Sulfur-TMTD. The starting composition for the hydraulic-fluid program was the best composition developed for Hycar 1001 in the Turbo Oil-15 program (Recipe A-23). This composition was cured with 1.5 phr stearic acid, 0.5 phr sulfur, and 0.25 phr tetramethylthiuram disulfide (TMTD). It will be recalled from previous work that reasonably wide variations in this curing system had little effect on the aging characteristics of Hycar 1001 in Turbo Oil-15 at 350 F. To determine whether there was an optimum system for Hycar 1014 aged in hydraulic fluids at 400 F, a series of samples was evaluated in which the ratio of the three vulcanizing agents was varied.

Data in Table 13 indicate that the unaged tensile strength was approximately twice that of the control (1270, compared with 670 psi) when the sulfur level in the recipe was doubled. However, very little of this improvement carried over to the aged samples. Although some ratios of the vulcanizing agents produced marginal improvements in the aged tensile strength, such gains were offset by an increase in cracking. Therefore, it does not appear likely that further modifications of this curing system will produce a significant improvement in the hot-oil aging characteristics of nitrile rubber.

Antioxidants. During the aging of Hycar 1014 in hydraulic oils, it was found that the tensile strength became quite low after 72 hours' aging. However, when the aging was continued for longer time periods, the tensile strength and hardness increased, and the elongation and swell decreased. These changes are illustrated in the results for the control (Recipe A-384) shown in Table 14. Additives were sought which would minimize this initial dip in tensile strength and reduce the tendency for the rubber to harden excessively during aging.

Selenium dioxide was the most effective of the materials evaluated. When 10 or 20 phr of this material was employed, the rubber tensile strength after 72 hours' aging was double that of the control, and further increase in this property during additional aging became much less. The initial hardness of these stocks was high, but the rate of increase in hardness during aging was not nearly so great as for the other stocks. The initial and aged elongations of the high-selenium dioxide stocks were lower than those of the control stock, and they appeared to be equally prone to cracking. Thus, although selenium dioxide greatly influenced the aging characteristics of nitrile rubber, there is some doubt whether the resulting rubber product has a better balance of physical properties, especially in view of the persistence of cracking.

The aged properties of the stocks containing mercaptobenzimidazole, BLE, and AgeRite Resin D were not significantly different from those of the control, except that these additives retarded cracking during the shorter aging periods. However, after aging 336 hours, all the stocks cracked, probably because of the considerable loss in elongation. Previous experience has indicated that, when the elongation is less than about 100 per cent, the rubber samples are unable to survive the 180-degree bend test.

Hycar 1014-Philprene VP-25 Blends. Blends of Philprene VP-25 and Hycar 1014 were investigated to determine whether Philprene VP-25 would enhance the performance of Hycar 1014. Since Philprene VP-25 has a very low brittle-point temperature, it was hoped that it might serve as a low-temperature plasticizer for Hycar 1014. As a vulcanizable polymer, Philprene VP-25 was not expected to degrade rubber physical properties in the manner usually associated with extractable plasticizers, such as Plasticizer SC.

Several samples were evaluated to test this idea, with results shown in Table 15. Recipe A-333 is for an unplasticized Hycar 1014 stock, whereas Recipe A-334 shows the effect of adding Plasticizer SC. Recipes A-353 to A-355 are for blends of Philprene VP-25 with Hycar 1014. The data indicate no advantage for the blending of these two rubbers. The physical properties, both before and after aging, appeared to be poorer for the blends than for Hycar 1014 alone.

Miscellaneous Vulcanizing Systems. In order to develop a Hycar 1014 composition which would not cross-link and harden rapidly during aging, two additional vulcanizing systems were investigated. These were based on (1) dinitrobenzene and (2) VA-7, an aliphatic polysulfide.

Dinitrobenzene has been reported in several Japanese literature references to give heat-resistant vulcanizates with nitrile rubber. Results of work at Battelle with this material as a vulcanizing agent are shown in Table 16. Stocks filled with ELC magnesia were undercured after 60 minutes, whereas Philblack A-filled stocks were satisfactorily cured after only 30 minutes. This indicates that filler selection is more critical with dinitrobenzene cures than with TMTD cures. Both unaged and aged tensile strengths were significantly higher for stocks cured with dinitrobenzene than for those cured with TMTD. However, dinitrobenzene contributed to very low aged elongation and high aged hardness, indicating considerable cross-linking during aging. Dinitrobenzene failed to reduce the amount of cracking. Because of this, no significant advantage is shown for dinitrobenzene as a curing agent.

VA-7, an aliphatic polysulfide manufactured by Thiokol Corporation, is reported to give vulcanizates with outstanding heat-aging resistance. Recipe A-394 in Table 16 shows the results obtained with this material. There was no significant difference between results from Recipe A-394 and those obtained with the control stock, A-384. Presumably, the aging conditions are too severe to show an advantage for this material.

Miscellaneous Additives. Three additives were evaluated in Hycar 1014: two in an effort to retard crosslinking during aging, and one as a substitute for the plasticizer normally used. These were RPA 6, Tenamene 2, and factice.

RPA 6 is a peptizing agent used to soften rubber during milling. It is believed to function by breaking polymer chains and reducing molecular weight. It was thought that action of this type might aid in preventing hardening during prolonged aging by compensating for or reducing the extent of polymer cross-linking during aging. The results in Table 17 indicate that this material had limited effectiveness in carrying out this action during short aging periods, as is shown by the slightly better aged elongation and crack resistance of stocks containing this material, when compared to the control. However, these advantages were lost after 336 hours' aging.

Tenamene 2, a gum inhibitor for fuels and gasoline, was investigated as a material that might reduce cross-linking during aging. Table 17 shows that this material contributed to a small increase in the aged elongation and a small reduction in aged hardness. It was about as effective as selenium dioxide, described in an earlier section of this report, which was of questionable value.

Factice, a polymerized vegetable oil, was evaluated as a substitute for Plasticizer SC. A comparison of Recipes A-397 and A-384 (the control) shows that factice increased the elongation and decreased the hardness after 336 hours' aging. In this respect, its action was similar to that of Tenamene 2 and selenium dioxide. The brittle point of the factice-containing stock was -41 F, compared with -49 F when using Plasticizer SC.

Although Tenamene 2, factice, and selenium dioxide possibly improved the aged properties, the extent of improvement was quite limited and was essentially lost after 336 hours' aging.

Compounding Studies With Philprene VP-25

Philprene VP (a copolymer of 2-methyl vinyl pyridine and butadiene) has been reported by the Phillips Petroleum Company to have outstanding resistance to hot oils and excellent low-temperature properties. Because of these reported properties, this polymer was evaluated in the hydraulic fluid program. At present, two copolymers of this type are available, Philprene VP-15 and Philprene VP-25. The 15 and 25 refer to the per cent of 2-methyl vinyl pyridine in the copolymer. Preliminary evaluation indicated that the VP-15 swelled too much to meet the target specifications of this project, so the effort was concentrated on Philprene VP-25. Variables investigated were fillers and quaternizing agents. Quaternizing agents were recommended by the manufacturer as materials that help develop maximum aged properties.

Effect of Cab-O-Sil. Cab-O-Sil was found to be the best of the fillers investigated, as shown by the results in Table 18. Recipe VP-36 was the best Philprene VP-25 composition prepared, and Recipe VP-34 was second best. These compositions show the improvement in aged tensile strength when using a quaternizing agent. The use of 5 phr of benzal chloride or benzotrichloride as quaternizing agents appeared to develop optimum properties. Table 18 shows that OS-45 degrades the rubber more than the other two fluids, as was found with compositions of Hycar 1014.

Effect of Philblack A. Results on several stocks filled with Philblack A and containing variable amounts of quaternizing agents are shown in Table 19. When less than 10 phr of quaternizing agent were used, the aged tensile strength of the rubber was well below the minimum target specification. On the other hand, increasing the quaternizing agent to 10 or 20 phr gave stocks with good aged tensile strength, but with very low aged elongation and high hardness. None of the stocks possessed a balance of properties equal to those of VP-34 or VP-36, containing Cab-O-Sil.

Effect of Silene EF. Studies with Silene EF as a filler are shown in Table 20. The aged tensile strength produced by this filler was very low, irrespective of the quaternizing agent or the vulcanizing system used. No further work with this filler is indicated.

In summary, stocks containing Cab-O-Sil as a filler, and 5 phr of benzal chloride or benzotrichloride as a quaternizing agent, had the best balance of aged properties.

After this work was completed, it was pointed out by WADC that their recent experience with Philprene VP-25 was that their stocks containing this material did not form an adequate seal at low temperatures. Although it has a low brittle point, it was found to be deficient in low-temperature retraction. Thus, there is some doubt whether this polymer could be compounded to make an adequate hydraulic seal at -65 F.

Studies With Hycar 1072

Preliminary studies were conducted with Hycar 1072, a carboxylic-modified Hycar 1042 supplied by B. F. Goodrich Chemical Company. Since this polymer is known to react with oxides, zinc oxide was added last in the milling procedure. This reactivity also influences the selection of filler material. Stocks prepared with ELC magnesia or Silene EF as filler scorched on the mill even before the vulcanizing agents were added, indicating a high degree of reactivity between these fillers and the polymer. However, Cab-O-Sil and Hi-Sil were handled in the normal manner.

The results in Table 21 show that the tensile strength of aged Hycar 1072 stocks was in the range of 2000 to 3000 psi, which is much higher than has been obtained with any other polymer. The hardness of all aged stocks was too high and seemed to be essentially independent of the hardness before aging.

A paper recently published on this type of polymer [Brown, H. P., and Gibbs, C. F., Ind. Eng. Chem., 47, 1006 (1955)] indicated that zinc stearate should give a softer stock than zinc oxide. An effort to verify this (Recipe A-395A) resulted in a stock that was full of pinholes after curing.

Results indicate that Hycar 1072 is not a suitable polymer for use in OS-45 or MLO-8200 for extended periods at 400 F. This conclusion is based largely on the excessively high hardness and cracking of this polymer after aging, which overshadows the excellent retention of tensile strength. If a means can be found for reducing the tendency of this polymer to harden and crack during aging, it should be reconsidered for this application.

Studies With Acrylon BA-12

Previous work with two acrylate polymers (Hycar 4021 and Acrylon EA-5) in the Turbo Oil-15 program indicated that they might be suitable in the hydraulic-fluid program, except for their very high brittle point. However, another acrylate polymer (Acrylon BA-12, a copolymer of 88 per cent butyl acrylate and 12 per cent acrylonitrile) has been claimed by its manufacturer to have a -65 F brittle point if properly compounded.

It was assumed that the compounding of Acrylon BA-12 would follow much the same pattern as described in the literature for similar acrylate-type polymers (see "Literature Survey on Acrylate Polymers" given in Appendix E to WADC TR 54-190). Although the butyl group should contribute better low-temperature properties to the polymer than will the ethyl group in ethylacrylate copolymers, it also produces a softer, weaker, and less swell-resistant polymer. These latter properties are balanced, to some extent, by the acrylonitrile portion of the polymer.

A recipe for Acrylon BA-12 received from a sales representative of American Monomer Corporation was evaluated in hydraulic fluids, with the results shown in Table 22. This stock (Recipe PA-282) had an unaged brittle point of -53 F, falling short of the -65 F target requirement. The very low original elongation and high original hardness indicate than an excessive amount of vulcanizing agent was used. After the stock was aged for 168 hours at 400 F, the tensile strength was just below 500 psi and its swell was well below the 30 per cent maximum allowed.

Three additional Acrylon BA-12 stocks were formulated and tested. The results in Table 22 show the obvious advantages of these stocks over stocks made with other polymers. The Acrylon BA-12 stocks (except Recipe PA-282) did not crack, harden, or decrease in elongation after 500 hours' aging at 400 F, as did stocks prepared from unsaturated polymers. Along with these advantages, each stock had at least one deficiency. The Philblack A and Hi-Sil stocks had poor aged tensile strength, and the Silene EF stock had a poor brittle point.

Because of the wide variation in properties obtained on the few stocks tested, and the excellent resistance to cross-linking and cracking during aging, it is believed that Acrylon BA-12 has more possibilities for meeting the target specifications of this project after 336 or 500 hours' aging at 400 F than any polymer tested. More work is definitely indicated on fillers, vulcanizing systems, and plasticizers. Nonextractable plasticizers were found to have merit when aging in Turbo Oil-15 and may have some merit when aging in hydraulic fluids. A recently announced liquid polybutadiene should be investigated as a plasticizer, as this should contribute to better low-temperature properties. Philprene VP-25 was found to have a very low brittle point, and there may be advantages in blends of Acrylon BA-12 and Philprene VP-25, if they can be covulcanized.

Studies With Miscellaneous Polymers

A limited evaluation was made of three additional polymers, Kel-F Elastomer, butyl rubber, and Philprene VP-A, with the results shown in Table 23.

Kel-F Elastomer, reported to be highly resistant to oils at high temperatures, was vulcanized with two systems recommended by the manufacturer*. The amine curing system used in Recipe KF-1 resulted in stocks that were found to become very hard and brittle after aging. In addition, corrosive reaction products were apparently released during the aging, as the hydraulic fluid turned solid and the stainless steel wire holding the samples was corroded in two.

Recipe KF-2 shows the effect of using a peroxide cure. No difficulty was encountered with corrosive products during the aging of this stock. The aged tensile strength of this stock was low, but it contained no filler and was probably undercured, as judged by the 1700 per cent unaged elongation. Further work with peroxide-cured Kel-F Elastomer should be considered.

Recipes Bu-4 and Bu-5 for a typical butyl-rubber stock showed that this polymer was unsuitable for use in these hydraulic fluids at high temperatures. All samples disintegrated during aging.

Data from Recipes VP-37 and VP-38 were the first results with Philprene VP-A (a terpolymer of butadiene, vinyl pyridine, and acrylonitrile) supplied by Phillips Petroleum Company. Results indicate better properties after 72 or 168 hours' aging than were obtained with any Hycar 1014 or Philprene VP-25 stocks. The greatest improvement was shown in the aged tensile strength. Although the limited results in Table 23 indicate some promise for the terpolymer, longer aging periods produced cracking in this polymer, as it has for all other butadiene-containing polymers.

Temperature-Retraction Tests

Because O-rings and packings must seal at very low temperatures, the type of test used to measure low-temperature properties is extremely important. As suggested by WADC, initial evaluations of the low-temperature performance of rubber stocks have been made on this program

*Kel-F Elastomer, "First Report on a New Fluorocarbon Rubber", M. W. Kellogg Company.

by a standard brittle-point test. However, since results from this test do not correlate well with the ability of rubber to perform at low temperatures, some other type of test was needed. WADC recently made some tests in which an approximate correlation was found between the results for a temperature-retraction (TR) test and the ability of a stock to seal at low temperatures. In this TR test, a rubber specimen is stretched and frozen in the stretched position. It is then warmed up slowly and is free to retract during this warm-up. The rate at which the specimen retracts is measured. Stocks which have a rapid rate of retraction at very low temperatures are more satisfactory in low-temperature service than those with a low rate of retraction.

Although WADC has not established a particular requirement on this project for the TR test, their best Neoprene WRT stock (26-C) has been found to seal satisfactorily at low temperatures. Consequently, a tensile sheet of 26-C stock was obtained from WADC and this was used as a control, while representative stocks from each type of polymer were tested.

The results of these tests are shown in Figures 1, 2, 3, and 4. The Neoprene WRT stocks began to retract at a lower temperature than any other stock and maintained this superiority over at least the lower half of the temperature range. Recipe N-3B (a Battelle stock with the same composition as WADC stock 26-C) was found to be superior to the 26-C stock over most of the temperature range. Above -25 C, some of the other stocks were somewhat better than 26-C, but this is not considered significant, as the lower temperatures are more important. Stocks having TR properties closest to those of 26-C were Recipe A-384, and ELC magnesia-filled Hycar 1014 stock, and VP-34, one of the best Philprene VP-25 stocks produced on this program. The poorest stock from this viewpoint was KF-2, a Kel-F Elastomer stock.

Data most frequently reported on temperature-retraction tests are the TR-10 and TR-70 values, that is, the temperatures at which the specimens retract 10 and 70 per cent. Where seals are concerned, the TR-10 value probably is more significant, as this is the temperature at which the specimen is beginning to regain its rubberlike properties.

Data in Table 24 show the TR-10 and TR-70 values. It can be clearly seen that the Neoprene WRT stock is best, with Philprene VP-25 and Hycar 1014 stocks somewhat poorer. These data also show that the Acrylon BA-12 stocks varied considerably, as might have been expected by the large range of brittle-point temperatures obtained for the stocks. Finally, these data show that Hycar 1072, Philprene VP-A, and Kel-F Elastomer stocks were much poorer than the others. Two polymers, Neoprene WRT and Acrylon BA-12, were evaluated in both black-filled and nonblack stocks. In each case, the black-filled stocks had better TR properties.

Studies With Nitrile-Type Rubbers

Severe surface cracking has been evidenced in all nitrile rubber compounds that were bent after exposure to Turbo Oil-15 at 350 F. Before bending, the rubber surfaces were hard and brittle, indicating a high degree of cross-linking and surface oxidation. Many attempts to eliminate or retard this type of failure have resulted in only slight improvements. The work with nitrile-type rubbers during the past quarter has been centered on an investigation of various promising leads for improving crack resistance.

The Effects of Additives to Turbo Oil-15. Earlier work showed that mercaptobenzimidazole caused inversion of cure in nitrile rubber and thiomalic acid retarded cure. As in previous studies with additives of this general type to reduce cracking, these materials were added to the rubber, to the oil, and to both the rubber and the oil. The results shown in Table 25 indicate that combinations of this type were not beneficial in reducing cracking.

Attempted Hydrogenation of the Surface of Hycar 1001 Compounds. A method for hydrogenating the surface of vulcanized rubber articles under mild conditions is described in U. S. Patent 2,678,892. Improved resistance to aging is claimed for the treated materials. A black-filled compound and a magnesia-filled compound of Hycar 1001 were vulcanized, and dumbbell-type specimens then exposed to hydrogen at the conditions suggested by the above patent. Although the hydrogen-pressure drop during hydrogenation indicated that some hydrogen probably was absorbed, the data were too erratic to be conclusive. In some cases, abnormally high absorption figures suggested there may have been gas leakage. The effects of the treatment on the aging of the rubber in Turbo Oil-15 ranged from none to markedly detrimental. In no instance were the physical properties of the compounds improved by the treatment.

These results do not necessarily indicate that the hydrogenation of the raw polymer under different conditions would not be a worthwhile undertaking. In fact, such an approach has been suggested to WADC in separate communications.

Miscellaneous Runs With Nitrile Rubber. The results of aging several magnesia-filled compounds of Hycar 1001 and Hycar 1041 are shown in Table 26. An earlier comparison of these two polymers showed them to age differently when compared in the same recipe. Although the aged properties of Hycar 1001 were superior to those of Hycar 1041, the latter was improved to a greater extent when mercaptans were used as additives. The results for two additional additives, Ionol (di-tertiary butyl paracresol) and

Thiokol ZL-190, to these two polymers show that the resulting compounds age very poorly. Thiokol ZL-190 appeared to have a harmful effect on the original as well as the aged physical properties.

Also shown in Table 26 are the results for Hycar 1001 compounds that contained selenium dioxide as an additive. These compounds had very good original physical properties, but they aged poorly. No improvement in crack resistance was obtained.

Studies With Hycar 4021

In previous reports (WADC TR 54-190 and TR 54-190, Part 2), it was shown that Hycar 4021 (a copolymer of ethyl acrylate and chloroethylvinyl ether) had considerable resistance to aging in Turbo Oil-15. The best compositions were able to meet all of the target specifications after aging for 500 hours at 350 F, except for the 30 per cent maximum swell. Therefore, emphasis was directed toward further reduction in swell.

Past work has shown that the choice of filler was one of the most important variables, with Silene EF being the best of those evaluated. An additional investigation has now been made of several materials as fillers. Limited earlier work on nonextractable plasticizers has been expanded, and AgeRite Resin D was evaluated as an antioxidant.

Comparison of Aging at 350 F and at 400 F. During the course of this program, the temperature for aging rubber in Turbo Oil-15 was increased from 350 F to 400 F. As might be expected, the higher temperature increased the severity of aging. The greatest effect was on tensile strength and swell, whereas little effect was observed on elongation and hardness.

These differences are apparent in Figures 5 and 6. Data for aging at 350 F were from Recipe PA-184, a Hycar 4021 stock containing 70 phr Silene EF and 10 phr DPR N-27. Data for aging at 400 F were from Recipe PA-284, a similar stock containing 20 phr DPR N-27, and the best stock tested to date at 400 F. For each stock, the average data for the 60- and 120-minute cures were plotted. Figure 5 shows that the tensile strength was lower at 400 F, regardless of the aging time. After 500 hours' aging at 400 F, the tensile strength was approximately one-half that obtained in an identical time at 350 F. Figure 6 shows the effect of temperature on swell. After 72 and 168 hours' aging, the swell was the same, whether the aging took place at 350 F or at 400 F. The biggest difference appeared when the aging period was extended to 500 hours. Since the elongation and hardness of these two stocks were almost the same at each aging temperature, these data were not plotted.

Results of this and subsequent work appearing in this report indicate that the chance of producing a Hycar 4021 stock meeting the complete target requirements at 400 F is rather remote. Swell was the one property which could not be made to meet the specifications at 350 F. Unfortunately, this same property was the one that was the most affected when raising the temperature from 350 F to 400 F.

Silene EF as a Filler. Previous aging studies at 350 F showed that one of the better compositions was filled with Silene EF and vulcanized with 2.0 phr tetramethylthiuram disulfide (TMTD) and 1.5 phr triethylene tetramine (TETA). This vulcanizing system was developed in a composition filled with Philblack A. Therefore, a study was made of vulcanizing systems for Hycar 4021 filled with Silene EF. At the same time, the aging temperature was advanced from 350 F to 400 F.

Data in Table 27 show that the aged tensile strength increased as the amount of TETA was increased. However, this increase in tensile strength was accompanied by more cracking at the shorter aging periods. The best balance of properties was found with Recipe PA-278, but even these properties fell far short of the target requirements. It can be seen that the optimum ratio of vulcanizing agents in Recipe PA-278 (1.0 phr TETA, 0.5 phr sulfur, and 2.0 phr TMTD) was similar to that in the recipe used for all previous work with Silene EF (1.5 phr TETA and 2.0 phr TMTD).

Calcene NC as a Filler. In the previous report (Table 13, TR 54-190 Part 2), preliminary data were given on the effect of Calcene NC as a filler in Hycar 4021 when aging at 350 F. Since these data were encouraging, the work was expanded, with complete results shown in Table 28 of this report.

These data indicate that the optimum aged properties were obtained when using 120 phr of Calcene NC (Recipe PA-225). Using less than this amount of filler resulted in excessive swell during aging, whereas greater amounts of filler resulted in cracking of the aged samples. After 500 hours' aging at 350 F, the Calcene NC stock (PA-225) compared favorably with the best stocks prepared with Silene EF, except that it had about 40 per cent swell, compared with about 35 per cent for the Silene EF stock. One unique property observed for the Calcene NC stocks is that, although their tensile strengths were low initially, they maintained all of their tensile strength after 500 hours' aging in Turbo Oil-15. No other filler exhibited this property.

Because of the encouraging results on Calcene NC-filled stocks aged at 350 F, this work was followed up by aging stocks at 400 F to compare results with Silene EF stocks aged under similar conditions. Several batches were evaluated, using different amounts and ratios of vulcanizing agents, to determine the optimum system. Preliminary results of aging tests at 400 F, shown in Table 29, indicate that compositions containing Calcene NC performed approximately equivalent to those containing Silene EF (Table 27).

Although Silene EF stocks appeared to be more likely to crack after 168 hours' aging, this may be more the result of higher initial hardness than of type of filler material.

Thermal Blacks as Fillers. Preliminary data on the use of thermal blacks (P-33 and Thermax) as fillers for Hycar 4021 were given in Table 13 of WADC TR 54-190 Part 2. These data indicated that P-33 black might have promise at loadings above 80 phr. Results from an extension of this work are shown in Table 30 of this report for loading levels of both P-33 and Thermax up to 120 phr. These data show no promise for either of these blacks. After 500 hours' aging at 350 F, compositions containing these fillers had very low tensile strength and were cracked.

Use of Nonextractable Plasticizers. In Battelle's previous report (WADC TR 54-190 Part 2), some success was attributed to the use of a liquid nitrile rubber (DPR N-27) as a nonextractable plasticizer for Hycar 4021. A nonextractable plasticizer should reduce hardness and permit higher filler loadings, thus decreasing the swell. Because of the success with DPR N-27, it was decided to investigate a liquid acrylate polymer (Hycar 4001X11, supplied by B. F. Goodrich Chemical Company) for this same purpose. Table 31 shows the results of adding 10 and 20 phr of each plasticizer to Silene EF-filled Hycar 4021 stocks and aging at 350 F. The plasticizers decreased unaged tensile strength about 200 psi and unaged hardness up to 15 durometer units. After aging, the plasticizers decreased swelling about 5 per cent, with only a slight loss in tensile strength.

Because of the advantage in using nonextractable plasticizers when aging at 350 F, comparable studies were made on stocks aged at 400 F. Two advantages of using nonextractable plasticizers are shown in Table 32. The most important was the reduction in cracking after aging. Cracking was first noted after 500 hours' aging when using a nonextractable plasticizer, compared with 72 hours' aging for the control stock containing no plasticizer. The second advantage of the plasticizers was the reduction in both unaged and aged hardness from 10 to 20 durometer units. This should permit higher filler loadings, with the possibility of lowering the swell.

AgeRite Resin D as an Antioxidant. It has been suggested that a good antioxidant might eliminate or reduce the cracking sometimes encountered when aging Hycar 4021, particularly Philblack A stocks aged to the maximum of 500 hours. Since AgeRite Resin D has been reported to be a good high-temperature antioxidant, it was given a brief evaluation to determine its effectiveness in reducing cracking. Two basic recipes were used, one filled with Philblack A and the other filled with Silene EF.

The results in Table 33 show that after aging for 500 hours at 350 F the compositions containing 5 phr AgeRite Resin D had about 5 per cent less swell than the control. This was accompanied by a slightly greater tendency for cracking for the compositions containing the antioxidant. It is quite possible that part of the reduction in swell may have been due to extraction of the antioxidant during aging.

In general, there appeared to be no advantage to using AgeRite Resin D in the Hycar 4021 compositions.

Compounding Studies With Acrylon EA-5

Previous studies showed that stocks containing Acrylon EA-5 swelled less in Turbo Oil-15 than those containing Hycar 4021, but the former consistently cracked after 500 hours' aging. In a continuing effort to eliminate cracking, additional studies were made on several fillers and one antioxidant.

Calcene NC as a Filler. Because of the encouraging results with Calcene NC as a filler in Hycar 4021, this filler also was evaluated in Acrylon EA-5. It was hoped that the large particle size of Calcene NC would minimize cracking. Data in Table 34 show that 70 phr of Calcene NC gave vulcanizates that did not crack, but that swelled excessively. Increasing the Calcene NC to 80 phr or more reduced the swell, but gave vulcanizates that cracked after aging. Thus, this filler was not promising in Acrylon EA-5, and no further work with it appears warranted.

Valron Estersil as a Filler. Valron Estersil was evaluated briefly in Acrylon EA-5, with the results shown in Table 34. Loadings of over 30 phr of this filler were found to give vulcanizates with excessive unaged hardness and which cracked after aging. Lesser amounts of filler gave vulcanizates that swelled excessively during aging.

