“The Compounding of Polyacrylate Elastomers for Ultimate Performance”

By:

*Joshua R. Kelley - ACM Applications Development Chemist
Paul E. Manley, Ph.D. - ACM Applications Development Supervisor

HyTemp® ACM Application Development Group
Zeon Chemicals L.P.
Louisville, KY U.S.A.

13th Brazilian Congress of Rubber Technology of ABTB
Sao Paulo, SP, Brazil
April 13-15, 2010
Recent trends in automotive technology continue to push the envelope in terms of performance, efficiency, and cost-effectiveness. These technical demands have coincided with new temperature and warranty requirements from major automobile manufacturers worldwide. As a result, the technical demands on seals, gaskets, and hoses used to seal and transfer the most advanced automotive fluids have continued to evolve. Zeon Chemicals has been innovative in the development of new ACM technology enabling polyacrylate polymers to be safely formulated, bin stored, and vulcanized using a variety of processing equipment. These development efforts have consequently resulted in state-of-the-art polyacrylate compounds with excellent cure rates, superior physical properties, and extended performance.

The choice of base rubber is the primary determinant of service temperature performance and oil resistance. Selecting the right polymer for a particular application is the most important step to developing a successful polyacrylate formulation for a given application. This document will explain in greater detail the characteristics of each ACM polymer family, the particular characteristics of various cure systems, and examples of demanding applications where polyacrylates are used successfully. This paper will also demonstrate the performance achievable by the latest advances in polyacrylate technology.
INTRODUCTION

The development of polyacrylate (ACM) rubber was started in the early 1940s at the U.S. Department of Agriculture’s Eastern Region Laboratory and at the University of Akron’s Government Laboratories. The efforts made by the U.S. Department of Agriculture were intended to result in a polymer product produced from whey, a by-product of cheese production. (1) The first commercially produced polyacrylate polymers became available in 1947 and were produced by BFGoodrich Chemical. The first two polymers were marketed under the names Hycar PA and Hycar PA-21. However, the Hycar PA-21 material showed the most promise and later development projects became focused around this grade. (2) Today, polyacrylates are used in various applications where heat and oil resistance is critical, and there are numerous grades available to fit a variety of functions.

Most recently, many improvements have been made to polyacrylate materials that have broadened the functional temperature ranges and environmental restraints of polyacrylate polymers. Improved vulcanization characteristics, through the incorporation of advanced curesites and curatives, have played a significant role in polyacrylate technology which has resulted in polyacrylates with improved low- and high-temperature performance, fluid resistance, and processing characteristics.

Polyacrylate Composition

Polyacrylate elastomers are polymers of acrylic acid esters with added reactive curesite monomers. Polyacrylate backbone monomers are responsible for the overall balance of physical properties and chemical resistance of ACM polymer. Backbone monomers account for 95–99% of the weight of a normal polyacrylate elastomer. These may consist of one or more different types of acrylic monomers. Typical backbone monomers are ethyl acrylate (EA), n-butyl acrylate (BA), and 2-methoxyethyl acrylate (MEA). The monomer structures are shown in Figure 1.

Ethyl acrylate based polymers have excellent high temperature and aromatic oil resistance. However, the low-temperature limit, expressed as the glass transition (T_g) temperature, is -18°C. Polymers based on EA are used in applications requiring maximum oil resistance. Addition of n-butyl acrylate to an ethyl acrylate based polymer lowers the T_g of the polymer. The T_g of a butyl acrylate based polymer is -55°C. While polymers containing BA have excellent heat resistance, increasing the content of BA decreases the oil resistance. A typical compound based on an EA/BA copolymer with a -40°C (T_g) would exhibit a typical volume swell of about +60% when aged in IRM 903 oil while an EA homopolymer would only increase 11% in volume. The addition of MEA to an EA or BA containing polymer improves the balance of oil resistance and low temperature. However, it has a negative effect on the heat resistance of the polymer. Available commercial grades of polyacrylate elastomers cover a wide range of temperature and oil resistance. Each grade is a compromise of heat resistance, low-temperature performance, and oil swell resistance.

