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AGING OF CURE DATED ITEMS
AND VARIOUS ELASTOMERIC
COMPOUNDS

To: Oklahoma City Air Material Area
Tinker Air Force Base, Oklahoma

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Norman, Oklahoma
Project 1190-18

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Approved by: C. M. Sliepeovich
Submitted by: Andrew Coegares, Jr.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1</td>
</tr>
<tr>
<td>II</td>
<td>17</td>
</tr>
<tr>
<td>III</td>
<td>30</td>
</tr>
<tr>
<td>IV</td>
<td>45</td>
</tr>
<tr>
<td>V</td>
<td>48</td>
</tr>
<tr>
<td>VI</td>
<td>50</td>
</tr>
<tr>
<td>VII</td>
<td>52</td>
</tr>
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<td>55</td>
</tr>
<tr>
<td>IX</td>
<td>57</td>
</tr>
<tr>
<td>X</td>
<td>62</td>
</tr>
<tr>
<td>XI</td>
<td>63</td>
</tr>
<tr>
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</tr>
<tr>
<td>b.</td>
<td>77</td>
</tr>
<tr>
<td>c.</td>
<td>103</td>
</tr>
<tr>
<td>d.</td>
<td>121</td>
</tr>
<tr>
<td>e.</td>
<td>131</td>
</tr>
<tr>
<td>f.</td>
<td>137</td>
</tr>
<tr>
<td>g.</td>
<td>144</td>
</tr>
<tr>
<td>h.</td>
<td>156</td>
</tr>
<tr>
<td>i.</td>
<td>162</td>
</tr>
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<td>j.</td>
<td>166</td>
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<tr>
<td>k.</td>
<td>173</td>
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The following text represents a summary of the work performed on Project 1190-18 at the University of Oklahoma Research Institute under Contract AF 36(601)-5233PA for the Oklahoma City Air Materiel Area. The report is entitled: Amin of Cure Data Items and Various Elastomeric Compounds.

The report is divided into eleven separate sections. Each section describes a particular phase of the entire problem that was studied and evaluated. Conclusions have been made wherever possible.
SECTION I

Correlations Between Natural and Accelerated Aging and Mechanical Properties
An extensive literature search has been carried out in order to obtain information relative to the air aging of nitrile rubber. It was desired to obtain a correlation between degradation (aging) and a corresponding change in engineering properties. Results of testing programs indicate that tensile strength and modulus may increase, decrease, or remain essentially unchanged while ultimate elongation decreases during aging for all types of rubber. The elongation decrease seems to vary regularly with time, thus enabling extrapolation of high temperature tests to room temperature shelf aging in some cases.

Air Oven Method

Tests have been conducted to determine the best method of accelerated high temperature aging: the air oven, oxygen bomb, and air bomb were compared. The air oven method gave more reproducible and uniform results than the oxygen and air bomb method. Work discussed in this report was performed by the air oven method.

Some difficulty arises in the air oven method because of the loosely defined operating conditions. One particular and very significant variable is air circulation. If correlation of data from different laboratories is desired the amount of air circulation must be controlled very precisely. A method that seems to improve the air oven technique is the test tube method, where samples are placed in a sealed test tube and inserted in the air oven.

Discussion

The physical changes in nitrile rubber vulcanizates that occur between 150°C and room temperature seem to be the same and have an
activation energy of 19,000± 2000 cal/mole; (2) therefore, extrap-
olation from high temperatures to room temperature should be permissible.
But extrapolation is possible only if: 1) accelerated aging temperatures
and service temperature are in the range of the same degradation mech-
anism, that is, degradation varies with time in a regular way; and, 2) 
the temperature dependence of the rate-limiting reaction for the specific
rubber is known; that is, the actual rate that the physical properties
vary with time-- some empirical equation to relate time with temperature.

Juve and Schoch have made extensive tests on aging of nitrile and
other types of rubber (2,3,4). In the first and second publications
tests were reported at temperatures of 121°C, 100°C, 70°C, 25°C and an
activation energy calculated. The data was somewhat incomplete and
scattered but a linear correlation was shown when the reciprocal
absolute temperature was plotted versus in (time) at a constant loss of
elongation. Hence, extrapolation to room temperature was possible.
This is shown in Figure 1.

During the same period a 12 year testing program was being carried
out in the United States (75°F) and in Liberia (85°F). Results of this
test are shown in Table I and the data plotted in Figure 2.
### TABLE I

<table>
<thead>
<tr>
<th>Aging Time</th>
<th>300% Mod.</th>
<th>% Retained</th>
<th>Tensile Strength</th>
<th>% Retained</th>
<th>Elong.</th>
<th>% Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Original</strong></td>
<td>1745</td>
<td>100</td>
<td>2500</td>
<td>100</td>
<td>465</td>
<td>100</td>
</tr>
<tr>
<td>1 year U.S.</td>
<td>1816</td>
<td>104</td>
<td>2487</td>
<td>99.5</td>
<td>450</td>
<td>96.7</td>
</tr>
<tr>
<td>2 years U.S.</td>
<td>1943</td>
<td>111.2</td>
<td>2450</td>
<td>98</td>
<td>417</td>
<td>89.6</td>
</tr>
<tr>
<td>3 years U.S.</td>
<td>1950</td>
<td>112</td>
<td>2540</td>
<td>101.6</td>
<td>410</td>
<td>88.4</td>
</tr>
<tr>
<td>4 years U.S.</td>
<td>2080</td>
<td>119.2</td>
<td>2580</td>
<td>103.1</td>
<td>400</td>
<td>86</td>
</tr>
<tr>
<td>8 years U.S.</td>
<td>2255</td>
<td>129</td>
<td>2545</td>
<td>102</td>
<td>362</td>
<td>77.8</td>
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<tr>
<td>12 years U.S.</td>
<td>2460</td>
<td>141</td>
<td>2700</td>
<td>108</td>
<td>310</td>
<td>66.6</td>
</tr>
<tr>
<td>1 year Liberia</td>
<td>2275</td>
<td>130.2</td>
<td>3210(?)</td>
<td>128.5</td>
<td>453</td>
<td>97.3</td>
</tr>
<tr>
<td>2 years Liberia</td>
<td>2100</td>
<td>120.2</td>
<td>2625</td>
<td>105</td>
<td>400</td>
<td>86</td>
</tr>
<tr>
<td>3 years Liberia</td>
<td>2200</td>
<td>126</td>
<td>2525</td>
<td>101</td>
<td>380</td>
<td>81.6</td>
</tr>
<tr>
<td>4 years Liberia</td>
<td>2400</td>
<td>137.5</td>
<td>2725</td>
<td>109</td>
<td>360</td>
<td>77.3</td>
</tr>
<tr>
<td>8 years Liberia</td>
<td>2625</td>
<td>150.5</td>
<td>2625</td>
<td>103</td>
<td>300</td>
<td>64.4</td>
</tr>
<tr>
<td>12 years Liberia</td>
<td>-</td>
<td>-</td>
<td>2575</td>
<td>103</td>
<td>240</td>
<td>51.6</td>
</tr>
</tbody>
</table>
ULTIMATE ELONGATION (PERCENT)

TIME (YEARS)

FIGURE 2

75°F (US)

85°F (LIBERIA)
Linear correlation is possible and yields a 33.4% decrease in elongation in 12 years. This decrease in elongation is permissible in most applications.

Mandel et al. (5) of the National Bureau of Standards made room temperature and high temperature tests independently and also used the data from the test previously mentioned and attempted to extrapolate to room temperature. It is important to note that different recipes were used.

**TABLE II**

Juve and Schoch (2)

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nycor OR-15</td>
<td>100</td>
</tr>
<tr>
<td>Zinc Oxide</td>
<td>5</td>
</tr>
<tr>
<td>Stearic Acid</td>
<td>1</td>
</tr>
<tr>
<td>Sulfur</td>
<td>1.5</td>
</tr>
<tr>
<td>Benzothiaaryl disulfide</td>
<td>1.5</td>
</tr>
<tr>
<td>SRV Black</td>
<td>75</td>
</tr>
<tr>
<td>Plasticizer GC</td>
<td>15</td>
</tr>
<tr>
<td>TEP</td>
<td>15</td>
</tr>
</tbody>
</table>

Mandel et al. (5)

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrile Rubber</td>
<td>100</td>
</tr>
<tr>
<td>Zinc Oxide</td>
<td>5</td>
</tr>
<tr>
<td>Stearic Acid</td>
<td>1.0</td>
</tr>
<tr>
<td>Sulfur</td>
<td>1.5</td>
</tr>
<tr>
<td>Benzothiaaryl disulfide</td>
<td>(7)</td>
</tr>
<tr>
<td>Gas Furnace Black</td>
<td>40</td>
</tr>
</tbody>
</table>

Mandel found that the equation \( E = E_0 - kt^h \) satisfactorily represented the behavior of nitrile rubber. \( E \) is the elongation after aging, \( E_0 \) and \( k \) are constants for a specific type rubber, and \( t \) the time in days. The change in elongation, \( E - E^* \), is plotted with respect to \( t^h \) at each test temperature (\( E^* \) is the initial elongation). The
value of \( k \) and \( E_o \) are read off the plot as the slope and ordinate intercept respectively. Results of Mandel's study of accelerated aging are shown in Figure 3. Correlation of data from Juve and Schoch by the equation proposed by Mandel is shown in Figure 4.

Values of \( k \) were determined at the measured temperatures and are listed in Table III.

**TABLE III**

<table>
<thead>
<tr>
<th>Temp (^\circ\text{C})</th>
<th>( k )</th>
<th>Temp (^\circ\text{C})</th>
<th>( k )</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>2.76</td>
<td>23</td>
<td>6.6</td>
</tr>
<tr>
<td>47</td>
<td></td>
<td>34</td>
<td>6.9</td>
</tr>
<tr>
<td>75</td>
<td></td>
<td>45</td>
<td>11.6</td>
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<tr>
<td>100</td>
<td></td>
<td>57</td>
<td>21.1</td>
</tr>
<tr>
<td>121</td>
<td>154</td>
<td>70</td>
<td>22.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>85</td>
<td>74.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100</td>
<td>100.6</td>
</tr>
</tbody>
</table>

An attempt was made to correlate \( \ln k \) with reciprocal temperature in hopes that a linear correlation may be obtained. Figure 3 shows this correlation. The non-linear plot from Mandel's work is in direct disagreement with the work of Juve and Schoch and says effectively that room-temperature aging can not be predicted from high temperature results only. Mandel reports that by using the above method the aging time for most rubber compounds may be predicted up to 10 years, but that the values of \( k \) and \( E_o \) must be experimentally determined for each type of rubber.

**Analysis**

Only two sources of data on nitrile rubber aging were found in the literature, and the two sets of data do not agree. Mandel's analysis
of the non-linear variation of k with 1/T seems to be consistent and represents a more sound approach than that of Juve and Schoch.

Figure 6 shows the analysis of data with the equation, $E = E_0 - kt^\frac{1}{2}$. The triangle points represent calculated data with an elongation decrease of 33.4% and the circles a decrease of 14%. The values for elongation decrease are taken from the 12 year in situ test discussed earlier. Points on the figure were plotted from calculations utilizing determined k-values and a 33.4 and 14% elongation decrease at a particular temperature. Because of the limited extent of data available it was possible to draw several lines through the data points. The data at 23°C was calculated from short time tests and extrapolated. A line through the four calculated points comes fairly close to the measured values (the 70°C point seems bad in both cases), but using only the high temperature point results in gross error. A predicted value for 14% decrease in elongation is 2.4 years (4 years actual) and for a 33.4% decrease— 13.3 years (12 years actual).

It is of interest to note that elongation is not a linear function in the early stages of deterioration (Figure 2). A similar trend was observed in preliminary tests made at OCMA. The tests were discontinued after 91 days but the non-linear portion of the curve is evident and the correlation is shown in Figure 7.
FIGURE 7

ELONGATION (PERCENT)

TIME (DAYS)

OCAMA TESTS AT 70°C
TABLE IV

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>E* (Percent)</th>
<th>E₀ (Percent)</th>
<th>E₀ - E* (Percent)</th>
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</thead>
<tbody>
<tr>
<td>23</td>
<td>652</td>
<td>657</td>
<td>+5</td>
</tr>
<tr>
<td>34</td>
<td>623</td>
<td>626</td>
<td>+3</td>
</tr>
<tr>
<td>45</td>
<td>609</td>
<td>608</td>
<td>-1</td>
</tr>
<tr>
<td>57</td>
<td>614</td>
<td>613</td>
<td>+17</td>
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<tr>
<td>70</td>
<td>596</td>
<td>600</td>
<td>-9</td>
</tr>
<tr>
<td>85</td>
<td>609</td>
<td>647</td>
<td>-8</td>
</tr>
<tr>
<td>100</td>
<td>&lt;656</td>
<td>&lt;654</td>
<td></td>
</tr>
</tbody>
</table>

Juve and Schoch

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>E* (Percent)</th>
<th>E₀ (Percent)</th>
<th>E₀ - E* (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>465</td>
<td>500</td>
<td>+35</td>
</tr>
<tr>
<td>70</td>
<td>465</td>
<td>532</td>
<td>+67</td>
</tr>
<tr>
<td>100</td>
<td>465</td>
<td>468</td>
<td>+3</td>
</tr>
<tr>
<td>121</td>
<td>465</td>
<td>450</td>
<td>-15</td>
</tr>
</tbody>
</table>

In Table IV values are given for E* (initial elongation) and E₀ at different temperatures from two different experiments (2,5). As can be seen the value of E₀ - E* goes from positive at low temperatures to negative at high temperatures. The relative time duration of the after-vulcanization effect is probably much shorter at high temperature than at low temperature. Thus, if two samples of the same rubber were aged at different temperatures for a short time, the after-vulcanization effect could still be present in the low temperature aging whereas it would have been completed in the high temperature test.

In Figure 8 an attempt has been made to graphically explain the variation of E₀ with E*. Percent elongation is plotted schematically at two temperatures as a function of time on different time scales for a given loss of elongation. Straight lines are fitted to the data. Note that the low temperature data will give an extrapolated value of E₀ at
Figure 8

Diagram showing elongation over time with two curves labeled 'Low Temperature' and 'High Temperature'.
time zero that is greater than $E^0$. At higher temperatures the extrapolated value of $E^0$ is lower than $E^0$. Thus the value of $E^0$ and $h$ are functions of the after-vulcanization effect as well as temperature and composition.

**Future Work**

In all the experimental accelerated aging tests the first determination gave a substantial loss in elongation. It is proposed to make tests at high temperatures in order to measure significant changes in elongation in short intervals of time. For example, at 100°C determine the elongation every 3 - 4 hours and at 125°C at intervals of 1 - 2 hours.

The change in cross-linking in the samples would be checked by swelling tests to determine how the cross-linking changed with the after-vulcanization effect. The amount of free sulfur could be checked at each interval to determine how much of the free sulfur has reacted. Infrared absorption spectra (7) would possibly indicate changes in chemical groups present and molecular rearrangements.

If the after-vulcanization effect could be understood and compensated, extrapolation of high temperature accelerated aging data to shelf aging temperatures would be more reliable than at the present time.
SECTION II

Vapor Phase Swelling
Introduction

In order to study the swelling of elastomers in organic solvents a new technique was devised that would allow determination of the extent of swelling as a function of varying solvent activity or partial pressure. The advantage of this technique over the more common techniques is that swelling measurements can be made without the necessity of immersing the sample in the swelling liquid. This not only eliminates leaching of soluble materials from the rubber but permits swelling studies at any desired solvent vapor pressure instead of only the saturation vapor pressure to which the immersion techniques are limited.

Apparatus

The modified test tube apparatus devised for this technique is shown in Figure 9. Tube $b$ is an 8 inch test tube fitted with a 24/40 $f$ cap $i$, which has a small glass hook, $k$, sealed to the inside of the top. A glass insert $j$ is suspended from the hook, $k$, by means of a wire, $m$, and hook $y$. The lower portion of the insert has a hook, $z$, sealed to the inside and is completely surrounded by the swelling fluid, $n$. The rubber sample, $l$, is suspended from hook $z$ by means of a wire, $y$, about one cm. or so below hook $z$. When the insert is lowered into the swelling fluid trapped air prevents the fluid from rising into the portion of the insert containing the rubber sample. To prevent the insert from floating in the fluid lead collars were placed around the stem of the insert. Hooks $a$ and $a'$ prevent the collar from slipping to the lower portion of the stem and can also be used to suspend additional weights if necessary. The entire tube is wrapped in aluminum foil to
FIGURE 9

MODIFIED TEST TUBE
SWELLING APPARATUS
aid in maintaining constant temperature and the tube is immersed in a constant temperature bath, so that the surface of the swelling liquid is several inches below the water surface. Several samples are run simultaneously by supporting six such tubes in the same constant temperature bath.

The swelling fluids used consisted of mixtures of hexadecane and benzene for which total vapor pressure had been determined as a function of the concentration. Approximately 30 ml. of varying concentrations of this mixture was placed in each tube.

Procedure

In making a run, weighed samples were suspended in the apparatus and the constant temperature bath was adjusted to the required temperature. After equilibrating for several days, each sample was taken from the apparatus, quickly transferred into a pre-weighed weighing bottle, and weighed. The concentration of benzene in the swelling fluid was determined by a refractometer measurement. It was discovered that samples reached a nearly constant weight within 2 or 3 days; hence, as a standard procedure, each specimen was left in the apparatus for three days.

Preliminary Results

Swelling isotherms were determined for specimens of Buna-N type rubber. The samples used in the modified test tube method measured approximately 1 cm x 2 cm x 3 mm, and weighed between 0.5 and 1.0 gram.

Results of measurements on the Buna-N samples in benzene are given in Figures 10 and 11, where isotherms at 10°, 20°, and 30° C are shown.
FIGURE 10

$100 \frac{\Delta W}{W}$ (PERCENT SWELL)

- $\bigcirc = 10^\circ C$
- $\square = 20^\circ C$
- $\triangle = 30^\circ C$

$100 \frac{P}{P_0}$ (RELATIVE VAPOR PRESSURE OF BENZENE)
Figure 11

Vapour Pressure of Benzene in mm of Hg

G = 10°C
G = 20°C
G = 30°C

100 ppm/w (Percent Swell)
In Figure 10 percent weight increase, \((\Delta W/W)_{100}\), is plotted versus percent of saturation vapor pressure, \((P/P_o)_{100}\). In Figure 11 percent weight increase, \((\Delta W/W)_{100}\), is plotted versus vapor pressure of benzene.