AgeRite Resin D as an Antioxidant. To reduce or eliminate the consistent cracking of Acrylon EA-5 vulcanizates after prolonged aging, it was thought that AgeRite Resin D might have some value. Several batches were evaluated with different loadings of AgeRite Resin D, using two different fillers, Philblack A and Silene EF. The results in Table 35 show that AgeRite Resin D displayed no significant antioxidant effect of Acrylon EA-5.

Studies With FBA Polymer

The Effects of Silica Fillers on Poly-FBA Compounds. Previously reported poly-FBA compounds containing 25 parts of Cab-O-Sil (formerly known as Aerosil) as a filler appeared to be slightly superior to similar compounds containing the optimum amount of furnace black (i.e., about 35 phr of black). Compared on this basis, Cab-O-Sil produced harder compounds than did furnace black. Therefore, additional poly-FBA compounds were made containing lower loadings (15 and 20 phr) of Cab-O-Sil. The results, shown in Table 36, suggest that poly-FBA is very sensitive to the amount of Cab-O-Sil used. The compounds containing lower amounts of Cab-O-Sil appeared to be undercured, although the amounts of triethylene tetramine used in these compounds produced tight cures when the loading was 25 phr. This behavior is the reverse of that expected, since greater amounts of acidic fillers (such as Cab-O-Sil) usually increase the demand for curatives.

Attempts to combine the best properties of furnace black and Cab-O-Sil by blending the two fillers are described in the next section.

Also shown in Table 36 are poly-FBA compounds in which Valron Estersil (formerly known as Du Pont Fine Silica) was used as the filler. Du Pont literature states that the organic coating of this silica can be decomposed and driven off by heating. Since it was thought that this surface coating might be harmful to the rubber composition, a quantity of Valron was heated in a circulating-air oven to remove this surface coating. However, after prolonged heating at 325 F, it was found that the weight loss obtained corresponded to only about one-half of the surface coating. The preheated silica and the silica as it is obtained from the manufacturer were compared as fillers for poly-FBA. The physical properties of both types of silica-containing compounds were very poor after they were aged in Turbo Oil-15.

The Effects of Cab-O-Sil - Philblack O Blenas on the Properties of Poly-FBA Compounds. The Cab-O-Sil-filled poly-FBA compounds described in an earlier report displayed better retention of physical properties and were superior in general to furnace black-filled compounds. The latter type, however, had better elongation, both before and after aging, than did Cab-O-Sil-filled compounds of the same hardness. The results for a series of compounds in which several blends of Cab-O-Sil and Philblack O were used are shown in Table 37. The physical properties shown are among the best obtained at Battelle for poly-FBA. Apparently, a fairly high level of curative is necessary to produce the optimum physical properties.

The Effect of Aging Temperature on Poly-FBA Compounds. Several of the poly-FBA compounds that performed well at 350 F also were aged at 400 F. Recipes FBA-68 and FBA-69, shown in Table 38, are repeats of Recipes FBA-61 and FBA-63. Although degradation occurred about twice as fast at 400 F, the poly-FBA compounds performed fairly well.

Compression Set of Poly-FBA Compounds. The compression sets of several poly-FBA compounds are shown in Table 39. For the test conditions used, 168 hours in Turbo Oil-15 at 350 F, all the compounds showed high compression set. It is evident, however, that Cab-O-Sil produced better (lower) set than did carbon black. This is not in agreement with reports by other laboratories for milder test conditions (70 hours at 250 F), which indicated that carbon black was better than Cab-O-Sil in this regard.

SUMMARY

The purpose of this research was to develop rubber compositions that would be suitable for use at 400 F (1) in silicate-ester-type hydraulic fluids (OS-45, MLO-8200, and a blend of MLO-8200 and DOS), and (2) in synthetic diester-type lubricants (Turbo Oil-15). Considerable progress was made in the compounding of rubbers for both of these applications, though none of the compositions developed maintained the WADC target properties at 400 F for the 500-hour period.

Neoprene WRT compositions were the most promising in the hydraulic fluids for aging periods up to 168 hours. However, for aging periods up to 500 hours, compositions of Acrylon BA-12 were superior to those of Neoprene WRT. Initial tests also indicated potential promise for compositions of Philprene VP-A. In the testing of all the polymers, OS-45 fluid was found to degrade the rubber more than MLO-8200 fluid or the blend containing MLO-8200.

Poly-FBA compositions continue to be the most promising for use in Turbo Oil-15. The best commercially available polymer for the latter fluid, however, was Hycar 4021. Its performance, however, fell off much more than did that of poly-FBA when the aging temperature was advanced from 350 to 400 F.

For clarity, each of the two programs will be discussed separately in this section.

Hydraulic-Fluid Program

Compounding Studies With Neoprene WRT

At the beginning of this program, information on prior work with the silicate-ester hydraulic fluids was supplied by WADC. Although the background material indicated that the best rubber compositions that had been developed were compounds of Neoprene WRT, these remained serviceable for only short periods. An immediate approach to the problem, therefore, was to try to extend the service life of neoprene compounds.

During the program at Battelle, two types of Neoprene WRT compounds have been developed which appear to offer advantages over the best compound

(26-C, WADC TR 54-458, December, 1954) developed at the Materials Laboratory, WADC. They are:

(1) Compositions containing 60 to 80 parts of zinc oxide and small amounts of carbon black

(2) Compositions containing nonblack materials as fillers.

Although the tensile strengths of the above compositions were usually inferior to those of the 26-C compound, they were superior in the retention of rubberlike properties after aging. Neoprene WRT compositions containing silica and silicate-type fillers were particularly promising. In the latter part of the program, considerable effort was directed toward improving the tensile strength of this type of compound. Recipe N-101, shown in Table 40, was one of the last compounds evaluated. It shows improvement over the earlier compositions shown in the same table. Although the gains made appear slight, they must be considered significant, since they occurred in the most critical of the aged physical properties, i.e., tensile strength and elongation.

Other studies with Neoprene WRT have dealt with (1) the evaluation of different types of carbon black as fillers, (2) the effects of varying the magnesia content, (3) the investigation of filler blends, and (4) an evaluation of accelerators other than NA-22. The results indicated that, although fine thermal black is probably the best carbon black filler, it is considerably inferior to nonblack materials. The magnesia content appears to be critical only when the magnesia and total oxide concentrations are very low. No advantage was found for the blending of black and nonblack fillers. None of the materials evaluated in a limited accelerator study provided as good aging stability as NA-22.

Studies With Hycar 1014

The best Hycar 1014 stock prepared on this program (Recipe A-385) is shown in Table 40. This was a Hi-Sil-filled composition vulcanized with 0.5 phr sulfur and 0.25 phr tetramethylthiuram disulfide (TMTD). This stock was found to be satisfactory for 72 hours' aging at 400 F, but became very hard and lost elongation as the aging period was extended.

Philblack A, Silene EF, Cab-O-Sil, ELC magnesia, Calcene NC, and dixie clay were evaluated as fillers, but none of these gave vulcanizates with a balance of properties equal to those obtained with Hi-Sil.

Several additives were evaluated in ELC magnesia stocks in an effort to retard hardening and cross-linking during aging. Selenium dioxide and Tenamene 2 were partially effective, but all others were ineffective.

The ratio of stearic acid, sulfur, and TMTD in the vulcanizing system of ELC magnesia-filled stocks was found to have considerable effect on the unaged tensile strength. However, this did not carry over to the aged properties.

Vulcanization with dinitrobenzene produced stocks with very low elongation and high hardness after aging, indicating that a high degree of cross-linking occurred during aging.

Blends of Hycar 1014 and Philprene VP-25 were found to have no advantage over Hycar 1014 alone.

Studies With Philprene VP-25

The best Philprene VP-25 stock prepared on this program (VP-36) was superior to the best Hycar 1014 stock in several respects, as is shown by the data in Table 40. The outstanding advantage of the Philprene VP-25 stock was that it had an unaged brittle point of <-71 F, even without a plasticizer. After aging 336 hours, this stock still was considerably better than any of the Hycar 1014 stocks. Cab-O-Sil was found to give much better properties than Philblack A or Silene EF. A quaternizing agent (benzal chloride or benzotrichloride) was needed to obtain satisfactory aging properties.

Studies With Acrylon BA-12

The outstanding property of Acrylon BA-12 stocks is their ability to withstand prolonged aging (336 or 500 hours) at 400 F without hardening or cracking. This polymer is potentially the most interesting one studied on this program. Although work with this polymer was done late on this program and was therefore limited, a composition was developed (PA-300, shown in Table 40) that showed considerable promise. This composition fell short of the target specifications only because of a -53 F brittle point and low tensile strength. Additional experimental work with this polymer would doubtless improve both these properties.

Studies With Miscellaneous Polymers

Studies with Hycar 1072 indicated no promise for this polymer because it hardened excessively during aging. The aged tensile strengths obtained with this polymer, however, were the highest obtained with any polymer tested (2000 to 3000 psi).

Limited work with Kel-F Elastomer indicated little promise for this polymer. The choice of vulcanizing system is apparently quite important, as an amine-type curing system apparently liberated a very corrosive reaction product during aging. Better aging properties were obtained when using a peroxide-type cure.

Butyl-rubber vulcanizates disintegrated during aging.

Preliminary work with Philprene VP-A was encouraging. Although only two stocks were made with this polymer (Recipes VP-37 and VP-38), the data in Table 40 for limited aging tests indicate that these were among the best stocks prepared on the entire program.

Turbo Oil-15 Program

Studies With Nitrile-Type Rubber

Limited additional work with butadiene-acrylonitrile-type rubber has continued to be aimed at reducing surface hardening during aging in hot Turbo Oil-15. Although past work with nitrile rubber resulted in improved physical properties after aging, the gains made toward the reduction of surface hardening and cracking were very slight.

Earlier experiments with thiomalic acid and mercaptobenzimidazole showed that they retard and invert cure, respectively. It was felt that these materials might protect the rubber surface more efficiently if they were also added to the Turbo Oil-15. Thus, magnesia-filled compounds were used for a series of experiments in which thiomalic acid or mercaptobenzimidazole was added to the Turbo Oil-15, to the rubber, and to both the oil and the rubber. No significant improvement in crack resistance was observed.

U. S. Patent 2,678,892 describes simple methods for improving ozone and age resistance of finished rubber articles by surface hydrogenation. A magnesia-filled and a black-filled vulcanized composition of Hycar 1001 were exposed to hydrogen under conditions suggested by the patent. The effects of such treatment on the aging of the rubber in Turbo Oil-15 ranged from slightly to markedly detrimental. Although in no case were the physical properties improved, there still remains the possibility that hydrogenation of the raw polymer would produce an oxidation-resistant material with the desired properties.

Earlier experiments showed that Hycar 1041 was improved to a greater extent by the use of additives (i.e., antioxidants) than was Hycar 1001. During the present report period, Thiokol ZL-190 and Ionol (ditertiary-butyl para-cresol) were evaluated as additives for both these rubbers. Not only did the additives fail to reduce cracking, but Thiokol ZL-190 was found actually to degrade the rubber's physical properties.

Two of the best nitrile rubber compositions are shown in Table 41. Although physical properties were improved during this program, the gains made toward the elimination of surface cracking were very slight. All Hycar 1001 compounds were aged in Turbo Oil-15 at only 350 F.

Studies With Hycar 4021

Advancing the aging temperature from 350 to 400 F increased the severity of aging. For example, the tensile strength of samples aged at 400 F was approximately one-half that of those aged at 350 F. The swell of rubber aged for 500 hours at 400 F was at least 55 per cent, which is almost 20 per cent greater than at 350 F.

The composition giving the best properties after aging at 400 F was a Silene EF-filled stock containing 20 phr DPR N-27. Results on this stock are shown in Table 41.

The optimum ratio of vulcanizing agents for Silene EF-filled stocks aged at 400 F was found to be 1.0 phr TETA, 0.5 phr sulfur, and 2.0 phr TMTD.

DPR N-27 and Hycar 4001X11 were found to offer some advantage as nonextractable plasticizers when Hycar 4021 was aged at 350 F, and considerable advantage when this polymer was aged at 400 F. For samples aged at 400 F, these plasticizers markedly decreased both cracking and hardness (10 to 20 durometer units).

Thermal blacks were unsatisfactory as fillers because they apparently promoted hardening of the stock during prolonged aging. AgeRite Resin D was found to be ineffective as an antioxidant at 400 F.

Studies With Acrylon EA-5

Past work showed that this acrylate-type polymer had outstanding resistance to swell, but consistently cracked after 500 hours' aging. Additional studies were made with two fillers, Calcene NC and Valron Estersil, to try to eliminate this cracking. AgeRite Resin D was evaluated as an antioxidant. None of these materials were successful in reducing or eliminating cracking after prolonged aging.

Compounding of Poly-FBA

Valron Estersil (formerly Du Pont Fine Silica) was examined as a filler for poly-FBA. For comparison, a portion of this silica was heated in an oven at 325 F in an attempt to drive off its organic coating. A check of the weight loss on the oven-treated material indicated that only about half of the coating had been removed. Neither the preheated material nor the material as it is obtained from the manufacturer proved to be a desirable filler for poly-FBA. It is possible that Valron Estersil with no organic coating might produce more desirable results.

Earlier experiments with Cab-O-Sil and furnace black as individual fillers for poly-FBA showed that Cab-O-Sil gave better retention of tensile strength, but Philblack O gave higher elongation. Several poly-FBA compounds loaded with blends of Cab-O-Sil and Philblack have shown considerably improved physical properties. Increased curative in this type of compound produced the best poly-FBA compositions found to date.

Several of the best poly-FBA compounds were aged at 400 F, and the results were compared with earlier data obtained at 350 F. Although degradation was more severe at the higher temperature, rubber-like properties were not completely lost, even after 500 hours' aging.

The compression set of poly-FBA compounds after 168 hours in Turbo Oil-15 at 350 F has been found to be very poor. Other laboratories report that black fillers give the best compression set for milder test conditions (70 hours at 250 F). However, the work at Battelle indicates that, at high temperatures, Cab-O-Sil may provide better compression set than furnace black.

Several of the best poly-FBA compositions found during this program are shown in Table 41, together with results obtained for aging these compositions at 350 F and 400 F.

RECOMMENDED FUTURE WORK

The results of the work in this report indicate that the cracking of rubber specimens, when given an 180-degree bend test following hot-oil aging, is just as serious for rubber aged in hydraulic fluid as it has been for rubber aged in lubricating fluid (Turbo Oil-15). This occurs despite the use of sealed caps on test tubes for aging rubber in hydraulic oil. Earlier tests with closed tubes for aging rubber in Turbo Oil-15 had indicated that denying access of air eliminated or reduced cracking of the rubber. In aircraft lubricating systems, of course, excess air is encountered, and the procedure followed in the testing of rubber for this application therefore has permitted free access to air. Thus, it had been anticipated that, in simulating closed hydraulic systems by using closed tubes, the cracking problem would be much less severe. Such has not been the case.

Though aging of rubber on the hydraulic-fluid phase of this program has not been in evacuated tubes, a limited study of preheating the fluid prior to adding specimens to flush out air did not reduce the severity of the cracking problem. This would imply that totally eliminating air probably would not totally eliminate the hardening and cracking problem. It would be interesting, of course, to resolve the academic question as to whether air, directly or indirectly, is responsible for cracking. Previous experience at Battelle and elsewhere has indicated that free radicals might be contributing to the situation by promoting cross-linking-type reactions. Free radicals could be generated by oxidation reactions involving air, but could also be formed by thermally induced chemical changes within the fluid or the rubber. The loss of elongation, which is one of the basic reasons for cracking when a specimen is bent, is doubtless due to both cross-linking and chain scission. Loss in tensile strength is evidence that chain scission occurs in many of the samples aged.

A review of the data on types of rubber that are susceptible to cracking indicates that saturated-type polymers should be preferred for contact with fluids used both in hydraulic and lubricating systems. Thus, at 400 F there is only a remote possibility that unsaturated-type polymers, such as nitrile rubber, could be compounded to endure 500 hours' aging in oil without cracking. Unsaturated polymers having more than usual resistance to cracking appear in the case of (1) Neoprene WRT, which is much more oxidation resistant than butadiene-containing polymers, and (2) Philprene VP-A, a terpolymer containing butadiene, vinyl pyridine, and acrylonitrile.

Hydraulic-Fluid Program

Neoprene WRT

The work done with Neoprene WRT during the program showed that crack resistance for 168 hours was attained only by a judicious choice of fillers and curing agents. Longer aging tests were not made with this rubber, but it is not considered likely that perfect crack resistance can be extended to the 500-hour mark. However, further compounding studies, along the line already followed, should produce a compound with better aged physical properties.

Acrylon BA-12 and Philprene VP-A

Work with both these polymers was initiated late in the present program and was therefore limited. Acrylon BA-12, a saturated copolymer of butyl acrylate and acrylonitrile, maintained excellent flexibility during 500 hours' aging. It did not harden, crack, or lose elongation. It was deficient, however, in tensile strength, both before and after aging. In view of the exceptionally high elongation of this rubber, it should be possible to reinforce it with either fillers or fiber material, without serious loss in rubberlike properties. A basic study of the mechanism by which this polymer "vulcanizes" might also lead to further strengthening of the rubber produced from this polymer.

Compounds of Philprene VP-A were equivalent in many ways to those of Neoprene WRT, but might prove to be more crack resistant. Further studies with fillers, vulcanizing agents, and quaternizing agents should further enhance its present performance.

In addition to suggested further compounding studies with both these polymers, it is recommended that polymerization studies be made to obtain structural modifications of these polymers. Polymerization studies, of course, should be accompanied by compounding studies on the products obtained to develop their optimum potential performance.

Turbo Oil-15 Program

Hycar 4021

Work to date with Hycar 4021 at 400 F indicates that a swell of at least 55 per cent can be expected after 500 hours' aging. On the basis of considerable experience with this polymer, it is believed that any future decrease in swell will be marginal. Therefore, it is felt that no future work is justified with this rubber.

Poly-FBA

Although work to date has shown that poly-FBA is the best of the polymers evaluated for use in Turbo Oil-15 at 400 F, the work at Battelle was all done on mill batches containing only 25 grams of this polymer, with the total research being done on less than 5 pounds of polymer. It is possible that larger batches of this rubber would not produce the same results. It likewise is possible that, when larger amounts of this polymer are made, the polymer might differ from that used during the investigation at Battelle. Although further compounding research might produce some improvements in performance, it is suggested that such research be deferred until larger laboratory batches can be used. Some assurance should also be sought that the polymer is being produced on a reproducible production basis.

APPENDIX I

EXHIBIT "C" TO CONTRACT AF 33(616)-476, SUPPLEMENTAL AGREEMENT S4(55-935)

I. GENERAL DESCRIPTION

A. History

To date effort has been directed toward the development of a rubber compound for use with Specification MIL-L-7808B diester type synthetic engine oils. Compounds have been developed which meet the objective aged physical properties, except for surface cracking on 180° bend. Further efforts directed specifically toward elimination of surface cracking so far have been unsuccessful.

B. Abstract

1. Emphasis is to be shifted to the development of a high-temperature oil-resistant rubber compound for service in experimental silicate ester hydraulic oils at elevated temperatures. It should be noted that this will not involve any basic change in scope of the work, techniques, facilities, or other aspects, but only involves a change in the type of oil used for high-temperature exposure. Effort toward development of a compound for engine oils shall not be completely discontinued but greatly reduced.

II. DETAILED TECHNICAL REQUIREMENTS

A. The high temperatures of operation anticipated in the hydraulic systems of supersonic and pilotless aircraft necessitate the development of a rubber compound which can be fabricated into hose, seals, gaskets, etc., and which will function satisfactorily over the required period of contact with experimental silicate-ester-type oils at elevated temperatures. Known work to date has resulted in compounds exhibiting reasonable rubberlike characteristics for periods of only 168 hours under laboratory test conditions. Compounds should therefore be developed with an eye toward acceptable physical properties after long time aging and not with emphasis on optimum original properties. Suggested approaches to the problem may include but shall not be limited to the following:

1. Evaluation of commercially available polymers, especially Neoprene, and blends.

2. Study of curing systems for high-temperature polymers.

3. Compounding and evaluation of commercially developed experimental polymers, and blends thereof.

4. Compounding and evaluation of Government-furnished experimental polymers.

5. A short investigation of anti-oxidant effectiveness at 400 F.

B. Desired properties and test methods are as follows:

1. The primary objective is the development of a rubber which will retain satisfactory physical properties after use in experimental silicate ester hydraulic oils for 500-1000 hours at 400 F.

2. Test fluids for this work will include MLO 8200, OS-45 and other fluids as designated by the Materials Laboratory, Wright Air Development Center.

3. As a secondary objective, work may continued on the development of a rubber for 500-1000 hours in MIL-L-7808-type fluids at 400 F if promising approaches are agreed upon by the Contractor and the Materials Laboratory.

4. Objective properties for compounds to be used in silicate ester hydraulic oils are as follows:

Original Properties

Tensile	1500 psi min
Elongation	200% min
Shore "A"	60-80
Low Temp Flexibility	-65 F

Properties at End of 400 F Immersion Period

Tensile	800 psi min
Elongation	100% min
Shore "A"	60-85
Volume Change	+5 to +30%
Low Temp Flexibility	-65 F

5. Objective properties for compounds to be used in synthetic lubricants are as follows:

Original Properties

Tensile	1200 psi min
Elongation	250% min
Shore "A"	55-80

The ultimate low temperature requirement shall be -65 F but in interim compounds the "as determined" value is acceptable.

Properties After Oil Immersion for 500-1000 Hours at 400 F

Tensile	800 psi min
Elongation	100% min
Shore "A"	60-85
Volume Change	+5 to +30 %

Appearance - no evidence of checking or crazing after 180-degree flat bend.

6. Additional specifications concerning test methods, where required, shall be as directed by the Materials Laboratory, Wright Air Development Center.