Vulcanization of the first commercial polyacrylate elastomer, a homopolymer of ethyl acrylate, proved to be very difficult. For this reason, curesite monomers are copolymerized with the backbone monomers to produce a usable polyacrylate elastomer. Examples of the common curesite functional groups used today are shown in Figure 2.
Basic Recipe

Polyacrylates generally offer a lower-cost solution versus the other oil-resistant, high-temperature types such as FVMQ (fluorinated silicone) and FKM (fluorinated hydrocarbon) elastomers. Polyacrylates also offer improved high-temperature resistance over HNBR (hydrogenated nitrile) and ECO/CO (epichlorohydrin ethylene oxide) elastomers. Improved oil resistance is their major advantage over the AEM (acrylic/ethylene) and MQ/VMQ (silicone/vinyl functional silicone) materials.

A typical polyacrylate recipe and physical properties are shown in Figure 3 and Figure 4, respectively. Suitably compounded and cured, polyacrylates offer the following general resistance:

- Temperatures from -40 to 200°C depending on type
- Petroleum-based oils/greases at elevated temperatures, including sulfur bearing types
- Ozone and ultraviolet (UV) light at normal and elevated temperatures
- Aliphatic solvents

On the other hand, typical grades are not resistant to steam and hot water, gasoline (except for certain grades), and alcohols/glycols.

POLYMER SELECTION AND CURE SYSTEMS

Recent advances in polyacrylate (ACM) polymer development continue to result in new, easily processed polymers. These technical advances have coincided with new temperature and warranty demands from major automobile manufacturers worldwide. The result is increasing demand for more flexible and efficient curing systems for ACM compounds. To meet these demands, manufacturers continue to develop new curing technology enabling polyacrylate polymers to be safely compounded, bin stored, and vulcanized using a variety of processing equipment. This provides the compounding chemist with safety and convenience, but with excellent cure rates and physical properties as well.

The choice of base rubber is the primary determinant of low-temperature and oil resistance. This also determines the choice of cure system. Selecting the right polymer for a particular application is the most important step to developing a successful polyacrylate application. The following paper will explain in greater detail the characteristics of each ACM polymer family, the particular characteristics of various cure systems, and examples of demanding applications where polyacrylates are used successfully. The information presented here is by no means a complete representation of all the technical data available, but can be used to better understand the general characteristics of available ACM elastomers.

Cure Systems

In order to facilitate cure, most commercial polyacrylic rubbers have a low level of reactive curesites. This varies among commercially available types. Since there is no universal cure system for all commercially available acrylic rubbers, cure systems must be matched with the type of reactive site. Typically, the polymer manufacturer will recommend an appropriate cure system.

As explained previously, the characteristics of ACM are dependent, as with most polymers, upon the monomers that make up the polymer backbone of the particular family of ACM
elastomers. A family, as defined here, is a class of polyacrylate elastomers that share common reactive cure sites and can be vulcanized by using the same, or similar, cure system chemistry. It is necessary to match the cure system with the specific polymer cure site type. As cure site types vary among polymer manufacturers, it is generally not possible to change base rubbers without making additional changes in the formulation. However, polyacrylates in the same family can be blended to achieve the desired physical properties. For example, a high-oil-resistant chlorine grade can be blended with a low-temperature chlorine grade polyacrylate to achieve a mid-range balance of oil and temperature resistance.

**Retarders**

Retarders are often used to increase scorch safety and shelf stability of polyacrylates. They work by keeping the compound from cross-linking prematurely. The cure sites used in polyacrylates are quite reactive, even at room temperatures; therefore, care should be taken to prevent premature vulcanization or scorch. The retarder selected should also be compatible with the cure system of choice. For example, a small amount of sulfur in an HT-ACM formulation will retard the rate of cure, while adding sulfur to a dual cure site formulation can increase the rate of cure.