In order to illustrate the advantage of the test tube swelling method over the immersion techniques, six rubber samples of the type used in the swelling determinations were immersed in benzene which was contained in an enclosed tube to prevent evaporation and allowed to swell from 2 to 118 hours. At a prearranged time the sample was removed from the solvent and evacuated under reduced pressure in a vacuum desiccator until a constant residue weight was obtained. The weight percent of the sample dissolved by the solvent was calculated by dividing the residue weight by the original sample weight. At the same time another sample was suspended above pure benzene for 120 hours. The benzene vapors were absorbed by the sample until the sample had become saturated, at which time the vapors condensed on the surface of the sample and dripped back into the liquid solvent producing a slight leaching effect.

In the tubes containing the immersed samples the sample became saturated with solvent within the first ten hours (The time required for saturation had been determined in a previous experiment). Leaching of the sample occurred rapidly during this time and appeared to become non-existent after the sample became saturated. However, more than five percent of the sample had been dissolved at the end of two hours and more than ten percent had been dissolved at the end of 22 hours. On the other hand the sample suspended above the solvent became saturated with solvent within 72 hours but at the end of 120 hours had lost less
then one percent of its weight due to dissolution. Results of this experiment are summarized in Table V.

**Table V**

<table>
<thead>
<tr>
<th>Initial Sample Weight (grams)</th>
<th>Weight of Sample Dissolved (grams)</th>
<th>Type of Exposure</th>
<th>Time of Exposure (hours)</th>
<th>Percent of Sample Dissolved</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8350</td>
<td>0.0425</td>
<td>Immersion</td>
<td>2.0</td>
<td>5.09</td>
</tr>
<tr>
<td>0.8129</td>
<td>0.0729</td>
<td>Immersion</td>
<td>7.5</td>
<td>8.97</td>
</tr>
<tr>
<td>0.8047</td>
<td>0.0857</td>
<td>Immersion</td>
<td>22.5</td>
<td>10.65</td>
</tr>
<tr>
<td>0.8456</td>
<td>0.0827</td>
<td>Immersion</td>
<td>46.5</td>
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<tr>
<td>0.7983</td>
<td>0.0809</td>
<td>Immersion</td>
<td>67.0</td>
<td>10.13</td>
</tr>
<tr>
<td>0.8713</td>
<td>0.0872</td>
<td>Immersion</td>
<td>118.0</td>
<td>10.01</td>
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<tr>
<td>0.7520</td>
<td>0.0062</td>
<td>Suspension</td>
<td>120.0</td>
<td>0.82</td>
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</tbody>
</table>

**Vapor Swelling Studies**

Vapor swelling studies were conducted on two Buna-N type rubbers (NH-81848-R from Continental Rubber Works and SR-822-60 from Stillman Rubber Company) and one silicone rubber to determine if there was a correlation between the degree of loss of useful properties of the rubber and its swelling behavior.

The first phase of this study involved the determination of the change in the swelling ability of a rubber sample with prolonged exposure to moderately high temperatures. The rubber samples were heated in a drying oven for the desired length of time, removed from the oven and allowed to cool to room temperature overnight. The samples were then weighed, swelled in the modified test tube apparatus for six days at 20°C and approximately 65.6 mm of benzene vapor pressure (normal vapor pressure of benzene at 20°C is 75.1 mm.), and reweighed to determine the amount of vapor absorbed by the rubber.
The results of one study using all three types of rubber are given in Figure 12, where the percentage change in sample weight due to swelling \( \left( \frac{W_W}{W_0} \right) \times 100 \) is plotted versus aging time in days. The samples were heated in air at 70°C.

The curves for all three types of rubber show a fairly rapid decrease in swelling ability during the first two weeks followed by a linear decrease for longer periods.

Of the two Buna-N rubbers the SR-822-60 exhibits the greatest stability against aging, while the silicone rubber is the most stable of the three. However, the curves for the two Buna-N rubbers have negative slopes in the linear portions of the curves whereas the linear portion of the curve for the silicone rubber seems to show a very slight positive slope, indicating that its swelling ability improves with aging time. This would in turn indicate a softening of the rubber due to chemical changes occurring in the rubber or to breaking of cross-links in the rubber.

In order to determine the dependence of swelling ability of rubber samples with aging temperature, SR-822-60 rubber samples were heated in air at 70°C and 50°C. After aging for a specified time the samples were removed from the ovens and swollen in the manner described above. Figures 13 and 14 show the results of these tests. Figure 13 is the curve for samples aged at 70°C and Figure 14 is the curve for samples aged at 50°C.

Examination of the curves shows that the rapid decrease in swelling ability during the first two weeks is absent. However, comparison
Figure 12
70°C Aging

$\Delta = S R - 8 2 2 - 6 0$
$\square = B N - 8 1 8 4 8 - R$
$\triangle = S I L I C O N E$

$\text{(Percent Swell)}$

Aging Time (Days)
of the linear portion of the BR-822-60 curve in Figure 12 with the curve in Figure 13 shows that both curves have the same slope. The only difference between the curves in Figures 13 and 14 is the more gradual slope in Figure 14. This is to be expected since the rubber should age at a slower rate when the aging temperature is decreased.

If one neglects the first portion of the curves in Figure 12 and considers only the linear portion, the curves in Figures 12, 13, and 14 can all be expressed by the mathematical formula for a straight line,

$$ y = m_D + b $$

where $m$ is the slope, $b$ is the $y$-intercept, $x_D$ is the aging time in days and $y$ is the percentage weight increase due to swelling.

Since the slope of the curve depends on the aging temperature the slope, $m$, becomes the aging factor.

Solving equation (1) for $m$ gives:

$$ m = \frac{y - b}{x_D} $$

(2)

which can also be written,

$$ m = \left[ \frac{(\Delta W/W) - (\Delta W/W)_0}{x_D} \right] 100 $$

(3)

where $(\Delta W/W)_0$ is the percentage weight increase at zero aging time and $t_D$ is the aging time in days. Because $(\Delta W/W)_0$ is usually larger than $(\Delta W/W)$ the curve will generally have a negative slope.

For a given rubber sample the slope, $m$, is dependent on the aging temperature and the aging stability of the rubber which should be a constant for each type of rubber. Therefore, it can be assumed that $m$
consists of two factors: the aging temperature factor \( \tau \), and a constant, \( \alpha \), which we shall call the stability constant of the rubber. The temperature factor, \( \tau \), is used instead of the temperature because the temperature functional relationship is not known.

Equation (3) can then be written,

\[
\alpha \tau = \frac{[(\Omega N/V) - (\Omega N/V)_0]}{\tau_D} \times 100
\]

(4)

Once \( \alpha \) and \( \tau \) have been determined for one type of rubber the swelling ability of this rubber at any aging temperature and time can be determined simply by determining \( (\Omega N/V)_0 \).

It is possible that the rubber may become so brittle if the aging is continued for a sufficiently long enough time that it does not swell \( (\Omega N/V) \) goes to zero}. However, there is no evidence to indicate that this actually happens. At any rate the percent swelling will decrease until a point is reached where continued aging will not affect the swelling properties of the rubber. At this point the slope goes to zero.
SECTION III

Vapor Phase Swelling Studies with the Quartz Beam

Microbalance Apparatus
**Introduction**

The apparatus used in these studies has been described in detail elsewhere. Essentially, the percent swell (100△W/W) of the rubber sample is measured as a function of the relative vapor pressure (P/P₀) of the swelling solvent.

The resulting data can be plotted by different methods. The simplest method is shown in Figure 15.

![Figure 15](image)

Here, the percent swell of the rubber sample is plotted against the relative vapor pressure of the swelling solvent. Although this graphical method is sensitive to the change in the swelling property with aging, a straight line can be produced by plotting the percent swell of an aged sample (at constant P/P₀) against the time of aging. This relationship is shown in Figure 16.
The equation of the line is given by

\[ \frac{100 \Delta w}{w} = kt + c \]  \hspace{1cm} (5)

where \( k \) is the rate constant for the aging process at constant temperature, \( t \) is the duration of aging and \( c \) is the percent swell of a non-aged sample at constant \( \frac{P}{P_0} \). The rate constant \( k \) is related to the temperature at which the sample was aged by:

\[ \log k = \frac{\Delta H}{2.303 R T} + \alpha \]  \hspace{1cm} (6)

where \( T \) is the absolute temperature, \( \Delta H \) is the heat of activation for the aging process, \( R \) is the gas constant, and \( \alpha \) is a constant of integration. It is evident that a linear relationship exists between \( \log k \) and \( \frac{1}{T} \). Thus \( k \) can be evaluated at the temperature of storage of the rubber sample if two or more values of \( k \) are known at higher temperatures. Then the loss in the swelling property at the temperature of storage can be calculated at any time \( t \) from equation (5). By combining this data
with the working properties of the rubber, the storage life can be evaluated.

A Comparison of Data for Aged and Non-aged Rubber

The swelling isotherms of rubber O-rings and sheet rubber are shown in Figures 17, 18, and 19 for both aged and non-aged samples. GEl was used as the swelling solvent. It is evident that a decrease in the swelling property occurs under accelerated aging conditions. Complete swelling isotherms were not run on aged rubber O-rings (Figure 19). Instead, the percent swell after different times of aging was measured at only one relative pressure (0.600P/P'). Two of these points are shown in Figure 19.

By plotting the data as in Figure 16 the rate constants for the aging processes at 70°C can be calculated by equation (5). The graphs are shown in Figures 20, 21, and 22. It should be noted that only two points are available in Figures 20 and 21 (from Figures 17 and 18, respectively). In Figure 22, five points are available, although only three of these are indicated in Figure 19. In all cases the points have been taken at a relative vapor pressure of 0.600. The rate constants are presented in Table VI.

<table>
<thead>
<tr>
<th>Rubber Type</th>
<th>Rate Constant at 70°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>M4-81948-R sheet</td>
<td>0.031 day⁻¹</td>
</tr>
<tr>
<td>M4-80496-DSFP2 sheet</td>
<td>0.076</td>
</tr>
<tr>
<td>BR-622-60 O-rings</td>
<td>0.033</td>
</tr>
</tbody>
</table>

The data indicates that M4-81948-R sheet rubber and BR-622-60 rubber O-rings age at about the same rate while M4-80496-DSFP2 sheet
SWELLING OF BN-81848-R BY CC1\textsubscript{4} AT 20\textdegree C

100\Delta w/w (PERCENT SWELL)

\( P/P_0 \) (RELATIVE PRESSURE OF CC1\textsubscript{4})

FIGURE 17
FIGURE 18

SWELLING OF BN-80496-DSP2 BY CC\textsubscript{14} AT 20°C

100\Delta W/W (PERCENT SWELL)

\( \frac{P}{P_0} \) (RELATIVE PRESSURE OF CC\textsubscript{14})
FIGURE 19

SWELLING OF SR-822-60 O-RINGS BY CC\(_4\) AT 20°C

100 ΔW/W (PERCENT SWELL)

P/P\(_o\) (RELATIVE PRESSURE OF CC\(_4\))

AGED AT 70°C

42 DAYS

91 DAYS

NON-AGED
Figure 20

Aging of BN-81848-R at 70°C
Swelling temperature = 20°C

100 ΔW/W = Kt + c
K = -0.031 day⁻¹
C = 21.5
FIGURE 22

AGING OF SR-822-60 O-RINGS AT 70°C
SWELLING TEMPERATURE = 20°C
EACH POINT IS AN AVERAGE OF 4-5 SAMPLES

100 ΔW/W AT 0.5 P/B OF CCl₄

100 ΔW/W = Kt + c
K = -0.033 DAY⁻¹
C = 27.1

AGING TIME (DAYS)
rubber ages more than twice as fast as the other two.

Because the aging data is available at only one temperature (70°C) the rates of aging at the temperature of storage cannot yet be calculated. Samples of rubber O-rings are presently being aged at 90°C to allow this calculation.

Theoretical Studies on the Aging Process

A theoretical investigation of the aging process should allow the evaluation of factors responsible for the break-down of rubber and permit the selection of rubber compounds better suited for a particular function. For these reasons an attempt is being made to interpret the swelling data according to the theory of Flory (9). This theory predicts that swelling data should fit the equation

\[ 2.303 \log \frac{P/P_0}{1-V_2} = X_1 V_2^2 \] 

(7)

where \( P/P_0 \) is the relative vapor pressure of the swelling solvent, \( V_2 \) is the volume fraction of the rubber in the rubber-solvent gel, and \( X_1 \) is a constant called the mixing parameter. By plotting

\[ \frac{P/P_0}{1-V_2} - V_2 \] 

against \( V_2^2 \) a straight line should result, with a slope equal to \( X_1 \). Plots have been made for the swelling data on both aged and non-aged sheet rubber (EM-80496-DMF2). The results are shown in Figures 23 and 24. Although some data scatter is present, the points fall reasonably well on a straight line. For non-aged samples \( X_1 \) equals 0.695. For samples aged 85 days at 70°C, \( X_1 = 0.695 \). Thus, the value of \( X_1 \) is sensitive to the break-down of the rubber samples.
FIGURE 23

SWELLING OF NON-AGED BN-80496-DSP2 BY CC14

$2.303 \log \frac{P/P_o}{1-V_2} - V_2 = x_1 \cdot V_2$

$x_1 = 0.695$
SWELLING OF AGED (70°C) BN-80496-DSP2 BY CCl₄
AGING TIME = 85 DAYS

2.303 \log \frac{P/P_0}{1-V_2} = x_1 \cdot V_2^2

x_1 = 0.895
A second means of plotting the data is shown in Figure 25. In this graph the points represent the experimental data and the curves are calculated from the values of $X_1$. It is evident that the results are different for aged and non-aged samples.

According to the theory, $X_1$ is related to the heat of dilution, $\Delta \bar{H}_1$, of the solvent in the rubber by

$$\frac{\Delta \bar{H}_1}{HT} = X_1 V_2^2$$

(8)

where $\Delta \bar{H}_1$ is given by the relationship

$$\log \frac{P}{P_0} = - \frac{\Delta \bar{H}_1}{2.303 \ HT} \times C^2$$

(9)

Thus, by measuring $P/P_0$ at constant $V_2$ as a function of the absolute temperature $\Delta \bar{H}_1$ and $X_1$ can be calculated. Providing the theory is correct, the value of $X_1$ as calculated from equation (8) should be the same (within the limits of experimental error) as the value calculated from equation (7). Alternatively, $\Delta \bar{H}_1$ can be calculated (at constant $V_2$) from equation (8) with the value of $X_1$ from equation (7). This value of $\Delta \bar{H}_1$ should then correspond to the measured values (from equation 9). Although the experimental technique in measuring $\Delta \bar{H}_1$ has not yet been perfected, the values obtained thus far are definitely of the right magnitude (150-300 cal/mole).

**Future Work on Swelling Studies**

Heat of dilution measurements will be continued as a further test of the Flory theory. Also, swelling data will be obtained on rubber O-rings aged at different temperatures. With this data the rate of loss in the swelling property at the temperature of storage will be calculated.
FIGURE 25

SWELLING OF BN-80496-DSP2 BY CO$_4$

SWELLING TEMPERATURE = 20°C

Curve is calculated points are experimental.
By combining the swelling data with data on other physico-mechanical properties (modulus, relative elongation, etc.) it should be possible to calculate the storage life of the O-rings.
SECTION IV

Vaporization of Volatile Components

In the Rubber
A rubber sample measuring approximately 1 cm x 2 cm x 2 mm and weighing approximately 0.6 gram was suspended in a drying oven maintained at a constant temperature of 70°C. The sample was suspended near the bulb of the thermometer to insure that the temperature in the vicinity of the sample remained at the desired temperature. Air was allowed to circulate freely through the oven by means of an opening in the top of the oven. The sample was removed from the oven at different intervals, allowed to cool in air for ten minutes, weighed with an analytical balance and returned to the oven. The sample used in this study was cut from the same sheet of SR-822-60 rubber that was used to obtain the curves in Figures 13 and 14. Results of this experiment are given in Figure 26, which is a plot of percentage weight decrease of the sample, \(-(\frac{W}{W_0})100\), versus aging time in hours.

Two curves are shown in Figure 26. Curve A is a plot of the data obtained in the experiment. This curve shows that there is a rapid decrease in weight during the first few hours of aging, probably due to vaporization of moisture and grease picked up by the sample during storage and handling. Beyond this point the curve becomes linear. If one assumes that the first portion of this curve is due to vaporization of grease and moisture (to be verified in future experiments) and that the weight loss with aging time is a linear function as indicated by the remainder of the curve, then the plot can be corrected for the presence of these foreign materials. This is done by extrapolating the linear portion of the curve to zero time, taking another point on curve A and subtracting the value determined by extrapolating the curve to zero time. A straight line can then be constructed through the two points,
Figure 26

SR-822-GO samples aged at 70°C

0 = data curve

Δ = true aging curve

AGING TIME (HOURS)

100

200

400

600

800

1000

-100 dl/w

(Percent weight loss)
one of which becomes the origin. Curve B in Figure 26 is the corrected curve and should be the true volatilization curve. This procedure in no way alters the slope of the line.
SECTION V

Neutron Irradiation of Rubber
In an attempt to learn more about the dependence of swelling on crosslinking several samples were placed in the University of Oklahoma research reactor and bombarded with neutrons.

Two samples of a Buna-N type rubber of the same size and composition as those used in the swelling studies were placed in the reactor at a flux position of $10^8$ neutrons/cm$^2$/second. The samples were bombarded for 240.45 watt-hours, removed from the reactor (radiation level of samples was negligible) and swelled in the modified test tube apparatus for 72 hours using benzene as the solvent at a temperature of $20^\circ$C.

In addition to these two samples three control samples that had not been bombarded were swelled under the same conditions. Experimental results are given in Table VII.