APPENDIX II
ILLUSTRATIONS AND TABLES

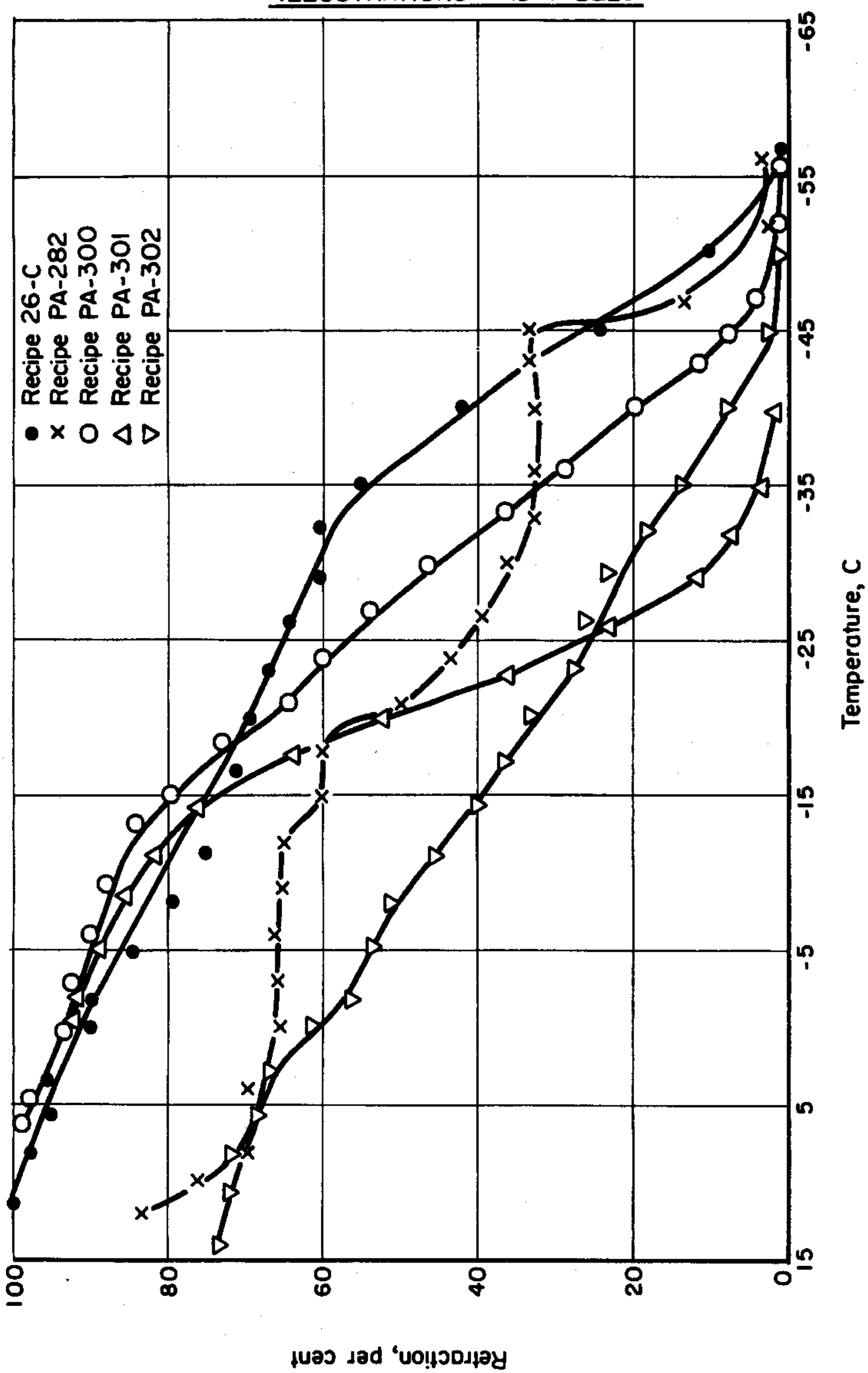

FIGURE I. TEMPERATURE-RETRACTION-TEST DATA ON ACRYLATE POLYMERS

A-15452

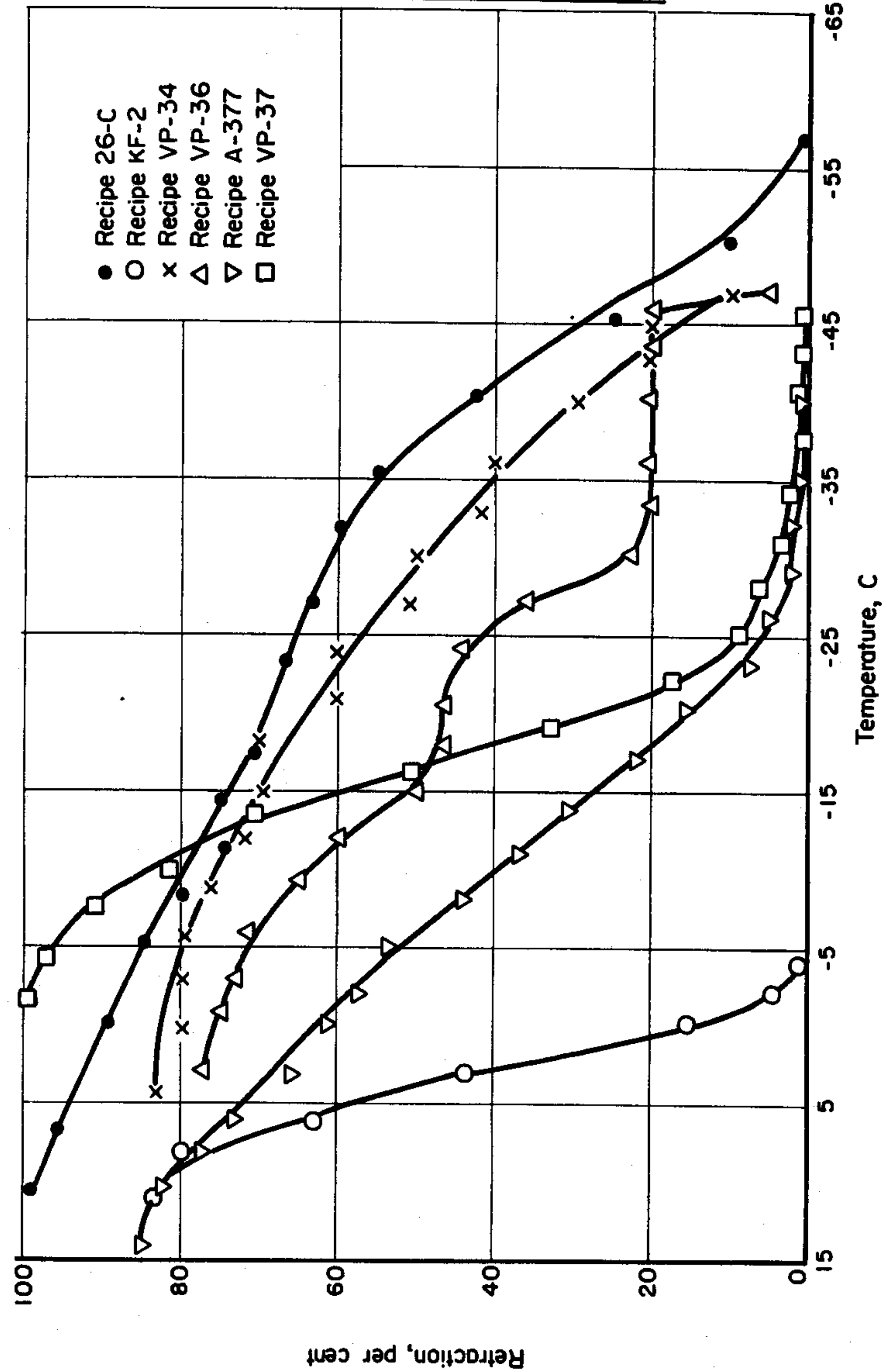

FIGURE 2. TEMPERATURE-RETRACTION-TEST DATA ON MISCELLANEOUS POLYMERS

A-15453

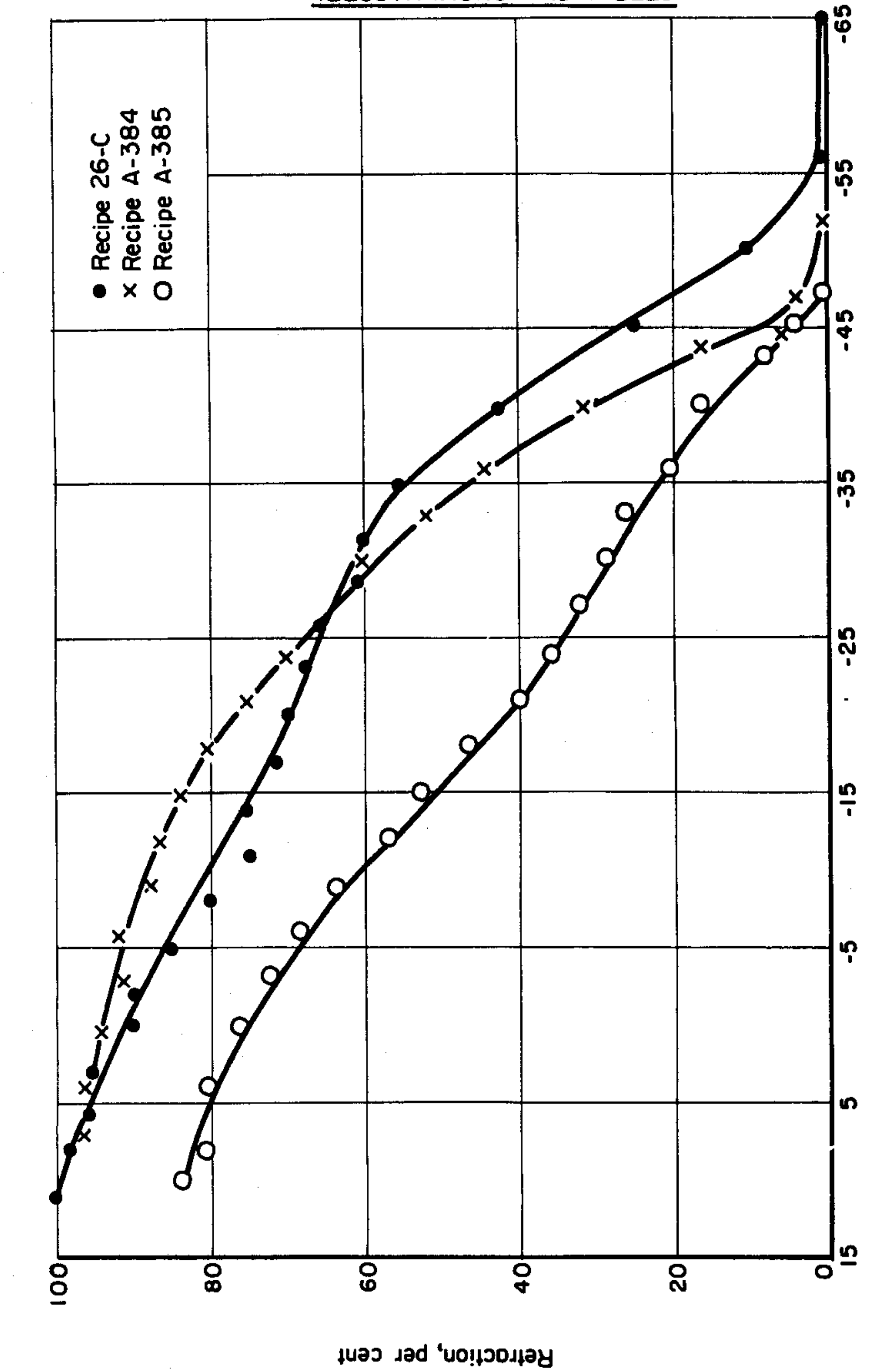

FIGURE 3. TEMPERATURE-RETRACTION-TEST DATA ON NITRILE POLYMERS

A-15454

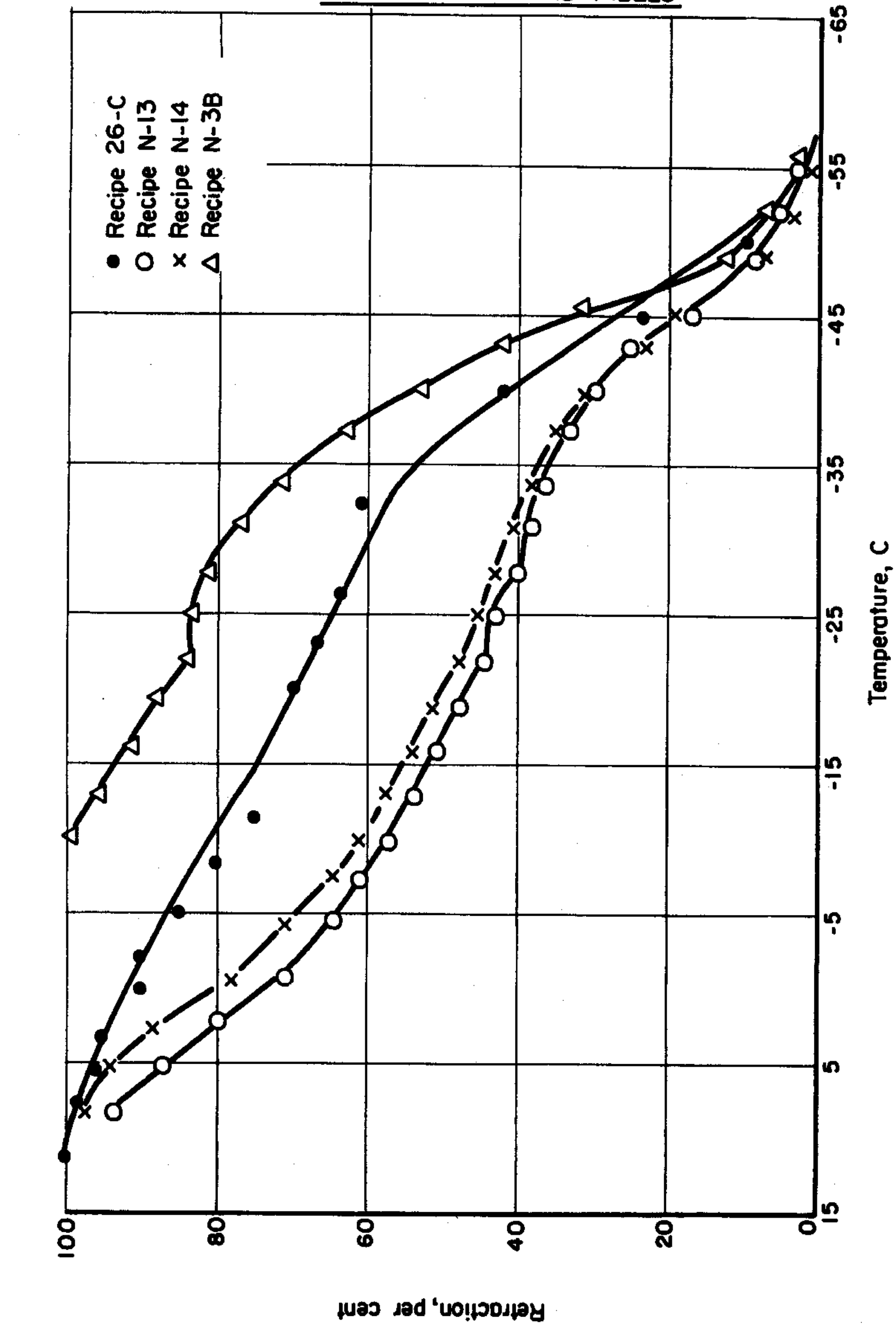

FIGURE 4. TEMPERATURE-RETRACTION-TEST DATA ON NEOPRENE POLYMERS

A-15455

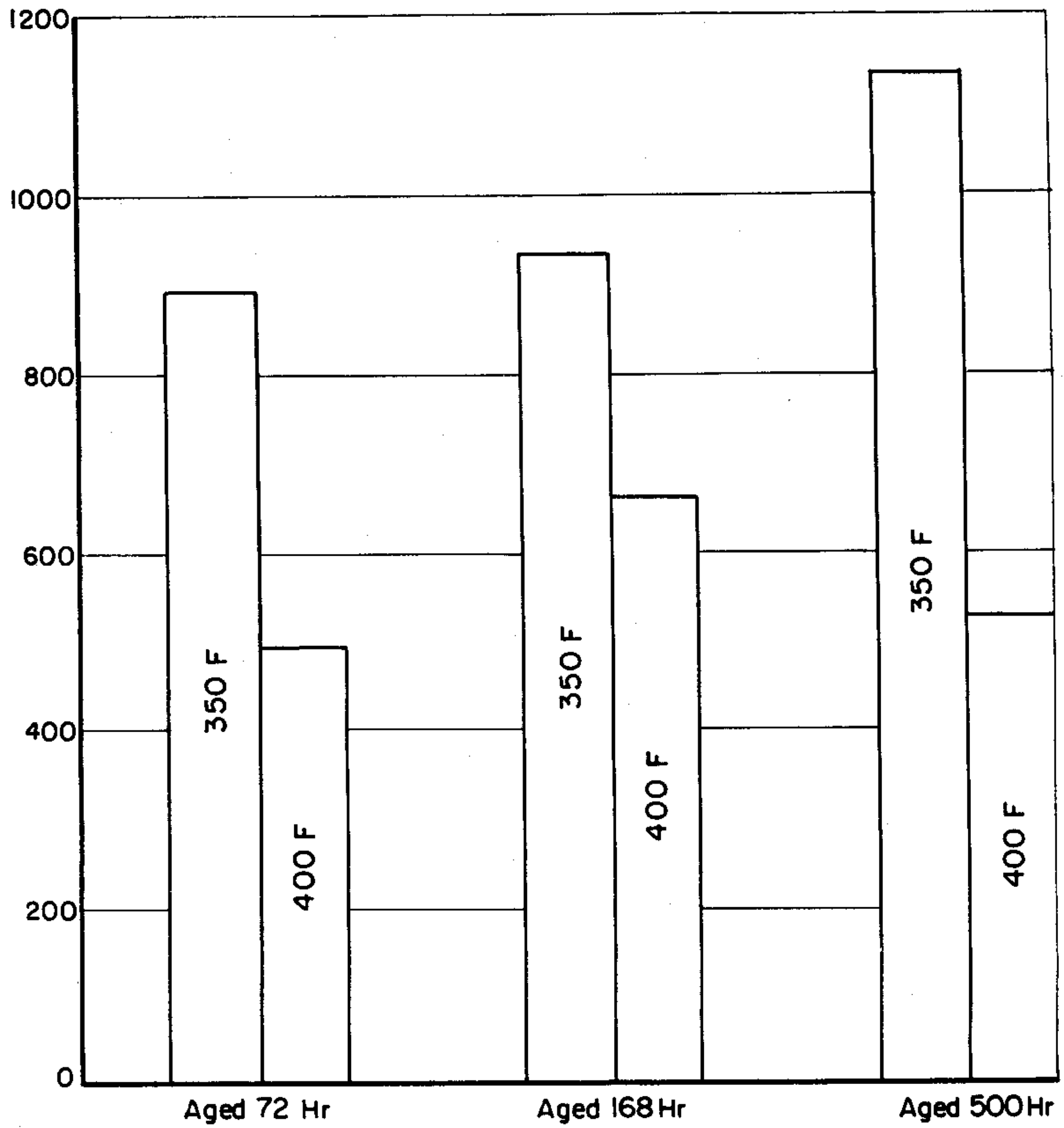

FIGURE 5. EFFECT OF TEMPERATURE ON TENSILE STRENGTH OF SILENE EF-FILLED HYCAR 4021 STOCKS AGED IN TURBO OIL-15

A-13456

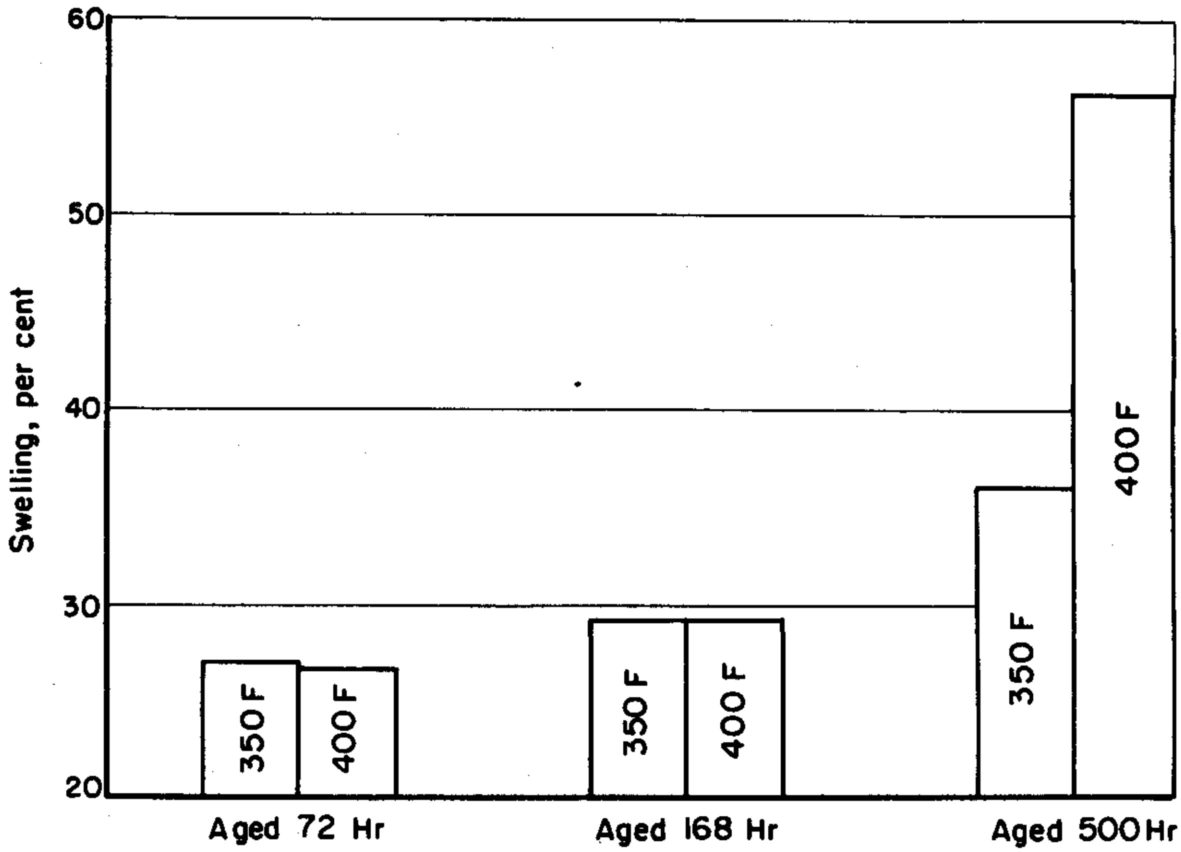

FIGURE 6. EFFECT OF TEMPERATURE ON SWELLING OF SILENE EF-FILLED HYCAR 4021 STOCKS AGED IN TURBO OIL-15

A-15457

TABLE 1. PRELIMINARY AGING STUDIES ON NEOPRENE WRT

		Original Physical Properties				Physical Properties After Aging in Hydraulic Fluids at 400 F														
						OS-45					MLO-8200/Monoplex DOS – 85/15					MLO-8200				
Recipe	ZnO, phr	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Aging Time, hours	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
N-2	5	2570	250	76	72	710	90	75	24.7	None	1130	130	72	22.8	None	1390	70	85	16.4	Cracked
					168	190	40	71	56.8	Cracked	260	40	79	61.7	Cracked	130	10	85	60.1	Cracked
N-3	2.5	1920	200	73	72	860	60	80	12.2	None	1290	110	75	10.7	None	1490	90	83	1.8	None
					168	870	30	91	12.3	Cracked	1390	30	92	16.8	Cracked	2290	10	99	23.2	Cracked
N-4	25	1470	330	64	72	910	80	86	–4.8	None	750	90	77	–2.5	None	2440	10	98	–10.8	Cracked
					168	1230	40	95	2.3	Cracked	940	50	88	3.0	Cracked	Very brittle				
N-5	1	2170	210	67	72	650	30	86	8.0	Cracked	960	70	81	8.4	None	960	40	88	1.4	Cracked
					168	1370	20	95	2.6	Cracked	1180	30	92	8.1	Cracked	2720	10	100	6.7	Cracked
					72 Vented(a)	760	30	83	5.9	Cracked	–	–	–	–	–	–	–	–	–	–
					168 Vented(a)	1310	20	94	3.2	Cracked	–	–	–	–	–	–	–	–	–	–
N-6	2	2390	230	69	72	720	50	80	7.2	Cracked	1540	110	75	10.9	None	1520	90	83	2.3	None
					168	1370	20	94	5.4	Cracked	3450	10	100	6.1	Cracked	1790	20	96	16.8	Cracked
					72 Vented(a)	750	60	81	8.4	Cracked	–	–	–	–	–	–	–	–	–	–
					168 Vented(a)	1450	20	94	3.9	Cracked	–	–	–	–	–	–	–	–	–	–
N-7	3	2260	220	68	72	610	50	80	11.4	Cracked	1420	120	75	11.5	None	1750	80	86	4.9	None
					168	1310	20	93	10.2	Cracked	2950	10	99	13.3	Cracked	2230	20	99	22.4	Cracked
					72 Vented(a)	880	70	80	9.0	Cracked	–	–	–	–	–	–	–	–	–	–
					168 Vented(a)	1390	30	91	8.1	Cracked	–	–	–	–	–	–	–	–	–	–
N-8	10	2220	220	69	72	870	60	81	9.2	Cracked	1310	100	77	12.0	None	2740	30	98	10.3	Cracked
					168	Partially disintegrated					540	40	82	65.7	Cracked	Partially disintegrated				
					72 Vented(a)	950	70	80	81	Cracked	–	–	–	–	–	–	–	–	–	–
					168 Vented(a)	210	30	77	65.3	Cracked	–	–	–	–	–	–	–	–	–	–
N-9	20	1950	210	70	72	1110	80	82	8.7	Cracked	1370	100	77	10.9	None	2430	50	97	1.5	Cracked
					168	1390	40	90	20.6	Cracked	1880	60	90	18.7	Cracked	Partially disintegrated				
					72 Vented(a)	1300	80	81	7.0	Cracked	–	–	–	–	–	–	–	–	–	–
					168 Vented(a)	430	20	96	40.2	Cracked	–	–	–	–	–	–	–	–	–	–

Note:
Base recipe:

Ingredients	Parts by Weight N-2	N-4	All Others
Neoprene WRT	100	100	100
Magnesia ELC	2	4	4
Continex SRF	–	40	40
Thermax	80	40	40
Neozone A	2	3	–
Neozone D	–	2	–
Butyl oleate	–	–	15
Monoplex DOS	–	30	–
Zinc oxide	As shown		
NA-22	0.35	0.5	1.0

Cure: 30 minutes at 310 F.

(a) Hydraulic fluid was allowed to heat in the aluminum block for 1 hour before the samples were immersed and the tubes sealed.

TABLE 2. THE EFFECT OF VARYING THE ZINC OXIDE CONTENT ON THE AGING OF NEOPRENE WRT

					Original Physical Properties				Physical Properties After Aging in Hydraulic Fluids at 400 F														
									OS-45					85/15-MLO-8200/Monoplex DOS					MLO-8200				
Recipe	ZnO, phr	Carbon Black, phr SRF	Carbon Black, phr Thermax	Carbon Black, phr P-33	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Aging Time, hours	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
N-20	0	40	40	–	1690	330	60	72	600	40	84	4.1	Cracked	1360	80	82	5.5	Cracked	1230	50	89	–2.8	Cracked
								168	670	30	93	2.4	Cracked	1040	30	91	5.6	Cracked	1240	20	97	0.5	Cracked
N-21	2	40	40	–	2170	220	71	72	780	70	80	9.7	None	890	80	77	8.0	None	1210	80	85	–0.4	None
								168	730	50	85	11.3	Cracked	1930	40	97	4.2	Cracked	1120	30	96	12.8	Cracked
N-22	3	40	40	–	1810	200	72	72	730	70	80	8.1	None	750	80	77	8.7	None	1000	80	85	–0.8	Cracked
								168	550	40	85	21.4	Cracked	1280	30	94	21.5	Cracked	8350	0	100	–2.7	Cracked
N-23	5	40	40	–	1900	200	72	72	730	70	77	6.5	None	790	80	75	8.0	None	1120	70	85	–0.8	Cracked
								168	330	40	85	40.4	Cracked	420	40	80	37.9	Cracked	310	20	87	–9.3	Cracked
N-24	10	40	40	–	1810	200	72	72	810	80	79	6.2	None	880	80	76	7.7	None	1170	80	85	–0.9	Cracked
								168	650	40	90	25.7	Cracked	230	30	80	13.5	Cracked	Cap blew off test tube				
N-25	20	40	40	–	1850	200	74	72	750	70	80	5.7	None	820	70	76	7.4	Cracked	1010	60	87	–0.8	Cracked
								168	810	40	92	6.9	Cracked	950	50	88	13.9	Cracked	Cap blew off test tube				
N-26	30	40	40	–	1840	200	74	72	760	70	81	4.6	Cracked	930	80	79	7.6	Cracked	1090	60	87	–1.5	Cracked
								168	890	40	91	4.7	Cracked	890	50	90	12.4	Cracked	910	0	100	Very brittle	
N-76	40	40	40	–	1790	210	73	72	990	90	82	5.4	None	980	80	81	9.0	None	1590	70	92	1.2	Cracked
								168	1390	60	92	4.9	Cracked	1320	50	94	14.7	Cracked	5130	10	100+	8.8	Cracked
N-77	60	40	40	–	1610	200	76	72	1350	70	90	6.8	Cracked	1370	60	92	13.4	Cracked	3650	20	100+	6.2	Cracked
								168	1260	20	99	16.4	Cracked	2290	20	99	27.6	Cracked	Cap blew off test tube				
N-78	80	40	40	–	1570	180	79	72	1630	60	93	8.5	Cracked	1510	60	93	13.0	Cracked	4860	10	100+	6.1	Cracked
								168	1590	10	99	20.9	Cracked	2630	20	100	27.1	Cracked	Too brittle to be tested				
N-79	100	40	40	–	1410	180	82	72	1710	60	95	8.5	Cracked	1450	60	94	11.7	Cracked	4380	10	100+	4.7	Cracked
								168	1570	10	99	15.3	Cracked	2280	20	99	24.0	Cracked	2000	0	100+	15.9	Cracked
N-5[a]	1	40	40	–	2170	210	67	72	650	30	86	8.0	Cracked	960	70	81	8.4	None	960	40	88	1.4	Cracked
								168	1370	20	95	2.6	Cracked	1180	30	92	8.1	Cracked	2720	10	100	6.7	Cracked
N-6[a]	2	40	40	–	2390	230	69	72	720	50	80	7.2	Cracked	1540	110	75	10.9	None	1520	90	83	2.3	None
								168	1370	20	94	5.4	Cracked	3450	10	100	6.1	Cracked	1790	20	96	16.8	Cracked
N-7[a]	3	40	40	–	2260	220	68	72	610	50	80	11.4	Cracked	1420	120	75	11.5	None	1750	80	86	4.9	None
								168	1310	20	93	10.2	Cracked	2950	10	99	13.3	Cracked	2230	20	99	22.4	Cracked
N-8[a]	10	40	40	–	2220	220	69	72	870	60	81	9.2	Cracked	1310	100	77	12.0	None	2740	30	98	10.3	Cracked
								168	Partially disintegrated					540	40	82	65.7	Cracked	Partially disintegrated				
N-9[a]	20	40	40	–	1950	210	70	72	1110	80	82	8.7	Cracked	1370	100	77	10.9	None	2430	50	97	1.5	Cracked
								168	1390	40	90	20.6	Cracked	1880	60	80	18.7	Cracked	Partially disintegrated				

TABLE 2. (Continued)

Recipe	ZnO, phr	Carbon Black, phr SRF	Carbon Black, phr Thermax	P-33	Original Physical Properties Tensile Strength, psi	Original Elongation, %	Original Hardness, Shore A	Aging Time, hours	OS-45 Tensile Strength, psi	OS-45 Elongation, %	OS-45 Hardness, Shore A	OS-45 Swell, %	OS-45 Cracking	85/15-MLO-8200/Monoplex DOS Tensile Strength, psi	85/15 Elongation, %	85/15 Hardness, Shore A	85/15 Swell, %	85/15 Cracking	MLO-8200 Tensile Strength, psi	MLO-8200 Elongation, %	MLO-8200 Hardness, Shore A	MLO-8200 Swell, %	MLO-8200 Cracking
N-80[a]	40	40	40	–	1690	210	74	72	1270	60	90	7.9	Cracked	1310	50	93	14.5	Cracked	5830	10	100+	6.5	Cracked
								168	1530	20	98	20.6	Cracked	2570	20	99	27.4	Cracked	Cap blew off test tube				
N-81[a]	60	40	40	–	1680	200	77	72	1980	60	95	11.5	Cracked	1310	50	92	13.5	Cracked	5710	10	100+	5.5	Cracked
								168	1510	10	99	20.8	Cracked	2790	20	100	31.2	Cracked	1520	0	100+	15.0	Cracked
N-82[a]	80	40	40	–	1530	190	79	92	1390	70	92	6.9	Cracked	1250	60	92	10.2	Cracked	3490	20	100+	3.4	Cracked
								168	1820	10	99	20.5	Cracked	1900	30	98	17.1	Cracked	1530	0	100+	18.6	Cracked
N-83[a]	100	40	40	–	1290	170	85	72	730	60	87	4.7	Cracked	1010	70	88	6.3	Cracked	1410	60	94	0.0	Cracked
								168	1390	50	95	6.0	Cracked	1500	40	97	13.8	Cracked	3550	10	100+	5.5	Cracked
N-32[a]	40	35	35	–	1950	250	71	72	1090	100	77	7.1	None	1180	240	70	0.7	None	2510	50	98	4.1	Cracked
								168	1430	60	87	6.0	Cracked	1560	70	87	18.2	Cracked	Fluid solidified				
N-33[a]	60	15	15	–	1540	300	69	72	720	120	70	6.1	None	1390	120	75	10.8	None	1450	140	79	–0.8	None
								168	810	80	81	4.0	Cracked	1160	90	81	15.1	Cracked	5310	10	100	16.2	Cracked
N-34[a]	80	15	15	–	1540	370	66	72	670	150	66	6.0	None	930	150	69	9.6	None	1670	140	79	–0.4	None
								168	930	90	82	3.5	Cracked	890	100	79	15.0	None	4630	10	100	15.9	Cracked
N-35[a]	100	0	0	–	1350	590	58	72	290	180	58	7.4	None	420	280	56	11.5	None	1180	240	70	0.7	None
								168	290	90	70	3.2	Cracked	600	120	72	20.1	None	3990	10	100	26.1	Cracked
N-73[a]	60	–	–	100	1350	240	77	72	970	70	86	6.0	Cracked	990	80	84	8.1	None	1420	50	95	0.7	Cracked
								168	1500	20	100	17.1	Cracked	2690	10	100+	29.2	Cracked	Too brittle to be tested				
N-74[a]	80	–	–	100	1280	230	80	72	950	70	86	6.0	Cracked	1070	80	87	8.2	Cracked	1560	50	96	2.0	Cracked
								168	1730	20	99	14.1	Cracked	2030	30	98	18.8	Cracked	2940	0	100+	13.7	Cracked
N-75[a]	100	–	–	100	1140	210	81	72	1210	70	91	5.5	Cracked	1080	70	89	9.2	Cracked	1590	70	92	1.2	Cracked
								168	1460	40	97	4.6	Cracked	1500	40	97	13.2	Cracked	4690	10	100+	4.8	Cracked

Note:

Base recipe:

Ingredients	Parts by Weight
Neoprene WRT	100
Magnesia ELC	4
Continex SRF	As shown
Thermax	As shown
Thermatomic P-33	As shown
Butyl oleate	15
Zinc oxide	As shown
NA-22	0.5

Cure: 30 minutes at 310 F.