The cure mechanism of most acrylic rubbers is alkaline in nature. Hence, they are accelerated by basic materials, e.g., magnesium oxide, and retarded by acidic materials, e.g., stearic acid. Polyacrylate non-black compounds can be formulated to achieve fast curing and low compression set characteristics. Increased curative levels are often required to overcome the acidic retarding effect of the non-black fillers.

Since retarders adversely affect compression set and sometimes heat-aging performance, the amount used is often small. The choice of retarder depends on the cure system that is being used. Stearic acid is the universal retarder for polyacrylates and also serves as an effective processing aid. Other common scorch retarders are also used.

The shelf life of a polyacrylate compound is fully dependent upon the choice of cure system and storage climate. Storage stability can vary from a few days to several months. To extend the shelf life of fully accelerated compound (containing curatives), the material can be stored in a “cool” room during summer months. Shipping of accelerated polyacrylate compound during summer months is best accomplished with the use of refrigerated shipping vehicles.

**POLYMER FAMILY AND CURE SYSTEM COMPARISON**

The following section will review a laboratory study constructed to show the unique characteristics of each polymer family coupled with different cure systems available for each family of polyacrylate. For this study polyacrylate grades having moderate low-temperature performance were compounded to have an original hardness of approximately 65-70 Shore A. The recipes, rheology, and original physical properties of the recipes are shown in Figure 5. The headings at the top of each recipe in Figure 5 will be used to reference each polymer/recipe combination in the following discussion. The recipes used for this study were designed to represent the typical construction of a seal or gasket compound with low-temperature performance of -30°C based upon Gehman T100 values (Figure 6). These types of recipes are typically compression, transfer, or injection molded, depending upon the part design.
Chlorine Curesite Family – Soap/Sulfur Cure vs. Trimercaptotriazine Cure

In general terms, the chlorine curesite family offers a range of performance from approximately -40°C to 175°C. They are well known for their resistance to high temperatures, but their compressive stress relaxation (CSR) properties, resistance to compression set, and the need for a post cure for optimum compression performance have led to the development of more advanced curing site technology as described later.

The chlorine curesite polyacrylate family incorporates the use of a chlorine curesite monomer. This curesite allows for a relatively flexible rate of cure, and the use of a post cure is generally recommended although not necessary for some applications. The cure rate can be adjusted based upon the choice of the accelerator chemistry, thus allowing for long, extrusion-friendly scorch times. Crosslinking is facilitated through a reactive chlorine atom which allows for the use of mild curatives such as a fatty-acid-soap/sulfur system or trimercaptotriazine. Soap/sulfur systems, developed in the earlier 1960s, are still very common. They offer good scorch safety, cure rate, and a good balance of physical properties. The trimercaptotriazine cure system also offers a good balance of physical properties and scorch safety but with improved short-term compression set performance. In this study, the soap/sulfur cure system (S-S) is compared to a cure system comprised of zinc diethyldithiocarbamate (ZDEC) accelerator and 2,4,6-trimercaptotriazine curative, which will be referred to in this discussion as the TMT cure system.

The test data for this study shows that both cure systems provide very similar original physical properties. Oscillating die rheology (ODR) indicates that both cure systems offer similar cure levels, measured by maximum torque (MH), but the TMT cure system provides a faster rate of cure based on Tc90 cure time. Mooney scorch analysis shows that the TMT cure system has only slightly lower scorch safety as indicated by a shorter T5 time (Figure 7).

As stated earlier, the TMT system provides for much improved compression set performance over the S-S cure system. This is highly dependent upon the length of time and the temperature at which the compression set specimens are aged. At both 150°C and 175°C aging temperatures, the TMT cure system outperforms the S-S cure system for short-term aging conditions. After long-term aging, the compression set performance of both cure systems are equivalent. This is shown in Figure 8 where the compression set results after aging for 175°C for 504 hours indicate that both cure systems take a compression set of approximately 80%, and when aged at 150°C for 1008 hours, both cure systems reach a compression set of around 70%.