Sample 1 was first swelled for 72 hours, allowed to deswell and then was placed in the reactor in an attempt to see if swelling changed the crosslinking or if the presence of solvent molecules during bombard- ing affected the degree of crosslinking. After being bombarded the sample was again swelled along with the other four samples.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Weight Before Bombarding (grams)</th>
<th>Weight After Bombarding (grams)</th>
<th>Weight of Swelled Sample (grams)</th>
<th>Weight Increase (grams)</th>
<th>Percent Weight Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.9915</td>
<td>0.9829</td>
<td>1.6925</td>
<td>0.7096</td>
<td>72.19</td>
</tr>
<tr>
<td>2</td>
<td>0.9564</td>
<td>0.9564</td>
<td>1.6542</td>
<td>0.6978</td>
<td>72.96</td>
</tr>
</tbody>
</table>
**Samples Not Bombarded**

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Original Sample Weight (grams)</th>
<th>Weight Of Swelled Sample (grams)</th>
<th>Weight Increase (grams)</th>
<th>Percent Weight Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.6885</td>
<td>1.2152</td>
<td>0.5267</td>
<td>76.50</td>
</tr>
<tr>
<td>4</td>
<td>0.6109</td>
<td>1.0662</td>
<td>0.4553</td>
<td>74.53</td>
</tr>
<tr>
<td>5</td>
<td>0.7503</td>
<td>1.3251</td>
<td>0.5748</td>
<td>76.61</td>
</tr>
</tbody>
</table>

As a control to see if swelling, deswelling and reswelling changed the percent weight increase, sample 5 was subjected to the same conditions as sample 1 but was not bombarded.

Examination of Table VII shows that there appears to be a decided change in the swelling ability of the rubber sample after neutron bombardment. If the bombardment were continued for a sufficiently long period of time enough crosslinking would occur to render the sample brittle and useless. The results obtained when sample 4 was swelled detract from the total results since this sample would make it appear that the percentage swell of all the samples is approximately $74 \pm 2\%$. Further experimentation would be necessary to show that the results from this sample can be disregarded.

Due to the lack of time, money and facilities this study was not pursued past the initial stages. There are many complicating factors that arise in a problem such as this and fruitful results can be obtained only with the proper equipment and an accurate knowledge of the material subjected to irradiation. Since none of these were available when the problem was started it was decided that preliminary studies would be made and then set aside to concentrate on more fundamental work with the intention of returning to this program at a future date if possible.
SECTION VI

Swelling Behavior

Under Stress Conditions
In another experiment designed to study the degree of crosslinking of an elastomer as well as its swelling behavior under stress, a stretching rack was designed that would permit rubber strips to be stretched to any desired elongation. The rack used in this experiment is shown in Figure 27.

The frame, $F$, is made of aluminum of single piece construction measuring 55 mm X 15 mm X 3 mm. A turn-screw, $S$, passes through the upper portion, $B$, of the frame, which also acts as a holding base, and is secured to a movable base, $B'$. The rubber sample is secured to the frame between base, $B$, and the removable clamp, $R$, in the upper portion of the frame and between base $B'$ and removable clamp $R'$ in the lower portion of the frame. Two screws pass through each removal clamp and are screwed into bases $B$ and $B'$ to hold the sample in place. The sample is stretched to the desired elongation by turning screw $S$, which causes the movable base, $B'$, to move down the frame. The sample can then be swelled by suspending the frame from hook $F$ in the modified test tube apparatus (Figure 9).

When making a determination rubber samples measuring approximately 20 mm X 5 mm X 2 mm were secured to the frame and swelled at zero elongation. The samples were then allowed to deswell, stretched to 100 percent elongation and re-swelled. The strain placed on the rubber sample due to stretching and swelling has caused every sample that has been used to date to break. The same results were obtained when a sample was stretched and aged at elevated temperatures. Stretching the sample to an elongation small enough to prevent breakage causes such a small change in the swelling ability of the sample that one can conclude that no change is found within experimental error.
Since aircraft engines and other Air Force equipment using rubber O-rings are stored in 1010 oil until needed it was considered necessary to determine what effect the 1010 oil had on O-rings that were saturated with this oil for long periods of time. In order to do this it was first necessary to find a method for removing the 1010 oil without causing a change in the properties of the rubber due to the method itself.

Placing O-rings saturated with 1010 oil in a reduced atmosphere system had very little effect on the oil because of its low vapor pressure. Heating the system to a temperature of 50°C for five days failed to remove more than a few milligrams of oil from the rings. Since heating the rubber samples changes the properties of the rubber and because such long periods of time are required to remove all the oil in a simple vacuum system this method was considered impractical. Attempts to remove the oil by soaking the rings in organic solvents or exposing the rings to solvent vapors and then evaporating the solvent from the rings under vacuum likewise failed because most organic solvents remove soluble constituents from the rubber along with the 1010 oil. Even soaking the rings in water containing a detergent caused solution of constituents from the rubber.

The method that appears most promising consists of placing the oil soaked rubber sample in a high vacuum system made up of an evacuating chamber, cold trap, mercury diffusion pump and fore pump with a minimum of connections. The rubber samples are placed in the evacuating chamber, held under vacuum for three days and weighed. Experimental results are given in Figure 28, where the sample weight is plotted versus the total number of days the sample was subjected to high vacuum.
SECTION VII

Removal of 1010 Oil from O-Rings
Since aircraft engines and other Air Force equipment using rubber O-rings are stored in 1010 oil until needed it was considered necessary to determine what effect the 1010 oil had on O-rings that were saturated with this oil for long periods of time. In order to do this it was first necessary to find a method for removing the 1010 oil without causing a change in the properties of the rubber due to the method itself.

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FIGURE 28

SAMPLE WEIGHT X 10^2 (GRAMS)

DAYS IN VACUUM

+5 +3 +1 0 +1 39 37 0
According to this graph the sample loses weight rapidly during the first ten days in the system and then gradually approaches a constant weight, achieving this constant weight in about five weeks.

To insure that the vacuum did not remove volatile components from the rubber and thereby change its properties, a control sample that had not been soaked in oil was placed in the vacuum system. At the end of eight days in the system the sample weight had been reduced by approximately 0.8 percent. This weight loss most likely represents the removal of moisture and grease present in the rubber due to handling and storage.

Once this method has been perfected the physical properties of O-rings that have been saturated with 1010 oil and then had the oil removed will be compared with the physical properties of control samples of the same type of rubber that have not been soaked in oil to see what effect the 1010 oil has on the properties of the rubber.
SECTION VIII

Leaching of Constituents from O-Rings
In an attempt to learn more about the effect of accelerated aging on rubber samples, a technique was devised to study the material leached from a rubber sample immersed in carbon tetrachloride by means of infrared spectrum analysis. The basis for the experiment was the possibility that aging affected the soluble materials in a definite manner and this change would be evident by changes in the infrared spectrum.

Rubber samples of two different types of Buna-N rubber were heated in air at 70°C for periods ranging from 1 3/4 hours to eight days. The rubber samples measured about 1 cm X 1 cm X 3 mm and weighed approximately 0.4 gram. When a sample was removed from the oven it was allowed to cool overnight, immersed in 50 ml of carbon tetrachloride for 72 hours and removed.

Since the amount of solvent present greatly exceeded the amount of leached material, solvent bands would mask bands due to the soluble material. To eliminate this, and to have a more concentrated solution, the solvent was evaporated by passing a stream of air over the solution contained in a beaker. As soon as the solvent had been completely evaporated the walls of the beaker were washed down with a small amount of solvent and the solution was carefully transferred to a sodium chloride disc where the solvent was again evaporated using compressed air. This was done three times to insure complete transfer of material to the disc. A second sodium chloride disc was placed over the first so the material was contained between the discs. The discs were then placed in a clamp which held the discs in the infrared beam.
Because all the samples used could not be subjected to identical conditions in making these determinations it was necessary to find an internal standard that could be used as a comparison against all other peaks in the spectrum. In other words it was necessary to find a peak that remained constant in relation to the other peaks in the same spectrum.

Extensive tests have been made using this technique but to date no definite correlation has been found between the infrared spectrum of the leached materials and the aging time. It is suspected that the reason for this is the difficulty involved in trying to duplicate the same conditions from sample to sample. The weights vary from sample to sample and may introduce some error although use of an internal standard should eliminate this. The most probable cause for error arises in transferring the solution from the beaker to the disc. In future studies a technique will be devised to eliminate this step from the procedure.
SECTION IX

Temperature Retraction Apparatus
The Temperature Retraction test (ASTM D 1329-60) provides a method for rapid evaluation of crystallization effects and for comparing viscoelastic properties of rubber and rubber-like materials at low temperatures.

Apparatus

The testing apparatus consists of a specimen rack, an insulated cooling bath which is equipped with a thermometer, an immersion heater, and a liquid coolant. A schematic drawing of the apparatus is shown in Figure 29. The specimen rack was designed so that it maintains a slight tension (1 to 3 psi) on the specimens and permits them to be stretched and anchored at any elongation up to a maximum of 250 percent. The length of the specimens can be read by an indicator at any time during the test within an accuracy of ± 0.05 centimeters. The rack was designed so that it can hold four specimens at the same time.

The bath consists of a silvered Dewar flask which sets in a wooden box. The liquid coolant equilibrium mixture used is methanol and dry ice.

Procedure

The Dewar flask is filled three-fourths full with the methanol-dry ice equilibrium mixture at about -70°C by adding chopped dry ice to methanol. One end of the test specimens are inserted into the stationary clamp at the bottom of the sample rack and the other end in the movable clamp. The three-inch samples are then stretched to the desired length and anchored in the elongated position by tightening the thumb nuts. The specimen rack is placed in the bath slowly to avoid frothing.
A - Specimen Rack
B - Test Specimen
C - Movable Clamp
C₁ - Stationary Clamp
D - Thumb Nut
E - Indicator
F - Connecting Wire
G - Graduated Scale
H - Flexible Cord
I - Pulley
M - Rack Support
N - Bath
O - Wooden Container
R - Heater
If the temperature of the bath rises above -70°C when the rack is inserted, a small amount of dry ice is added to reduce the temperature to between -70°C and -73°C. After 10 minutes the thumb nuts are released, and the specimens are allowed to retract freely. At this point the heater is turned on. The first reading is taken at -70°C, and continued at two minute intervals until retraction is complete.

Preliminary Results

Data is given below in Table VIII and in Figure 30 on three Buna-N rubber samples of different cure data (not the same rubber compound in all three samples). Three inch samples are given an initial elongation of five centimeters (65.7% testing elongation) and placed in a methanol-dry ice bath at -70°C for 10 minutes. The samples are then released and allowed to retract.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cure Date</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TR 10</td>
<td>-61</td>
<td>1-54</td>
<td>5-56</td>
</tr>
<tr>
<td>TR 30</td>
<td>-55.8°C</td>
<td>-62°C</td>
<td>-34.6°C</td>
</tr>
<tr>
<td>TR 50</td>
<td>-50.4</td>
<td>-37.7</td>
<td>-30.8</td>
</tr>
<tr>
<td>TR 70</td>
<td>-43.8</td>
<td>-34.7</td>
<td>-28.0</td>
</tr>
<tr>
<td>(TR 70 - TR 10)</td>
<td>-41.0</td>
<td>-29.6</td>
<td>-24.5</td>
</tr>
<tr>
<td>Freezing Point</td>
<td>14.8</td>
<td>12.4</td>
<td>10.1</td>
</tr>
<tr>
<td></td>
<td>-59</td>
<td>-44.5</td>
<td>-36</td>
</tr>
</tbody>
</table>

Future Work

Since the difference between the temperature at which a vulcanizate retracts 10 percent (TR 10) and the temperature at which a vulcanizate retracts 70 percent (TR 70) increases as the tendency to crystallize increases, sample no. 1 crystallizes before sample no. 2; and sample no. 2 crystallizes before sample no. 3.
FIGURE 30

°C

0 = SAMPLE 1
□ = SAMPLE 2
△ = SAMPLE 3

TEMPERATURE (%)

PERCENT RETRACTION
The temperature retraction test will be performed on samples that have undergone accelerated aging. It is believed that measurable changes will occur in (TR 70 - TR 10) and hence represent an indication of the degree of aging.
SECTION X

Bibliography
BIBLIOGRAPHY


SECTION XI

Literature Bibliography


Anderson, R. F., A Method for Eliminating Cross Artifacts in Drying Specimens; Extrait du Congres De Microscopie Electronique, Editions de la Rayne D'Optique, Paris (1952)


Barnes, R. B., McDonald, R. S., Williams, V. F., Small Prism Infra-Red Spectrometry; J. Appl. Phys., 16:77 (1945)


Bergeram, D. W., A Single Quartz Crystal Point Focusing X-Ray Monochromator; Presented to the Nat. Acad. Of Sc., Calif. Inst. of Tec.; (Nov. 1953)


Bishop, F. W., A Revolving Specimen Stage for the Electron Microscope; Rev. Sci. Instr., 23:504 (1952)


Bishop, F. W., Exposure Timer for the Electron Microscope; Electronics, (Mar. 1955)


Blaek, E. D., Margaost, J. D., Wyman, C. M., Sample Handling for Qualitative Infrared Microspectroscopy; Anal. Chem., 29:169 (1957)


Clark, G. L., Kabler, M., Blaker, E., Ball, J. M., Hysteresis in Crystallization of Stretched Vulcanized Rubber from X-Ray Data; Correlation with Stress-Strain Behavior & resilience; Ind. Eng. Chem., 32:1474 (Nov. 1940)


Clews, C. J. B., X-Rays and Rubber; Trans. Inst. Rubber Ind. 14:225 (1943)


Farbenfabriken Bayer Akt.-Ges., Stable Polychloroprene; Brit. 843,906 (Aug 10, 1960)


Fox, R. E., Hickam, W. M., Grove, D. J., Kjeldaaas, T., Ionization in a Mass Spectrometer by Monoenergetic Electrons; Rev. Sci. Instr., 26:1101


Fuller, C. S., Baker, W. O., Structure of Synthetic Chain Polymers as Shown by X-Rays; J. Chem. Educ., 20:3 (1943)


Hauser, E. A., LeBeau, D. S., Microscopic Studies of Lyogels; Preparation of Samples for Ultra-illumination by Incident Light; Ind. Eng. Chem., 33:335 (1946)


Hock, C. W., An Electron-Microscopical Examination of Rayon; Textile Research J., 13:366 (1943)


Kraus, Gerard, Silica-Reinforced Rubber; U.S. 2964,457 (dec. 15, 1960)


Kress, K. E., Spectrophotometric Analysis of Accelerator, Rubber Mixtures; Anal. Chem., 23:313 (1951)


Ladd, W. A., Braendle, H. A., High-Speed Microscope for Electron Microscopy; Rubber Age., 57 (Sept, 1945)


Ladd, W. A., Wiegand, W. B., Electron Microscope Studies of Colloidal Carbon Reticulate Chain Structure; Rubber Age, (June 1945)

Ladd, W. A., Wiegand, W. B., Electron Microscope Studies of Colloidal Carbon Reticulate Chain Structure; Rubber Age, 57 (Sept 1945)


Mack, W., Bibliography of X-Ray Spectrochemical Analysis: Fluorescence & absorption; Norelco Report, 3:37


Martin, L., A 100-kv Electron Microscope; *J. Appl. Phys.*, 16:131 (1945)


Maata, G., Corradini, P., Crystal Structure of Cis-1, 4-Polybutadiene; Nuovo cimento, 15:111 (1960)


O'Brien, H. C., Jr., A Vibrating Muller for the Preparation of Dispersior) of Fine Pigments for Electron Microscopy; Science, 103:429 (1946)


O'Brien, H. C. Jr., Thin Sections Methods for the Electron Microscopic Examination of Cured Polymer; No official pub.,

Apply X-Ray Analysis Techniques to Rubber Problems, Rubber
Age, N.J.: 81:276 (1957)

Parrish, W., Engstrom, A., Modern X-Ray Chemical Analysis;

Parrish, W., X-Ray Intensity Measurements with Counter Tubes;

Parrish, W., X-Ray Spectrochemical Analysis; Phillips Tech.
Rev., 17:269 (1950)

Parrish, W., Kohler, T. R., A Comparison of X-Ray Wavelengths

Parrish, W., Kohler, T. R., Use of Counter Tubes in X-Ray
Analysis; Rev. Sci. Instr., 27:795

Piero, E. R., Kingston, R. H., Gyorgy, E. M. Harvey, G. G.,
The Soft X-Ray Spectroscopy of Solids; Rev. Sci. Instr.,
22:543 (1951)

Plesrenko, A., and Shtarkh, B., The Microheterogeneity of
Synthetic Rubbers, Kauhuck i Rezina 17; No. 5, 10 (1958)

Post, B., Fankuchen, H., X-Ray Diffraction; Anal. Chem.,
28:591 (1950)

Preuss, L. B., Watson J. H. L., A Technique for Taking Motion
Pictures of Electron Microscope Images; J. Appl. Phys.,
21:902 (1950)

Rady, A. (Al Shams Univ. Cairo) Dynamic Properties of the
New Rubberlike Irradiated Polyethylene, J. Appl. Polymer Sci.
1:129 (1959)

Rainc, H. C., Richards, R. B., Hyder, H., Heat of Solution
and Heat Capacity Crystallinity of Polyethylene, Trans. Faraday
Soc., (Feb. 1945)

Ramberg, E. G., Hillier, J., Chromatic Aberration and Resolving

Reiney, G. J., Tryon, M., Achhammer, B. G., Study of Degradation
of Polystyrene, Using Ultraviolet Spectrophotometry;

Reisner, J. H., Dornelf, E. G., A Small Electron Microscope;
J. Appl. Phys., 21:113; (1950)

Reynolds, J. H., High Sensitivity Mass Spectrometer for Noble


Salomon, G., van der Schee, A. C., Infrared Analysis of Isomerized, Vulcanized and Oxidized Natural Rubber; *J. Polymer Sci.*, 14:181 (1954)


Seal, M., The Fine Structure of Films of Rubber and Other Polymers; *Phil Mag.*, 5:78 (1960)

Sears, W. C., Infrared Spectra of Rubber and High Polymers; *J. Appl. Phys.* 12:35 (1954)


Setkina, 01, and Uryan, R., Spectroscopic Analysis of Mineral Components in Rubber Compounds, *Nauchuk i Rezina* 18 3:10 (1959)

Shelberg, W. E., Gevantman, L. H., X-Ray Diffraction Comparison of Radiation Damage in Rubbers; Rubber Age, 87:263 (1960)


Statten, W. O., Crystallite Regularity and Void Content in Cellulose Fibers as Shown by Small-Angle X-Ray Scattering; J. Polymer, 22:384 (1956)


Stein, R. S., The X-Ray Diffractions, Birefringence, and Infrared Dichroism of Stretched Polyethylene, II. Generalized Uniaxial Crystal Orientation; J. Polymer Sci., 31:327 (1958)


Stevens, H. P., the Fine Structure of Rubber and Related Colloids; Comment on Electron Microscopic Studies of "Natural and Synthetic Rubber Fibers"; Indian Rubber J., 324 (Mar. 1945)


Wiegand, W. B., Ladd, W. A., Colloidal Carbon as Revealed by the Electron Microscope; Rubber Age, (Mar. 1942)


Zyorykin, V. K., Ramberg, E. G., Applications De La Microscopic Electronique Et. De La Diffraction Electronique A LA Metallurgie; Centenaire de l'A. I. Lg. Congres 1947, Section Metallurgic Physique.