(a) NA-22 was increased to 1.0 phr.

TABLE 3. THE EFFECTS OF CARBON BLACK AND ZINC OXIDE ON THE AGING OF NEOPRENE WRT

	Carbon Black		Original Physical Properties				Physical Properties After Aging in Hydraulic Fluids at 400 F: OS-45					85/15 MLO-8200/Monoplex DOS					MLO-8200				
Recipe	Name	Phr	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Aging Time, hours	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
N-15	Thermatomic P-33	110	1630	300	69	72	1270	90	80	8.0	None	1590	130	78	9.6	None	1830	100	88	1.0	None
						168	1610	40	93	9.3	Cracked	1610	70	90	7.5	Cracked	3630	10	100	16.4	Cracked
N-16	Continex SRF	80	2150	160	75	72	1000	60	82	9.7	Cracked	1480	90	81	10.4	None	1720	80	90	3.0	None
						168	1130	30	93	10.0	Cracked	2230	20	97	11.7	Cracked	1810	20	98	21.3	Cracked
N-17	Philblack O	60	2220	160	77	72	970	60	85	15.9	Cracked	1530	80	85	13.6	None	1450	60	93	4.7	Cracked
						168	1040	30	93	16.8	Cracked	1490	30	95	21.7	Cracked	1300	10	99	26.3	Cracked
N-18	Wyex EPC	60	2290	200	76	72	1090	60	86	11.5	Cracked	1450	90	85	11.1	None	1710	70	93	4.9	Cracked
						168	1490	30	95	12.9	Cracked	2680	20	99	17.9	Cracked	1830	10	99	22.2	Cracked
N-19	Kosmobile HPC	60	2540	240	75	72	1350	50	87	12.9	Cracked	1430	80	85	12.1	None	1610	60	93	6.6	Cracked
						168	1420	40	95	12.5	Cracked	1560	10	98	14.8	Cracked	1950	10	100	20.7	Cracked
N-65	Continex SRF	70	1800	160	82	72	1170	70	88	6.2	Cracked	1270	80	87	9.0	Cracked	2170	40	98	2.5	Cracked
						168	1750	10	100	22.6	Cracked	1720	20	99	24.9	Cracked	Cap blew off test tube				
N-69	Continex SRF	50	1660	220	73	72	1040	80	83	7.3	Cracked	930	100	77	10.2	None	1290	80	88	1.5	Cracked
						168	1170	10	97	18.5	Cracked	1590	30	98	30.7	Cracked	Cap blew off test tube				
N-66	Philblack O	50	1710	160	83	72	1510	60	92	8.3	Cracked	1120	60	90	11.3	Cracked	2660	30	100	1.4	Cracked
						168	1590	10	100	21.0	Cracked	2790	20	100	31.7	Cracked	1610	0	100	33.8	Cracked
N-70	Philblack O	30	1570	260	72	72	860	80	82	6.8	Cracked	800	100	78	9.7	None	980	70	87	0	Cracked
						168	1440	10	100	28.4	Cracked	1950	20	98	39.0	Cracked	2330	0	100	31.0	–
N-67	Wyex EPC	50	1770	210	76	72	1360	60	91	6.3	Cracked	1230	60	92	11.4	Cracked	1850	40	98	2.5	Cracked
						168	1650	40	97	4.5	Cracked	1740	40	97	16.9	Cracked	3770	10	100+	12.7	Cracked
N-71	Wyex EPC	30	1270	270	66	72	1010	90	82	5.9	None	930	100	80	11.3	None	1440	90	90	0.8	None
						168	1180	50	92	5.9	Cracked	1560	60	94	17.7	Cracked	2750	10	100+	17.8	Cracked
N-68	Kosmobile HPC	50	1500	200	80	72	1920	40	98	5.3	Cracked	1890	40	98	7.5	Cracked	3030	30	100+	0.7	Cracked
						168	1850	20	100	11.0	Cracked	2340	20	100	12.8	Cracked	3210	10	100+	10.3	Cracked
N-72	Kosmobile HPC	30	2030	370	62	72	1190	100	82	9.7	None	880	110	76	12.2	None	1530	90	91	5.3	None
						168	1250	60	91	9.3	Cracked	1280	70	89	19.6	Cracked	3950	10	100+	22.6	Cracked
N-74	Thermatomic P-33	100	1280	230	80	72	950	70	86	6.0	Cracked	1070	80	87	8.2	Cracked	1560	50	96	2.0	Cracked
						168	1730	20	99	14.1	Cracked	2030	30	98	18.8	Cracked	2940	0	100+	13.7	Cracked

Note:
Base recipe:

Ingredients	Parts by Weight: N-65 to N-74	Parts by Weight: N-15 to N-19
Neoprene WRT	100	100
Magnesia ELC	4	4
Filler	As shown	As shown
Butyl oleate	15	15
Zinc oxide	80	2.5
NA-22	1.0	1.0

Cure: 30 minutes at 310 F.

TABLE 4. THE EFFECTS OF VARYING THE MAGNESIA CONTENT ON THE AGING OF NEOPRENE WRT

			Original Physical Properties				Physical Properties After Aging in Hydraulic Fluids at 400 F														
							DS45					85/15 MLO-8200/Monoplex DOS					MLO-8200				
Recipe	Magnesia, phr	Zinc Oxide, phr	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Aging Time, hours	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
N-51	0	2.5	1570	380	69	72	860	70	83	2.7	Cracked	1430	90	81	2.3	None	1750	80	92	−3.4	Cracked
						168	990	20	97	1.2	Cracked	6200	0	100+	−3.8	Cracked	2870	0	100+	0.4	Cracked
N-52	2	2.5	1530	300	72	72	940	80	82	7.7	None	1590	130	77	7.6	None	1730	90	90	0	None
						168	1380	30	93	8.3	Cracked	4230	0	100+	7.8	Cracked	4730	0	100+	14.1	Cracked
N-53	6	2.5	1530	270	72	72	1220	80	86	7.7	Cracked	1360	110	81	7.1	None	1690	90	89	−0.7	None
						168	1340	50	92	11.4	Cracked	1470	60	90	14.2	Cracked	1490	30	95	16.5	Cracked
N-54	10	2.5	1660	230	75	72	1130	70	88	8.8	Cracked	1330	80	87	10.0	Cracked	1530	70	92	1.9	Cracked
						168	1670	40	95	13.6	Cracked	1930	40	98	11.0	Cracked	2030	40	98	10.4	Cracked
N-55	20	2.5	1670	260	74	72	1030	70	88	8.7	Cracked	1280	90	86	9.5	Cracked	1530	80	91	−0.2	Cracked
						168	1490	40	95	14.3	Cracked	1350	50	94	14.4	Cracked	1940	40	97	11.2	Cracked
N-56	30	2.5	1690	260	75	72	1190	80	89	8.5	Cracked	1390	90	88	10.1	None	1670	80	94	1.1	Cracked
						168	1790	40	98	15.6	Cracked	1780	60	97	15.1	Cracked	1830	50	97	10.5	Cracked
N-57	50	2.5	1730	330	72	72	920	60	91	9.3	Cracked	940	80	88	10.8	Cracked	1070	60	91	0.9	Cracked
						168	1510	40	98	15.8	Cracked	1650	40	99	15.9	Cracked	1450	40	97	10.1	Cracked
N-58	0	60	1530	490	62	72	410	120	71	4.6	None	710	170	65	6.3	None	950	120	79	−1.8	None
						168	600	60	88	5.4	Cracked	1050	70	85	14.4	Cracked	5070	0	100+	15.6	Cracked
N-59	2	60	1330	410	63	72	530	120	70	4.9	None	830	190	65	9.1	None	1540	140	81	0	None
						168	900	80	86	6.3	Cracked	1280	90	85	17.9	Cracked	5270	0	100+	12.9	Cracked
N-60	6	60	1460	430	65	72	590	130	71	6.3	None	550	130	69	10.8	None	1050	140	77	0.9	None
						168	1010	70	84	7.6	Cracked	1250	70	88	19.1	Cracked	4850	0	100+	19.9	Cracked
N-61	10	60	1370	390	67	72	670	130	70	6.0	None	790	160	70	10.1	None	1590	140	81	1.4	None
						168	790	80	82	4.9	Cracked	1310	90	86	17.3	Cracked	5680	0	100+	14.3	Cracked
N-62	20	60	1490	380	68	72	670	120	74	7.2	None	770	140	75	10.6	None	1050	130	80	0.7	None
						168	1350	70	88	6.1	Cracked	1210	80	88	17.4	Cracked	2890	10	100	13.7	Cracked
N-63	30	60	1570	370	70	72	790	120	76	8.0	None	840	150	76	10.3	None	1120	100	85	0.7	None
						168	1230	80	91	8.4	Cracked	1240	70	90	15.0	Cracked	3190	10	100+	15.2	Cracked
N-64	50	60	1540	440	71	72	710	130	75	10.1	None	790	180	75	12.5	None	930	120	83	2.2	None
						168	1160	90	90	10.5	None	1190	90	91	17.3	None	2390	10	100+	13.8	Cracked

Note:
Base recipes:

	Parts by Weight			
Ingredients	N-51 to N-56	N-57	N-58 to N-63	N-64
Neoprene WRT	100	100	100	100
Magnesia ELC	As shown	As shown	As shown	As shown
Thermatomic P-33	110	80	40	20
Butyl oleate	15	15	15	15
Zinc oxide	2.5	2.5	60	60
NA-22	1.0	1.0	1.0	1.0

Cure: 30 minutes at 310 F.

TABLE 5. THE EFFECTS OF SEVERAL ACCELERATORS ON THE AGING OF NEOPRENE WRT

				Original Physical Properties				Physical Properties After Aging in Hydraulic Fluids at 400 F														
								OS-45					85/15-MLO-8200/Monoplex DOS					MLO-8200				
Recipe	Accelerator Name	Accelerator Phr	ZnO, phr	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Aging Time, hours	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
N-15	NA-22	1.0	2.5	1630	300	69	72	1270	90	80	8.0	None	1590	130	78	9.6	None	1830	100	88	1.0	None
							168	1610	40	93	9.3	Cracked	1610	70	90	7.5	Cracked	3630	10	100	16.4	Cracked
N-36	Permalux	1.5	2.5	1030	390	69	72	970	80	82	10.4	Cracked	1300	80	86	18.3	Cracked	1410	40	97	25.3	Cracked
							168	960	40	92	10.6	Cracked	1620	30	97	19.5	Cracked	—	Brittle	100+	6.7	–
N-37	Pemalux	1.5	5	1110	350	70	72	990	60	89	11.3	Cracked	860	60	91	35.2	Cracked	Cap blew off tube				–
							168	440	40	85	24.1	Cracked	910	40	93	32.1	Cracked	Fluid solidified				–
N-38	Pemalux	2.0	2.5	1060	390	70	72	920	80	84	10.7	Cracked	1110	70	86	26.6	Cracked	1540	30	98	25.6	Cracked
							168	890	40	91	11.7	Cracked	1210	10	100+	30.8	Cracked	1340	0	100	26.7	Cracked
N-39	Pemalux	2.0	5	1070	380	70	72	990	70	88	10.0	Cracked	1190	70	89	24.7	Cracked	1840	20	98	21.7	Cracked
							168	500	40	86	19.8	Cracked	770	30	92	31.3	Cracked	Cap blew off tube				–
N-40	Retarder W	1.5	2.5	1420	490	63	72	1340	100	81	13.7	None	1250	120	75	19.7	None	1950	40	98	21.0	Cracked
							168	1230	50	89	11.7	Cracked	2040	30	96	18.6	Cracked	1750	30	97	26.1	Cracked
N-41	Retarder W	1.5	5	1450	490	63	72	1680	110	85	8.5	None	2030	130	80	13.8	None	1640	30	98	29.3	Cracked
							168	1010	60	85	15.3	Cracked	870	40	83	37.5	Cracked	1660	0	100	17.0	Cracked
N-42	Retarder W	2	2.5	1410	510	65	72	1070	100	81	13.5	None	1330	130	72	17.7	None	1640	30	98	18.3	Cracked
							168	1170	40	89	10.2	Cracked	3470	10	100	12.5	Cracked	2780	10	100	21.8	Cracked
N-43	Retarder W	2	5	1390	500	65	72	1770	120	83	10.7	None	1980	140	80	10.8	None	1200	30	94	28.9	Cracked
							168	560	50	79	27.1	Cracked	760	50	76	36.5	Cracked	1770	10	99	29.5	Cracked
N-48	TEPA(a)	1.5	0	1830	240	75	72	1070	40	93	5.4	Cracked	1070	50	89	6.6	Cracked	1560	50	94	–1.8	Cracked
							168	1190	20	97	6.2	Cracked	1510	10	97	7.1	Cracked	1580	30	97	5.1	Cracked
N-49	TEPA	1.5	2.5	1750	290	70	72	1190	70	90	7.5	Cracked	1570	90	85	7.3	None	1620	70	91	–1.2	Cracked
							168	1120	40	93	12.4	Cracked	1170	50	90	12.3	Cracked	1670	30	96	9.6	Cracked
N-50	TEPA	1.5	0	1020	600	73	72	530	50	80	0	Cracked	650	130	75	3.0	None	830	130	83	–5.2	Cracked
							168	1010	20	97	–2.8	Cracked	800	40	91	–1.3	Cracked	960	50	93	–7.5	Cracked

Note:

Base recipes:

Ingredients	Parts by Weight N-50	Parts by Weight All Others
Neoprene WRT	100	100
Magnesia ELC	4	4
Thermatomic P-33	–	110
Silene EF	60	–
Butyl oleate	15	15
Zinc oxide	As shown	As shown
Accelerator	As shown	As shown

Cure: 30 minutes at 310 F.

(a) TEPA = Tetraethylene pentamine.

TABLE 6. THE EFFECTS OF NONBLACK FILLERS ON THE AGING OF NEOPRENE WRT

				Original Physical Properties				Physical Properties After Aging in Hydraulic Fluids at 400 F														
								OS-45					MLO-8200/Monoplex DOS – 85/15					MLO-8200				
Recipe	Filler Material	Filler Phr	NA-22, phr	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Aging Time, hours	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
N-10	Valron Estersil	45	1.0	2010	640	69	72	440	200	66	23.3	None	750	280	76	25.4	None	990	260	82	10.3	None
							168	90	90	53	35.5	None	470	90	67	40.1	None	1090	0	97	42.0	Cracked
N-11	Calcene NC	60	1.0	1790	630	54	72	390	170	58	10.1	None	550	250	56	10.5	None	650	210	64	–1.9	None
							168	520	90	70	7.2	None	630	120	72	11.3	None	510	100	68	–0.3	None
N-12	Hi-Sil C	60	1.0	1600	600	81	72	610	110	85	4.4	None	820	170	85	4.9	None	–	–	–	–	–
							168	810	110	91	4.8	None	730	130	90	7.4	None	–	–	–	–	–
N-13	Cab-O-Sil	45	1.0	2400	620	73	72	970	160	88	9.4	None	1050	210	85	12.8	None	1350	170	89	1.6	None
							168	550	90	80	24.9	None	660	130	75	26.6	None	890	10	96	28.3	Cracked
N-14	Silene EF	60	1.0	1400	600	66	72	450	130	65	7.4	None	530	190	61	10.5	None	860	180	72	–3.3	None
							168	450	100	68	5.9	None	590	160	66	10.0	None	750	140	74	–1.9	None
N-27	Valron Estersil	45	1.5	2010	620	74	72	270	200	58	20.7	None	380	230	57	20.1	None	730	260	69	5.6	None
							168	580	130	80	27.6	None	530	130	76	32.1	None	930	140	88	17.8	None
N-28	Calcene NC	70	1.5	1650	610	61	72	320	110	65	8.0	None	370	130	62	10.3	None	570	130	68	–2.1	None
							168	570	70	80	11.2	Cracked	570	80	76	12.2	Cracked	570	80	78	–0.7	Cracked
N-29	Hi-Sil C	50	1.5	1890	570	73	72	560	150	70	9.8	None	670	180	68	10.7	None	740	140	80	0.6	None
							168	760	80	87	11.2	Cracked	600	100	85	14.2	None	840	90	90	3.4	Cracked
N-30	Cab-O-Sil	45	1.5	2150	580	77	72	790	190	77	3.5	None	790	190	77	7.7	None	990	180	85	–3.5	None
							168	850	70	96	12.7	Cracked	850	100	91	14.9	None	1080	70	97	1.6	Cracked
N-31	Silene EF	60	1.5	1270	530	76	72	530	120	75	5.1	None	520	130	71	7.2	None	570	110	78	–2.8	None
							168	470	80	78	5.3	None	420	80	76	7.5	Cracked	570	70	85	–2.6	Cracked

Note:
Base recipe:

Ingredients	Parts by Weight
Neoprene WRT	100
Magnesia ELC	4
Filler	As shown
Butyl oleate	15
Zinc oxide	2.5
NA-22	As shown

Cure: 30 minutes at 310 F.

TABLE 7. THE EFFECTS OF VARYING ACCELERATOR AND ACTIVATOR ON THE AGING OF NEOPRENE WRT

						Original Physical Properties				Physical Properties After Aging in Hydraulic Fluids at 400 F														
										OS-45					85/15-MLO 8200/Monoplex DOS					MLO 8200				
Recipe	Filler	Filler, phr	ZnO, phr	MgO, phr	NA-22, phr	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Aging Time, hours	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
N-91	Valron Estersil	40	5	6	1.0	1790	610	72	72	570	180	79	18.5	None	690	160	86	29.0	None	1510	30	98	16.7	Cracked
									168	650	100	85	26.6	None	530	40	85	43.6	Cracked			Cap blew off tube		
N-92	Calcene NC	70	5	6	1.0	1360	600	59	72	450	150	65	7.1	None	500	120	72	15.9	None	910	130	77	3.6	None
									168	780	80	83	7.5	Cracked	740	60	86	24.6	Cracked	1690	30	98	12.8	Cracked
N-93	Hi Sil-C	45	5	6	1.0	1810	610	78	72	600	140	85	5.0	None	450	110	82	9.2	None	610	100	92	-1.3	None
									168	180	60	76	29.4	Cracked			Cap blew off tube			1470	0	100+	-7.3	Cracked
N-94	Cab-O-Sil	40	5	6	1.0	2310	610	76	72	710	150	84	10.1	None	610	140	85	10.5	None	1010	120	90	2.8	None
									168	80	50	75	41.2	Cracked	390	60	81	37.0	Cracked			Cap blew off tube		
N-95	Silene EF	55	5	6	1.0	990	510	70	72	400	110	70	3.6	None	420	120	69	7.1	None	570	100	78	-2.4	None
									168	380	100	71	2.2	None	370	100	73	5.9	None	430	80	81	-0.9	None
N-96	Silene EF	60	1	4	1.0	1080	500	73	72	580	140	70	6.2	None	700	140	76	-0.7	None	750	140	76	-1.5	None
									168	570	60	81	4.9	Cracked	450	70	76	7.7	None	690	60	85	-1.4	Cracked
N-97	Silene EF	60	1	4	0.6	1170	520	69	72	550	110	71	5.1	None	730	130	79	-1.3	None	760	140	80	-1.6	None
									168	600	60	83	5.3	Cracked	560	70	83	5.3	Cracked	870	50	90	-2.5	Cracked
N-98	Silene EF	60	2.5	4	0.6	1170	480	74	72	530	130	69	7.7	None	740	160	75	-0.8	None	760	160	76	-1.3	None
									168	580	100	75	6.2	None	640	80	81	13.0	Cracked	610	80	82	1.0	Cracked
N-99	Cab-O-Sil	40	1	4	1.0	2730	580	73	72	730	150	78	11.2	None	1080	210	81	1.4	None	1100	220	82	1.4	None
									168	510	40	84	17.4	Cracked	1050	40	95	13.8	Cracked			Cap blew off tube		
N-100	Cab-O-Sil	40	1	4	0.6	2780	620	66	72	650	120	85	12.9	None	920	190	82	11.7	None	1040	200	84	1.3	None
									168	750	20	91	15.6	Cracked	3010	10	100+	8.2	Cracked			Cap blew off tube		
									168(a)	350	60	80	16.5	Cracked	540(a)	70	78	20.3	Cracked					
N-101	Cab-O-Sil	40	2.5	4	0.6	3010	700	68	72	910	250	75	10.8	None	950	280	75	12.8	None	1520	320	80	3.0	None
									168	390	20	87	32.5	Cracked	1790	40	97	23.9	Cracked			Cap blew off tube		
									168(a)	790	140	87	11.2	None	630(a)	170	69	28.1	None					

Note:

Base recipe:

Ingredients	Parts by Weight
Neoprene WRT	100
Magnesia	As shown
Filler	As shown
Butyl oleate	15
Zinc oxide	As shown
NA-22	As shown

Cure: 30 minutes at 310 F.

(a) There was evidence that the seals were not air-tight in the original runs. Runs N-100 and N-101 were repeated.

TABLE 8. THE EFFECTS OF BLENDING CARBON BLACK AND NONBLACK FILLERS ON THE AGING OF NEOPRENE WRT

Recipe	Nonblack Filler			Original Physical Properties			Aging Time, hours	Properties After Aging in Hydraulic Fluids at 400 F: OS-45					85/15 MLO 8200/Monoplex DOS					MLO-8200				
	Type	Phr	P-33 phr	Tensile Strength, psi	Elongation, %	Hardness, Shore A		Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
N-44	Calcene NC	35	55	1430	420	61	72	610	90	77	9.1	None	700	110	74	8.6	None	830	110	77	−1.2	None
							168	800	50	87	9.6	Cracked	710	50	87	11.2	Cracked	810	50	88	1.5	Cracked
N-45	Hi-Sil C	25	55	1540	360	70	72	560	80	82	7.4	Cracked	650	100	79	7.1	None	710	80	88	−1.2	Cracked
							168	840	50	93	10.1	Cracked	820	60	90	10.1	Cracked	1060	50	97	2.0	Cracked
N-46	Silene EF	30	55	1430	360	70	72	440	80	75	6.0	None	470	100	72	7.4	None	570	70	80	−2.8	Cracked
							168	570	60	84	7.4	Cracked	670	60	85	9.8	Cracked	770	60	88	0	Cracked
N-47	Cab-O-Sil	25	55	1710	380	66	72	630	100	79	5.7	None	710	120	73	6.4	None	870	110	80	−3.6	None
							168	670	40	89	15.1	Cracked	670	50	87	14.7	Cracked	1680	30	100	10.4	Cracked
N-84	Valron Estersil	40	20	1810	550	73	72	400	190	67	14.0	None	600	240	64	13.3	None	820	210	78	3.4	None
							168	120	80	63	25.5	Cracked	220	100	62	30.6	None	570	50	90	23.7	Cracked
N-85	Calcene NC	70	20	1090	440	60	72	420	120	66	8.1	None	310	140	64	11.4	None	370	120	68	1.3	None
							168	350	100	73	8.9	None	270	70	76	14.4	None	230	60	78	6.1	Cracked
N-86	Hi-Sil C	45	20	1800	480	80	72	670	120	87	4.4	None	810	150	86	5.1	None	610	110	92	−3.9	None
							168	670	80	91	5.0	None	850	20	97	15.3	Cracked	810	70	93	−0.2	Cracked
N-87	Cab-O-Sil	40	20	2370	540	77	72	890	150	83	9.6	None	1070	200	80	10.1	None	1170	180	83	1.4	None
							168	310	50	84	19.6	Cracked	850	20	92	18.7	Cracked	770	70	89	19.0	Cracked
N-88	Silene EF	55	20	1230	450	71	72	440	100	73	3.2	None	530	120	74	3.2	None	630	100	80	−4.9	None
							168	390	70	82	3.7	Cracked	390	90	77	4.0	None	600	60	86	−4.0	Cracked

Note:

Base recipe:

Ingredients	Parts by Weight
Neoprene WRT	100
Magnesia ELC	4
Nonblack filler	As shown
Thermatomic P-33	As shown
Butyl oleate	15
Zinc oxide	2.5
NA-22	1.0

Cure: 30 minutes at 310 F.

TABLE 9. THE EFFECTS OF CHANGES IN MILLING PROCEDURE ON A STANDARD COMPOUND

	Original Physical Properties				Physical Properties After Aging in Hydraulic Fluids at 400 F														
					OS-45					85/15-MLO-8200/DOS					MLO-8200				
Recipe	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Aging Time, hours	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
N-3A(a)	1960	230	68	72	650	80	76	11.9	None	1050	100	72	13.5	None	1290	70	83	13.7	Cracked
				168	950	40	89	13.5	Cracked	2110	40	95	22.2	Cracked	790	40	87	26.7	Cracked
N-3B(b)	2270	230	68	72	710	70	76	11.4	None	1090	120	71	11.5	None	1240	70	83	10.5	Cracked
				168	640	40	84	14.0	Cracked	1300	60	85	22.1	Cracked	1840	10	100	38.6	Cracked

Note:

Base recipe:

Ingredients	Parts by Weight
Neoprene WRT	100
Magnesia ELC	4
Continex SRF	40
Thermax	40
Butyl oleate	15
Zinc oxide	2.5
NA-22	1.0

(a) Milled according to Du Pont recommended procedure. Cured 30 minutes at 310 F.

(b) Milled according to WADC recommended procedure. Cured 20 minutes at 310 F.