Although the TMT system may provide enhanced compression set performance, the S-S system provides for better air aging performance. This is seen in Figure 9, where tensile specimens were aged for 1008 hours at 175°C. Both cure systems have a similar increase in hardness, but the S-S system retains a higher level of % elongation over time. This same trend is also observed for tensile strength retention, except that both cure systems have equivalent tensile strength retention after 1008 hours. This is true even though the TMT system shows a greater loss of tensile strength after short-term aging at 175°C. These same trends are observed after aging these cure systems at 190°C for 168 hours (Figure 10).

The apparent air aging performance of the TMT cure system could possibly be the result of zinc induced degradation of the polyacrylate polymer chains. The accelerator used in this cure system is a zinc compound and is the source of a low level of zinc. Zinc compounds are known prodegradants of polyacrylate formulations, and high levels of zinc containing materials should be avoided where possible.
Dual Chlorine/Carboxyl Curesite Family – NPC System vs. Dimethylurea Cure System

In order to develop low compression set resistance, most polyacrylates require a post cure, also referred to as a temper. The emphasis for the development of the dual curesite polymers was to eliminate the need for post curing of the rubber article. The dual curesite polymers can give good physical properties, especially compression set resistance, without the use of a post cure. In some applications a post cure may still be necessary, however. In the late 1970s, soap/amine/urea systems were developed for dual chlorine/carboxyl functional polyacrylics. These have become the most popular systems in Europe. In the late 1980s, even more efficient cure systems were developed in the USA, Europe, and Japan. The HyTemp NPC-50 cure package, which is marketed by Zeon Chemicals in the USA, utilizes this technology and provides for faster cures and lower compression set values, with or without a post cure. Dual curesite polyacrylates can also be vulcanized using 3-(3,4-dichlorophenyl)-1,1-dimethylurea. This cure system provides greater scorch safety and excellent physical properties but generally requires a post cure to achieve the optimum level of compression set performance. In this study, the NPC cure system is compared to the dimethylurea cure system, which will be referred to in this discussion as the DMU cure system. Both of these cure systems require the addition of approximately 4 phr of sodium stearate per the recipes outlined in Figure 5.

Both cure systems provide similar original % elongation and tensile strength characteristics. However, the NPC cure system generally results in compounds with slightly lower hardness values compared to the DMU cure system. This is reflected by the data in this study (Figure 11). Oscillating die rheology (ODR) indicates that the NPC cure system provides a much faster rate of cure based on Tc90 cure time. The most distinguishing feature of the NPC system is that it allows for a very fast rate of cure. This can potentially eliminate the need for a post curing operation, provided that a sufficient state of cure is reached in the molding stage to obtain the desired level of compression set performance. The NPC cure system is very sensitive to traditional rubber processing conditions. Temperature control is extremely critical to prevent premature vulcanization (i.e., scorch). The NPC cure reaction starts around 85°C, which means that dual curesite polyacrylate grades which utilize the NPC cure system should be kept below 85°C during mixing, milling, or other processing after the NPC cure system has been added to the compound. The DMU cure system is much more forgiving in terms of scorch safety.

The NPC cure system yields much lower compression set results compared to the DMU system. This is evident at compression set aging temperatures of 150°C and 175°C displayed in Figure 12. The air aging performance of the NPC cure system is also superior to that of the DMU cure system as seen in Figure 13 and Figure 14. However, the scorch safety of the NPC cure system limits its use to processes with good temperature control. It is most commonly used for injection or compression molded seals and gaskets which require very good compression set performance.

High-Temperature Polyacrylate (HT-ACM) Family

Automotive-related demands on elastomers continue to become more severe. Not only are the temperature demands becoming greater, but the specification-related constraints both in time and newer test techniques, such as compressive stress relaxation (CSR), are more demanding as well. This combination is requiring suppliers to turn to ever more exotic, yet cost-effective, polymers and cure chemistry in order to fulfill modern automobile specifications.