PHYSICAL PROPERTIES, SWELLING,

THERMODYNAMICS

BIBLIOGRAPHY
Trudy Nauch.-Issledovatel. Inst. Rezin Prom., 52 (1960)


Allen, P.J., (Brit. Rubber Producers Research Assoc., Wolvyn Garden City, Engl.), The Swelling Behavior of Natural Rubber Lakes; J. Colloid Sci., 13, 483-7 (1958)

Altgelt, K., Schulz, G.V., (Univ. Mainz, Ger.): Determination of the Molecular Constants of Natural Rubber. II. Intrinsic Viscosity (Staudinger-Index) Sedimentation and Diffusion Constants in Cyclohexane; Makromol. Chem., 32, 66-78 (1959)


Badische Anilin & Soda-Fabrik Akt.-Ges., Polymers with High Impact Strength; Z. 1, 019, 965 (Nov. 14, 1957)


Bardwell, J., Winkler, C.A., Network Formation, II. Can J. Research, B27, 128 (1949)


Boyer, R.F., Effect of Plasticizers on Some Physical Properties of Polymers; Tappi, 34:357 (1951)


Bueche, F., (Univ. of Wyoming, Laramie), Dynamics of Lossely Cross-Linked Polymer Networks; J. Appl. Polymer Sci., 1:240 (1959)


Bueche, F., (Univ. of Wyoming, Laramie), Tensile Strength of Filled GR-S Vulcanizates, J. Polymer Sci., 33:259 (1958)


Church, W.M., Shivers, J.C., Structure-Property Relationships in Synthetic Fibers: II. Elastomeric Condensation Block Copolymers; *Textile Research J.*, 29:536 (1959)


Chien, Pao-Kung, et al., Viscoelastic Properties of Native Hevea Rubber: II. Effect of Crystallinity on the Type of Flow; *Tung Pei Jen Hsin Ta Hwa-h-Tzu Jan Lu Haush Pao*, 4:57, No 2, 115-25

Clews, C.J.B., Schallamach, A., Structure of Isoprene; *Nature*, 157:160 (1946)


Crespi, G., Bruzzone, M., Cross-Link Density and Physical Properties of Ethylene-Propylene Copolymer Elastomers; *Chim. e Ind.* (Milan), 41:741-8 (1959)

Dean, H.R., Legatski, T.W., Specific Gravity of Butadiene; *Ind. Eng. Chem.*, 16:7 (1944)


Deutsche Shell AKt.-Ges. and Metallgesellschaft AKt.-Ges., Rubber Mixtures with Improved Physical Properties; *Ger. 1,077,865* (Mar. 17, 1960)


Dingle, A.D., Dynamic Mechanical Properties of Some New Elastomers; *Rubber World*, 14:393 (1960)


Dogadkin, B.A., (Inst. Rubber Ind., Moscow), Vulcanizate Structures and Their Changes During Vulcanization; Hot Stress Relaxation and Fatigue; *Kautschuk u Gummi.*, 12, MT 5 (1959)


Edwards, D.C., A Simple Direct Method for Measuring the Permeability of Rubber Vulcanizates to Gases; Rubber Age, (1956)

Farbenfabriken Bayer AKt.-Ges., Synthetic Rubber Having Improved Slip Resistance; Ger. 1,041,797 (Oct. 9, 1958)


Flinn, C. Falconer, Use of Paint in Butyl Rubber: III. Effect on Special Properties of Butyl Rubber; Rubber J. and Intern. Pyastics, 139:490 (1960)


Flory, P.J., Rabjohn, M., Shafter, M.C., Dependence of Tensile Strength of Vulcanized Rubber on Degree of Cross-linking; J. Polymer Sci., 4:435 (1949)


General Electric Co., Organopolysiloxane Elastomers; Brit. 847,556 (Sept. 7, 1960)


Gasserer, A.H., Effect of Attrited Blacks on Butyl-Rubber Properties; Rubber Age, 87:364 (1960)

Grisdale, R.O., Pfister, A.C., van Roosbroeck, W., Pyrolytic Film Resistors: Carbon and Borocarbon; Bell System Tech. J., 30:271 (1951)

Haim, E., Thermodynamic of the Elasticity of Rubber in the Light of The Work of G.H. Bartenev; Ind. Macara (Bucharest) 31321 (1956)


Harper, R.H., The Effect of Di-Ester Lubricants on Aircraft Rubber Parts; Rubber Age, (June, 1953)


Houwink, R., Ueber die Struktur des Kautschuks; *Kolloid Z.*, 95:303 (1941)

Hsiang, C.C., Sauer, J.A., Effect of Strain Rate on the Tensile and Compressive Stress-Strain Properties of Polystyrene; *ASTM Bulletin*, No. 172 (Feb., 1951)

Huggins, M.L., A New Approach to the Theory of Rubberlike Elasticity; *J. Polymer Research* 1:1 (1946)


James, H.M., Network Theory of Rubber Elasticity; *Record Chem. Progr.*; Fall Issue:173 (1949)


James, H.M., Guth, E., Theory of the Elasticity of Rubber; *J. Appl. Phys.*, 15:294 (1944)


Kasuya, Tameichi, Hirata, Yoshiaki, Mixture of Natural Rubber — Butadiene-Styrene Rubber; II. Relation Between Ratio of Mixture and Physical Properties; Nippon Gummi Kyokaishi, 33:169 (1960)

Kase, S., (Togawa Rubber Co., Osaka), The Method of Adjusting Tensile Data of Vulcanizates VIII; Nippon Gummi Kyokaishi 30:852 (1957)


Kesemitz, G., (Glanzstoff-Court., G. m. G. K., Kohn-Weidemensch, Ger.), Investigation of Compression Fatigue and Damping Phenomena for Tire Cords; Kautschuk u. Gummi 12 WT 270-WT 282 (1959)

Kempermann, Th., Claaro, R., (Farbenfabriken Bayer Akt. Ges., Leverkusen, Ger.), Determination of Relative Damping in the Presence of Different Pre-Stresses; Kautschuk u. Gummi 12 WT 96, WT 100, WT 102, WT 104, WT 106 (1959)


Koningsberger, C., Salomon, G., Preparation and Properties of Rubber like High Polymers; I. Polymerization of Dienes and Vinyl Compounds in Bulk; J. Polymer Sci., 1:200 (1946)

Koningsberger, C., Salomon, G., Preparation and Properties of Rubber like High Polymers; II. Polymerization of Mixture in Bulk; J. Polymer Sci., 1:353 (1946)


Kostina, S., An Accelerated Method for the Determination of Swelling of Synthetic Rubber Vulcanizates; Kautschuk i Rezina 16, 12:30 (1957)

Kraus, Gerard, Degree of Cure in Filler-Reinforced Vulcanizates by the Swelling Methods; Rubber World, 135:67 (1956)
Kraus, G., Short, J. L., Thornton, V., Effect of Cis-Trans Ratio on the Physical Properties of 1,4-Polybutadienes; Rubber & Plastics Age, (Oct., 1957)

Kress, K. E., Determination of Polyisobutylene in Rubber Products; Anal. Chem., 30:287 (1958)

Kress, K. E., Determination of Sulfur by Versatile Ultraviolet Absorption Spectrophotometric Method; Beckman Technical Data BU-62-G(2) (May, 1957)

Kress, K. E., Photometric Determination of Zinc Oxide in Rubber Products Absorption and Absorbance Methods Using Sodium Diethyl Dithiocarbamate; Anal. Chem., 30:432 (1958)


Landel, Robert L., Stedry, Paul J., Stress as a Reduced Variable: Stress Relaxation of SBR Rubber at Large Strains; J. Appl. Phys., 31:885 (1960)


Lens, On the Solutions of Rubber Sol: Vapor Pressure Data on Rubber Swelling; Rec. Trav. Chim., 51:971 (1932)


LuKemakaya, A.I., Some Features of the Reinforcing Action of Carbon Blacks Following from the Tear Behavior of Filled Rubbers; Vysokomolekulyarnaya Sirodeniya, 1:1287 (1959)

Lutttropp, H., Swelling and Deswelling of Soft Rubber Vulcanizes; Kautschuk u. Gummi 12 WT 147 WT155 WT 186 WT 190 (1959)


Madorsky, S.L., Rates and Activation Energies of Thermal Degradation of Styrene and Acrylate Polymers in a Vacuum; J. Polymer Sci., 11:491 (1953)


Hulvile, H.W., Valentme, G.R.S., Valentine, L., Studies in Co-
polymerization I. Evaluation of the Kinetic Coefficients for the 
Copolymerization of Styrene and Methyl Methacrylate; J. Am.

Stress Relaxation Studies of Scission in Rubber Vulcanizates; J.

Meyer, J., Taylor, J., Effect of Highly Aromatic Gasolines on Fuel 
Hose Compounds; Rubber World, 140:573-8 (1959)

Heynord, C., Thalamen, Brominated Butyl Rubber; Rev. ren.
couche, 33:620 (1958)

Michaelisen, J.D., Wall, L.A., Further Studies on the Pyrolysis 
of Polytetrafluoroethylene in the Presence of Various Gases; J. Research 
Nat. Bur. Standards, 58: (June, 1957)

Mochel, W.E., Petersen, J.H., The Structure of Neoprene: II. De-
termination of End-Groups by Means of Radiosulfur; J. Am. Chem.
Soc., 71:426 (1949)

Mochel, W.E., Nichols, J.B., The Structure of Neoprene: IV. The 
Molecular Weight Distribution of Neoprene Type GG; J. Am. Chem.
Soc., 71:435 (1949)

Mochel, W.E., Nichols, J.B., Nighton, C.J., The Structure of 
Neoprene: II. The Molecular Weight Distribution of Neoprene Type 

Mochel, W.E., Structure of Neoprene: V. Viscosity-Conversion 
Sci., 8:583 (1952)

Hooney, M., Rheology of Raw Rubber; Physics, 7:413 (1936)

Moore, C.G., Scanlan, J., Determination of Degree of Cross-Linking 
in Natural Rubber Vulcanizates: VI. Evidence for Chain Scission 
During the Cross-Linking of Natural Rubber with Organic Peroxides; 

Rubber World, 137:250 (1957)

Morris, R.S., Barrett, A.E., Effect of Arctic Exposure on Hardness 
of Klastomer Vulcanizates; India Rubber World, (March, 1954)

Hullins, L., Determination of Degree of Cross-Linking in Natural 
Rubber Vulcanizates: IV. Stress-Strain Behavior at Large 


O'Mahoney, Joseph F. Jr., Adhesion of Butyl Rubber Cured with Bis (Hydroxymethyl) - Phenols to Copper and Copper-Containing Alloys; U.S. 2,960,426 (Nov. 15, 1960)


Pinner, S., Stress-Strain Properties of Irradiated Filled Natural Rubber; Intern. J. Appl. Radiation and Isotopes 5:121 (1959)


Poddubnyi, I. Ya., Erenburg, E.G., Branching in Macromolecules of Different Synthetic Rubbers; J. Polymer Sci., 29:605 (1958)


Posnjak, Uber den Quellungsdruck; Koll. Reihbste, 3:417 (1912)


Prandlergast, J.J., Gasoline versus Elastomers; Rubber Age, 84: 619-26 (1959)

Price, F.P., A Light Scattering Investigation of Crystal Growth in Polyethylene; Growth & Perfection of Crystals, John Wesley and Sons, New York (1958)


Rehner, J.Jr., Heat Conduction and Molecular Structures in Rubberlike polymers; J. Polymer Sci., 2:263 (1947)


Richards, R.B., Oriented Overgrowth on Cold-Drawn Polymers; J. Polymer Sci., 6:397 (1951)


Rostler, P.S., Rostler, K.S., Morrison, R.E., Swelling of Rubber: II. A Comparison of the Swelling Behavior of Vulcanized Natural Rubber and GR-S in Organic Liquids; \textit{Rubber Age}, (June, 1946)

Rostler, P.S., Morrison, R.E., Swelling of Rubber: IV. Effect of Carbon Blacks on the Swelling of Vulcanized GR-S; \textit{Rubber Age}, (April, 1947)

Rostler, P.S., Rostler, K.S. Swelling of Rubber: III. The Swelling Behavior of Vulcanized Natural Rubber and GR-S in Mixtures of Hydrocarbons; \textit{Rubber Age}, (Oct., 1946)

Roush, C., Braley, S. (Dow Corning Corp., Midland, Mich.), Compression Set of Silicone Rubber; \textit{Rubber Age} II.X. 84:75 (1958)


Salomon, G., Correlation Entre la Structure et les Propriétés Mécaniques des Polymères en Chaîne; \textit{Chim & Ind.} (Paris) Special Number for the 21st International Congress of the Chemical Industry


Salomon, G., Polymerization Induced by Silver Salts; Rec. Trav. Chim., 63:903 (1944)


Salomon, G., Quantitative Determination of Organic Matter; Analyt. v. vv. 77:1017 (1952)


Smith, F. (Firestone Tire and Rubber Col, Akron, Ohio) Properties of Elastomers up to 550°F; Rubber World 139:533-689 (1959)

Smith, T. Dependence of the Ultimate Properties of an SBR Rubber on Strain and Temperature; J. Polymer Sci. 32:99 (1958)


Societe Auxiliaire de l'Institut Francais du Caoutchouc, Improvement of Mechanical Properties of Elastomers by Formation of Resinous Condensation Products in Dry Rubber; Fr. 1,182,648 (Sept. 14, 1959)


Ueberreiter, K., Kanig, G., Die Kettenlängenabhängigkeit des Volumens, des Ausdehnungskoeffizienten und der Einfrier-temperatur von Fraktionierten Polystyrolen; Z Naturforsch., 6a: 551 (1951)


Ueberreiter, K., Kanig, G., Self-Plasticization of Polymers; J. Colloid Sci., 7:569 (1952)

United States Rubber Co., Adhesion of Butyl Rubber to Other Elastomers; Brit. 853,215 (Nov. 2, 1960)

Uret, R.B., Bloom, W., Zirkle, R.E., Irradiation of Parts of Individual Cells: II. Effect on an Ultraviolet Microbeam Focused on Parts of Chromosomes; Science, 120:197 (1954)

Vasilev, Az., Nedialkova, K., The Effect of Various Types of Carbon Black on the Physical Properties of High-Modulus Carcass, Breaker and Protector Mixtures Based on Natural Rubber; Leka Prom., 8:15 (1959)


Wagner, Helvin P., Kinetics of Filler-Polymer Interaction Between Fine Particle Silica and SBR or Butyl Rubber; Ind. Eng. Chem., 51:961 (1959)


Wall, L., Pyrolysis of Copolymers; Nat. Bur. Standards Circ. 525 (1953)


Weinreb, A., Avivi, P., Comparison Between Energy Transfer in Liquid and Plastic Solutions; Liquid Scintillation Counting; 1270 (1958)


Will, D.W., Bishop, F., Bogen, E., Djang, A.H.K., Carpenter, C.M., Comparative Morphology of Acid-Fast Bacilli; Diseases of the Chest, 19:387 (1951)

Wilson, A., Griffith, G.D., Montermino, J.C., Effect of Swelling on the Properties of Elastomers; Rubber World (Oct., 1958)

Woo, H.K., Dusenbury, J.H., Dillon, H.H., The Reaction of Formaldehyde with Cellulose Fibers; I. Rate and Mechanism of the Reaction; II. Mechanical Behavior; Textile Research J., 26:745 (1956)


Wormuth, Wilbur J., Low-Shrinkage Silicone Rubber Compositions; U.S. 2,938,011 (May 24, 1960)


Yashunskaya, F.I., Markovich, G.A., High-Elasticity Synthetic Rubbers as Compared with Butadiene-Styrene; Kauchuk i Rezina, 18:1 (1959)


Zanamonets, N., Fogel, V., Thermophysical Characteristics and Thermal Effects of Reaction of Vulcanization of Hard Rubber Compositions from Styrene-Butadiene Rubber; Kauchuk i Rezina 18 No. 2:21 (1959)


Zapp, R., Dynamic Properties of Butyl Rubber and Their Applications; Proc. Inst. Rubber Ind., 5:172 (1958)


Zirkle, R.E., Bloom, W., Irradiation of Parts of Individual Cells; Science, 117:487 (1953)
ADDITIVE, COMPOUNDING

BIBLIOGRAPHY


Ambelang, Joseph C., Reaction Products of Alkylene Dihalides and Substituted Phenylelenediamines for use as Antioxidants in Rubber; U.S. 2,929,967 (June 7, 1960)


Andakushkin, V.Ya., Savel'ev, A.I., et al, An Improved Method of Producing Copolymers of Butadiene and Acrylonitrile; II. Production of SKL-26 Rubber by Continuous Polymerization; Kachural 1 Razina, 16:6 (1959)


B.F. Goodrich Co., Rubbery Material Reinforced with Pigments Containing Silicon and Oxygen; Brit. 855,424 (Nov. 30, 1960)

B.F. Goodrich Co., Silicon-Oxygen Compounds as Reinforcing Pigments for Elastomers; Can. 1,041,019 (Oct. 16, 1958)