TABLE 10. BRITTLE POINTS OF SEVERAL NEOPRENE COMPOUNDS

	Compound N-3	Compound N-11	Compound N-15	Compound N-29	Compound N-34
Brittle Point, F	−60	−60	−58	−56	−60
Ingredients, parts by weight					
Neoprene WRT	100	100	100	100	100
Magnesia ELC	4	4	4	4	4
Continex SRF	40	–	–	–	15
Thermatomic P-33	–	–	110	–	–
Thermax	40	–	–	–	15
Calcene NC	–	60	–	–	–
Hi-Sil C	–	–	–	50	–
Butyl oleate	15	15	15	15	15
Zinc oxide	2.5	2.5	2.5	2.5	80
NA-22	1.0	1.0	1.0	1.5	1.0

Note:

Cure: 30 minutes at 310 F.

TABLE 11. THE EFFECTS OF MISCELLANEOUS FILLERS ON THE AGING OF HYCAR 1014

Recipe	Filler Type	Filler Phr by Weight	Original Tensile Strength, psi	Original Elongation, %	Original Hardness, Shore A	Aging Time, hours	OS-45 at 400 F Tensile Strength, psi	OS-45 Elongation, %	OS-45 Hardness, Shore A	OS-45 Swell, %	OS-45 Cracking	MLO-8200 at 400 F Tensile Strength, psi	MLO-8200 Elongation, %	MLO-8200 Hardness, Shore A	MLO-8200 Swell, %	MLO-8200 Cracking	85/15 MLO-8200/DOS Blend at 400 F Tensile Strength, psi	Blend Elongation, %	Blend Hardness, Shore A	Blend Swell, %	Blend Cracking
A-384	ELC magnesia	100	920	450	56	72	250	70	67	15.7	Cracked	510	80	76	4.6	None	260	70	70	13.9	None
						168	460	50	81	10.9	Cracked	1120	50	91	−0.5	Cracked	590	60	80	9.3	Cracked
						336	1780	20	98	8.1	Cracked	2610	10	100	−2.4	Cracked	2490	20	99	3.4	Cracked
A-335	Philblack A	50	1100	350	58	72	320	70	67	13.5	Cracked	440	70	76	0.8	Cracked	380	80	67	12.6	None
						168	350	50	71	13.1	Cracked	770	60	81	0.2	Cracked	430	70	72	10.4	Cracked
A-336	Philblack A	100	910	170	78	72	560	50	84	12.2	Cracked	810	40	92	1.0	Cracked	610	50	83	10.6	Cracked
						168	570	30	88	14.9	Cracked	1400	30	94	−0.2	Cracked	830	50	86	9.7	Cracked
A-337	Silene EF	50	680	620	52	72	110	100	57	18.1	None	200	120	61	8.2	None	110	130	54	15.6	None
						168	240	80	66	14.4	Cracked	390	80	72	2.4	Cracked	220	90	64	12.8	Cracked
A-338	Silene EF	100	830	410	73	72	230	80	71	19.6	None	420	100	77	8.6	None	330	100	70	18.4	None
						168	330	70	77	17.6	Cracked	500	70	83	7.7	Cracked	440	70	80	14.2	Cracked
A-390	Calcene NC	120	790	660	50	72	80	60	63	9.8	Cracked	200	50	75	0.5	Cracked	80	70	67	10.3	Cracked
						168	170	60	70	8.6	Cracked	300	40	81	−1.8	Cracked	130	50	71	7.3	Cracked
A-391	Dixie clay	120	390	460	54	72	510	60	71	11.7	Edge cracking	1190	60	82	0.9	Edge cracking	590	60	76	11.1	None
						168	450	40	78	10.3	Cracked	1230	40	87	−1.2	Cracked	630	40	80	8.2	Cracked

Note:

Base recipe:

Ingredients	Parts by Weight
Hycar 1014	100
Filler	As shown
Zinc oxide	5
Stearic acid	1.5
Plasticizer SC	10
Sulfur	0.5
Tetramethylthiuram disulfide	0.25

Cure: 60 minutes at 310 F.

TABLE 12. THE EFFECTS OF SILICA FILLERS ON THE AGING OF HYCAR 1014

	Filler		Original Physical Properties				Physical Properties After Aging in OS-45 at 400 F					Physical Properties After Aging in MLO-8200 at 400 F					Physical Properties After Aging in 85/15 MLO-8200/DOS Blend at 400 F				
Recipe	Type	Phr by Weight	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Aging Time, hours	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
A-339	Hi-Sil	50	790	710	56	72	420	110	62	17.6	None	590	120	72	4.8	None	460	130	65	15.7	None
						168	470	70	78	13.4	Cracked	830	80	86	0.9	Cracked	640	90	78	11.3	None
						336	–	–	–	–	–	–	–	–	–	–	1090	70	84	7.8	Cracked
A-385	Hi-Sil	60	800	640	56	72	600	90	77	15.6	None	770	80	86	4.6	Cracked	580	90	77	14.3	None
						168	940	50	89	12.4	Cracked	1490	50	93	1.7	Cracked	1080	60	89	9.5	Cracked
						336	1670	40	93	11.4	Cracked	3100	20	98	−0.5	Cracked	2130	40	95	5.9	Cracked
A-386	Hi-Sil	70	830	470	76	72	630	60	83	16.5	Cracked	1090	80	90	5.8	None	810	70	85	14.3	None
						168	1190	40	93	12.4	Cracked	1930	50	96	0.6	Cracked	870	60	90	10.3	Cracked
A-387	Hi-Sil	80	730	520	80	72	580	60	87	17.0	Cracked	780	60	93	7.1	Cracked	710	70	87	15.3	Cracked
						168	870	30	93	14.4	Cracked	1360	40	97	3.8	Cracked	830	40	92	12.4	Cracked
A-340	Hi-Sil	100	1220	470	91	72	800	70	93	15.5	Cracked	1440	90	96	6.1	Cracked	1110	110	93	15.7	None
						168	1160	40	97	14.4	Cracked	1910	60	98	4.7	Cracked	1390	60	96	13.8	Cracked
A-341	Cab-O-Sil	50	330	680	63	72	210	80	77	16.0	Cracked	520	110	78	4.9	None	510	160	67	18.8	None
						168	370	80	77	18.3	None	870	80	87	2.4	Cracked	490	90	80	14.4	None
						336	–	–	–	–	–	–	–	–	–	–	830	60	87	9.5	Cracked
A-388	Cab-O-Sil	60	290	310	68	72	550	110	76	17.4	None	850	90	86	3.9	None	530	100	76	16.5	None
						168	740	70	85	15.8	Cracked	1540	50	94	1.3	Cracked	790	70	85	13.6	Cracked
A-389	Cab-O-Sil	70	930	560	81	72	730	120	84	16.8	None	1030	90	92	3.8	Cracked	700	110	86	16.1	None
						168	1030	60	90	15.1	Cracked	1920	60	96	1.7	Cracked	1050	70	91	13.4	Cracked
A-342	Cab-O-Sil	75	710	650	86	72	790	140	85	17.5	None	930	100	93	5.2	None	790	130	86	16.7	None
						168	750	90	90	16.6	None	1590	70	97	3.0	Cracked	750	80	90	15.3	None

Note:

Base recipe:

Ingredients	Parts by Weight
Hycar 1014	100
Filler	As shown
Zinc oxide	5
Stearic acid	1.5
Plasticizer SC	10
Sulfur	0.5
Tetramethylthiuram disulfide	0.25

Cure: 60 minutes at 310 F.

TABLE 13. THE EFFECTS OF VULCANIZING AGENTS ON THE AGING OF HYCAR 1014

	Vulcanizing Agent, phr			Original Physical Properties				Physical Properties After Aging in OS-45 at 400 F					Physical Properties After Aging in MLO 8200 at 400 F					Physical Properties After Aging in 85/15 MLO 8200/DOS Blend at 400 F				
Recipe	Stearic Acid	Sulfur	TMTD[a]	Tensile Strength, psi	Elongation %	Hardness, Shore A	Aging Time, hours	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation %	Hardness, Shore A	Swell, %	Cracking
A-334 (Control)	1.5	0.5	0.25	670	760	50	72	190	110	58	20.0	None	470	130	65	7.3	None	390	160	56	19.2	None
							168	390	70	70	15.9	None	650	90	78	4.2	None	450	100	67	15.8	None
A-343	1.5	0.5	–	450	510	49	72	210	100	60	18.4	None	510	120	70	6.3	None	390	130	61	17.4	None
							168	280	60	75	14.7	None	650	70	81	2.1	None	440	80	74	12.9	None
A-344	1.5	0.5	0.5	1060	530	55	72	250	110	61	15.4	None	470	110	70	5.7	None	280	130	61	17.0	None
							168	300	80	74	13.6	None	610	70	81	1.8	None	440	80	74	11.4	None
A-345	1.5	0.5	1.0	990	450	58	72	290	120	62	15.3	None	490	120	71	4.8	None	450	150	61	15.8	None
							168	360	80	76	11.4	None	710	80	82	1.0	None	430	80	75	10.9	None
A-346	1.5	–	0.25	(Undercured)																		
A-347	1.5	0.25	0.25	400	470	58	72	190	120	62	20.0	None	490	110	70	6.3	None	440	170	58	17.4	None
							168	340	80	75	14.3	None	580	70	81	3.3	None	410	70	74	13.0	None
A-348	1.5	0.75	0.25	1050	510	65	72	410	100	64	17.8	None	570	100	72	5.4	None	440	120	62	16.6	None
							168	470	70	76	13.3	Cracked	570	70	82	3.9	Cracked	500	70	77	12.5	Cracked
A-349	1.5	1.0	0.25	1270	510	67	72	300	80	65	15.9	None	440	90	70	5.1	None	370	100	63	15.9	None
							168	500	70	79	12.2	Cracked	840	60	87	1.9	Cracked	450	70	78	10.9	None
A-350	–	0.5	0.25	910	450	68	72	410	100	65	17.9	None	570	100	73	5.9	None	660	150	63	17.7	None
							168	510	60	78	12.7	Cracked	780	70	85	2.4	Cracked	470	70	76	12.6	Cracked
A-351	1.0	0.5	0.25	780	420	63	72	270	100	62	18.2	None	480	110	70	7.0	None	340	130	61	19.1	None
							168	410	60	77	13.6	Cracked	730	60	84	2.7	Cracked	510	80	74	13.4	Cracked
A-352	2.0	0.5	0.25	850	430	63	72	310	100	60	17.0	None	580	110	70	6.6	None	330	110	65	16.8	None
							168	350	70	73	14.1	Cracked	630	70	81	3.2	Cracked.	430	80	72	13.7	None

Note:
Base recipe:

Ingredients	Parts by Weight
Hycar 1014	100
ELC magnesia	100
Zinc oxide	5
Plasticizer SC	10
Vulcanizing agents	As shown

Cure: 60 minutes at 310 F.

(a) Tetramethylthiuram disulfide.

TABLE 14. THE EFFECTS OF ANTIOXIDANTS ON THE AGING OF HYCAR 1014

	Antioxidant		Original Physical Properties				Physical Properties After Aging in OS-45 at 400 F					Physical Properties After Aging in MLO-8200 at 400 F					Physical Properties After Aging in 85/15 MLO-8200/DOS Blend at 400 F				
Recipe	Type	Phr by Weight	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Aging Time, hours	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
A-384	None	–	920	450	56	72	250	70	67	15.7	Cracked	510	80	76	4.6	None	260	70	70	13.9	None
						168	460	50	81	10.9	Cracked	1120	50	91	−0.5	Cracked	590	60	80	9.3	Cracked
						336	1780	20	98	8.1	Cracked	2610	10	100	−2.4	Cracked	2490	20	99	3.4	Cracked
A-360	AgeRite Resin D	1	930	340	55	72	350	110	62	15.5	None	550	110	72	6.2	None	470	120	63	16.2	None
						168	410	70	75	13.4	Cracked	740	70	82	2.6	Cracked	490	70	74	11.9	Cracked
						336	2410	30	98	7.1	Cracked	4220	10	99	−2.7	Cracked	3130	20	100	2.8	Cracked
A-361	AgeRite Resin D	5	570	480	51	72	190	140	59	16.5	None	500	130	70	4.5	None	390	130	61	15.1	None
						168	410	80	73	10.4	None	660	80	80	0.9	Cracked	440	80	73	10.9	None
						336	2170	20	98	6.2	Cracked	4130	10	99	−4.7	Cracked	2630	20	100	2.5	Cracked
A-375	AgeRite Resin D	10	560	640	48	72	180	120	62	12.0	None	490	100	72	−0.2	None	300	100	66	9.6	None
						168	210	90	67	11.6	None	410	100	75	1.2	None	170	100	65	9.8	None
						336	1830	30	98	5.1	Cracked	3790	10	100	−6.9	Cracked	2270	20	100	−1.3	Cracked
A-376	AgeRite Resin D	20	490	500	41	72	230	110	62	7.1	None	530	130	72	−3.8	None	340	140	61	6.4	None
						168	250	110	64	7.6	None	460	110	74	−2.4	None	270	100	67	4.8	None
						336	1870	30	99	0.6	Cracked	3640	10	100	−10.2	Cracked	2470	20	99	−4.6	Cracked
A-362	BLE	1	630	530	54	72	250	100	60	17.6	None	430	100	70	4.8	None	380	120	61	17.5	None
						168	330	60	73	14.0	Cracked	570	70	80	2.6	Cracked	290	70	72	13.4	Cracked
						336	2670	20	96	7.0	Cracked	4220	10	100+	−2.9	Cracked	2250	20	98	4.1	Cracked
A-363	BLE	5	580	310	53	72	350	130	59	16.4	None	470	110	68	4.4	None	330	120	61	15.6	None
						168	290	70	72	12.2	Cracked	530	70	77	2.5	Cracked	420	80	71	11.8	Cracked
						336	1210	50	93	8.0	Cracked	4100	10	100	−4.3	Cracked	3010	20	99	2.5	Cracked
A-364	Mercaptobenzimidazole	1	540	370	53	72	240	120	58	18.3	None	410	100	70	5.8	None	370	130	58	18.0	None
						168	330	70	72	14.2	Cracked	660	70	80	3.5	Cracked	290	80	70	15.0	Cracked
A-365	Mercaptobenzimidazole	5	900	510	56	72	400	120	62	16.6	None	470	110	75	4.9	None	250	120	66	14.8	None
						168	410	70	75	11.6	Cracked	570	70	83	2.4	Cracked	580	70	76	11.5	Cracked
						336	2150	20	100	6.9	Cracked	3750	10	100	-2.5	Cracked	2050	20	100	4.6	Cracked
A-366	Selenium dioxide	1	910	430	58	72	270	100	62	16.6	None	390	90	71	5.6	None	280	110	66	16.7	None
						168	380	70	73	13.6	Cracked	610	70	84	2.6	Cracked	410	70	72	12.9	Cracked
						336	530	60	84	10.9	Cracked	1130	50	94	0.4	Cracked	860	60	87	8.0	Cracked
A-367	Selenium dioxide	5	1430	340	68	72	290	100	65	16.9	None	440	90	76	5.9	None	350	100	70	16.1	None
						168	410	60	77	12.9	Cracked	790	60	87	2.6	Cracked	270	80	77	12.2	Cracked
						336	710	50	87	10.5	Cracked	810	40	91	1.7	Cracked	490	60	85	10.8	Cracked
A-380	Selenium dioxide	10	830	160	76	72	470	60	83	8.7	Cracked	710	50	90	1.9	Cracked	400	60	83	9.0	None
						168	580	40	87	6.9	Cracked	850	40	92	1.0	Cracked	580	50	87	7.0	Cracked
A-381	Selenium dioxide	20	1070	120	81	72	520	60	84	8.4	Cracked	790	60	90	1.9	Cracked	590	50	88	7.3	Cracked
						168	510	40	89	5.8	Cracked	810	40	94	1.0	Cracked	600	50	87	5.7	Cracked

Note:

Base recipe:

Ingredients	Parts by Weight
Hycar 1014	100
ELC magnesia	100
Zinc oxide	5
Stearic acid	1.5
Antioxidant	As shown
Plasticizer SC	10
Sulfur	0.5
Tetramethylthiuram disulfide	0.25

Cure: 60 minutes at 310 F.

TABLE 15. THE AGING OF HYCAR 1014–PHILPRENE VP BLENDS

	Original Physical Properties					Physical Properties After Aging in OS-45 at 400 F					Physical Properties After Aging in MLO-8200 at 400 F					Physical Properties After Aging in 85/15 MLO-8200/DOS Blend at 400 F				
Recipe	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Brittle Point, F	Aging Time, hours	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation %	Hardness Shore A	Swell %	Cracking
A-333	740	590	67	-60	72	380	100	63	23.8	None	750	110	76	9.3	None	610	120	65	21.9	None
					168	420	70	76	20.2	None	1010	70	87	6.0	None	580	80	76	18.4	None
A-334	670	760	50	-62	72	190	110	58	20.0	None	470	130	65	7.3	None	390	160	56	19.2	None
					168	390	70	70	15.9	None	650	90	78	4.2	None	450	100	67	15.8	None
					336	1850	30	97	9.7	Cracked	1780	60	95	0.5	Cracked	1250	60	86	8.7	Cracked
A-353	860	290	60	-	72	140	80	57	31.8	None	510	130	67	12.7	None	310	130	60	27.5	None
					168	170	80	62	29.6	None	560	70	79	10.3	Cracked	430	70	72	19.6	Cracked
A-354	620	420	63	-60	72	160	80	52	31.1	None	520	120	67	12.7	None	370	130	58	27.2	None
					168	290	60	70	27.6	Cracked	730	70	80	8.5	Cracked	470	80	71	20.7	Cracked
					336	-	-	-	-	-	3960	20	100+	0.9	Cracked	2910	30	100	10.2	Cracked
A-355	830	550	57	-70	72	20	110	44	41.5	None	350	130	63	14.8	None	210	140	52	32.6	None
					168	130	80	58	34.9	None	560	100	71	11.4	None	390	100	62	25.1	None
					336	-	-	-	-	-	3330	20	99	2.0	Cracked	1970	40	97	12.0	Cracked

Note:

Recipes used:

Ingredients	A-333	A-334	A-353	A-354	A-355
	Parts by Weight				
Hycar 1014	100	100	100	100	100
Philprene VP-25	-	-	20	20	40
ELC magnesia	100	100	100	100	100
Zinc oxide	5	5	5	5	5
Stearic acid	1.5	1.5	1.5	1.5	1.5
Plasticizer SC	-	10	-	-	-
Sulfur	0.5	0.5	0.5	0.6	0.7
Tetramethylthiuram disulfide	0.25	0.25	0.25	0.3	0.35

Cure: 60 minutes at 310 F.

TABLE 16. THE EFFECTS OF MISCELLANEOUS VULCANIZING SYSTEMS ON THE AGING OF HYCAR 1014

Recipe	Cure, minutes at 310 F	Original Physical Properties: Tensile Strength, psi	Elongation, %	Hardness, Shore A	Aging Time, hours	Physical Properties After Aging in OS-45 at 400 F: Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Physical Properties After Aging in MLO-8200 at 400 F: Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Physical Properties After Aging in 85/15 MLO-8200-DOS Blend at 400 F: Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
A-384 (Control)	60	920	450	56	72	250	70	67	15.7	Cracked	510	80	76	4.6	None	260	70	70	13.9	None
					168	460	50	81	10.9	Cracked	1120	50	91	−0.5	Cracked	590	60	80	9.3	Cracked
A-382	60	Undercured																		
A-383	60	Undercured																		
A-392	30	1800	370	62	72	1110	30	92	6.6	Cracked	1990	30	96	0.2	Cracked	1140	20	92	6.5	Cracked
					168	1310	30	94	6.2	Cracked	3250	20	99	−1.4	Cracked	1800	30	94	5.6	Cracked
	60	1950	310	64	72	1130	30	92	7.2	Cracked	2020	30	95	0.4	Cracked	1350	30	91	6.2	Cracked
					168	1480	30	94	6.8	Cracked	2610	20	99	−0.3	Cracked	1710	30	94	5.5	Cracked
A-393	60	Undercured																		
A-398	30	1190	410	53	72	870	30	86	5.8	Cracked	1110	20	90	0.4	Cracked	930	30	84	8.7	Cracked
					168	1430	30	93	4.7	Cracked	2180	20	96	−2.3	Cracked	1280	30	91	5.2	Cracked
	60	1530	350	58	72	610	20	86	6.9	Cracked	1400	30	90	−1.1	Cracked	830	40	85	7.5	Cracked
					168	1030	20	92	5.9	Cracked	1960	20	96	−0.8	Cracked	1130	30	91	4.7	Cracked
A-399	30	900	400	52	72	590	40	82	9.4	Cracked	1270	40	86	2.9	Cracked	880	50	79	11.4	Cracked
					168	770	30	88	10.2	Cracked	1370	30	92	0.3	Cracked	1190	50	85	8.5	Cracked
	60	1330	400	56	72	570	40	83	8.8	Cracked	1210	40	87	2.5	Cracked	870	60	81	9.9	Cracked
					168	830	30	88	8.7	Cracked	1490	30	92	−0.4	Cracked	1140	40	87	6.3	Cracked
A-394	30	340	720	51	72	370	90	69	16.5	None	550	100	76	4.7	None	330	100	66	16.8	None
					168	380	70	74	14.2	Cracked	600	70	81	2.4	Cracked	380	80	71	14.2	None
	60	450	770	56	72	370	80	71	16.0	None	550	80	78	5.0	None	350	100	67	17.1	None
					168	450	70	75	14.5	Cracked	650	70	81	3.7	Cracked	410	80	73	14.1	Cracked

Note:
Base recipes:

Ingredients	Parts by Weight: A-384	A-382	A-383	A-392	A-393	A-398	A-399	A-394
Hycar 1014	100	100	100	100	100	100	100	100
ELC magnesia	100	100	100	–	100	–	–	100
Philblack A	–	–	–	50	–	50	50	–
Zinc oxide	5	–	–	–	–	–	–	5
Litharge	–	5	5	10	10	5	5	–
Stearic acid	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Plasticizer SC	10	10	10	10	10	10	10	10
Dinitrobenzene	–	3	5	5	5	5	3	–
Tetramethylthiuram disulfide	–	–	–	–	–	–	–	–
Sulfur	0.5	–	–	–	–	–	–	–
VA-7	0.25	–	–	–	–	–	–	1
Benzothiazyl disulfide	–	–	–	–	–	–	–	2
Retarder W	–	–	–	–	–	–	–	1

TABLE 17. THE EFFECTS OF MISCELLANEOUS ADDITIVES ON THE AGING OF HYCAR 1014

Recipe	Additives		Original Physical Properties			Brittle Point, F	Aging Time, hours	Physical Properties After Aging in OS-45 at 400 F					Physical Properties After Aging in MLO-8200 at 400 F					Physical Properties After Aging in 85/15 MLO-8200/DOS Blend at 400 F				
	Type	Phr by Weight	Tensile Strength, psi	Elongation, %	Hardness, Shore A			Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
A-384	None	–	920	450	56	–	72	250	70	67	15.7	Cracked	510	80	76	4.6	None	260	70	70	13.9	None
							168	460	50	81	10.9	Cracked	1120	50	91	–0.5	Cracked	590	60	80	9.3	Cracked
							336	1780	20	98	8.1	Cracked	2610	10	100	–2.4	Cracked	2490	20	99	3.4	Cracked
A-372	RPA 6	1	750	380	54	–	72	230	80	65	15.4	None	530	80	78	3.3	Cracked	360	80	70	13.6	None
							168	350	70	71	13.7	Cracked	560	70	80	4.0	Cracked	370	80	70	13.1	Cracked
A-373	RPA 6	2	920	660	52	–	72	330	90	67	13.3	None	590	80	80	2.3	Cracked	440	90	73	11.9	None
							168	450	70	77	12.3	Cracked	750	70	84	2.9	Cracked	440	70	79	9.8	Cracked
A-374	RPA 6	5	1170	730	56	–	72	380	80	72	17.1	None	650	70	82	4.1	Cracked	490	90	74	14.6	None
							168	590	60	82	15.6	Cracked	810	60	88	5.4	Cracked	470	70	76	14.7	Cracked
							336	3290	10	100	9.9	Cracked	4680	10	100+	–1.1	Cracked	3830	10	100+	5.7	Cracked
A-395	Tenamene 2	1	830	360	53	–	72	200	100	58	17.0	None	350	100	67	6.5	None	250	100	61	17.0	None
							168	310	80	70	13.5	Cracked	440	70	79	3.4	Cracked	250	70	70	14.0	None
							336	530	50	83	9.9	Cracked	1490	40	93	–0.4	Cracked	710	50	84	8.3	Cracked
A-396	Tenamene 2	5	840	480	48	–	72	170	120	56	12.4	None	260	100	66	2.2	None	190	110	58	14.6	None
							168	250	70	70	8.6	Cracked	430	70	77	–0.3	Cracked	270	90	69	9.9	None
							336	640	60	80	5.4	Cracked	1270	50	91	–3.5	Cracked	670	60	83	4.6	Cracked
A-397	Factice	20	770	450	61	–41	72	380	130	60	20.0	None	610	100	73	8.1	None	470	140	63	20.4	None
							168	480	80	72	17.9	Cracked	800	70	83	5.3	Cracked	510	70	73	16.8	Cracked
							336	770	60	83	13.3	Cracked	1990	40	97	1.1	Cracked	950	50	86	11.5	Cracked

Note:

Base recipe:

Ingredients	Parts by Weight
Hycar 1014	100
ELC magnesia	100
Zinc oxide	5
Stearic acid	1.5
Additive	As shown
Plasticizer SC	10 (except A-397)
Sulfur	0.5
Tetramethylthiuram disulfide	0.25

Cure: 60 minutes at 310 F.

TABLE 18. THE EFFECT OF CAB-O-SIL ON THE AGING OF PHILPRENE VP-25

Recipe	Quaternizing Agent: Type	Quaternizing Agent: Phr by Weight	Original: Tensile Strength, psi	Original: Elongation, %	Original: Hardness, Shore A	Original: Brittle Point, F	Aging Time, hours	OS-45 at 400 F: Tensile Strength, psi	OS-45: Elongation, %	OS-45: Hardness, Shore A	OS-45: Swell, %	OS-45: Cracking	MLO-8200 at 400 F: Tensile Strength, psi	MLO-8200: Elongation, %	MLO-8200: Hardness, Shore A	MLO-8200: Swell, %	MLO-8200: Cracking	85/15 MLO-8200/DOS Blend at 400 F: Tensile Strength, psi	Blend: Elongation, %	Blend: Hardness, Shore A	Blend: Swell, %	Blend: Cracking
VP-32	None	–	1960	250	70	–	72	170	90	56	42.6	Cracked	250	70	67	16.7	Cracked	160	80	59	32.7	Cracked
							168	170	60	64	28.2	Cracked	410	50	77	9.0	Cracked	130	60	67	23.7	Cracked
VP-33	Benzal chloride	2	1990	260	69	–	72	190	80	58	38.6	Cracked	300	80	68	17.1	Cracked	210	80	61	29.8	None
							168	190	70	64	32.1	Cracked	440	60	77	10.6	Cracked	210	60	72	21.2	Cracked
VP-34	Benzal chloride	5	2880	290	72	<–71	72	510	90	67	30.4	None	860	100	76	13.1	None	600	100	70	25.6	None
							168	600	80	73	26.4	Cracked	880	60	86	8.4	Cracked	470	60	78	19.4	Cracked
							336	590	50	81	29.2	Cracked	1630	40	92	4.5	Cracked	1020	40	92	4.5	Cracked
VP-35	Benzotrichloride	2	2560	260	72	–	72	470	90	65	32.9	None	570	80	75	13.0	Cracked	490	90	69	25.7	None
							168	490	60	71	25.8	Cracked	780	60	82	9.2	Cracked	410	60	74	21.0	Cracked
VP-36	Benzotrichloride	5	3320	300	77	<–71	72	460	100	67	28.3	None	870	130	75	12.5	None	750	130	70	22.8	None
							168	470	80	71	25.3	None	1010	80	84	7.8	Cracked	750	90	76	18.6	None
							336	590	70	76	20.6	Cracked	1330	70	85	6.4	Cracked	1150	80	81	13.4	Cracked

Note:

Base recipe:

Ingredients	Parts by Weight
Philprene VP-25	100
Cab-O-Sil	40
Quaternizing agent	As shown
Zinc oxide	3
Stearic acid	1.5
Sulfur	1.5
Benzothiazyl disulfide	1.5

Cure: 30 minutes at 310 F.