The very latest developments in polyacrylate technology have resulted in a new family of polyacrylic polymers known as high-temperature ACM, or HT-ACM. The HT-ACM family of polyacrylate elastomers provides better heat resistance over traditional ACM materials due to
the optimization of the backbone monomers along with improved amide cross-linking technology. When aged at elevated temperatures, the unique polymer construction of HT-ACM has led to superior compression set stability and physical property retention never before achieved with prior ACM technology. The superiority of these new elastomers over traditional ACM elastomers has been successfully demonstrated in many under-the-hood applications, including valve cover and oil pan gaskets, seals, hoses, and air ducts.

HT-ACM polymers are vulcanized with hexamethylene diamine carbamate (HMDC) and a highly alkaline accelerator such as N, N'-di-o-tolylguanidine (DOTG). Recent concerns over health risks associated with DOTG and other guanidine chemicals have led to the development of DOTG-free formulations, such as the one used in this study. There are other DOTG alternatives commercially available. As with many of the other ACM cure systems, a post cure is required to achieve the best compression set and high-temperature performance that this outstanding cure system has to offer.

Based upon the data from this study (Figure 15), the cure system used for HT-ACM offers a moderate cure rate and scorch safety compared with the cure systems associated with other polyacrylate materials. The original physical properties of HT-ACM are also similar to other ACM grades. The fluid resistance characteristics of the polyacrylate materials in this study are shown in Figure 16 and Figure 17. The elastomers from the chlorine and dual cure site families have very similar volume change values while the HT-ACM values are slightly higher in some fluids. This difference is a result of the backbone monomer optimization required to achieve an excellent level of high-temperature performance and low-temperature functionality. With this said, the elongation change of the HT-ACM compound after aging in motor oil is very good compared to many of the other compounds. The benefits provided by HT-ACM are more easily observed when comparing the compression set and heat aging performance between this grade and the more traditional ACM materials.

As mentioned earlier, this cure system offers superior compression set stability and physical property retention even when aged at temperatures approaching the limit of traditional ACM operating conditions. As observed in air aging data displayed in Figure 18 and Figure 19, HT-ACM offers improved hardness change stability and elongation retention. The compression set performance of the HT-ACM technology is excellent as seen in Figure 20. The short-term compression set values are somewhat comparable to those obtained by the dual cure site technology but with one important difference. The most beneficial characteristic of the HT-ACM technology is its long-term compression set stability.

Compression set correlates well with compressive stress relaxation (CSR) performance. New worldwide automotive specifications are being written to include percent retained force measured by CSR. The proposed target by some automotive manufacturers for these new specifications is a minimum of 10% force retained after 1008 hours. HT-ACM compounds can easily exceed this requirement in both an air or oil environment. Figure 21 shows a CSR comparison of HT-ACM and two conventional ACM grades when aged in standard test motor oil, SF-105, at 150°C.

APPLICATIONS

Polyacrylic elastomers are classified as high-temperature, oil-resistant, specialty-type rubbers. They are also often called polyacrylates or simply acrylic rubber. The American Society for Testing Materials (ASTM) approved designation is ACM for acrylic monomer. ASTM and the Society of Automotive Engineers (SAE) have a classification system (D2000/J200) designed for rubbers used primarily in automotive applications. ACMs fit within the DF (150°C capable), DH
(150°C capable), and EH (175°C capable) oil-resistant elastomer tables of this system. This is appropriate as nearly 80% of acrylic rubber sold is used to manufacture automotive components. They are generally formulated with reinforcing, curing, and other modifying agents. These saturated elastomers offer excellent resistance to severe environments in thermoset applications and are processed into parts designed for applications requiring -40°C to 200°C performance. There are many grades of ACM which possess -40°C flexibility without the use of plasticizer.