B.F. Goodrich Co., Stable Latexes from Acrylonitrile and Butadiene; Can. 1,055,241 (Apr. 16, 1959)

Bailey, Donald L., Black, Wm. T., Dunham, Hilton L., Dialkyl Peroxide - Cured Silicone Elastomers; Brit. 819,245 (Sept. 2, 1959)

Barta, Zoltan, New Synthetic Rubbers; Narvar Kem. Lapla, 15:446 (1960)


Baum, Sidney J., Moldable Compositions from Styrene and Styrene-Rubber Interpolymers; U.S. 2,957,833 (Oct. 25, 1960)


Beaver, David, Stoffel, Paul J., Nitrosoamines as Additives to Rubber to Prevent Cracking Under Stress; U.S. 2,931,765 (Apr. 5, 1960)

Bergstrom, E.W., Antioxidants for Nitrile and Natural Rubbers; Rock Island Arsenal Lab. Tech. Rpt. 21: (Jul., 1956)

Bergstrom, E.W., Preservation of Tires in Outdoor Storage at Rock Island, Ill.; Rock Island Arsenal Lab. Tech. Rpt. 58:106

Berman, H.L., Sachkulik, V.I., Luminescence Method for the Control of Rubber Composition; Kauchuk i Rezina 16: 12:33-6 (1957)


Blanchard, A.F., Role of Particle Diameter and Linkage Formation in Rubber Reinforcement; Proceedings of the Third Rubber Technology Conference (1954)


British Resin Products Ltd., Acrylates of Phenox Alcohol Ethers and Polymers thereof; Brit. 828,496 (Feb. 17, 1960)


Brockey, Robert S., Miller, Alfred L., Stable Butyl Rubber Latexes; U.S. 2,936,265 (May 10, 1960)


Burke, Oliver W., Compounding of Vulcanizable Elastomers; Brit. 844,164 (Aug. 10, 1960)

Casefort, Z.T., Shaw, R.F., Bergstrom, E.W., Curing Systems for Improved Aging Resistance of Rubber Vulcanizates; Rubber World; (March, 1957)

Chemische Werke Huls Akt.-Ges., Butadiene-Styrene Rubber; Ger. 1,082,413 (May 25, 1960)

Clark, R.A., Dennis, J.B., Compounding Acrylonitrile-Type Rubber for Low Temperature Flexibility; Ind. Eng. Chem., 43:771 (1951)

Clark, R.A., Cheyney, L. E., Compounding of O-Rings Hydraulic Packings; Rubber Age, (Aug., 1949)

Cobb, Joseph R. Jr., 1,3-Butadiene; U.S. 2,963,522 (Dec. 6, 1960)

Cohan, L.H., Steinberg, M., Determination of Rate of Cure for Natural and Synthetic Rubber; Ind. Eng. Chem., 16:15 (1944)

Cohan, L.H., Fundamental Properties of Carbon Black Relation to Behavior in Rubber; India Rubber J., (Nov., 1947)


Cohan, L.H., Steinberg, M., Reinforcement of Natural and Synthetic Rubber - Effect of Particle Size of Channel Blacks; Rubber Age and Synthetica (Jan., 1945)

Cohan, L.H., Watson, J.H.L., Shape Factor and Other Fundamental Properties of Carbon Black; Rubber Age, (March, 1947)

Cohan, L.H., Smith, E.B., The Effect of Pigments on the Hardness of Natural and Synthetic Rubbers; Rubber Age, 1465 (July, 1948)

Cohan, L.H., The Mechanism of Reinforcement of Elastomers by Pigments; India Rubber J., 117 (1947)


Cottle, Belmer L., Hinckler, Leon S. Jr., Lemisaka, Theodore, Bromination of Butyl Rubber; U.S. 2,962,432 (Nov. 29, 1960)

Cotton, F.H., Lee, K.O., Effects of Antioxidants on Rate of Breakdown of Rubber During Mastication; India Rubber J. (May, 1951)


Craig, D., Davison, W.L., Juve, A.E., Tetramethylthiuram Disulfide Vulcanization of Extracted Rubber: IV. Behavior of Rubber as an Acid; J. Polymer Sci., 6:13 (1951)

Craig, D., Davidson, W.L., Juve, A.E., Tetramethylthiuram Disulfide Vulcanization of Extracted Rubber: V. Low Molecular Products and the Mechanism of Zinc Oxide Activation; J. Polymer Sci., 6:177 (1951)

Craig, D., Davidson, W.L., Juve, A.E., Tetramethylthiuram Disulfide Vulcanization of Extracted Rubber: III. Short-Path Distillation of TETD and Its Reaction Products From Rubber; J. Polymer Sci., 6:7 (1951)


Daly, Lawrence E., Thermoplastic Mixture of Betadine-Acrylonitrile Rubber, Styrene-Acrylonitrile Resin, and Vinyl Chloride Resin; J. Appl. Polym. Sci., 2,924,545 (Feb. 9, 1960)


Dannenberg, E.H., Opie, W.H., Jr., A Study of the Moisture Adsorption Properties of Carbon Blacks; Rubber World (March, April, 1958)


Deutsche Gold- und Silber-Scheideanstalt vorm. Roessler, Synthetic Silicates as Rubber Fillers; *Ger.* 1,035,354 (July 31, 1958)

Deutsche Shell Akt.-Ges. and Metallgesellschaft Akt.-Ges., Synthetic-Rubber Vulcanizates or Reclams; *Ger.* 1,077,864 (March 17, 1960)

Dow Chemical Co., Copolymers of Styrenes and Rubber; *Ger.* 1,040,793 (Oct. 9, 1958)

Dow Corning Corp., Siloxane Elastomers Containing Zinc Oxide or Zinc Peroxide; *Ger.* 1,033,408 (July 3, 1958)

Dow Corning Corp., Siloxane Elastomers Curing at Room Temperature; *Ger.* 1,019,462 (Nov. 14, 1957)

Dow Chemical Co., Synthetic Latexes Containing Aliphatic Nitro Alcohols; *Brit.* 836,335 (June 1, 1960)

Dumonthier, Jean, A Special Filler for Butyl Rubber: Tuborlyl; *Rev. gen. caoutchouc* 34:469 (1957)


Dunlop Rubber Co. Ltd., Adhesives from Betadiene Copolymers and Phenol Condensation Products; *Ger.* 1,015,166 (Sept. 5, 1957)

Dunlop Rubber Co. Ltd., Bonding Elastomeric Materials to Natural Rubber; *Brit.* 834,223 (May 4, 1960)

Eby, Lawrence T., Thomas, Robert H., Heat-Reacting Butyl Rubber, Halogenated Butyl Rubber and Zinc Oxide, and Composition Obtained Thereby; *U.S.* 2,948,700 (Aug. 9, 1960)

Eitingon, L.I., Paliashlian, N.S., Strel'nikova, N.P., Pevzner, D.N., Vulcanization of Rubber Mixes Having a Synthetic-Rubber or Natural-Rubber Base; *U.S.S.R.* 124,111 (Nov. 20, 1959)

Ernst, John L., Small, Augustus B., Polymerization of Olefins and Diolenfs to Synthetic Rubber; *U.S.* 2,931,791 (Apr. 5, 1960)

Esser, H., Sinn, G., The Reinforcement of Films from Natural and Synthetic Latex with Silica Sol; *Mautschuk u. Gummi* 126 (1960)
Esso Research and Engineering Co., Brominated Butyl Rubber; Brit. 838,045 (June 22, 1960)

Esso Research and Engineering Co., Brominated Polymeric Elastomers; Brit. 835,639 (May 25, 1960)

Esso Research and Engineering Co., Treatment of Butyl Rubber with Hard Kaolin Clay; Brit. 855,137 (Nov. 30, 1960)


Farbenfabriken Bayer Akt.-Ges., Copolymers of 2-Chloro-1,3-Butadiene and Acrylonitrile; Brit. 858,441 (Jan. 11, 1961)

Farbenfabriken Bayer Akt.-Ges., Emulsifiers for the Preparation of Synthetic Rubber; Ger. 1,072,270 (Jan. 28, 1960)

Fekete, Frank., Silicone Elastomer Compositions; U.S. 2,954,357 (Sept. 27, 1960)

Firestone Tire & Rubber Co., Butyl Rubber Compositions Containing Chlorosulfonated Polyethylene; Brit. 836,716 (June 9, 1960)

Firestone Tire & Rubber Co., Polymerization of Butadiene in the Presence of Lithium; Brit. 877,693 (Aug. 6, 1959)


Ford, F.P., Hottlau, A.Y., Studies in the Dispersion of SRF Carbon Black in Butyl Rubber; Rubber Age (Jan. 1952)


Frank, R.L., Drake, S.S., Smith, P.V.Jr., Stevens, C., Mercaptan Derivatives as Codispersers in the Copolymerization of Butadiene and Styrene; J. Polymer Sci., 3:50 (1948)

General Electric Co., Silicone Rubber; Ger. 1,025,621
(March 6, 1958)

Gerson, Wesley H., Compositions of Vinyl Chloride Resins,
Copolymers of Butadiene-Acrylonitrile, and a Graft of Butadiene
on a Copolymer of Styrene-Acrylonitrile; U.S. 2,927,093
(Mar. 1, 1960)

Gessler, A.B.K.H., Rehner, J., The Reinforcement of Butyl
and Other Synthetic Rubbers with Silica Pigments: I. Effect
of Heat Treatment; Rubber Age (Sept., 1955)

Gessler, A.B.K.H., Wiese, K.H., Rehner, J., The Reinforcement of
Butyl and Other Synthetic Rubbers With Silica Pigments: II.
Effect of Surface Modification of Silica and Subsequent Heat
Treatment; Rubber Age (Oct., 1955)

Gessler, A.M., The Reinforcement of Butyl With Carbon Black:
I. Heat Treatment; Methods & Effects; Rubber Age (Oct., 1953)

Gessler, A.M., Ford, F.P., The Reinforcement of Butyl With
Carbon Black: III. The Action of Promoting Agents; Rubber Age
(Dec., 1953)

Gomory, Paul L., Contact of Materials for Reaction; U.S.
2,951,061 (Aug. 30, 1960)

Goodyear Tire & Rubber Co., Compositions of Vinyl Chloride
Resins, Copolymers of Butadiene-Acrylonitrile, and a Graft of
Butadiene on a Copolymer of Styrene-Acrylonitrile; Brit.
841,744 (July 20, 1960)

24:1082 (1963)

Phys., 24:1288 (1953)

Gruber, V.N., Ponomareva, N.N., Mukhina, L.S., Siloxane Rubber;
U.S.S.R. 122,876 (Oct. 10, 1959)

Habgood, B.J., Synthetic Rubber; Ann. Rept. Progr. Rubber
Technol., 23:29 (1959)

Rubber Technol., 23:43 (1959)

Hercules Powder Co., Methylolated Rosins in Emulsion Polymer-
ization, Especially of Butadiene and Styrene; Brit. 829,213
(Mar. 2, 1960)
Honn, Francis J., Copolymers of Fluoro Dienes and Styrene; U.S. 2,962,484 (Nov. 29, 1960)

Honn, Francis J., Copolymers of Fluoro Butadienes and Acrylates; U.S. 2,917,496 (Dec. 15, 1959)

Honn, Francis J., Copolymers of Styrene with Fluorinated Dienes; U.S. 2,949,446 (Aug. 16, 1960)


Ingredients de Melanges: Accelerateurs de Vulcanisation; Rev. Gen. Caoutchouc, 36:166 (1959)

Ingredients de Melanges: Evaluation des Qualites de Mica in Tant Que Charges Pour Mousse de Latex; Rev. Gen. Caoutchouc, 36:164 (1959)

Instytut Przemyslu Skorzanego, Cationic Latex from Synthetic and Natural Resins; Pol. 41,902 (Apr. 30, 1959)


Knobloch, Fred W., Hamlin, Horace C., Polymers Derived from Dihydroperfluorobutyl Acrylate; U.S. Govt. Research Reports, 31:159 (1959)


Konkle, G.R., New Developments in Special-Purpose Silicone Polymers: Rubber Age, 84:975 (1959)


Koppers, Co., Inc., Styrene-Butadiene Rubber Compositions Containing Microcrystalline Waxes; Brit. 832,303 (Apr. 6, 1960)


Kunisawa, Shintaro, Graft-Block Copolymer: IV. Effect of Milling and Heat Polymerization on the Preparation of Natural Rubber-Acrylamide Block Copolymer; Nippon Gomu Kyoukai, 33:17 (1960)

Kunisawa, Shintaro, Graft-Block Copolymer: III. Natural Rubber-Acrylamide Block Polymer; Nippon Gomu Kyoukai, 33:16 (1960)

Kunisawa, Shintaro, Graft-Block Copolymer: II. Natural Rubber-Acrylonitrile Graft Copolymer; Nippon Gomu Kyoukai, 33:5 (1960)

Kunisawa, Shintaro, Graft-Block Copolymer: I. Natural Rubber-Methyl Methacrylate Copolymer; 33:9 (1960) Nippon Gomu Kyoukai
Knupp, Peter C., Finigan, Charles M., Purification of Butadiene by Using an Ammoniacal Solution of Copper Ions; U.S. 2,944,095 (July 5, 1960)


Le Foll, J., Mixtures of Neoprene and Hypalon with Other Elastomers and Plastomers; Peintures, pigments vernis 35:370 (1959)

Le, Elizabeth S., Crawford, Geo. H., Jr., Elastomeric 2-(Trifluoromethyl) Butadiene Copolymers with Fluorinated Hydrocarbons; U.S. 2,951,065 (Aug. 30, 1960)


Lucas, Glennard R., Modified Fillers for Polysiloxane Elastomers; U.S. 2,938,009 (May 24, 1960)


Maizels, N.O., Raevskii, V.O., Parshina, E.A., Butyl Rubber; I. Principles of Building a Rational Technology of Production of Technical Rubber Products Based on Butyl Rubber; Kauuch i Razina, 17:11 (1958)


Martin, B.J.A., Controlling Quality of Compounding Laboratory Results; Trans. Inst. Rubber Ind., V.30 no. 3:57 (1954)


Midland Silicones Ltd., Siloxane Elastomers; Brit. 832,488 (Apr. 13, 1960)

Midland Silicones Ltd., Siloxane Elastomers; Brit. 844,128 (Aug. 10, 1960)

Mikhant'ev, B.I., Raevshii, A.B., Butadiane-Styrene v-Polymer; Kaučuk i Rezina, 18:24 (1959)


Minoura, Yuji, Synthetic Rubber of Polysulfide Series: I Formation Reaction of Thiokol A.; Nippon Gum Kyokaishi, 33: 110 (1960)


Monsanto Chemical Co., Modifying Butyl Rubber with p-Nitros-aniline Derivatives; Brit. 841,530 (July 20, 1960)

Monsanto Chemicals Ltd., Styrene-Rubber Copolymers; Ger. 1,056,373 (Apr. 30, 1959)

"Montecatini" Societa generale per l'industria mineraria e chimica; Polybutadienes; Brit. 849,589 (Sept. 28, 1960)

Morris, R.E., Barrett, A.E., Permanence of Plasticizers in GR-S Vulcanizates Exposed to Weather; Rubber Age (1951)


Nippon Chemical Fiber Research Foundation, Strengthening Butyl Rubber; Japan 14,781 (Oct. 6, 1960)


Novy, L.E., Clark, R.A., Compounding Rubbers for Resistance to Silicate-Ester Fluids; I. Neoprene W.R.T.; Rubber Age, (July-June 1957)


Ossefort, Z.T., The Influence of Accelerator Residues on Age Resistance of Elastomeric Vulcanizates; Rock Island Arsenal Lab. Rpt. No. 56-2474


Parker, C.A., Berriman, J.M., Chromatographic Analysis of Vulcanized Rubbers; Trans. Inst. Rubber Ind., 28:279 (1952)


Parker, C.A., Chromatography of Rubber Accelerators and Anti-Oxidants on Silica Gel; Nature, 170:539 (1952)

Petrochemicals Ltd., Copolymers of Styrene and Butadiene; Ger. 1,037,135 (Aug. 21, 1958)


Polmanteer, Keith E., Siloxane Elastomers; U.S. 2,927,907 (Mar. 8, 1960)

Polymer Corp. Ltd., Butadiene-Styrene Latexes of Improved Stability; Ger. 1,639,231 (Sept. 18, 1958)

Polymer Corp. Ltd., Modified Butyl Polymer; Brit. 819,293 (Sept. 2, 1959)


Raamsdonk, G.W. von, Coating of Metals with Latex-Rubber; Rubber Age, 84:967 (1959)

Railback, H.E., New Developments in cis-Polybutadine Elastomers; Rubber Age, 84:967 (1959)

Rehner, J. Jr., Holowchak, J., Determination of Total and Combined Sulfur in Butyl Rubber; Ind. Eng. Chem., 16:98 (1944)

Rehner, J., Gessler, A.J., The Reinforcement of Butyl with Carbon Black: IV. Effect of Polymer Composition and Molecular Weight on Efficiency of Heat Treatment; Rubber Age (Jan., 1954)

Raamsdonk, G.W. von, Latex-Klebstoffe; Chem. Rundschau (Solothurn), 8165 (1955)

Reich, M.H., Thift, W.K., Laundrie, R.W., Breakdown of Synthetic Elastomers in a Banbury Mixer with Added Air; Rubber Age, (Oct., 1951)


Saunders, I. (Hobay Chem. Co., New Martinsville, W.Va.) Reactions of Isocyanates and Isocyanate Derivatives at Elevated Temp.;
Rubber Chem. Technol. 32:337 (1959)

Savage, R.H., New Developments in Silicone Rubbers; Rubber Age, 84:972 (1959)

Savage, R.H., Silicone-Rubber Compositions; U.S. 2,938,007
(May 24, 1960)

(1951)

Schneider, Paul, Scriba, Gottfried, Granich, Wilhelm, Mixtures of Elastomeric Copolymers of Butadiene with Thermoplastic Copolymers of Styrene and Acrylonitrile; U.S. 2,925,399 (Feb. 16, 1960)

Schreiber, Charles K., Polypropylene-Butyl Rubber Blends; U.S. 2,939,860 (June 7, 1960)