TABLE 19. THE EFFECT OF PHILBLACK A ON THE AGING OF PHILPRENE VP-25

	Quaternizing Agent		Original Physical Properties					Physical Properties After Aging in OS-45 at 400 F					Physical Properties After Aging in MLO-8200 at 400 F					Physical Properties After Aging in 85/15 MLO-8200/DOS Blend at 400 F				
Recipe	Type	Phr by Weight	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Brittle Point, F	Aging Time, hours	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
VP-5	None	–	3280	400	69	<–94	72	40	80	48	37.2	None	390	80	58	14.7	None	200	110	51	35.2	None
							168	20	60	58	30.2	None	290	60	68	9.6	Cracked	170	70	59	26.3	Cracked
VP-28	Benzal chloride	2	2200	290	63	–	72	230	100	56	41.2	None	210	60	68	14.7	Cracked	230	70	62	29.4	None
							168	180	60	72	23.0	Cracked	660	40	84	4.6	Cracked	230	50	75	15.4	Cracked
VP-29	Benzal chloride	5	2560	270	67	–	72	420	70	67	26.6	Cracked	760	70	76	9.8	Cracked	490	70	69	21.9	Cracked
							168	790	50	82	15.8	Cracked	1320	30	94	0.8	Cracked	820	50	84	10.2	Cracked
VP-4	Benzal chloride	10	3730	370	73	–	72	460	60	74	21.3	Cracked	840	70	81	8.6	Cracked	770	80	76	18.7	None
							168	520	40	85	14.5	Cracked	2050	40	95	1.0	Cracked	1260	50	88	8.7	Cracked
VP-6	Benzal chloride	20	3110	330	74	–	72	630	40	86	16.5	Cracked	1510	30	97	1.6	Cracked	1260	40	93	9.9	Cracked
							168	1270	40	95	9.7	Cracked	3590	10	100+	–6.6	Cracked	2440	30	98	–0.8	Cracked
VP-30	Benzotrichloride	2	2790	280	67	–	72	270	80	62	32.4	Cracked	450	70	72	11.2	Cracked	280	80	63	27.5	Cracked
							168	10	10	79	18.3	Cracked	950	40	87	3.5	Cracked	510	50	80	11.6	Cracked
VP-31	Benzotrichloride	5	3340	260	72	–	72	450	70	65	29.0	None	810	80	76	10.0	Cracked	500	90	64	24.2	None
							168	450	50	76	17.5	Cracked	1070	50	88	1.9	Cracked	730	60	80	11.8	Cracked
VP-10	Benzotrichloride	10	3680	310	75	–	72	590	70	76	21.7	Cracked	1390	50	92	4.7	Cracked	1000	60	84	13.5	Cracked
							168	1000	40	93	10.9	Cracked	3610	30	100+	–3.5	Cracked	1890	40	95	4.7	Cracked
VP-11	Benzotrichloride	20	3510	330	73	–	72	870	30	93	11.7	Cracked	2210	20	100	–2.6	Cracked	1890	30	98	3.5	Cracked
							168	1800	20	100	2.9	Cracked	4330	10	100+	–6.2	Cracked	3260	10	100+	–4.9	Cracked

Note:

Base recipe:

Ingredients	Parts by Weight
Philprene VP-25	100
Philblack A	40
Quaternizing agent	As shown
Zinc oxide	3
Stearic acid	1.5
Sulfur	1.5
Benzothiazyl disulfide	1.5

Cure; 30 minutes at 310 F.

TABLE 20. THE EFFECT OF SILENE EF ON THE AGING OF PHILPRENE VP-25

Recipe	Quaternizing Agent: Type	Quaternizing Agent: Phr by Weight	Original: Tensile Strength, psi	Original: Elongation, %	Original: Hardness, Shore A	Original: Brittle Point, F	Aging Time, hours	OS-45 at 400 F: Tensile Strength, psi	OS-45: Elongation, %	OS-45: Hardness, Shore A	OS-45: Swell, %	OS-45: Cracking	MLO-8200 at 400 F: Tensile Strength, psi	MLO-8200: Elongation, %	MLO-8200: Hardness, Shore A	MLO-8200: Swell, %	MLO-8200: Cracking	85/15 MLO-8200/DOS Blend at 400 F: Tensile Strength, psi	Blend: Elongation, %	Blend: Hardness, Shore A	Blend: Swell, %	Blend: Cracking
VP-7	None	–	980	580	62	-45	72	0	150	33	56.4	None	30	120	50	25.7	None	10	130	41	45.3	None
							168	50	120	42	46.1	None	150	90	61	19.2	None	0	80	51	35.4	None
VP-17	Benzal chloride	5	1570	630	61	–	72	10	110	43	54.0	None	110	90	57	21.1	None	10	90	47	42.1	None
							168	10	90	43	46.9	None	70	50	68	15.5	Cracked	10	70	59	31.6	Cracked
VP-18	Benzal chloride	10	1710	590	65	–	72	10	110	53	44.2	None	230	90	64	18.7	None	80	90	56	35.3	None
							168	30	80	55	38.5	None	260	50	76	12.3	Cracked	110	60	65	28.4	Cracked
VP-22	Benzotrichloride	2	970	530	60	–	72	0	100	44	52.2	None	90	80	61	20.1	Cracked	30	90	49	36.6	Cracked
							168	20	100	49	47.1	None	190	60	68	15.9	Cracked	30	70	57	33.6	Cracked
VP-23	Benzotrichloride	5	1260	520	66	–	72	30	80	53	41.7	Cracked	100	40	71	16.2	Cracked	50	70	57	32.6	Cracked
							168	20	70	57	37.7	None	180	60	70	15.7	Cracked	70	70	62	29.5	Cracked
VP-24	Benzotrichloride	10	1680	460	67	–	72	50	80	56	35.9	Cracked	370	80	70	14.4	Cracked	200	80	63	25.9	Cracked
							168	110	70	61	32.0	Cracked	430	80	72	10.9	Cracked	210	70	67	22.6	Cracked
VP-19	None	–	510	410	59	–	72	0	220	26	83.6	None	20	150	45	30.5	None	10	150	35	54.2	None
							168	10	130	36	56.9	None	80	90	55	23.6	None	20	100	45	42.8	None
VP-20	Benzal chloride	5	1680	660	62	–	72	0	170	32	68.3	None	80	100	55	27.9	None	10	100	44	47.6	None
							168	10	120	41	59.0	None	190	70	70	17.7	Cracked	30	70	58	35.0	Cracked
VP-21	Benzal chloride	10	1660	530	67	–	72	170	150	45	49.2	None	230	110	61	20.5	None	110	100	50	37.2	None
							168	80	100	51	45.0	None	410	60	74	12.7	Cracked	210	70	65	26.6	Cracked
VP-25	Benzotrichloride	2	660	350	63	–	72	10	130	41	56.0	None	120	100	56	22.2	None	20	90	52	36.4	None
							168	10	100	47	47.5	None	170	70	63	18.4	None	50	80	57	30.3	None
VP-26	Benzotrichloride	5	940	400	68	–	72	160	110	51	43.7	None	330	90	65	17.7	None	210	100	58	32.0	None
							168	190	70	60	34.4	Cracked	410	70	72	14.2	Cracked	110	60	66	25.9	Cracked
VP-27	Benzotrichloride	10	1730	470	71	–	72	320	110	56	36.1	None	580	110	71	13.4	None	400	100	64	26.0	None
							168	250	70	66	30.8	Cracked	640	80	76	12.1	None	420	80	69	22.4	None

Note:
Base recipes:

Ingredients	Parts by Weight: VP-7, -17, -18, -22, -23, -24	Parts by Weight: VP-19, -20, -21, -25, -26, -27
Philprene VP-25	100	100
Silene EF	46.6	46.6
Quaternizing agent	As shown	As shown
Zinc oxide	3	5
Stearic acid	1.5	1.5
Sulfur	1.5	0.25
Benzothiazyl disulfide	1.5	3
Tetramethylthiuram disulfide	–	2

Cure: 30 minutes at 310 F.

TABLE 21. THE EFFECTS OF FILLERS ON THE AGING OF HYCAR 1072

Recipe	Filler: Type	Filler: Phr by Weight	Original Physical Properties: Tensile Strength, psi	Original: Elongation, %	Original: Hardness, Shore A	Aging Time, hours	Physical Properties After Aging in OS-45 at 400 F: Tensile Strength, psi	OS-45: Elongation, %	OS-45: Hardness, Shore A	OS-45: Swell, %	OS-45: Cracking	Physical Properties After Aging in MLO-8200 at 400 F: Tensile Strength, psi	MLO-8200: Elongation, %	MLO-8200: Hardness, Shore A	MLO-8200: Swell, %	MLO-8200: Cracking	Physical Properties After Aging in 85/15 MLO-8200/DOS Blend at 400 F: Tensile Strength, psi	85/15: Elongation, %	85/15: Hardness, Shore A	85/15: Swell, %	85/15: Cracking
A-356	ELC magnesia	100	Batch scorched on mill																		
A-357	Cab-O-Sil	50	4030	570	88	72	2070	60	95	2.2	Cracked	3100	80	97	−2.1	Cracked	2280	80	95	3.0	None
						168	2350	40	98	5.0	Cracked	4050	40	100	−1.5	Cracked	3560	60	98	3.3	Cracked
A-368	Cab-O-Sil	40	4710	540	85	72	2140	60	95	1.1	Cracked	3240	80	97	−4.0	None	2150	70	95	0.5	None
						168	2810	40	98	0.3	Cracked	3830	60	100	−4.6	Cracked	3260	60	98	0.0	Cracked
A-377	Cab-O-Sil	20	3200	570	61	72	1820	80	88	2.9	None	2520	80	92	−3.2	None	1950	80	89	0.0	None
						168	1720	60	93	0.0	Cracked	3310	80	97	−5.1	Cracked	2230	70	95	−1.6	Cracked
A-369	Silene EF	50	Batch scorched on mill																		
A-370	Hi-Sil	50	3460	510	85	72	2480	60	95	3.5	Cracked	3820	70	97	−1.5	Cracked	3540	90	95	3.4	None
						168	3480	50	97	1.9	Cracked	4410	50	99	−2.4	Cracked	4080	60	97	1.2	Cracked
A-379	Hi-Sil	30	2920	560	66	72	2470	60	93	4.7	Cracked	3700	80	95	−1.6	None	3240	80	94	2.7	None
						168	2470	50	95	1.4	Cracked	4290	50	99	−2.9	Cracked	3570	70	96	2.1	Cracked
A-378	Hi-Sil	20	2870	580	58	72	2130	70	90	3.8	Cracked	2960	80	92	−2.3	None	1930	70	90	2.1	None
						168	1830	50	93	2.1	Cracked	3360	50	98	−3.4	Cracked	2580	70	95	0.3	Cracked
A-395A(a)	Hi-Sil	30	Full of pinholes after curing																		

Note:

Base recipe:

Ingredients	Parts by Weight
Hycar 1072	100
Filler	As shown
Zinc oxide	5
Stearic acid	1.5
Plasticizer SC	10
Sulfur	0.5
Tetramethylthiuram disulfide	0.25

Cure: 60 minutes at 310 F.

(a) 5.0 phr of zinc stearate substituted for the zinc oxide and stearic acid in this recipe.

TABLE 22. THE AGING OF ACRYLON BA-12

	Original Physical Properties					Physical Properties After Aging in OS-45 at 400 F					Physical Properties After Aging in MLO-8200 at 400 F					Physical Properties After Aging in 85/15 MLO-8200/DOS Blend at 400 F				
Recipe	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Brittle Point, F	Aging Time, hours	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
PA-282	1040	70	90	–53	72	550	70	82	10.7	None	830	60	89	0.5	Cracked	560	70	82	12.9	None
					168	320	50	80	12.9	Cracked	690	70	89	1.6	Cracked	470	70	81	12.1	Cracked
PA-300	720	240	59	–53	72	410	200	49	23.0	None	580	210	58	6.9	None	350	190	49	23.7	None
					168	450	210	51	21.8	None	570	180	65	5.0	None	470	210	52	20.3	None
					336	190	240	39	35.5	None	420	190	56	7.6	None	230	230	40	27.2	None
					500	250	230	42	29.9	None	410	200	53	7.6	None	200	200	43	26.2	None
PA-301	670	240	67	–8	72	770	100	83	–2.9	None	870	100	86	–5.7	None	790	110	83	–2.2	None
					168	740	90	80	0.5	None	800	90	85	–3.8	None	760	100	84	–2.2	None
					336	710	90	76	14.0	None	870	80	84	–0.7	None	910	90	80	•2.2	None
					500	680	80	77	9.7	None	890	70	85	–2.7	None	830	80	81	1.4	None
PA-302	310	530	71	–39	72	370	560	54	25.6	None	730	530	67	11.0	None	430	540	48	26.4	None
					168	390	530	49	29.7	None	600	520	65	10.6	None	390	520	47	31.1	None
					336	130	430	42	31.0	None	450	500	59	12.4	None	200	470	42	28.5	None
					500	10	380	38	27.4	None	390	450	57	14.1	None	200	450	39	28.2	None

Note:

Base recipe:

Ingredients	Parts by Weight PA-282	PA-300	PA-301	PA-302
Acrylon BA-12	100	100	100	100
Philblack E	50	–	–	–
Philblack A	–	40	–	–
Silene EF	–	–	70	–
Hi-Sil	–	–	–	60
Stearic acid	1	1	1	1
TP-90B	20	20	20	20
Sulfur	1	0.9	0.9	0.9
Tetramethylthiuram disulfide	–	1	1	1
Triethylene tetramine	5	2.1	2.1	2.1

Cure: 60 minutes at 310 F.

TABLE 23. THE AGING OF MISCELLANEOUS POLYMERS

			Original Physical Properties					Physical Properties After Aging in OS-45 at 400 F					Physical Properties After Aging in MLO-8200 at 400 F					Physical Properties After Aging in 85/15 MLO-8200/DOS Blend at 400 F				
Recipe	Polymer	Cure, minutes at 310 F	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Brittle Point, F	Aging Time, hours	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
KF-1	Kel-F Elastomer	(a)	1520	430	86	–	72	1330	90	84	27.4	None	1410	40	92	15.1	Cracked	1460	80	84	25.2	None
							168	2670	30	95	50.4	Cracked(b)	7680	0	97	29.9	Cracked(b)	5450	0	100+	32.6	Cracked(b)
KF-2	Kel-F Elastomer	(a)	560	1700	64	–	72	410	870	57	18.4	None	220	270	63	19.1	Crazed	50	220	52	37.8	None
							168	130	420	50	24.6	None	350	250	62	25.3	Crazed	130	210	57	41.8	Crazed
Bu-4	Butyl	60	1320	300	69	–	72	Samples disintegrated during aging														
							168	Samples disintegrated during aging														
Bu-5	Butyl	60	1390	440	57	–	72	Samples disintegrated during aging														
							168	Samples disintegrated during aging														
VP-37	Philprene VP-A	30	2670	380	76	–72	72	530	120	69	12.9	None	790	130	74	6.3	None	640	130	68	13.7	None
							168	730	70	79	11.2	None	1270	80	84	5.0	None	800	90	78	11.9	None
							336	1890	50	94	9.5	Cracked	2890	50	98	2.8	Cracked	1610	60	90	9.8	Cracked
VP-38	Philprene VP-A	30	2970	370	78	–45	72	700	110	73	10.5	None	1310	150	77	4.0	None	1200	160	73	11.0	None
							168	890	70	83	10.2	Edge cracking	2070	100	91	3.3	None	1590	110	83	9.5	None
							336	2110	40	95	9.3	Cracked	3710	40	99	0.6	Cracked	2740	50	96	7.1	Cracked

Note:
Base recipes:

	Parts by Weight					
Ingredients	KF-1	KF-2	Bu-4	Bu-5	VP-37	VP-38
Kel-F Elastomer	100	100	–	–	–	–
Butyl (GR-I 25)	–	–	100	100	–	–
Philprene VP-A	–	–	–	–	100	100
Hi-Sil X-303	20	–	–	–	–	–
SRF black	–	–	50	50	–	–
Cab-O-Sil	–	–	–	–	40	40
Zinc oxide	5	10	5	5	3	3
Stearic acid	–	–	0.5	0.5	1.5	1.5
Triethylene tetramine	4	–	–	–	–	–
Dyphos	–	10	–	–	–	–
Benzoyl peroxide	–	3	–	–	–	–
Plasticizer SC	–	–	–	10	–	–
Sulfur	–	–	2	2	1.5	1.5
Tetramethylthiuram disulfide	–	–	1	1	–	–
Benzothiazyl disulfide	–	–	1	1	1.5	1.5
Benzal chloride	–	–	–	–	–	–
Benzotrichloride	–	–	–	–	5	5
Polyac	–	–	1	1	–	–

(a) Cured 30 minutes in press at 230 F, removed from mold, and cured in oven 16 hours at 300 F.
(b) Hydraulic fluid was solid at the end of aging. The stainless steel wire holding the samples was corroded in two.

TABLE 24. TEMPERATURE-RETRACTION-TEST RESULTS

Recipe	Base Polymer	Filler	TR-10, C	TR-70, C
N-3B	Neoprene WRT	Carbon black	-50	-35
26C	Neoprene WRT	Carbon black	-50	-18
N-13	Neoprene WRT	Cab-O-Sil	-48	-2
N-14	Neoprene WRT	Silene EF	-48	-5
PA-282	Acrylon BA-12	Carbon black	-48	+8
VP-36	Philprene VP-25	Cab-O-Sil	-47	-6
VP-34	Philprene VP-25	Cab-O-Sil	-47	-16
A-384	Hycar 1014	ELC magnesia	-45	-24
PA-300	Acrylon BA-12	Carbon black	-43	-19
A-385	Hycar 1014	Hi-Sil	-41	-4
PA-302	Acrylon BA-12	Hi-Sil	-38	+8
PA-301	Acrylon BA-12	Silene EF	-33	-16
VP-37	Philprene VP-A	Cab-O-Sil	-24	-13
A-377	Hycar 1072	Cab-O-Sil	-23	+4
KF-2	Kel-F Elastomer	None	-1	+7

TABLE 25. THE EFFECTS OF ADDITIVES TO TURBO OIL-15 ON THE AGING OF HYCAR 1001

	Rubber Additive		Oil Additive		Original Physical Properties			Physical Properties After Aging in Penola Turbo Oil-15 72 Hours at 350 F					Physical Properties After Aging in Penola Turbo Oil-15 168 Hours at 350 F					Physical Properties After Aging in Penola Turbo Oil-15 500 Hours at 350 F				
Recipe	Material	Phr	Material	Parts Per 100 Parts Oil	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
A-23M	None		None	–	2510	670	71	1430	380	72	25.9	Cracked	840	200	82	25.1	Cracked	620	60	86	28.3	Cracked
			Mercaptobenzimidazole	1.5				1330	420	66	26.5	Cracked	910	260	70	24.7	Cracked	610	100	83	27.0	Cracked
			Thiomalic acid	1.5				590	200	84	15.1	Cracked	610	100	89	14.4	Cracked	630	50	89	11.6	Cracked
A-320	Mercaptobenzimidazole	1.0	None	–	2260	620	72	1380	310	74	20.9	Cracked	920	160	80	22.3	Cracked	660	70	86	25.9	Cracked
			Mercaptobenzimidazole	1.5				1060	350	66	31.5	Cracked	760	220	70	29.7	Cracked	530	60	86	29.6	Cracked
			Thiomalic acid	1.5				590	130	84	14.3	Cracked	530	70	89	13.9	Cracked	580	50	89	10.6	Cracked
A-321	Thiomalic acid	8.4	None	–	2710	420	74	1790	170	76	15.7	Cracked	1150	130	80	14.4	Cracked	670	60	82	15.7	Cracked
			Mercaptobenzimidazole	1.5				1680	190	75	18.7	Cracked	900	110	76	20.8	Cracked	700	60	80	18.5	Cracked
			Thiomalic acid	1.5				560	70	85	13.1	Cracked	580	50	88	11.6	Cracked	590	50	88	9.4	Cracked
A-322	Mercaptobenzimidazole	1.0	None	–	2850	410	75	1800	190	76	15.5	Cracked	920	110	79	14.3	Cracked	670	60	83	14.8	Cracked
	Thiomalic acid	8.4																				
			Mercaptobenzimidazole	1.5				1620	160	74	20.2	Cracked	970	120	75	17.8	Cracked	680	70	79	19.9	Cracked
			Thiomalic acid	1.5				610	50	85	12.1	Cracked	560	40	87	11.9	Cracked	580	40	86	9.7	Cracked

Note:
Base recipe:

Ingredients	Parts by Weight
Hycar 1001	100
Zinc oxide	5
Magnesia ELC	100
Stearic acid	1.5
Sulfur	0.5
Tetramethylthiuram disulfide	0.5
Additive	As shown

Cure: 60 minutes at 310 F.

TABLE 26. THE EFFECTS OF MISCELLANEOUS ADDITIVES ON THE AGING OF NITRILE RUBBER

	Additive		Original Physical Properties			Physical Properties After Aging in Penola Turbo Oil-15 168 Hours at 350 F				
Recipe	Material	Phr	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
41AC-2	None	–	2440	680	67	480	180	76	22.9	Cracked
41A-9	Ionol	2	2430	650	67	440	200	76	20.5	Cracked
41A-10	Ionol	5	2120	700	62	400	190	74	18.6	Cracked
41A-11	Thiokol ZL-190	3	2200	370	73	510	90	80	15.6	Cracked
41A-12	Thiokol ZL-190	10	2000	200	82	680	40	92	6.9	Cracked
A-23N	None	–	2900	560	70	570	150	79	19.9	Cracked
A-323	Ionol	2	3230	610	69	580	160	78	18.0	Cracked
A-324	Ionol	5	3060	610	68	570	170	78	15.3	Cracked
A-325	Thiokol ZL-190	3	2800	330	78	860	70	84	13.1	Cracked
A-326	Thiokol ZL-190	10	2670	230	81	830	40	91	5.8	Cracked
A-327	Selenium dioxide	2	3260	550	81	1030	130	84	14.1	Cracked
A-328	Selenium dioxide	5	3140	340	85	1000	90	89	10.7	Cracked

Note:
Base recipe:

	Parts by Weight		
Ingredients	Recipes 41AC-2, 41A-9, 41A-10, 41A-11, 41A-12	Recipes A-23N, A-323, A-324, A-325, A-326	Recipes A-327 and A-328
Hycar 1041	100	–	–
Hycar 1001	–	100	100
Zinc oxide	5	5	5
Magnesia ELC	100	100	100
Stearic acid	1.5	1.5	1.5
Sulfur	0.5	0.5	0.5
Tetramethylthiuram disulfide	0.75	0.75	0.25
Additive	As shown	As shown	As shown

Cure: 60 minutes at 310 F.

TABLE 27. THE EFFECTS OF VULCANIZING AGENTS ON THE AGING OF HYCAR 4021 FILLED WITH SILENE EF

	Vulcanizing Agents, phr					Original Physical Properties			Physical Properties After Aging in Penola Turbo Oil-15 72 Hours at 400 F					Physical Properties After Aging in Penola Turbo Oil-15 168 Hours at 400 F					Physical Properties After Aging in Penola Turbo Oil-15 500 Hours at 400 F				
Recipe	TETA	Sulfur	TMTD	Cure, minutes at 310 F	Treatment After Cure	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
PA-281	0.5	2.0	1.0	60	None	990	270	82	440	100	50	43.4	None	380	90	48	38.3	None	160	80	37	57.5	Cracked
				120	None	1100	140	85	500	80	55	40.2	None	440	80	54	37.1	None	190	70	39	89.7	Cracked
				60	Tempered(a)	1200	140	83	600	70	60	40.6	None	470	60	62	38.4	None	130	60	48	74.7	Cracked
				120	Tempered	1210	100	85	720	70	64	38.6	None	590	60	65	36.5	None	110	50	48	111.1	Cracked
PA-277	0.5	–	3.0	60	None	860	310	77	460	50	66	35.9	None	390	50	65	34.6	None	260	60	57	58.5	Cracked
				120	None	970	200	80	570	50	69	32.7	None	500	50	69	34.6	None	300	60	57	73.2	Cracked
				60	Tempered	1100	110	83	530	50	69	34.3	None	480	50	70	32.5	None	310	50	60	76.5	Cracked
				120	Tempered	1120	100	85	690	50	72	33.6	None	520	50	70	31.1	None	190	50	60	58.2	Cracked
PA-280	1.0	1.0	1.5	60	None	1110	160	85	490	50	67	34.2	None	580	50	67	32.4	None	130	40	63	68.6	Cracked
				120	None	1200	120	88	710	50	71	31.1	None	710	50	71	34.9	None	360	50	64	63.6	Cracked
				60	Tempered	1240	80	86	760	50	73	32.6	Cracked	710	50	73	31.4	Cracked	–	–	–	–	–
				120	Tempered	1330	70	90	740	40	76	29.2	Cracked	570	40	73	32.1	Cracked	–	–	–	–	–
PA-278	1.0	0.5	2.0	60	None	1190	230	82	670	50	71	32.0	None	610	50	71	34.9	None	400	40	71	71.6	Cracked
				120	None	1250	150	86	820	60	73	32.2	None	830	50	75	33.0	None	200	40	62	83.0	Cracked
				60	Tempered	1360	100	86	750	50	73	31.8	Cracked	710	50	72	39.1	None	480	40	72	60.9	Cracked
				120	Tempered	1390	90	88	900	50	75	30.8	Cracked	820	50	72	39.9	None	190	40	62	98.8	Cracked
PA-276	1.0	–	2.5	60	None	930	230	82	640	50	72	29.5	Cracked	610	40	74	32.4	Cracked	–	–	–	–	–
				120	None	980	150	84	710	50	74	29.1	Cracked	610	40	75	28.8	Cracked	–	–	–	–	–
				60	Tempered	1180	70	88	680	50	74	29.6	Cracked	630	40	75	40.6	Cracked	–	–	–	–	–
				120	Tempered	1220	70	89	750	40	76	27.3	Cracked	690	40	76	33.2	Cracked	–	–	–	–	–
PA-279	1.5	0.5	1.5	60	None	1100	140	89	800	50	80	27.5	Cracked	800	40	79	27.9	Cracked	–	–	–	–	–
				120	None	1170	100	90	860	50	80	26.3	Cracked	830	50	79	29.6	Cracked	–	–	–	–	–
				60	Tempered	1240	70	92	900	40	81	25.1	Cracked	900	40	79	31.2	Cracked	–	–	–	–	–
				120	Tempered	1320	70	92	800	40	81	25.0	Cracked	900	40	79	31.6	Cracked	–	–	–	–	–
PA-273	1.5	–	2.0	60	None	1100	230	84	850	50	76	30.9	None	790	50	75	34.3	None	590	40	75	60.2	Cracked
				120	None	1120	200	86	900	50	80	27.1	Cracked	910	50	79	35.5	Cracked	–	–	–	–	–
				60	Tempered	1410	80	91	1030	50	80	25.6	Cracked	930	50	79	42.2	Cracked	410	30	75	72.7	Cracked
				120	Tempered	1450	80	93	1080	50	82	24.0	Cracked	1020	50	79	36.9	Cracked	–	–	–	–	–
PA-274	2.0	–	1.5	60	None	1000	320	80	640	40	78	27.2	Cracked	660	50	76	42.5	Cracked	–	–	–	–	–
				120	None	1090	220	82	780	50	81	29.2	Cracked	710	40	77	41.0	Cracked	–	–	–	–	–
				60	Tempered	1300	70	89	750	40	81	29.4	Cracked	750	40	79	34.6	Cracked	–	–	–	–	–
				120	Tempered	1360	70	93	820	40	82	23.6	Cracked	830	40	81	37.6	Cracked	–	–	–	–	–
PA-275	2.5	–	1.0	60	None	970	280	86	750	40	86	22.9	Cracked	760	40	86	24.9	Cracked	–	–	–	–	–
				120	None	1060	150	87	930	30	86	21.6	Cracked	830	30	86	23.5	Cracked	–	–	–	–	–
				60	Tempered	1350	60	94	910	30	86	20.5	Cracked	770	30	86	27.9	Cracked	–	–	–	–	–
				120	Tempered	1290	50	94	890	30	86	20.3	Cracked	760	30	86	26.2	Cracked	–	–	–	–	–

Note:
Base recipe:

Ingredients	Parts by Weight
Hycar 4021	100
Silene EF	70
Stearic acid	1
Vulcanizing agents	As shown

(a) All tempering was for 7 hours at 350 F.