Seaman, R.G., Carlton, C.A., Available Dry Styrene-Butadiene Rubbers (SBR) - United States and Canada; Rubber World, 146:421 (1959)

Semenov, S.T., Wabelin, J.H., Studies on the Vulcanization and Structure of Polyacrylic Rubber; Rubber Age, 71: (Apr., 1952)

Serniuk, Geo. B., Aldehyde-Modified Butyl Rubber; U.S. 2,952,657 (Sept. 13, 1960)


(1957)


Shimosato, Joji, Yasumaga, Hidetoshi, et al., Manufacture of High-Styrene Resin; I.; Nippon Gum Kyokaishi, 33:87 (1960)

Small, Augustus B., Ernst, John L., High-Molecular-Weight Polyisobutylene; U.S. 2,927,104 (Jul. 1, 1960)

Smirnov, R.N., Mercured Rubber; I. Mercured Butadine Rubbers; Vysokomole Kulturnye Soedinenia, 2:558 (1960)

Smith, J.F., Dithiol Curing Agent for "Viton" a Fluoroelastomer; Rubber World, 140:263 (1959)


Smith, W.R., The Behavior of Carbon Black in Rubber and Plastics; India Rubber World, 325 (Dec., 1951)

Société auxiliaire de l'institut français du caoutchouc, Foam Rubber; Fr. 1,165,874 (Oct. 30, 1958)

Société des usines chimiques Rhone-Poulenc, Elastomers Based on Diorganopoly siloxanes; Fr. 1,188,495 (Sept. 23, 1959)

Solvay & Cie, Precipitated Calcium Carbonate; Brit. 831,921 (Apr. 6, 1960)

Stearns, R.S., Forman, L.E., Stereoregular Polymerization of Isoprene with Lithium and Organo-lithium Compounds; J. Polymer Sci., 41:381 (1959)

Stickney, P.B., Effect of Cure on Low-Temperature and Aging Properties of Nitrile Rubbers; Rubber World, (1956)


Studebaker, H.L., Chemical Forces in Reinforcement of Rubber by Carbon Black; Rubber Age, 77:69 (1955)

Studebaker, H.L., Some Recent Concepts in the Colloid Chemistry of Carbon Black and Its Reinforcement of Rubber; Kunststoff u. Gummi (German), 6:193 (1953)


Switzer, C.W., Hess, W.H., Callan, J.E., The Dispersion of Carbon Black in Rubber and Its Role in Vulcanizate Properties; Rubber World, 1; 1869 (Sept., 1958), II. 2174 (Oct., 1958)


Tufts, Edgar. New Developments in Fluoroelastomers; Rubber Age, 84:1963 (1959)

Union Carbide Corp., Curing and Forming of Silicone Rubber; Ger. 1,012,069 (July 11, 1957)

Union Carbide Corp., Siloxane Elastomers; Brit. 834,261 (May 4, 1960)

United States Rubber Co., Synthetic Rubber and Leather; Ger. 1,023,219 (Jan. 23, 1958)

Vanderbilt News, Classification of Compounding Materials; 24:4-8 (1958)

Vanderbilt News, Commercial Compounds and Properties; 24:30-56 (1958)

Vanderbilt News, Compound Development; 24:12-29 (1958)


Vanderbilt News, Introduction to Rubber Compounding; 24:2 (1958)

Vanderbilt News, Major Commercial Rubbers and Properties; 24:3 (1958)
Vanderbilt News, Objectives in Compounding; 24:9 (1958)


Vinogradov, P.A., Arsenyeva, N.G., Gavshinova, K.E., Products from Nitrile Rubbers or from Nitrile Copolymers with Butadiene or with Other Unsaturation Compounds; U.S.S.R. 127,386 (Mar. 25, 1960)


Volkova, M.S., Khutareva, G.V., et al., Synthesis and Investigation of Stereoregular Copolymers of Propylene and Isoprene; Vysokomolekulyarnye Soedineniya, 1:1758 (1959)

Wacker-Chemie G.m.b.H., Organopolysiloxane Elastomers; Ger. 1,058,254 (May 27, 1959)

Wadlin, G.W., Ultraviolet Determination of Phenolic Antioxidants in Rubber; Anal. Chem., 28:1530 (1956)


Wick, M., Boron Siloxane Elastomers; Kunststoffe, 50:433 (1960)


Wolf, Ralph F., Non-Discoloring Promoters of Butyl Rubber-Reinforcing Silica Thermal Interaction; Rubber World, 142:81 (1960)

Yokose, Kyochi, Kakimoto, Hiroshi, Arai, Tetsuo, Behavior of Sulfur in Butyl Rubber; Nippon Gum Kyokaishi, 32:460 (1959)


CHEMISTRY OF RUBBER BIBLIOGRAPHY

Alridge, Clyde L., Curing Unsaturated Polymers; U. S. 2,962,479 (Nov. 29, 1960)


Anchor Chemical Co., Ltd., Vulcanization of Butyl Rubber; Brit. 835,469 (May 16, 1960)


Baldwin, Francis P., Thomas, Robert M., Chlorinating Butyl Rubber and Vulcanizing the Chlorinated Product; U. S. 2,964,489 (Dec. 13, 1960)


Bluestein, Ben A., Curing Silica-Containing Organopolysiloxane Elastomers with Amines; U. S. 2,938,010 (May 24, 1960)

Braidwood, Clinton A., Non sulfure Vulcanization of Butyl Rubber; U. S. 2,963,462 (Dec. 8, 1960)

Bresler, S. F., Investigation of the Mechanism of Vulcanization of Rubber with the Help of Radiosulfur; Ricerca sci. 25:923 (1954)

Brodkey, Robert S., Miller, Alfred L., Stabilization of Butyl Rubber Latexes; U. S. 2,955,094 (Oct. 4, 1960)
Brooks, Lester A., Bacon, Jack C., Vulcanization of Neoprene Type W; U. S. 2,911,392 (Nov. 3, 1959)


Columbia - Southern Chemical Corp., Curing and Fabricating Butyl Rubber; Brit. 858,125 (Jan. 4, 1961)


Cunneen, J. I., Higgins, G. M. C., Watson, W. F., Cis-Trans Isomerization in Polyisoprenes. V. The Isomerization of Natural Rubber, Guttapercha, Squalene, Cis-and Trans-3-Methylpent-2-ene, and Cis-polybutadiene, and its Quantitative Estimation; J. Polymer Sci., 40:1 (1959)


Devirts E., and Novikov, A. S., Mechanical and Thermo-oxidizing Plastication of Butadiene-Nitrile Rubbers, Kauchuk i Rezina, 18 No. 7, 21, (1959)


Dogadkin, B. A., Vulcanizing Structures and Their Change in Curing and in the Thermo-chemical and Fatigue Treatment of the Vulcanizes, Khim Nauka i Prom. 4, 55, (1959)

Dow Corning Corp., Curing for Vulcanizing Organopolysiloxanes; Ger. 1,039,228 (Sept. 18, 1958)

Dow Corning Corp., Vulcanization of Organopolysiloxanes Containing Vinyl Groups; Ger. 1,034,355 (July 17, 1958)

Dunham, Milton L., Bitner, Clarence L., Curing Silicone Elastomers; Brit. 821,477 (Oct. 7, 1959)

Dunlop Rubber Co. Ltd., Curing Elastomeric Copolymers of Butadiene and Alkyl Acrylates; Brit. 851,045 (Oct. 12, 1960)

Edgerley, Peter G., Laville, Jocelyn R., Polymerization or Copolymerization of 1,3-Butadiene; Brit. 622,640 (Nov. 4, 1959)


Edd, Egon, Vulcanization of Synthetic Rubber Containing Carboxyl Groups; Ger. 1059,699 (Apr. 9, 1959)

Esso Research and Engineering Co., Catalytic Halogenation of Butyl Rubber; Brit. 839,270 (June 29, 1960) U. S. 2,948,709 (Aug. 9, 1960)

Esso Research and Engineering Co., Halogenation of Butyl Rubber; Brit. 847,544 (Sept. 7, 1960)

Esso Research and Engineering Co., Polymerization of Olefins and Diols to Synthetic Rubber; Ger. 1,046,885 (Dec. 18, 1958)

Esso Research and Engineering Co., Vulcanization of Chlorinated Butyl Rubber; Brit. 829,598 (Mar. 2, 1960)

Esso Research and Engineering Co., Vulcanization of Chlorinated Butyl Rubbers; Brit. 835,505 (May 18, 1960)

Esso Research and Engineering Co., Vulcanizing Brominated Butyl Rubber; Brit. 840,005 (July 6, 1960)

Esso Research and Engineering Co., Vulcanization of Synthetic Rubber with Polyhalomethyl Phenols; Brit. 857,428 (Dec. 29, 1960)


Farbenfabriken Bayer Akt. - Ges., Curing Catalysts for Natural and Synthetic Rubbers; Ger. 1,050,997 (Feb. 19, 1959)

Farbenfabriken Bayer Akt. - Ges., Polymerization of 2-Chloro-1,3-Butadiene; Ger. 1,040,247 (Oct. 2, 1958)

Farbenfabriken Bayer Akt. - Ges., Sulfur-free Vulcanizing Agents; Ger. 1,057,104 (May 14, 1959)

Farbenfabriken Bayer Akt. - Ges., Silicone Elastomers; Ger. 1,019,084 (Nov. 7, 1957)


Ford, Francis P., Co-vulcanized Butyl Rubber with Highly Unsaturated Rubbers by Amino Compounds; U. S. 2,948,320 (Aug. 9, 1960)


Gregg, Earl C. Jr., Nonsulfur Curing of Butadiene-Styrene Elastomers; U. S. 2,968,640 (Jan. 17, 1961)


Hilton, Frederick, Reaction Products of Natural and Synthetic Rubbers with Organic Sulfenyl Halides; Brit. 826,319 (Feb. 17, 1960)


Imperial Chemical Industries Ltd., Vulcanization of Synthetic Rubber; Brit. 841,079 (July 13, 1960)


II. Interaction with Diphenylpicrylhydrazyl; Vysokeomole. Soedin, 1:1246 (1959)


Kress, K. E., Adsorption Microdetermination of Total Sulphur in Rubber Products; Anal. Chem. 27:1618 (1955)

Kress, K. E., Sunmicro Rapid Reflex Method for Solvent Extraction of Rubber Products; Rubber World, 709 (Aug. 1956)


Lebrun, J., Pizzazz, G., Milbert, G., Modification of Natural Rubber by Reaction with Maleic Anhydride; Rev. gen. canad. 3, 609 (1958)


Kulinec, L., Retosky, M., Ionic Oxidation of Butadiene-1,3; Anal. Chem., 17:15 (1948)


Kerrett, T. J., Watts, J. T., Polysuccinimides in Bonding (Polyene) Polymer Fiber to Rubber; Ind. Rubber J., 25:150 (1952)


Mitchell, Harold S., Jr., Cottle, Delmar L., How, Lawrence T., Compositions Resisting Reclaimed Butyl Rubber and Commination Metal and Their Vulcanization; U. S. 2,941,795 (June 21, 1960)

Monsanto Chemicals Ltd., Craft Polymerization, Especially of Styrene on a Styrene-Butadiene Copolymer; Brit. 847,802 (Sept. 7, 1958)

Mori, Yayo, Sato, Takeshi, Minura, Yuji, Polymerization of Methyl Methacrylate in the Presence of Natural Rubber; Kogyo Kagaku Zasshi, 61:616 (1958)


Oddoux, J., Donnet, J. F., Drying of SBR-Type Polymers; Rev. gen. Caoutchouc, 35:615 (1958)


Powers, Kenneth W., Robison, Samuel D., Fusco, James V., Vulcanization of Butyl Rubber; U.S. 2,977,344 (Mar. 28, 1961)

Revertex Ltd., Vulcanization of Natural Rubber; Ber. 1,031,506 (June 4, 1958)

Romanovsky, Cyril, Jordan, Thomas E., Butadiene Catalysts; U.S. 2,920,049 (Jan. 5, 1960)

Rysanek, Antonin, Preparation of Concentrated Synthetic Latexes; Chem. Prumyl, 10:100 (1960)

Safford, Moyer M., Meyers Robert L., Curing of Polyethylene-Polybutadiene Blends with High-Energy, Ionizing Radiation; U.S. 2,924,559 (Feb. 9, 1960)


Schultz, E. F., An Improved Water Extraction Test for Polyvinyl Chloride Elastomers; ASTA Bulletin No. 183 (Jul. 1952)

Shatalov, V. P., Popova, E. N., et al., Increasing the stability of the Polymerization System of SKS-30; Kauchuk i Rezina, 19:3 (1960)


Shimasato, Joji, VI. Studies on Scission Reaction of Cross-Linking by Using Model Compounds; Nippon Gomu Kyakaishi, 32:452 (1959)
Shimosato, J., and Yokata, S. (Nippon Rubber Co., Kurume City, Japan) Vulcanization Accelerators: IV. Mechanism of Thiol and Disulfide Type Acceleration and of Non-Sulfur Vulcanization; VII. Vulcanization with Various Accelerators Followed by Estimation of Zinc Sulfide; Nippon Gum Kyokaishi 32 423 (1959)


Small, Augustus B., Polymerization of Butyl Rubber in Solution; U. S. 2,927,912 (Mar. 8, 1960)

Smirnov, R. N., Mercured Rubbers. II. Reaction of Mercury Derivatives of Butadiene Rubbers with p-Nitrobenzoyl Chloride; Vysookomole Kulyarnye Soedineniya, 2:679 (1960)

Spath, W., Vulcanization as a Statistical Problem, Gummi u. Asbest. 12 706: 792 (1959); 13 228 (1960)

Smith, John F., Curing Fluoroelastomers; U. S. 2,955,104 (Oct. 4, 1960)


Szurrat, J., Production and Applications of Silicene Rubber Vulcanizates; Gummi u. Asbest, 12:713 (1959)


Thiokol Chemical Corp., A Study of Butyl Solvent and Chemical Resistance; Thiokol Bulletin 102 (Mar. 1957)


United States Rubber Co., Vulcanization of Butyl Rubber;Brit. 826,092 (Dec. 23, 1959)


Vaclavek, Vladimir, Molecular-Weight Regulation in the Emulsion Copolymerization of Butadiene with Styrene; Chem. Prumysl, 10:103 (1960)


Wacker-Chemic G. m. b. H., Cold Vulcanization of Silicone-Rubber Laminates; Ger. 1,026,520 (Mar. 20, 1958)


Watson, Wm. B., Butyl Rubber Plasticized with Crude-Oil Fractions; U. S. 2,959,560 (Nov. 8, 1960)


Zakharov, N. D., Porochin, Bv V., Sulfurless Vulcanization of Synthetic Rubbers. II. Curing of Nitrile-Butadiene Rubbers with the Use of Some Metal Chlorides; Kauchuk i Rezina, 18:14 (1959)


TEMPERATURE BIBLIOGRAPHY


Barlow, Red. W., Cretney, Robert W., Effect of Carbon Black on Rubbers for Low-Temperature Use; *Rubber Age*, (35:32) (1959)


Bobear, W. J., Behavior of Silicone Rubber in Sealed Systems at High Temperatures; *Rubber Age*, 84:48 (1958)

Boonstra, B. S. T. T., Tensile Properties of Natural & synthetic Rubbers at Elevated & Subnormal Temperatures; *India Rubber World*, 121:290 (1949)


Bradbury, E. J., Clark, R. A., Aluminum Block Heater for Aging Rubber and Rubber Compounds at high Temperatures; *Rubber World*, (Sep. 1956)


Dick, Willie, Muller, F. H., Calorimetric Measurements of the Thermal Effects Involved in the Stretching of Rubber; *Kolloid-Z.* 172:1 (1960)

Dillman, J. H., Prettyman, L. B., The Effects of Temperature and Humidity on All Physical Properties of Tire Cords; *J. Appl. Phys.* 16:159 (1945)

Eccher, S., Oberto, S., Improvements in Artificial Aging Ovens; *Trans. Inst. Rubber Ind.,* 27:325 (1951)


Esso Research and Engineering Co., Heat-Treated Compositions of Butyl Rubber and Alkenylhalosilane-Modified Silica; Brit. 823,279 (Nov. 11, 1959)

Fejfar, Miroslav, Jirasek, Karol, Increasing the Heat and Fungus Resistance of Vulcanized Rubber; Czech. 92,727 (Nov. 15, 1959)


Geesler, Albert M., Wiese, Hervert K., Rehner, John Jr., Heat-Treated Composition of Butyl Rubber and Alkenylhalosilane-Modified Silica; U.S. 2,906,722 (Sept. 29, 1959)

Gregory, J. B., Effect of Temperature on the Air Permeability of Silicone Rubber; *Rubber World,* (Dec, 1955)


Hanok, M., et al. (N. York Naval Shipyard, Brooklyn) Comparison of Instruments Used to Determine the Suitability of Elastomers for Low Temp. Service; *Rubber Age,* 31:100 (1957)
Harrington, Robert, How Hot Water Affects Elastomers; Rubber Age, 84:798 (1959)


Jones, H. C., Snyder, E. G., Further Studies on the Effect of Temperature on the Resilience of Natural and Synthetic Rubber; India Rubber World, 110:Jul. 1944

Juve, A. E., Schoch, M. G., Jr., The Effect of Temperature on the Air Aging of Rubber Vulcanizates; No Official Publication

Juve, A. E., Schoch, M. G., Jr., The Effect of Temperature on the Air Aging of Rubber Vulcanizates; ASTM Bulletin No. 195 (Jan. 1954)

Juve, A. E., Shearer, R., Migration Effects in Oven Aging; India Rubber World, (Aug 1953)

Konkle, G. W., McIntyre, J. T., Fenner, J. V., The Effect of High Temperature on the Properties of Organic and Silicone Rubbers; Rubber Age, 79 (June, 1946)


MacRae, D., and Zapp, R. (Enjay Labs, Linden, N. J.) Thermal Diffusivity of Butyl Rubber and its Compounds I. Determination of Diffusivity Coefficients, Rubber Age, 32:831 (1958)

MacRae, Donald R., Zapp, R. L., Thermal Diffusivity of Butyl Rubber and its Compounds, II. Application of Diffusivity Coefficients; Rubber Age 32:1024 (1958)


Martin, James Grubb, Neu, R. F., Temperature Coefficient of Vulcanization of Butyl Rubber; Rubber Age, 86:825 (1960)


Phillips Petroleum Co., Thermal Vulcanization of Polymers of 1, 3-Butadiene; Brit. 323,523 (Feb. 17, 1960)

Polymer Corp. Ltd., Catalyst Injection in Low-Temperature Polymerization Especially in the Manufacture of Butyl Rubber; Brit. 823,536-7 (Feb 17, 1960)


Schulz, E. F., Effect of Temperature and Composition Upon the Resilience of Elastomers; Modern Plastics, (Aug. 1952)


Shelton, J. R., Wann, H., Oven and Bomb Aging of GR-S at Corresponding Temperatures; Ind. Eng. Chem., 39:1133 (1947)


Williams, G. B., Behavior of Natural and Synthetic Rubbers at High Temperature; Proc. Inst. Rubber Ind., Paper read before London Section, May, 1956


ASTM The Applications of Synthetic Rubbers, Rzemposium on; March, 1944

Bell, J. M., Randal, Rl L., The Effect of Whole Tire Reclaimed Rubber on the Accelerated Aging of Natural Rubber and CR-e; Rubber Age., (March, 1949)

Barnhart, R. R., Calward, J. E., Paracril: Paracril Ozo for Ozone Resistance and Mill Resistance; Bulletin #219, Naugatuck Chem.,


Bekkedahl, N., Natural and Synthetic Rubbers; Anal. Chem., 24:279 (1952)


Braendle, H. A., Wieand, W. B., GR-S, An Elastically Inverted Polymer; Indiana Rubber World, (May 1944)
Brale, S. A., Jr., Properties and Applications of Silicone Rubber Paper given at semi-annual meeting ASME, June, 1956, Cleveland, Ohio


Buache, F., Tensile Strength of Filled Gr-S Vulcanizates; J. Polymer Sci., 33:259 (1953)

Clark, R. A., Rubber for Unusual Applications; Battelle Tech Rev., (Dec. 1955)

Clinebell, B. J., O-Rings -- An annotated Bibliography; India Rubber World (Oct. 1952)

Connecticut Hard Rubber Co., High Temperature Testing of Silicone Rubber; (May, 1958)


Deasy, J. J., White, B. B., Compounding Silicone Rubber for Minimum Shrinkage; Rubber Age., (Mar. 1957)


Dellaria, J., Outlook for 600 Deg Silicone Rubber; Aviation Age June, 1958

Dow Corning Corp., Characteristics of Silicone Elastomers; Dow Corning Corp. Pub.