TABLE 28. THE EFFECT OF CALCENE NC ON THE AGING OF HYCAR 4021 AT 350 F

Recipe	Calcene NC Phr by Weight	Calcene NC Phr by Volume	Cure, minutes at 310 F	Treatment After Cure	Original Physical Properties Tensile Strength, psi	Elongation, %	Hardness, Shore A	Physical Properties After Aging in Penola Turbo Oil-15 72 Hours at 350 F Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Physical Properties After Aging in Penola Turbo Oil-15 168 Hours at 350 F Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Physical Properties After Aging in Penola Turbo-Oil-15 500 Hours at 350 F Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
PA-224	90	36.6	30	None	830	510	51	420	80	53	33.1	None	510	80	55	43.7	None	–	–	–	–	–
			60	None	870	450	54	460	80	54	34.6	None	560	80	55	43.0	None	–	–	–	–	–
			120	None	800	360	58	570	80	58	32.8	None	650	90	56	39.8	None	–	–	–	–	–
			30	Tempered(a)	760	120	74	600	80	60	29.7	None	640	70	58	42.1	None	–	–	–	–	–
			60	Tempered	840	140	78	720	80	61	30.7	None	610	70	59	37.8	None	–	–	–	–	–
			120	Tempered	840	150	78	670	80	62	30.8	None	680	80	60	36.6	None	–	–	–	–	–
PA-225	120	48.8	30	None	810	530	63	800	70	63	28.9	None	710	70	60	36.3	None	1020	120	55	42.6	None
			60	None	770	390	69	840	70	65	27.7	None	880	70	61	34.2	None	980	100	60	40.6	None
			120	None	730	310	71	840	70	65	27.2	None	860	70	65	34.5	None	860	100	59	42.8	None
			30	Tempered	1020	120	84	920	70	70	26.0	None	880	70	65	32.4	None	980	90	62	38.8	None
			60	Tempered	1080	110	85	920	60	71	25.3	None	880	70	67	32.5	None	860	80	65	37.9	Edge cracking
			120	Tempered	1010	100	85	990	70	71	25.7	None	860	60	68	31.5	None	980	90	65	37.0	Edge cracking
PA-266	140	56.9	30	None	770	500	72	–	–	–	–	–	800	70	70	31.2	None	910	100	63	41.3	None
			60	None	850	430	76	–	–	–	–	–	860	60	71	31.7	None	440	70	64	37.0	None
			120	None	750	310	80	–	–	–	–	–	910	60	72	31.5	None	540	70	66	37.5	Cracked
			30	Tempered	1210	90	88	–	–	–	–	–	990	60	75	28.4	None	840	70	66	35.6	Cracked
			60	Tempered	1260	90	90	–	–	–	–	–	910	60	76	27.9	None	750	70	67	37.4	Cracked
			120	Tempered	1230	90	90	–	–	–	–	–	950	60	75	28.1	None	660	60	70	34.7	Cracked
PA-267	150	61.0	30	None	900	450	74	–	–	–	–	–	850	60	73	30.3	None	–	–	–	–	–
			60	None	890	400	75	–	–	–	–	–	540	50	69	33.1	None	–	–	–	–	–
			120	None	880	280	80	–	–	–	–	–	800	60	74	29.0	None	–	–	–	–	–
			30	Tempered	1460	80	90	–	–	–	–	–	870	50	77	26.1	None	–	–	–	–	–
			60	Tempered	1480	80	88	–	–	–	–	–	760	50	72	28.3	None	–	–	–	–	–
			120	Tempered	1470	70	91	–	–	–	–	–	880	50	76	26.8	None	–	–	–	–	–
PA-268	160	65.0	30	None	860	450	78	–	–	–	–	–	770	50	71	30.4	None	780	80	61	38.9	Edge cracking
			60	None	870	350	81	–	–	–	–	–	840	60	72	27.9	None	950	80	65	39.4	Cracked
			120	None	940	260	81	–	–	–	–	–	910	60	74	26.6	None	740	70	63	36.1	Cracked
			30	Tempered	1600	80	90	–	–	–	–	–	840	50	76	26.3	None	890	70	68	37.0	Cracked
			60	Tempered	1620	80	91	–	–	–	–	–	920	50	77	26.7	None	1020	70	71	33.2	Cracked
			120	Tempered	1560	70	91	–	–	–	–	–	980	50	77	28.0	None	740	60	68	32.3	Cracked

Note:

Base recipe:

Ingredients	Parts by Weight
Hycar 4021	100
Calcene NC	As shown
Stearic acid	1
Tetramethylthiuram disulfide	2
Triethylene tetramine	1.5

(a) All tempering was for 7 hours at 350 F.

TABLE 29. THE EFFECT OF CALCENE NC ON THE AGING OF HYCAR 4021 AT 400 F

Recipe	Vulcanizing Agent, phr: TETA	Vulcanizing Agent, phr: Sulfur	Vulcanizing Agent, phr: TMTD	Cure, minutes at 310 F	Original Physical Properties: Tensile Strength, psi	Original: Elongation, %	Original: Hardness, Shore A	After Aging in Penola Turbo Oil-15 72 Hours at 400 F: Tensile Strength, psi	72 Hours: Elongation, %	72 Hours: Hardness, Shore A	72 Hours: Swell %	72 Hours: Cracking	After Aging in Penola Turbo Oil-15 168 Hours at 400 F: Tensile Strength, psi	168 Hours: Elongation, %	168 Hours: Hardness, Shore A	168 Hours: Swell, %	168 Hours: Cracking
PA-291	1.5	–	2.0	30	620	500	62	660	60	62	33.0	None	630	60	61	35.5	None
				60	720	460	66	670	60	63	31.6	None	650	60	62	35.3	None
				120	640	350	66	830	60	63	31.1	None	670	60	63	37.7	None
PA-292	2.0	–	1.5	30	670	530	62	670	50	65	31.3	None	640	50	66	35.4	None
				60	650	410	67	700	50	66	27.8	None	710	50	67	33.1	None
				120	770	390	68	830	50	67	28.8	None	760	50	67	32.5	None
PA-293	2.5	–	1.0	30	790	400	64	490	40	71	28.0	Cracked	510	40	73	31.2	Cracked
				60	750	280	69	450	40	73	27.5	Cracked	520	40	73	31.3	Cracked
				120	710	190	72	520	40	74	25.7	Cracked	630	40	76	29.1	Cracked
PA-294	1.0	–	2.5	30	880	530	62	620	70	61	36.6	None	530	60	58	37.4	None
				60	860	430	70	630	60	64	35.6	None	530	60	61	36.3	None
				120	830	320	70	710	60	64	32.9	None	670	60	63	36.4	None
PA-295	0.5	–	3.0	30	770	940	54	520	80	53	43.1	None	500	70	51	37.7	None
				60	930	760	58	500	70	55	40.8	None	610	70	51	39.0	None
				120	880	520	62	680	80	58	39.1	None	550	70	54	37.0	None
PA-296	1.0	0.5	2.0	30	860	470	63	560	70	60	39.7	None	560	60	57	40.5	None
				60	930	320	72	850	70	62	34.8	None	770	70	61	39.5	None
				120	950	260	75	880	70	62	34.6	None	730	70	62	37.2	None
PA-297	1.5	0.5	1.5	30	920	300	70	870	70	62	34.0	None	740	60	62	38.4	None
				60	880	240	72	870	70	63	32.3	None	730	60	62	37.5	None
				120	890	200	76	930	70	65	31.9	None	790	60	63	35.8	None
PA-298	1.0	1.0	1.5	30	910	450	66	740	80	54	42.3	None	570	70	51	43.8	None
				60	980	420	66	700	90	54	42.9	None	450	70	51	44.6	None
				120	930	340	70	700	80	57	40.7	None	590	70	52	42.4	None
PA-299	0.5	2.0	1.0	30	540	580	60	410	150	35	49.2	None	300	100	31	41.4	None
				60	800	440	70	540	110	41	48.4	None	460	110	34	41.2	None
				120	810	310	73	810	130	43	46.0	None	520	110	36	45.0	None

Note:

Base Recipe:

Ingredients	Parts by Weight
Hycar 4021	100
Calcene NC	120
Stearic acid	1
Vulcanizing agents	As shown

All samples untempered.

TABLE 30. THE EFFECTS OF THERMAL BLACKS ON THE AGING OF HYCAR 4021

		Filler		Cure, minutes		Original Physical Properties			Physical Properties After Aging in Penola Turbo Oil-15 72 Hours at 350 F					Physical Properties After Aging in Penola Turbo Oil-15 168 Hours at 350 F					Physical Properties After Aging in Penola Turbo Oil-15 500 Hours at 350 F				
Recipe	Type	Phr by Weight	Phr by Volume	at 310 F	Treatment After Cure	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
PA-210	P-33	60	36.6	60	None	840	210	56	550	130	48	36.0	None	570	120	44	42.3	None	–	–	–	–	–
				120	None	930	210	58	600	140	50	35.0	None	550	110	50	40.7	None	–	–	–	–	–
				60	Tempered[a]	1000	180	66	600	120	50	39.5	None	580	120	49	42.7	None	–	–	–	–	–
				120	Tempered	930	160	67	580	130	50	38.7	None	610	120	50	43.5	None	–	–	–	–	–
PA-211	P-33	80	48.8	60	None	890	200	65	780	140	54	32.9	None	770	120	54	38.9	None	370	100	45	47.3	None
				120	None	960	170	66	720	130	57	30.8	None	740	110	54	33.3	None	410	100	52	47.1	None
				60	Tempered	1000	170	75	750	130	56	36.1	None	580	100	54	38.0	None	340	100	47	54.1	None
				120	Tempered	1000	150	76	700	120	58	33.8	None	650	110	57	39.2	None	420	100	53	49.7	None
PA-261	P-33	100	61.0	60	None	1010	160	75	–	–	–	–	–	890	100	62	34.5	None	–	–	–	–	–
				120	None	1110	150	77	–	–	–	–	–	940	110	65	35.0	None	–	–	–	–	–
PA-262	P-33	120	73.2	60	None	1100	110	81	–	–	–	–	–	1090	80	73	28.6	None	420	70	69	39.0	Cracked
				120	None	1200	110	83	–	–	–	–	–	1060	80	76	26.2	None	470	60	73	35.2	Cracked
PA-263	Themax	80	48.8	30	None	920	160	64	–	–	–	–	–	620	90	50	36.0	None	–	–	–	–	–
				60	None	1030	160	65	810	120	52	31.3	None	730	100	55	34.9	None	–	–	–	–	–
				120	None	1010	160	66	860	120	54	31.2	None	840	110	55	33.2	None	–	–	–	–	–
				30	Tempered	1000	130	71	780	110	52	34.7	None	780	130	51	38.9	None	–	–	–	–	–
				60	Tempered	870	110	72	800	110	53	33.1	None	820	120	54	37.2	None	–	–	–	–	–
				120	Tempered	900	110	72	760	110	54	34.2	None	800	120	53	38.1	None	–	–	–	–	–
PA-264	Themax	100	61.0	30	None	950	160	71	1060	130	57	29.5	None	890	100	57	33.0	None	–	–	–	–	–
				60	None	1070	140	72	1060	120	56	30.1	None	920	100	57	32.6	None	–	–	–	–	–
				120	None	1000	120	74	980	110	58	28.2	None	910	90	61	30.2	None	–	–	–	–	–
				30	Tempered	1050	120	77	880	100	59	30.8	None	830	100	60	35.6	None	–	–	–	–	–
				60	Tempered	1020	110	77	970	110	58	32.4	None	880	110	54	36.7	None	–	–	–	–	–
				120	Tempered	1020	100	80	960	110	59	29.8	None	860	110	59	33.6	None	–	–	–	–	–
PA-265	Themax	120	73.2	30	None	900	130	80	1190	100	65	25.5	None	1140	90	68	28.1	None	250	80	53	39.5	Cracked
				60	None	960	130	73	1170	90	66	24.6	None	1060	80	68	28.1	None	430	90	57	33.7	Cracked
				120	None	1030	100	82	1170	80	67	25.7	None	1040	80	69	26.2	None	200	70	59	43.8	Cracked
				30	Tempered	1110	100	86	1070	90	66	28.3	None	950	80	68	30.4	None	–	–	–	–	–
				60	Tempered	1000	110	79	980	90	68	26.7	None	930	80	67	31.7	None	–	–	–	–	–
				120	Tempered	1150	90	87	1210	90	68	26.3	None	1020	80	68	28.8	None	–	–	–	–	–

Note:

Base recipe:

Ingredients	Parts by Weight
Hycar 4021	100
Filler	As shown
Stearic acid	1
Sulfur	0.9
Tetramethylthiuram disulfide	1.0
Triethylene tetramine	2.1

(a) All tempering was for 7 hours at 350 F.

TABLE 31. THE EFFECTS OF NONEXTRACTABLE PLASTICIZERS ON THE AGING OF HYCAR 4021 AT 350 F

	Plasticizer			Original Physical Properties			Physical Properties After Aging in Penola Turbo Oil-15 72 Hours at 350 F					Physical Properties After Aging in Penola Turbo Oil-15 168 Hours at 350 F					Physical Properties After Aging in Penola Turbo Oil-15 500 Hours at 350 F				
Recipe	Type	Phr by Weight	Cure, minutes at 310 F	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
PA-254	None	–	60	1150	270	85	900	60	76	28.7	None	970	70	75	34.2	None	1120	90	72	39.8	None
			120	1210	210	88	970	60	80	26.9	None	940	60	79	30.7	None	1110	70	73	36.9	None
PA-255	Hycar 4001 x 11	10	60	960	390	86	1000	70	77	26.0	None	990	70	75	30.2	None	–	–	–	–	–
			120	990	320	86	1000	60	80	26.1	None	1070	70	79	27.8	None	–	–	–	–	–
PA-256	Hycar 4001 x 11	20	60	900	540	70	700	80	63	27.9	None	800	90	64	31.0	None	890	110	60	37.8	None
			120	750	400	74	810	80	71	25.3	None	880	80	71	27.9	None	960	90	69	34.4	None
PA-184	DPR N-27	10	60	800	330	77	860	60	73	28.2	None	800	50	72	29.4	None	1100	70	75	37.6	None
			120	890	210	80	910	50	75	25.7	None	1060	40	76	28.4	None	1150	60	78	34.1	None
PA-185	DPR N-27	20	60	840	630	71	710	70	66	30.0	None	750	70	72	31.7	None	980	70	80	39.8	None
			120	960	480	71	680	50	70	29.6	None	740	60	73	30.7	None	930	70	77	36.4	None

Note:

Base recipe:

Ingredients	Parts by Weight
Hycar 4021	100
Silene EF	70
Plasticizer	As shown
Stearic acid	1
Tetramethylthiuram disulfide	2
Triethylene tetramine	1.5

All samples untempered.

TABLE 32. THE EFFECTS OF NONEXTRACTABLE PLASTICIZERS ON THE AGING OF SILENE EF-FILLED HYCAR 4021 AT 400 F

Recipe	Plasticizer		Cure, minutes	Original Physical Properties			Physical Properties After Aging in Penola Turbo Oil-15 72 Hours at 400 F					Physical Properties After Aging in Penola Turbo Oil-15 168 Hours at 400 F					Physical Properties After Aging in Penola Turbo Oil-15 500 Hours at 400 F				
	Type	Phr	at 310 F	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
PA-285	None	–	30	970	260	82	800	50	75	28.2	Cracked	700	40	74	30.0	Cracked	–	–	–	–	–
			60	1000	210	83	870	50	77	26.0	Cracked	630	40	75	27.3	Cracked	–	–	–	–	–
			120	990	160	85	930	50	80	24.4	Cracked	850	40	78	29.8	Cracked	–	–	–	–	–
PA-283	DPR N-27	10	30	790	610	72	560	50	70	32.9	Cracked	640	50	71	33.8	None	–	–	–	–	–
			60	840	440	74	710	50	72	28.2	Cracked	770	50	73	30.4	Cracked	–	–	–	–	–
			120	870	290	77	810	50	75	25.4	Cracked	840	50	75	27.9	Cracked	–	–	–	–	–
PA-284	DPR N-27	20	30	670	810	64	440	50	67	30.9	None	550	60	68	34.1	None	380	50	72	70.6	Cracked
			60	720	610	68	500	50	69	27.5	None	640	50	70	29.5	None	510	50	75	61.4	Cracked
			120	770	390	71	520	50	71	25.9	Cracked	670	50	73	28.8	None	520	40	78	50.7	Cracked
PA-286	Hycar 4001 x 11	20	30	750	640	61	420	70	54	35.8	None	430	60	58	36.6	None	110	50	45	84.4	Cracked
			60	700	480	68	610	70	61	31.2	None	530	60	62	33.2	None	100	50	47	94.3	Cracked
			120	690	380	72	680	70	65	29.0	None	560	60	65	36.5	None	90	50	50	81.2	Cracked
PA-287	Hycar 4001 x 11	30	30	600	710	57	340	70	51	33.0	None	310	60	52	34.4	None	–	–	–	–	–
			60	580	540	62	500	70	57	29.1	None	390	60	57	30.4	None	–	–	–	–	–
			120	590	480	66	510	70	61	27.7	None	440	60	59	31.3	None	–	–	–	–	–

Note:

Base recipe:

Ingredients	Parts by weight
Hycar 4021	100
Silene EF	70
Stearic acid	1
Plasticizer	As shown
Tetramethylthiuram disulfide	2
Triethylene tetramine	1.5

All samples untempered.

TABLE 33. THE EFFECT OF AGERITE RESIN D ON THE AGING OF HYCAR 4021

				Original Physical Properties			Physical Properties After Aging in Penola Turbo Oil-15 168 Hours at 350 F					Physical Properties After Aging in Penola Turbo Oil-15 500 Hours at 350 F				
Recipe	AgeRite Resin D, phr by weight	Cure, minutes at 310 F	Treatment After Cure	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Tensile Strength psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
PA-231	0	60	None	1680	200	66	550	90	52	46.0	None	490	130	40	62.1	Cracked
		120	None	1610	170	68	620	90	54	41.9	None	340	110	41	71.4	Cracked
PA-232	1	60	None	1730	220	65	650	90	52	44.6	None	280	100	40	70.4	Cracked
		120	None	1710	190	67	630	80	55	42.3	None	420	100	42	69.9	Cracked
PA-233	5	60	None	1650	240	64	580	70	58	36.4	None	340	70	57	58.4	Cracked
		120	None	1650	200	67	600	60	60	35.1	None	280	60	60	50.9	Cracked
PA-270	0	60	None	1230	280	81	940	80	69	33.3	None	1120	90	71	43.7	None
		120	None	1260	220	85	920	60	75	31.8	None	1060	90	70	40.1	None
		60	Tempered(a)	1370	100	87	1040	70	72	32.5	None	980	80	70	42.9	None
		120	Tempered	1330	80	87	980	60	77	31.0	None	1020	80	73	38.4	Edge cracking
PA-271	1	60	None	1060	260	82	900	70	71	32.3	None	1000	90	69	40.3	None
		120	None	1090	210	85	970	60	74	29.1	None	960	70	71	40.4	Edge cracking
		60	Tempered	1310	90	89	1030	60	77	29.9	None	1030	80	73	39.8	None
		120	Tempered	1330	80	90	1010	60	77	29.9	Cracked	970	80	74	39.2	None
PA-272	5	60	None	1070	280	81	1000	70	72	27.6	None	920	70	70	34.1	Cracked
		120	None	1110	240	82	1010	60	75	26.8	None	1110	70	71	35.1	Cracked
		60	Tempered	1440	90	87	1090	60	75	29.9	None	970	70	74	36.6	Cracked
		120	Tempered	1500	90	89	1130	60	76	29.1	None	1130	70	75	36.8	Cracked

Note:
Recipes used:

Ingredients	Parts by Weight PA-231 to -233	Parts by Weight PA-270 to -272
Hycar 4021	100	100
Philblack A	40	–
Silene EF	–	70
Stearic acid	1	1
AgeRite Resin D	As shown	As shown
Sulfur	0.9	–
Tetramethylthiuram disulfide	1	2
Triethylene tetramine	2.1	1.5

(a) All tempering was for 7 hours at 350 F.

TABLE 34. THE EFFECTS OF FILLERS ON THE AGING OF ACRYLON EA-5

	Filler		Cure, minutes		Original Physical Properties			Physical Properties After Aging in Penola Turbo Oil-15 72 Hours at 350 F					Physical Properties After Aging in Penola Turbo Oil-15 168 Hours at 350 F					Physical Properties After Aging in Penola Turbo Oil-15 500 Hours at 350 F				
Recipe	Type	Phr by Weight	at 310 F	Treatment After Cure	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
PA-203	Calcene NC	70	30	None	1020	640	53	880	440	30	43.5	None	870	330	32	46.5	None	–	–	–	–	–
			60	None	1130	510	58	860	300	35	35.2	None	720	210	36	40.9	None	–	–	–	–	–
			120	None	1080	370	61	–	–	–	–	–	740	160	43	36.5	None	–	–	–	–	–
			30	Tempered[a]	1280	470	62	920	420	32	42.8	None	830	340	31	45.9	None	–	–	–	–	–
			60	Tempered	1310	340	67	980	320	38	38.5	None	770	220	40	40.5	None	–	–	–	–	–
			120	Tempered	1340	260	72	–	–	–	–	–	610	140	48	38.2	None	–	–	–	–	–
PA-240	Calcene NC	80	30	None	1170	480	65	–	–	–	–	–	930	200	47	34.4	None	330	80	60	30.5	Cracked
			60	None	1230	370	71	–	–	–	–	–	890	150	58	31.8	None	390	50	74	24.4	Cracked
			120	None	1280	290	77	–	–	–	–	–	840	110	65	28.1	None	–	–	–	–	–
			30	Tempered	1390	300	80	–	–	–	–	–	1010	190	50	35.7	None	340	90	61	29.2	Cracked
			60	Tempered	1380	220	82	–	–	–	–	–	890	140	59	30.9	None	450	60	75	25.9	Cracked
			120	Tempered	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
PA-241	Calcene NC	100	60	None	1470	290	86	–	–	–	–	–	1570	170	67	26.9	None	560	40	87	22.1	Cracked
			120	None	1470	250	90	–	–	–	–	–	940	80	76	23.2	Cracked	–	–	–	–	–
			60	Tempered	1720	200	89	–	–	–	–	–	1040	90	69	25.9	Cracked	–	–	–	–	–
			120	Tempered	1680	150	92	–	–	–		–	860	70	75	24.2	Cracked	–	–	–	–	–
PA-242	Calcene NC	120	60	None	1580	260	88	–	–	–	–	–	1130	90	76	23.3	Cracked	–	–	–	–	–
			120	None	1650	200	91	–	–	–	–	–	940	60	83	21.6	Cracked	–	–	–	–	–
			60	Tempered	1780	140	93	–	–	–	–	–	1040	70	76	23.6	Cracked	–	–	–	–	–
			120	Tempered	1840	110	95	–	–	–	–	–	850	40	84	19.8	Cracked	–	–	–	–	–
PA-243	Valron Estersil	41.3	30	None	1390	500	88	1490	180	87	22.2	None	1300	100	87	25.0	Cracked	–	–	–	–	–
			60	None	1440	430	90	1500	140	89	20.2	None	1380	80	91	22.0	Cracked	–	–	–	–	–
			120	None	1550	360	91	1870	130	90	18.4	None	1440	60	92	20.3	Cracked	–	–	–	–	–
PA-244	Valron Estersil	31.0	30	None	1320	470	81	1310	220	78	26.2	None	1020	120	81	30.2	Edge cracking	–	–	–	–	–
			60	None	1250	360	84	1420	170	82	23.8	None	980	90	83	26.4	Cracked	–	–	–	–	–
			120	None	1340	340	84	1420	160	84	21.4	None	1070	90	85	23.8	Cracked	–	–	–	–	–
PA-245	Valron Estersil	20.7	30	None	1030	530	70	820	340	58	37.6	None	500	150	62	38.5	None	–	–	–	–	–
			60	None	1170	450	71	900	280	62	35.4	None	540	130	67	33.7	None	–	–	–	–	–
			120	None	1030	330	72	1010	220	67	30.9	None	570	90	71	30.0	Cracked					

Note:

Base recipe:

Ingredients	Parts by Weight
Acrylon EA-5	100
Filler	As shown
Stearic acid	1.0
Tetramethylthiuram disulfide	1.0
Sulfur	0.9
Triethylene tetramine	2.1

(a) All tempering was for 7 hours at 3^0 F.

TABLE 35. THE EFFECTS OF AGERITE RESIN D ON THE AGING OF ACRYLON EA-5

				Original Physical Properties			Physical Properties After Aging in Penola Turbo Oil-15 72 Hours at 350 F					Physical Properties After Aging in Penola Turbo Oil-15 168 Hours at 350 F					Physical Properties After Aging in Penola Turbo Oil-15 500 Hours at 350 F				
Recipe	AgeRite Resin D, phr by weight	Cure, minutes at 310 F	Treatment After Cure	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
PA-213	0	30	None	1430	570	72	1100	450	31	47.0	None	580	280	34	40.8	None	770	40	90	10.2	Cracked
		60	None	1640	480	73	1230	460	33	45.5	None	610	250	38	35.0	None	730	30	92	12.5	Cracked
		120	None	1750	410	76	1400	360	40	40.2	None	480	190	44	33.7	None	600	40	88	13.9	Cracked
		30	Tempered[(a)]	1710	370	80	1250	370	40	42.1	None	560	250	38	37.0	None	350	40	82	23.4	Cracked
		60	Tempered	1900	320	80	1130	410	41	42.6	None	280	140	44	33.2	None	600	30	80	18.3	Cracked
		120	Tempered	1770	260	82	1270	330	46	38.8	None	480	170	47	33.6	None	490	30	89	14.8	Cracked
PA-234	1	30	None	1900	340	70	1360	250	53	36.6	None	650	170	45	32.4	None	500	50	85	15.4	Cracked
		60	None	2120	300	71	1520	200	57	33.8	None	730	130	58	34.1	None	670	40	91	14.6	Cracked
		120	None	2210	260	75	1500	180	57	32.7	None	500	80	65	28.4	Cracked	810	30	93	12.7	Cracked
		30	Tempered	1900	230	85	1330	220	57	37.6	None	570	140	56	38.5	None	980	10	97	17.7	Cracked
		60	Tempered	2030	180	86	1390	170	62	34.0	None	580	110	61	37.5	None	860	10	97	17.7	Cracked
		120	Tempered	1960	150	88	1150	150	61	36.5	None	470	70	67	35.0	Cracked	920	10	97	18.8	Cracked
PA-235	5	30	None	1970	400	67	1350	280	48	33.7	None	580	150	55	36.0	None	360	60	77	14.2	Cracked
		60	None	1960	380	70	1280	230	55	32.0	None	710	140	55	31.4	None	480	40	86	16.8	Cracked
		120	None	2070	320	73	1230	200	56	29.8	None	650	120	57	30.5	None	430	30	86	12.8	Cracked
		30	Tempered	1710	200	84	900	190	55	38.5	None	480	130	54	41.3	None	430	20	88	20.9	Cracked
		60	Tempered	1680	180	88	770	150	60	36.5	None	440	90	61	37.8	Cracked	660	10	95	21.8	Cracked
		120	Tempered	1560	150	90	670	110	61	34.1	None	510	80	65	37.3	Cracked	700	10	95	19.7	Cracked
PA-226	0	60	None	1230	500	80	–	–	–	–	–	1070	300	64	38.8	None	730	240	67	39.4	None
		120	None	1510	330	81	–	–	–	–	–	1370	150	67	32.0	None	1030	120	75	29.6	Cracked
		60	Tempered	1560	440	87	–	–	–	–	–	910	310	62	41.9	None	600	190	63	41.6	Edge cracking
		120	Tempered	1750	300	88	–	–	–	–	–	1340	160	67	34.0	None	1090	130	74	34.3	Cracked
PA-229	1	60	None	1230	590	83	–	–	–	–	–	1160	350	66	39.5	None	740	240	67	36.5	Edge cracking
		120	None	1650	410	83	–	–	–	–	–	1460	180	68	31.7	None	1150	140	77	29.7	Cracked
		60	Tempered	1710	480	88	–	–	–	–	–	1000	320	64	41.3	None	870	260	70	38.5	Edge cracking
		120	Tempered	1900	320	90	–	–	–	–	–	1340	170	70	33.0	None	1190	140	75	33.1	Cracked
PA-230	5	60	None	1030	730	80	–	–	–	–	–	1040	380	62	35.0	None	720	220	73	35.2	Edge cracking
		120	None	1610	540	82	–	–	–	–	–	1480	240	74	28.0	None	940	130	81	27.7	Cracked
		60	Tempered	1740	410	90	–	–	–	–	–	1000	370	64	37.6	None	780	190	73	38.3	Cracked
		120	Tempered	1970	330	91	–	–	–	–	–	1440	230	73	32.6	None	1040	120	83	33.6	Cracked

Note:
Recipes used:

	Parts by Weight					
Ingredients	PA-213	PA-234	PA-235	PA-226	PA-229	PA-230
Acrylon EA-5	100	100	100	100	100	100
Philblack A	50	50	50	–	–	–
Silene EF	–	–	–	70	70	70
Stearic acid	1	1	1	1	1	1
AgeRite Resin D	As shown					
Sulfur	1	1	1	0.9	0.9	0.9
Tetramethylthiuram disulfide	–	–	–	1	1	1
Triethylene tetramine	1.5	1.5	1.5	2.1	2.1	2.1

(a) All tempering was for 7 hours at 350 F.

TABLE 36. THE EFFECTS OF SILICA FILLERS ON THE AGING OF POLY-FBA

	Filler			Original Physical Properties			Physical Properties After Aging in Penola Turbo Oil-15 168 Hours at 350 F					Physical Properties After Aging in Penola Turbo Oil-15 500 Hours at 350 F				
Recipe	Material	Phr	TETA, phr	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
FBA-42	Cab-O-Sil[a]	20	1.0	1280	570	45	890	490	52	8.3	None	270	580	45	10.9	None
FBA-43	Cab-O-Sil	20	1.2	1300	500	48	790	330	56	6.5	None	440	410	56	8.8	None
FBA-44	Cab-O-Sil	15	1.0	790	400	43	650	300	53	7.5	None	420	350	52	9.9	None
FBA-45	Cab-O-Sil	15	1.2	820	330	45	630	240	59	7.6	None	430	250	54	9.9	None
FBA-46	Valron Estersil[b]	20	1.0	860	630	59	840	430	65	8.1	None	400	120	76	18.0	None
FBA-47	Valron Estersil	20	1.2	930	550	64	660	210	76	7.1	None	470	90	80	17.1	None
FBA-48	Valron Estersil	25	1.0	1010	510	75	710	180	85	7.7	None	750	40	90	16.4	None
FBA-49	Valron Estersil	25	1.2	1040	460	72	740	90	87	8.4	None	830	40	91	10.9	Cracked
FBA-50	Valron Estersil[c]	20	1.0	640	570	52	350	420	56	6.2	None	80	370	49	12.2	None
FBA-51	Valron Estersil[c]	20	1.2	710	470	57	410	390	54	6.9	None	130	350	45	12.6	None
FBA-52	Valron Estersil[c]	25	1.0	Was not tested												
FBA-53	Valron Estersil[c]	25	1.2	780	360	65	450	250	62	7.3	None	130	220	55	14.3	None

Note:

Base recipe:

Ingredients	Parts by Weight
Poly-FBA	100
Paraffin	1.0
Sulfur	1.0
Filler	As shown
Triethylene tetramine	As shown

Cure: 60 minutes at 310 F.

(a) Cab-O-Sil formerly was sold under the name Aerosil.
(b) Valron Estersil formerly was known as Du Pont Hydrophobic Silica and Du Pont Fine Silica.
(c) The Estersil was preheated sufficiently to drive off approximately one-half of its organic surface coating.

TABLE 37. THE EFFECTS OF CAB-O-SIL[a]–PHILBLACK O BLENDS ON THE AGING OF POLY-FBA

			Original Physical Properties			Physical Properties After Aging in Penola Turbo Oil-15 168 Hours at 350 F					Physical Properties After Aging in Penola Turbo Oil-15 500 Hours at 350 F				
Recipe	Cab-O-Sil[a], phr	Philblack O, phr	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
FBA-54	20	5	1160	460	66	680	330	63	8.3	None	370	270	63	9.3	None
FBA-55	20	10	1120	450	66	670	300	60	9.0	None	410	260	62	8.9	None
FBA-56	15	10	1270	440	63	790	310	59	8.6	None	540	300	61	9.0	None
FBA-57	15	15	1140	470	62	710	310	58	6.5	None	410	260	58	10.6	None
FBA-58	10	20	1270	370	67	860	280	61	5.0	None	540	270	67	9.1	None
FBA-59	10	25	Tore apart when taken from the mold												
FBA-60	5	30	1160	360	66	780	260	56	6.4	None	450	230	61	6.3	None
FBA-61[b]	15	10	1230	390	57	970	300	62	4.5	None	640	300	60	5.5	None
FBA-62[b]	15	15	1230	380	57	980	280	62	5.9	None	590	260	62	7.6	None
FBA-63[b]	10	20	1340	280	60	940	190	67	7.1	None	700	180	67	5.7	None

Note:

Base recipe:

Ingredients	Parts by Weight
Poly-FBA	100
Paraffin	1
Fillers	As shown
Sulfur	1
Triethylene tetramine	1.2

Cure: 60 minutes at 310 F.

(a) Formerly sold under the name Aerosil.
(b) Triethylene tetramine was increased to 1.4 phr.

TABLE 38. THE EFFECT OF AGING TEMPERATURE ON THE BEST POLY-FBA COMPOUNDS

			Original Physical Properties				Physical Properties After Aging in Penola Turbo Oil-15 72 Hours					Physical Properties After Aging in Penola Turbo Oil-15 168 Hours					Physical Properties After Aging in Penola Turbo Oil-15 500 Hours				
Recipe	Cab-O-Sil, phr	Philblack O, phr	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Aging Temperature, F	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
FBA-61	15	10	1230	390	57	350	–	–	–	–	–	970	300	62	4.5	None	640	300	60	5.5	None
FBA-68	15	10	1350	390	60	400	830	200	61	4.5	None	590	170	63	5.7	None	290	60	72	3.8	None
FBA-63	10	20	1340	280	60	350	–	–	–	–	–	940	190	67	7.1	None	700	180	67	5.7	None
FBA-69	10	20	1490	380	60	400	910	180	62	3.4	None	600	170	63	4.2	None	350	70	73	3.8	None
FBA-62	15	15	1230	380	57	350	–	–	–	–	–	980	280	62	5.9	None	590	260	62	7.6	None
FBA-70	–	40	1230	280	71	400	830	130	71	3.1	None	740	160	69	4.6	None	400	50	81	1.1	Crazed
FBA-71[(a)]	–	40	1330	220	72	400	900	140	71	3.2	None	710	120	74	3.1	None	390	40	83	0.2	Cracked

Note:
Base recipe:

Ingredients	Parts by Weight
Poly-FBA	100
Paraffin	1
Fillers	As shown
Sulfur	1.0
Triethylene tetramine	1.4

Cure: 60 minutes at 310 F.

(a) FBA-71 contained 1.6 phr of triethylene tetramine.

TABLE 39. COMPRESSION SET OF POLY-FBA COMPOSITIONS

Recipe	Treatment After Cure	Hardness, Shore A	Compression Set[a], %
FBA-1	Untempered	63	98
FBA-2	Untempered	66	-
	Tempered[b]	71	95
FBA-19	Untempered	43	93
FBA-20	Untempered	44	89
FBA-31	Untempered	72	100
	Tempered	78	85
FBA-32	Untempered	74	100
FBA-35	Untempered	55	-
	Tempered	66	90
FBA-43	Untempered	48	77
	Tempered	48	72
FBA-45	Untempered	45	-
	Tempered	45	69

Note:

Base recipes:

Ingredients	Parts by Weight								
	FBA-1	FBA-2	FBA-19	FBA-20	FBA-31	FBA-32	FBA-35	FBA-43	FBA-45
Poly-FBA	100	100	100	100	100	100	100	100	100
Philblack O	35	-	35	-	-	-	35	-	-
Philblack A	-	-	-	35	-	-	-	-	-
Philblack E	-	35	-	-	-	-	-	-	-
Cab-O-Sil[c]	-	-	-	-	25	25	-	20	15
Paraffin	1	1	-	-	1	1	1	1	1
Sulfur	1	1	1	1	1	1	1	1	1
Triethylene tetramine	1	1.25	1	1	1.1	1.2	1	1.2	1.2

Cure: 60 minutes at 310 F.

(a) 168 hours at 350 F in Turbo Oil-15.

(b) All tempering was for 4 hours at 350 F.

(c) Formerly sold under the name Aerosil.

TABLE 40. SUMMARY OF BEST STOCKS PREPARED IN HYDRAULIC-FLUID PROGRAM

		Original Physical Properties					Physical Properties After Aging in OS-45 at 400 F					Physical Properties After Aging in MLO-8200 at 400 F					Physical Properties After Aging in 85/15 MLO-8200/DOS Blend at 400 F				
Recipe	Base Polymer	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Brittle Point, F	Aging Time, hours	Tensile Strength, psi	Elonga-%	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elonga-%	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elonga-%	Hardness, Shore A	Swell, %	Cracking
A-385	Hycar 1014	800	640	56	−54	72	600	90	77	15.6	None	770	80	86	4.6	Cracked	580	90	77	14.3	None
						168	940	50	89	12.4	Cracked	1490	50	93	1.7	Cracked	1080	60	89	9.5	Cracked
						336	1670	40	93	11.4	Cracked	3100	20	98	−0.5	Cracked	2130	40	95	5.9	Cracked
VP-36	Philprene VP-25	3320	300	77	<−71	72	460	100	67	28.3	None	870	130	75	12.5	None	750	130	70	22.8	None
						168	470	80	71	25.3	None	1010	80	84	7.8	Cracked	750	90	76	18.6	None
						336	590	70	76	20.6	Cracked	1330	70	85	6.4	Cracked	1150	80	81	13.4	Cracked
VP-37	Philprene VP-A	2670	380	76	−72	72	530	120	69	12.9	None	790	130	74	6.3	None	640	130	68	13.7	None
						168	730	70	79	11.2	None	1270	80	84	5.0	None	800	90	78	11.9	None
						336	1890	50	94	9.5	Cracked	2890	50	98	2.8	Cracked	1610	60	90	9.8	Cracked
VP-38	Philprene VP-A	2970	370	78	−45	72	700	110	73	10.5	None	1310	150	77	4.0	None	1200	160	75	11.0	None
						168	890	70	83	10.2	Edge cracking	2070	100	91	3.3	None	1590	110	83	9.5	None
						336	2110	40	95	9.3	Cracked	3710	40	99	0.6	Cracked	2740	50	96	7.1	Cracked
PA-300	Acrylon BA-12	720	240	59	−53	72	410	200	49	23.0	None	580	210	58	6.9	None	350	190	49	23.7	None
						168	450	210	51	21.8	None	570	180	65	5.0	None	470	210	52	20.3	None
						336	190	240	39	35.5	None	420	190	56	7.6	None	230	230	40	27.2	None
						500	250	230	42	29.9	None	410	200	53	7.6	None	200	200	43	26.2	None
PA-302	Acrylon BA-12	310	530	71	−39	72	370	560	54	25.6	None	730	530	67	11.0	None	430	540	48	26.4	None
						168	390	530	49	29.7	None	600	520	65	10.6	None	390	520	47	31.1	None
						336	130	430	42	31.0	None	450	500	59	12.4	None	200	470	42	28.5	None
						500	10	380	38	27.4	None	390	450	57	14.1	None	200	450	39	28.2	None
N-34	Neoprene WRT	1540	370	66	−60	72	670	150	66	6.0	None	1670	140	79	−0.4	None	930	150	69	9.6	None
						168	930	90	82	3.5	Cracked	4630	10	100	15.9	Cracked	890	100	79	15.0	None
N-14	Neoprene WRT	1400	600	66	–	72	450	130	65	7.4	None	860	180	72	−3.3	None	530	190	61	10.5	None
						168	450	100	68	5.9	None	750	140	74	−1.9	None	590	160	66	10.0	None
N-13	Neoprene WRT	2400	620	73	–	72	970	160	88	9.4	None	1350	170	89	1.6	None	1050	210	85	12.8	None
						168	550	90	80	24.9	None	890	10	96	28.3	Cracked	660	130	75	26.6	None
N-101	Neoprene WRT	3010	700	68	–	72	910	250	75	10.8	None	1520	320	80	3.0	None	950	280	75	12.8	None
						168	790	140	87	11.2	None	Cap blew off test tube					630	170	69	28.1	None
N-3B (26-C)	Neoprene WRT	2270	230	68	–	72	710	70	76	11.4	None	1240	70	83	10.5	Cracked	1090	120	71	11.5	None
						168	640	40	84	14.0	Cracked	1840	10	100	38.6	Cracked	1300	60	85	22.1	Cracked

Note:

Base recipes:

	Parts by Weight					
Ingredients	A-385	VP-36	VP-37	VP-38	PA-300	PA-302
Hycar 1014	100	–	–	–	–	–
Philprene VP-25	–	100	–	–	–	–
Philprene VP-A	–	–	100	100	–	–
Acrylon BA-12	–	–	–	–	100	100
Hi-Sil	60	–	–	–	–	60
Cab-O-Sil	–	40	40	40	–	–
Philblack A	–	–	–	–	40	–
Zinc oxide	5	3	3	3	–	–
Stearic acid	1.5	1.5	1.5	1.5	1.0	1.0
Plasticizer SC	1.0	–	–	–	–	–
TP-90B	–	–	–	–	20	20
Sulfur	0.5	1.5	1.5	1.5	0.9	0.9
Tetramethylthiuram disulfide	0.25	–	–	–	1.0	1.0
Benzothiazyl disulfide	–	1.5	1.5	1.5	–	–
Triethylene tetramine	–	–	–	–	2.1	2.1
Benzotrichloride	–	5	–	5	–	–
Benzal chloride	–	–	5	–	–	–
Cure, minutes at 310 F	60	30	30	30	60	60

Neoprene base recipes:

	Parts by Weight				
Ingredients	N-34	N-14	N-13	N-101	N-3B
Neoprene WRT	100	100	100	100	100
Magnesia	4	4	4	4	4
Continex SRF	15	–	–	–	40
Thermax	15	–	–	–	40
Silene EF	–	60	–	–	–
Cab-O-Sil	–	–	45	40	–
Butyl oleate	15	15	15	15	15
Zinc oxide	80	2.5	2.5	2.5	2.5
NA-22	1.0	1.0	1.0	0.6	1.0

N-3B cured 20 minutes at 310 F. All others cured 30 minutes at 310 F.

TABLE 41. SUMMARY TABLE SHOWING THE BEST COMPOUNDS FOR TURBO OIL-15 APPLICATIONS

				Original Physical Properties			Physical Properties After Aging in Penola Turbo Oil-15 72 Hours					Physical Properties After Aging in Penola Turbo Oil-15 168 Hours					Physical Properties After Aging in Penola Turbo Oil-15 500 Hours				
Recipe	Base Polymer	Cure, minutes at 310 F	Treatment After Cure	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking	Tensile Strength, psi	Elongation, %	Hardness, Shore A	Swell, %	Cracking
										Aging Temperature 350 F											
A-23L	Hycar 1001	60	None	2000	680	70	1270	370	71	27.1	Cracked	840	160	78	26.8	Cracked	650	90	80	24.0	Cracked
A-319	Hycar 1001	60	None	2460	610	77	1940	280	77	17.9	Cracked	1300	190	80	17.2	Cracked	750	80	85	16.1	Cracked
FBA-61	Poly-FBA	60	None	1230	390	57	–	–	–	–	–	970	300	62	4.5	None	640	300	60	5.5	None
FBA-63	Poly-FBA	60	None	1340	280	60	–	–	–	–	–	940	190	67	7.1	None	700	180	67	5.7	None
PA-95	Hycar 4021	30	None	1080	430	85	760	80	74	35.4	None	800	90	71	37.6	None	1000	100	64	42.7	None
			Tempered[a]	1260	100	93	900	80	80	28.6	None	940	80	79	30.8	None	1240	90	72	35.7	None
PA-184	Hycar 4021	60	None	800	330	77	860	60	73	28.2	None	800	50	72	29.4	None	1100	70	75	37.6	None
			Tempered	1210	100	86	980	50	80	24.0	Cracked	1030	50	78	28.5	None	1130	60	80	34.3	None
		120	None	890	210	80	910	50	75	25.7	None	1060	40	76	28.4	None	1150	60	78	34.1	None
			Tempered	1320	90	88	1010	50	80	24.0	Cracked	1010	40	79	28.8	None	1240	60	83	33.3	Cracked
PA-225	Hycar 4021	30	None	810	530	63	800	70	63	28.9	None	710	70	60	36.3	None	1020	120	55	42.6	None
			Tempered	1020	120	84	920	70	70	26.0	None	880	70	65	32.4	None	980	90	62	38.8	None
		60	None	770	390	69	840	70	65	27.7	None	880	70	61	34.2	None	980	100	60	40.6	None
			Tempered	1080	110	85	920	60	71	25.3	None	880	70	67	32.5	None	860	80	65	37.9	Edge cracking
		120	None	730	310	71	840	70	65	27.2	None	860	70	65	34.5	None	860	100	59	42.8	None
			Tempered	1010	100	85	990	70	71	25.7	None	860	60	68	31.5	None	980	90	65	37.0	Edge cracking
										Aging Temperature 400 F											
FBA-68	Poly-FBA	60	None	1350	390	60	830	200	61	4.5	None	590	170	63	5.7	None	290	60	72	3.8	None
FBA-69	Poly-FBA	60	None	1490	380	60	910	180	62	3.4	None	600	170	63	4.2	None	350	70	73	3.8	None
PA-284	Hycar 4021	30	None	670	810	64	440	50	67	30.9	None	550	60	68	34.1	None	380	50	72	70.6	Cracked
		60	None	720	610	68	500	50	69	27.5	None	640	50	70	29.5	None	510	50	75	61.4	Cracked
		120	None	770	390	71	520	50	71	25.9	Cracked	670	50	73	28.8	None	520	40	28	50.7	Cracked

Note:
Base recipes:

Hycar 4021

Ingredients	PA-95	PA-184	PA-225	PA-284
	Parts by Weight			
Hycar 4021	100	100	100	100
Silene EF	70	70	–	70
Calcene NC	–	–	120	–
DPR N-27	–	10	–	20
Stearic acid	1	1	1	1
Tetramethylthiuram disulfide	2	2	2	2
Triethylene tetramine	1.5	1.5	1.5	1.5

Hycar 1001

Ingredients	A-23L	A-319
	Parts by Weight	
Hycar 1001	100	100
Magnesia ELC	100	100
Zinc oxide	5	5
Stearic acid	1.5	1.5
Sulfur	0.5	0.5
Flectol H	–	3
Thioglycolic acid	–	5.2
Tetramethylthiuram disulfide	0.25	0.5

Poly-FBA

Ingredients	FBA-61 and -68	FBA-63 and -69
	Parts by Weight	
Poly-FBA	100	100
Paraffin	1	1
Cab-O-Sil	15	10
Philblack O	10	20
Sulfur	1.0	1.0
Triethylene tetramine	1.4	1.4

(a) All tempering was for 7 hours at 350 F.

SOURCE OF COMPOUNDING MATERIALS

Material	Composition	Source
Acrylon EA-5	Copolymer of ethyl acrylate and acrylonitrile	American Monomer Corporation
Acrylon BA-12	Copolymer of butyl acrylate and acrylonitrile	American Monomer Corporation
AgeRite Powder	Phenyl-beta-naphthylamine	R. T. Vanderbilt Company
AgeRite Resin D	Poly-trimethyldihydro-quinoline	R. T. Vanderbilt Company
Altax	Benzothiazyl disulfide	R. T. Vanderbilt Company
Benzal chloride	Benzal chloride	Fisher Scientific Company
Benzotrichloride	Benzotrichloride	Hooker Electro-chemical Company
Benzoyl peroxide	Benzoyl peroxide	Lucidol Division, Novadel-Agene Corporation
BLE	Mixture of complex diarylamineketone aldehyde reaction product and N,N' -diphenyl-p-phenylene-diamine	Naugatuck Chemical Division, U. S. Rubber Company
Butyl oleate	Butyl oleate	Witco Chemical Company
Cab-O-Sil	Silicon dioxide	Godfrey L. Cabot, Incorporated
Calcene NC	Calcium carbonate	Columbia-Southern Chemical Corporation

Material	Composition	Source
Continex SRF	Semireinforcing furnace carbon black	Continental Carbon Company
Dinitrobenzene	Dinitrobenzene	Fisher Scientific Company
Dixie clay	Hard clay	R. T. Vanderbilt Company
Dow Corning 410 Gum	Silicone rubber	Dow Corning Corporation
DPR N-27	Depolymerized copolymer of butadiene and acrylonitrile	DPR, Incorporated
Dyphos	Dibasic lead phosphite	National Lead Company
Factice	Vulcanized vegetable oil	Witco Chemical Company
FBA polymer	Polymer of 1, 1-dihydroperfluorobutyl acrylate	Minnesota Mining & Manufacturing Company
Butyl rubber (GRI-25)	Copolymer of isoprene and isobutylene	Standard Oil Company of New Jersey
Hi-Sil	Hydrated silica	Columbia-Southern Chemical Corporation
Hi-Sil C	Hydrated silica	Columbia-Southern Chemical Corporation
Hi-Sil X-303	Hydrated silica	Columbia-Southern Chemical Corporation
Hycar 1001	Copolymer of butadiene and acrylonitrile	B. F. Goodrich Chemical Company
Hycar 1014	Copolymer of butadiene and acrylonitrile	B. F. Goodrich Chemical Company

Material	Composition	Source
Hycar 1041	Copolymer of butadiene and acrylonitrile	B. F. Goodrich Chemical Company
Hycar 1072	Carboxylic modified copolymer of butadiene and acrylonitrile	B. F. Goodrich Chemical Company
Hycar 4001X11	Liquid acrylate polymer	B. F. Goodrich Chemical Company
Hycar 4021	Copolymer of ethyl acrylate and chloroethylvinyl ether	B. F. Goodrich Chemical Company
Hycar 4021X26	Unknown	B. F. Goodrich Chemical Company
Ionol	Di-tertiary-butyl para-cresol	Shell Chemical Corporation
Kel-F Elastomer	Fluorocarbon copolymer	M. W. Kellogg Company
Kosmobile HPC	Hard-processing channel carbon black	United Carbon Company
Litharge	Lead monoxide	National Lead Company
Magnesia (ELC)	Magnesium oxide	Michigan Chemical Corporation
Mercaptobenzimidazole	Mercaptobenzimidazole	Monsanto Chemical Company
Methyl Tuads	Tetramethyl thiuram disulfide (TMTD)	R. T. Vanderbilt Company
MLO-8200	Silicate ester hydraulic fluid	Oronite Chemical Company
Monoplex DOS	Di-(2-ethylhexyl) sebacate	Rohm & Haas Company
NA-22	2-mercaptoimidazoline	Du Pont
Neozone A	Phenyl-alpha-naphthylamine	Du Pont
Neozone D	Phenyl-beta-naphthylamine	Du Pont
Neoprene	Polychloroprene	Du Pont

Material	Composition	Source
OS-45	Silicate-ester-type fluid	Monsanto Chemical Company
Paraffin	Soft hydrocarbon wax	Shell Chemical Company
Permalux	Di-ortho-tolylguanidine salt of dicatechol borate	Du Pont
Philblack A	Fast-extrusion furnace carbon black	Phillips Chemical Company
Philblack E	Superabrasion furnace carbon black	Phillips Chemical Company
Philblack O	High-abrasion furnace carbon black	Phillips Chemical Company
Philprene VP-15	Copolymer of butadiene and vinyl pyridine	Phillips Chemical Company
Philprene VP-25	Copolymer of butadiene and vinyl pyridine	Phillips Chemical Company
Philprene VP-A	Terpolymer of butadiene-vinyl pyridine-acrylonitrile	Phillips Chemical Company
Plasticizer SC	Glycol ester of a fatty acid	E. F. Drew and Company
Plexol 201	Di(2-ethyl-hexyl) sebacate	Rohm and Haas
Polyac	Polypara-dinitrosobenzene	Du Pont
Retarder W	Salicylic acid	Du Pont
Selenium dioxide	Selenium dioxide	Battelle preparation
Silene EF	Calcium silicate	Columbia-Southern Chemical Corporation
Stearic acid	Stearic acid	Binney and Smith Company
Sulfur	Sulfur	Stauffer Chemical Company
P-33	Fine Thermal carbon black	Thermatomic Carbon Company

Material	Composition	Source
RPA No. 6	Pentachlorothiophenol	Du Pont
Tenamene 2	N, N'-disec-butyl-p-phenylenediamine	Eastman Chemical Products, Inc.
Tetraethylene pentamine	Tetraethylene pentamine	Carbide and Carbon Chemicals Company
Thermax	Medium Thermal carbon black	Thermatomic Carbon Company
Thiokol ZL-190	Liquid polysulfide polymer	Thiokol Corporation
Thiomalic acid	Mercapto succinic acid	Evans Chemetics, Incorporated
TP-90B	Unknown	Thiokol Corporation
Triethylene tetramine	Triethylene tetramine (TETA)	Carbide and Carbon Chemicals Company
VA-7	Aliphatic polysulfide	Thiokol Corporation
Valron Estersil	Organic-coated silicon dioxide	Du Pont
Wyex EPC	Easy-processing channel carbon black	J. M. Huber Corporation
Zinc oxide	Zinc oxide	New Jersey Zinc Sales Company
Zinc stearate	Zinc stearate	Baker Chemical Company