Dow-Corning Corp., Down-Corning Silicone Notes

Fuller, B. W., Where to Use Hypalon: Materials & Methods, (Jan. 1957)


Gee, G., Tensile Strengths of Pure Gum Natural Rubber Compounds; J. Polymer Sci., 2:451 (1947)


Goodrich Chemical Co., Hyacar Rubber and Latex; Goodrich Chemical Co., Pub.


Goodrich Chemical Company, Malving Cements with Hyacar Rubber; Manual HM-4 (June, 1959)


Gregory, J. B., Silicone Rubber - A Literature Review; Rubber Age, (Nov. 1951)

Gregory, J. B., Effect of Temperature on the Air Permeability of Silicone Rubber; Rubber World, (Dec, 1955)

Harris, T. H., Stiehler, R. D., The Aging of GR-S A Review of the Literature; India Rubber World, (June 1943)

Hauser, E. A., Morphological Studies of Silicone Rubbers; Rubber Age, (Oct. 1954)

Jedlicka, Helmut, Silicone Rubber as Bonding Material; Ger. 1,016,391 (Sept 26, 1957)


Kilbourne, W. L., Deeds, C. A., Stasimmas, K. J., Compounding of Silicone Rubber; Rubber World, (May 1955)


Konkle, G. M., New Developments in Silicone Rubber; Paper given at semianual meeting ASME, June, 1958, Detroit, Michigan.


Monack, A. J., Electrical Insulation Materials; Material & Methods, manual No. 157 (April 1957)


Neoprene Notebook, Accelerated Aging vs. Long Term Aging; No. 54 (1945)


Rogers, T. H., Hecker, K. C., Present Status of Latex Rubber Foam; Rubber World, (Dec. 1953)

Rouwad, K., Rubber as an Engineering Material; Materials & Methods (May 1955)

Rouwad, K., Two New Synthetic Rubbers - They Offer: Excellent Chemical Resistance; Long Wear Life and High Toughness and Flexibility; Materials and Methods (May 1953)

Rouwad, K., What's New in Synthetic Rubber Modifications; Materials & Methods, (Sept. 1953)

Rouwad, K., Silicones - Properties and Uses; Materials & Methods, (Feb. 1955)

Rough, C. W., Braley, S. A., Effects of Fillers, Vulcanizing Agents and Additives on Compression Set of Silicone Rubber; Rubber Age, (Oct. 1953)


Sauer, Wilhelm, Maintenance of Rubber Parts; Ger. 1,037,044 (Aug. 21, 1953)

Showa Electric Wire and Cable Co., Ltd., Heat-Resistant Insulated Electric Wires; Japan 6137 (July 16, 1959)

Smith, T. L., Dependence of the Ultimate Properties of a GR-S Rubber on Strain Rate and Temperature; J. Polymer Sci., 32:99 (1958)

Smith, F. W., Properties of Elastomers up to 550° F. Rubber World; 139:533 (1959)


Vacca, G. N., Lundberg, C. V., Aging of Neoprene in a Weather-meter; Wire and Wire Products, 32:413 (1957)

Vanderbilt News, K-Stay, A New Processing Aid in the Vanderbilt Line; 24:6 (1958)


Wagner, C. E., Heat Resistance of Enjay Butyl; Rubber Age, (May 1957)

Vanderbilt News, Thiate, Neoprene Acceleration Studies; 24:8 (1958)


Anonymous, Flourine + Silicone Rubber = New Heat and Solvent Resistant Elastomer; *Materials & Methods* (Nov. 1956)
TESTING BIBLIOGRAPHY


ASTM, Conditioning of Elastomeric Materials for Low-Temperature Testing; ASTM Standard 4-32-60

ASTM, Evaluating Low-Temperature Characteristics of Rubber and Rubber-Like Materials by a Temperature-Retraction Procedure (T R Test); ASTM Standard d-1329-60

ASTM, Recent Developments in the Evaluation of Natural Rubber, Symposium on, ASTM Special Tech. Pub. 136


Barreira, P., Laranjeira, M., Analytical Distinction Between Natural Rubber and Neoprene by Neutron Irradiation; Rev. port. quim., 1:73 (1958)


Bogina, L. L., and Martyukhina, I. R., Determination of Total Chlorine and Bromine in Rubber Compositions and Vulcanizates by Combustion Method, Kauchuk i Rezina id, 2:35 (1959)


Beatty, J. R., A Test for Crystallization Effects in Rubbers; Ind. Rubber World, Jan. 1952


Biggs, B. S., Organic Corrosion, Bell Lab. Record, Jan. 1956


Bowell, S. T., The Errors of Stress-Strain Testing; Rubber Age, Nov. 1952


Breber, P., Salomon, G., Methods of Testing Abrasion and Wear in the Netherlands; Engineering, 173:725 (1952)


Buist, J. M., International Standardization of Rubber Test Methods, Amon, 1950; India Rubber J., (March 1951)

Buist, J. M., Abrasion and Wear of Rubber Engineerin; Fib., 1952


Buist, J. M., Geldof, H., Comparison of Crescent and Delft Methods of Measuring Tear Strength; India Rubber World, June, 1950


Buist, J. M., Kennedy, R. L., Tear Resistance, More Accurate Results Using I. C. I. Cutter; India Rubber J., (June 1946)

Buist, J. M., Williams, C. E., Belt-Flexing Test of the DuPont Type; Trans. Inst. Rubber Ind., 27:209 (1951)

Burleigh, E. G., Wakeham, H., Stress Relaxation of Cotton and Rayon Cords at Constant Length; Textile Research J., 17:245 (1947)

Calhoun, V. B., Minco, R. W., Reed, J. R., Mooney-Viscosity Determinations of Butyl Rubber at Elevated Temperature; Rubber World, 141:688 (1960)

Calhoun, V. B., Reed, J. R., Minco, R. W., Elevated Temperature method for Determining Mooney Viscosity of Butyl Rubber; Rubber Age, 86:834 (1960)


Chilton, B. G., Dynamic Characteristics of Rubber Supports from Vibration Table Data; J. Appl. Phys., 17:492 (1946)


Eller, S. A., Stress Relaxation of Vulcanized Rubber in Compression and Tension; ASTM Bul. no. 207 (1955)

Eller, S. A., Bondek, W. K., A Laboratory Grinding Machine for Preparing Test Specimens from Rubber and Other Flexible Products; ASTM Bul. no. 206 (May 1955)


Forester, W. J., Unilateral Compression of Rubber; J. Appl. Phys. 26:1101 (1955)


Greensitu, H. W., Thomas, A. C., Rupture of Rubber. II. The Strain Concentration at an Incision. III. Determination of Tear Properties; J. Polymer Sci., 131:177 (1955)

Gregory, J. B., Pockel, I., Stiff, J. F., Effect of Storage and Temperature on Flexibility of Natural and Synthetic Rubbers; Ind. Rubber World, (Feb. 1943)


Jones, H. C., Syder, E. G., Effect of Temperature on Resilience of Natural and Synthetic Rubber; India Rubber World, 103: May 1943


Fieldin, J. H., Juve, A. E., Grove, F. L., Report on Correlation of Laboratory and Service Abrasion Test of Rubber Tire Treads; ASTM Bul. (1947)

Kasatkina, N., Determinatio of the Percentage of 1,4; 3,4; and 1,2 Isoprene Units in Synthetic Isoprene Rubbers by the Curves of the Rate of Oxidation with Benzoyl Peroxide, Zhur. Priklod. Khim., 32:170 (1959)

Kase, Shigeo, Method for Adjusting Tensile Date of Vulcanizates. X.; Nippon Gomu Kyokaishi, 53:266 (1960)

Kirchhof, F., The Weber Color Test for Analytically Distinguishing Natural Rubber from Butyl Rubber, Polyisobutylene, and Cyclorubber; Kautschuk u Gummi, 13 Mt402 (1963)

Kragalski, I., The wearing quality of Tread Blocks, Kauchuk i Guma 18, 11:20 (1959)

Legoni, H. and Merten, D., A Method for Recording Damage to Rubber Surfaces, Naturwissenschaften 44:177 (1957)


Mano, Eloisa, B., Rapid Test for Identification of Natural Rubber in Vulcanizates; Analis Assoc. Brasileira Quim., 18:223 (1959)


Maron, B. J., Control of Errors in Physical Test Calculations in a Rubber Laboratory; India Rubber J., (Jan. 1954)

Maron, S., Ulevitch, I. M., Mechanical Stability Test for Rubber Latices; Anal. Chem., 25:1087 (July 1953)


Martin, B. J., Control of Errors in Physical Test Calculations in a Rubber Laboratory; India Rubber J., (Jan. 1954)


Mooney, R. E., Barrett, A. E., Permanence of Plasticizers in GR-S Vulcanizates Exposed to Weather; Rubber Age, (April 1954)


Morris, R. E., James, R. R., Guyton, C. W., A New Method for Determining the Dynamic Mechanical Properties of Rubber; Rubber Age, (Feb. 1956)


Oehme, F., Testing Materials with Dielectric Methods, Kunststoff-Rundschau, 5:524 (1958)


Ore, Svein, A Modification of the Method of Intermittent Stress Relaxation Measurements on Rubber Vulcanizates; J. Appl. Polymer Sci., 2:313 (1959)


Painter, G. W., Rubber to Metal Adhesion; Rubber Age, 36:262 (1959)


Philippoff, W., Mechanical Investigations of Elastomers in a Wide Range of Frequencies; J. Appl. Phys., 24:687 (1953)


Resnikovskii, W., Evolution of Heat During Deformations of Rubber and New Methods of Dynamic Tests, Starenie Utoslenie Akhchov i Resin i Povyshenie ikh stoikosti Sobornik, 63:75 (1955)

Roamdonk, G. W. van, The Significance of Accelerated Aging Tests Rubber Stichting, Defft Com.uem. No. 295


Roth, E. L., Schade, J. J., Development & Improvements in Methods of Stress-Strain Testing of Rubber; ASTM Symposium on Rubber Testing, (1947)


Rozaci, Ü., Polarographic Determination of Free Sulfur in Rubber and Rubber Compounding Chemicals, Cene prumvial, 33:335 (1958)

Schwunkler, F. W., Electrical Measurements for Interpreting Activation, Oxygen Effect, and Zinc Dithiocarbamate Function During the Vulcanization of Synthetic Rubber; Kautschuk u. Gummi, 14:WT61 (1961)

Schmuckal, R. P., Rubber has Dynamic Properties Too; Paper presented at SAE National Passenger Car, Boat and Materials meeting, Detroit, Michigan, March, 1955


Scott, J. R., Rubber Hardness Testing; Rubber Age, (July 1955)


Shearer, R., An Automatic Spark Recorder for Stress-Strain Testing; India Rubber World, (July, 1947)


Simpson, W. J., Status of Accelerated Testing of Automotive Rubber Parts; Paper presented at SAE meeting, Atlantic City, June, 1957

Smith, F. B., Tulguy, N. F., Accelerated Testing of Oxone Cracking Inhibitors; Rubber World, 140:243 (1959)

Smith, Ward A., Willis, Jones W., Compounding and Testing Dione Rubber; Rubber Age, 37:315 (1960)


Smith, J. F. D., Rubber Springs Under Compression Loading; Iowa Engineering Experiment Station Report No. 2, 1950-51


Smith, J. F. D., Research on Rubber for Mechanical Engineers; Mech. Eng. (Feb. 1943)

Smith, J. F. D., The Design of Rubber Mounting; Iowa Engineering Experiment Station Report No. 2, 1950-51


Stambaugh, R. B., Rohner, W., Gehman, R. D., Speed of Retraction of Rubber; J. Appl. Phys., 15:740 (1944)


Straka, L. E., Rubber Developments: June 1957-June 1959; Paper presented at annual meeting ASME, Atlantic City, Dec. 1959

Taylor, R. H., Fixtures Aid in Shapening Dies used to Cut Rubber Tensile Test Specimens; India Rubber World, Jan. 1951


Thomas, A. G., Rupture of Rubber V. Cut Growth in Natural Rubber Vulcanizates; J. Polymer Sci., 31:467 (1953)

Tichava, M., Contribution to the Method of Estimating the Tear Strength of Rubber; Chem prumyval, 9:43d (1959)


Taylor, R. H. Use of the Shore Durometer for Measuring the Hardness of Synthetic and Natural Rubbers; ASTM Bull No. 123, Aug. 1943

Vovra, Jozef, Application of Zimm's Method for the Determination of the Molecular Weight of Natural Rubber; Chem zvesti, 14:3 (1960)
Vervloet, Ch., Laboratory Abrasion Tests of Black Filled Vulcanizates, *Kautschuk u. Gumi.*, 11:733-6, 6342 (1958)


Wakeham, H., Honold, E., Application of the Torsional Hysteresis Test to Tires; *India Rubber World*, 105:577 (1945)


Zapp, R. L., Abrasion of Buty Rubber; *Rubber World*, (Oct. 1955)

Zapp, R. L., Umland, C. W., Sperberg, L. R., Butyl Tire Tread Abrasion; *Rubber World*, 141:669 (1950)
OXIDATION BIBLIOGRAPHY

Bauman, R. G., Maron, S. H., Oxidation of Polybutadiene. I. Rate of Oxidation; J. Polymer Sci., 22;1 (1956)

Bauman, R. G., Maron, S. H., The Oxidation of Polybutadiene. II. Property Changes During Oxidation; J. Polymer Sci., 22;203 (1956)

Baxter, B., Morgan, W., Keabuck, D. S. P., Rubber Oxidation and Antioxidant Actions; Ind. Eng., Chem., 43:446 (1951)


Bevilaqua, E. M., Chain Scission in the Oxidation of Nevas. IV. Low Molecular Weight Products from Dry Rubber; J. Am. Chem. Soc., 79:2915 (1957)

Bevilaqua, E. M., End Groups of Oxidized Rubber; Science, 126:396 (1957)


Carpenter, A. S., Absorption of Oxygen by Rubbers; Rubber Chem. and Technol., 20:728 (1947)

Cotton, F. H., Lee, K. O., Hastication of Natural Rubber. Oxygen Uptake During Hastication of Rubber; Research. 4:44 (1951)


Dufrasnes, C., Manomètre Pour la Mesure de L'Oxydabilité; Rev. Gen. Caoutchouc, 18:185 (June, 1939)


Dunn, J. R., Oxidative Stress Relaxation of Radiation Vulcanizates with and without Antioxidants; Kauchuk u. Gummi, 14:WT 114 (1961)


Goodyear Tire and Rubber Co., Phenolic Antioxidants for Rubber; Brit. 810,035 (Aug. 12, 1959)


Kasatkina, M., Determination of the Percentage of 1, 4: 3, 4; and 1, 2 Isoprene Units in Synthetic Isoprene Rubbers by the Curves of the Rate of Oxidation with Benzoyl Peroxide, Zhur. Priklod. Khim. 32 170 (1959)


Marvel, C. S., et al., Oxidative Hydrolysis of the Osmides of Polybutadienes, II. Isolation of 1,2,3-Propanetriacetic Acid; J. Org. Chem., 16:838 (1951)


Ore, S., The Oxidative Stress Relaxation of Natural Rubber Vulcanized With Di-tert-butyl peroxide, Oslo Univ. Press 1958 1-84


Pollack, Louis R., Determination of Oxygen Absorption Rate; Taken from a round-robin test evaluation program performed by 3 navy and 3 manufacturers (Laboratories. Project 1190-2 Mare Island Naval shipyard.)


Shelton, J. R., Aging and Oxidation of Elastomers; Rubber Chem., and Technol. 30;1231 (1957)


Tobolsky, A. V., Mercuro, A., Oxidative Degradation of Polydiene Vulcanizates; J. Appl. Polymer Sci., 2;186 (1959)


Wall, Leo A., Harvey, Mary E., Tryon, Max, Oxidative Degradation of Styrene and a-Deuterostyrene Polymers; J. Phys. Chem., 60;1306 (1956)

Warner, W. C., Shelton, J. R., Oxidation of Olefins Representing Some Structural Units of GR-8; Ind. Eng. Chem., 43;1160 (1951)
OZONE BIBLIOGRAPHY


Ambelang, Joseph C., Antioxidants for Butadiene-Styrene Rubbery Copolymers; U. S. 2, 905, 654 (Sept. 22, 1959)

ASTM, Symposium on Effect of Ozone on Rubber, St. Louis, Mo.; Feb. 1958, Special Technical Publication No. 229


Bibliography on Ozone Deterioration of Rubber; Prevention of Deterioration Center, Division of Chemistry and Chemical Technology, National Academy of Sciences, National Research Council, (Nov., 1957) Revised Sept., 1960

Boucher, M., Jesquat, G., Quelques Precisions sur un Nouvel Agent de Protection: Le KPN-1; Rev. Gen. Caoutchouc; 35:904 (1958)


Crabtree, J., Biggs, B. S., Cracking of Stressed Rubber by Free Radicals; J. of Polymer Sci., 11:280 (1953) R1 7016


Denhale, W. L., Phelan, R. R., Accelerated Ozone Aging; Enjay Laboratories, (Sept. 1957)
Ikehara, S., L'Asione Dell' Osmose nel Fenomeno delle Scrosciateure della Gomma Sottoposte a Solicitatione Meccaniche Ripetute; Gomma, 4:1 (1940)


Greene, Albert J., Protection of Rubber Against Ozone, U. S. 2, 926, 155 (Feb. 23, 1960)

Grossman, R. F., Bluestein, A. C., Ozone Resistance of Butyl Rubber; Rubber Age, 84:440 (1958)


Koller, L. R., The Production and Decomposition of Ozone by Low Pressure Mercury Vapor Lamps; J. of Appl. Phys., 16:816 (1945)


Lundberg, C. V., Vacca, G. W., Biggs, B. S., Resistance of Rubber Compounds to Outdoor and Accelerated Ozone Attack; Presented Before the Division of Rubber Chemistry, AGS, Atlantic City, N. J., Sept. (1956)

Manufactures de produits chimiques du Nord, Protection of Elastomers Against Atmospheric Agents; Fr. 1, 151, 090 (Jan. 23, 1958)

Milanes, D. J., Artificial Weathering of Rubber (The ozone factor in weathering and a technique for generation and control of an ozonised atmosphere.); Rubber Age. (Mar. 1955)

Nee, F., Ozone Resistance and Weatherability of Butyl Compounds; Rubber Age, 5:81 (May 1957)


Osaefort, Z. T., Ozone Bibliography; RIA Lab. No. 55-88 (Jan. 1955)


Oosafort, Z. T., Touhey, W. J., Ozone Cracking of Biaxially Stressed GR-S Vulcanizates; Rubber World, 132:62 (1955)


Sharpe, F. D., Petroleum Waxes for Protecting Rubber Compounds From Cracking. Rubber Age, (Sept. 1955)

Smith, D. M., Gough, V. E., Ozone Cracking; A Cinematographic Study; Rubber Chem. and Technol., (Jan. 1954)

Smith, G. E. F., Antiflex-Cracking Agents in Rubber; U. S. Patent Office No. 2,481,906 (Jan. 1952)


Wadefem, C. W., Determination of Ozone and Other Oxidants in Air; Anal. Chem, 29:441 (Mar. 1957)


Winkelmann, E. A., Rubber's Tendency to Crack Is Unpredictable; SAE Journal, 164 (Oct., 1955)


AGING BIBLIOGRAPHY


Anderson, Herbert R. Jr., Rubber Cured and Reinforced with Sulfides: (improved physical properties after oven aging), U. S. 2,944,042 (July 5, 1960)

ASTM, Aging of Rubber, Symposium on; ASTM Spec. Tech. No. 89


Bergstrom, H. W., Aging of Unstressed Elastomeric Vulcanizes During Outdoor and Controlled Humidity Exposures; Rock Island Arsenal Lab. Tech. Report 58-1808

B. F. Goodrich Co., Nonstaining Rubber Antioxidant; (effect on NR compounds during accelerated aging are described), Brit. 820,170 (Sept. 18, 1959)

B. F. Goodrich Co., Nonstaining and Nondiscoloring Deterioration Retarders; Brit. 825,630 (Dec. 16, 1959)

Biggs, B. S., Deterioration of Organic Polymers; Bell System Tech. J., 30:1078 (1951)

Bluestein, A.C., Grossman, R. F., Effects of Brominated Butyl in Butyl Compounds; Rubber World, 142:98 (1960)

British Rubber Producers Research Assoc., Preservation of Hevea Latex; Brit. 821,872 (Oct. 14, 1959)

Buist, J. M., Aging and Weathering of Rubber; Rubber Chem. and Technol. 38:230 (1955)


Burks, Oliver W. Jr., Antioxidants for Rubber and Other Unsaturated High Polymers; Brit. 841,281 (July 13, 1960)

Chemische Werke Huls Akt.-Ges., Stabilization of Hydrocarbon Polymers; Brit. 826,262 (Dec. 31, 1959)

Dumke, W. L., Phelan, R. E., Accelerated Ozone Aging, Rubber Age, 83:281 (1950)

Dunlop Rubber Co. Ltd., Elastomers with Improved Stability from Polycondensates and Isocyanates; Ger. 1,040,779 (Oct. 9, 1958)


E. I. du Pont de Nemours Co., Elastomers Resistant to Oxygen, Ozone, and Other Oxidants, Ger. 1,052,676 (Mar. 12, 1959)


Eepo Research and Engineering Co., Stabilization of Butyl-Rubber Latex; Brit. 831,833 (Apr. 6, 1960)

Eepo Research and Engineering Co., Stabilised Halogenated Butyl Rubber; Brit. 850,429 (Oct. 5, 1960)

Farbenfabriken Bayer Akt.-Ges., Hydroxybenzyl Ethers and their Use as Age-Resistants; Brit. 822,693 (Mar. 11, 1958)

Farbenfabriken Bayer Akt.-Ges., Hydroxybenzyl Ethers and their Use as Age-Resistants; Ger. 1,071,092 (Dec. 17, 1959)

Farbenfabriken Bayer Akt.-Ges., High-Molecular-Weight Polyurethane Foam Rubbers; Brit. 840,097 (July 6, 1960)


Fiedler, Hans W., Deterioration - Retarding Agents for Vulcanised Rubber; Ger. 1,057,778 (May 21, 1959)

Fusco, James F., Stabilization of Halogenated Butyl Rubber; U. S. 2, 962,474 (Nov. 29, 1960)

General Tire and Rubber Co., Weather and Age-Resistant Polyurethanes; Brit. 846,176 (Aug. 24, 1960)


Gillette, H. G., Shelf Aging of Elastomers; Precision Rubber Products Corp. No Official Publication

Goodyear Tire and Rubber Co., Preservation of Natural Rubber Latex; Brit. 836,250 (June 1, 1960)

Greathouse, G. A., Effect of Microorganisms on Rubber Degradation; Rubber Age, 63:337 (June, 1948)


Harris, James O., Improving the Resistance of Rubber to Degradation; U. S. 2,921,922 (Jan. 19, 1960)


Juve, R. D., Johnson, F. M., Storage Stability of Tread Rubber and Tire-Repair Materials; Rubber World, 141:820 (1960)


Kimishima, Takazo, Antiaging Agent for Rubber; Japan 15, 968 (Oct. 19, 1960)


Le Bras, J., Bewertung Betrachtungen über Alterungsproblemen von Kautschuk; Kautschuk u Gumm. 11:332 (1958)


Manufacturers de produits Chimiques du Nord, etablissements Kuhlmann; Protection of Elastomers Against Atmospheric Agents; Brit. 830,914 (Mar. 23, 1960)


Matsuda, Sumio, Antioxidant; (age resister for rubber); Japan 2313 (April 11, 1959)


Monsanto Chemical Co., Vulcanising Control and Aging Prevention of Rubber; Ger. 1,031958 (June 12, 1958)

Morris, Roger E., Alkylated Indamols Used as Deterioration Retarders for Rubber; U. S. 2,948,704 (Aug. 9, 1960)

Morris, Roger E., Alkylideneindamols as Deterioration Retarders for Rubbers; U. S. 2,969,343 (Jan. 24, 1961)

Morris, Hollister, J. W., Barrett, A. E. Wakenthuin, T. A., Natural and Accelerated Light Aging of Hevea and GR-S Vulcanizates; Rubber Age. Apr., 1944
Morris, James, R. E., Wakeham, T. A., Sunlight and Accelerated Light Aging of Synthetic Rubbers; Rubber Age, June, 1942


Netto, I. T., Pomortseva, E. V., Koslova, E. I., Microbiological Degradation of Rubber; Mikrobiologiya, 28:881 (1959)


Oberst, E., Aging Fluorescence of Vulcanized Rubber; Rubber Tech. Conf., London Reprint No., 75 (May, 1938)

Ossenfort, Z. T., Influence of Accelerator Residues on Age Resistance of Elastomeric Vulcanizates; Rubber World, 140:69 (1959)


Ossenfort, F. T., Shaw, E. F., Bergstrom, E. W., Curing Systems for Improved Aging Resistance of Rubber Vulcanizates; Rubber World (Mar. April, 1957)


Philpott, H., New Methods of Preserving Rubber Latex, Australian Plastics and Rubber J., 14 (159) 14-16 (1958)

Phoenix Gummiwerke AG., Rubber of Improved Aging Resistance; Ger. 1,023,560 (Jan. 30, 1958)

Phoenix Gummiwerke AG., Additives for Protecting Rubber and Synthetic Resins Against Aging; Ger. 1,054,700 (Apr. 9, 1959)

Plantations des terres rouges, Preservation of Latex; Fr. 1,177,179 (Apr. 21, 1959)

Prober, Maurice, Amide - Stabilized Elastomeric Organopolysiloxanes, U. S. 2,945,838 (July 19, 1960)


Belsher, R. C., Degradation and Cross-Linking of Polysisoprene in Neven Brazilian Latex During Processing and Storage; Mashteerend Symposium po Raukhim, Khim., Doklady, Moscow, Sektaly 3; 232 (1960)

Shaw, M. C., Adams, S. E., Nedestructive Aging Tests for Rubber; Anal. Chem., 25; 1649 (1951)


Stevens, R. F., Photovulcanization - A Study of the Products of the Action of Light on Rubber Under Conditions Precluding or Restricting Oxidative Degradation; India Rubber J., Jan., 1945

Soffin Co. Ltd., Preservation of Natural Rubber Latex; Brit. 856, 095 (Dec. 14, 1960)

Thein, J. H., Davis, A. R., Antioxidant - Antioxidant Activities; Rubber Age, 86; 81 (1959)


United States Rubber Co., Polyurethane Foams; Ger. 1,040,760 (Oct. 9, 1958)

Wald, Wilbur J., Age Resistors for Light-Colored Rubber Products; U. S. 2,932,662 (Sept. 13, 1960)

Webb, Frederick J., Nondiscoloring Age Resistors; U. S. 2,905,737 (Sept. 22, 1959)

Werkenthin, R. Z., Richardson, D., Thornley, R. E., Morris, R. E., Light and Accelerated Light Aging of Rubber, Synthetic Rubber; and Rubber Substitutes; Rubber Age, Nov., 1941


Anonymous, The Chemical Problem of Rubber Degradation, No Official Publication

Anonymous, Ordinance Corps Program to Prevent The Deterioration of Elastomers; Lab. Rept. 55-3307 Aug., 1953
MISCELLANEOUS BIBLIOGRAPHY

Baech, K. C., Comer, L. F., Lowery, V. E., Laboratory Processing Properties of Two Synthetic Polymers; *Rubber Age*, 85:253 (1959)

Bauman, R. G., (E. F. Goodrich Center, Brecksville, Ohio), Radiation Damage to Elastomers; *J. Appl. Polymer Sci.*, 1:528 (1959)


Bioldi, M. A., Fox, R. E., Dissociative Attachment of Electrons in Iodine, III. Discussion; *Phys. Rev.*, 109:2012 (1958)


Chloride Electrical Storage Co., Ltd., Microporous Foils of Rubber of Synthetic Resins; Ger. 1,013,421 (Aug. 8, 1957)

Conant, F. S., Lindsay, J. W., Friction Studies on Rubber-like Materials; Rubber Chem. and Technol., 33:1218 (1960)

Crabtree, J., Bell. Lab. Record, J., Rubber and the Weather; 26:119 (1948)


Esso Research and Engineering Co., Butyl Rubber Emulsions; Brit. 818,109 (Aug. 12, 1959)

Esso Research and Engineering Co., Improving the Adhesion of Chlorinated Butyl Rubber Tire Liners; Brit. 814,368;* (May 4, 1960)

Esso Research and Engineering Co., Irradiation of Polymers and Copolymers of Isobutylene; Brit. 818,919 (Aug. 26, 1959)

Esso Research and Engineering Co., Stripping Solvent from Isobutylene-Isoprene Copolymer Latexes; Brit. 841,289 (July 13, 1960)

Palm, Charles M., Spehar, John P., Antifoam Agents for Butadiene Desorption; U.S. 2,864,474 (Apr. 28, 1959)


Fox, R. E., Hickam, W. M., Kjeldaeas, T., Jr., Ionization Probability Curves for Krypton and Xenon Near Threshold, Phys. Rev. 89:555 (1953)


Fujikura, Electric Wire Co., Adhering of Aluminium to Natural Rubber; Japan, 2037 (April 9, 1959)


General Electric Co., Removal of Condensing Agents from Organopolysiloxane Elastomers; Ger. 1,017,795 (Oct. 17, 1957)


Hall, O. L., Rigby, J. B., Canent, F. S., High Speed Photography in the Rubber Industry; Rubber Age, (May, 1958)


Hickam, W. M., Fox, R. E., The Use of Ionization Probability Curves for the Analysis of CO and N2 Mixtures, Westinghouse Research Laboratories, Scientific Paper 1650, (1952)


Hofstemberg, W., Tire Dynamics, Deutschuk u. Gesellschaft, 12:21 (1950)


Kelsey, R., and Johnson, P., (Firestone Tire and Rubber Co., Akron, Ohio) The Influence of Particle Size on the Viscosity of Synthetic Latex II. Effect of Particle Spacing, Rubber World, 139:227 (1958)


Kotitsch Ledertuch-und Wachstuchwerke Akt., Ges., Aescous, Rubberlike Polyisobutylene Dispersions; Ger. 271,363 (Jan. 15, 1959)

Krems, K., Effect of Radiation on Polysiloxanes, Kunststoffe, 10: 524 (1958)

Kraminskiei, A., and Zhuvskekaya, E., Stability of Elastomers to the Action of Ionising Irradiation; Khim Neft i Prom, 4:69 (1959)


Line, C. L., Determination of Sulfur in Iron and Steel; Bell Telephone Laboratories, No official publication.


Madsen, R., (Firestone Tire and Rubber, Brentford, England) Absorption Determination of Traces of Copper In Rubber Chemicals and Products; Rubber Age, 84:1451 (1958)

Mardis, Y., (Hitachi C.o., Tokyo) Ultrasonic Velocity and Attenuation in Silicone Rubbers; Kobunshi Kagaku, 14:620 (1957)

Maishel, M., et al., Failure of Rubberized Fabric During Wet, Kasabuk i Resina 18, 8:28 (1959)


Morris, R. E., James, R. R., Caggagi, P., Effects of X Radiation on Compression Set of Rubbers; Rubber Age, 85:243 (1959)

Muller, W., Battelle Mem. Inst., Columbus, Ohio), Permeability of Rubber to Organic Liquids, Rubber Age, 81:982 (1957)
Muller, P., and Huff, K., (Univ. Marburg/Lehn, Marburg/Lehn, Germany) Alteration of the Dielectric Relaxation Spectrum of Rubber by Stretching; Rechtschuk u. Guemli, II, MT 278-281 (1958)

Natural Rubber Producers Research Association, Inhibition of Volatile Fatty Acid Hydrogenation in Hevea Latex; Brit. 861,946 (Mar. 1, 1961)


Phillips Petroleum Co., Foam Suppression on Stripping Monomers from Butadiene-Styrene Elastomer Latex; Brit. 851,082 (Mar. 23, 1960)


Salomon, G., Morphological Aspects of Abrasion and Wear; Engineering (London 173:310 (1952)


Schulz, G. J., Fox, R. E., Excitation of Metastable levels in Helium near Threshold; Phys. Rev., 106:1179 (1957)


Smith, W. M., Eberly, K. C., Hanson, E. E., Binder, J. L., cis-and trans-Polyesters Formed by Condensation of Geometric Isomers of 2-Butene-1, 4-Diols and Ethene-1, 2-Decarboxylic Acids; J. Am. Chem. Soc., 78:626 (1956)

Societe des usines chimiques Rhone-Poulenc, Regeneration of Organopolyisocyanate Elastomers; France, 1,169659 (Dec. 31, 1956)


Stillson, V. M., Automotive Application of Vacuum Metallizing; Paper presented before the SAE National Passenger Car, Body and Materials meeting, Detroit, Michigan, March, 1957

Studebaker, Merton L., Nabors, Lester G., Chemistry of Reinforcement. IV. Modular Systems Based on Carbon Black, Squalene, TMTD, and Leuor; Rubber Age, 35:984 (1959)

Thirion, P., The Tack of Crude Rubber and the Difficulties of its Determination; Adhesion, 2:65 (1959)


Toyo Rubber Industry Co., Ltd., Chemical-Resistant Rubber; Japan, 10:354 (Aug. 1, 1960)


Valclavak, Vladaimir, Regulation of Molecular Weight in Styrene-Butadiene Emulsion Copolymerizing; Chem. Prumysl, 10:327 (1960)


Wacker-Chemie G.m.b.H., Adhering Silicone Rubber to Other Materials; Ger. 970,125 (Aug. 21, 1958)


Watson, J. H. L., Crystalline Alpha-Ray-Acetylene Reaction Products, Radiation Research; 3:121 (1955)