The most important properties of polyacrylate elastomers are heat and oil resistance; therefore, they find use in a wide range of automotive applications. Polyacrylate elastomers are used in a number of demanding automotive applications including valve cover gaskets, oil pan gaskets, rocker cover gaskets, and various seals. These applications, where sealing force retention for greater than 160,000 kilometers is a typical expectation, require the excellent long-term high-temperature performance, excellent compression set, compressive stress relaxation (CSR) resistance, and stable modulus that these elastomers provide. These new HT-ACMs have become the standard, or preferred, material of choice for many automotive companies. Polyacrylate materials are not only used in molded part applications. They are also widely used in hose constructions and can provide outstanding high-temperature performance and oil resistance in applications such as turbo diesel (TDi), transmission oil cooler, power steering hoses. They find more limited use in adhesives and as binders for propellants and flexible magnets.

**SUMMARY**

Polyacrylate elastomer compounds are ideal for the fabrication of seals, gaskets, and hoses for the sealing or conveying of hydrocarbon lubricants or hot air, even in high-temperature environments. As demonstrated in the discussion above, ACM compounds can be tailored to material specifications through the proper choice of ACM elastomer grade. The proper choice of cure system is also critical to the performance of the resulting compound.

Recent scientific developments in polyacrylate chemistry have improved ACM performance. The latest HT-ACM technology has broadened the temperature range of polyacrylate functionality and long term sealing dynamics. The use of HT-ACM elastomer provides an excellent engineering solution for low- and high-temperature sealing applications while minimizing the cost associated with the use of higher priced sealing materials such as silicone or fluorocarbon elastomers.
FIGURES

Figure 1 - Common Polyacrylate Backbone Monomers

Ethyl Acrylate

n-Butyl Acrylate

2-Methoxy Ethyl Acrylate

Figure 2 - Common Polyacrylate Curesite Functional Groups

Carboxyl

Chlorine

Epoxy
### Typical ACM Compound

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>phr</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymer</td>
<td>100</td>
<td>Oil Swell/Low Temp.</td>
</tr>
<tr>
<td>Filler</td>
<td>25-150</td>
<td>Reinforcement</td>
</tr>
<tr>
<td>Retarder</td>
<td>1-6</td>
<td>Increase scorch safety</td>
</tr>
<tr>
<td>Process Aid/Lubricant</td>
<td>1-4</td>
<td>Improve mill release</td>
</tr>
<tr>
<td>Antioxidant</td>
<td>0-4</td>
<td>Help thermal stability</td>
</tr>
<tr>
<td>Plasticizer</td>
<td>0-20</td>
<td>Soften the compd./ Improve low temp.</td>
</tr>
<tr>
<td>Curatives</td>
<td>1-10</td>
<td>Crosslink the ACM</td>
</tr>
</tbody>
</table>

**Figure 3 – Typical ACM Recipe**

### Typical ACM Compound Physical Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Typical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength, Mpa</td>
<td>7 - 14</td>
</tr>
<tr>
<td>Elongation, %</td>
<td>100 - 250</td>
</tr>
<tr>
<td>Hardness, Shore A</td>
<td>45 - 90</td>
</tr>
<tr>
<td>Compression Set (%), 70 Hrs @ 150°C</td>
<td>5 - 60</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.30 - 1.40</td>
</tr>
</tbody>
</table>

**Figure 4 - Typical ACM Compound Physical Properties**
Figure 5 - Study Recipes with Rheology and Original Physical Properties

<table>
<thead>
<tr>
<th></th>
<th>HT-ACM</th>
<th>DC/NPC</th>
<th>DC/DMU</th>
<th>CC/S-S</th>
<th>CC/TMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>HyTemp AR12</td>
<td>100.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HyTemp 4065</td>
<td>100.00</td>
<td>100.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HyTemp AR72LF</td>
<td></td>
<td></td>
<td></td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>N 550</td>
<td>55.00</td>
<td>65.00</td>
<td>65.00</td>
<td>60.00</td>
<td>60.00</td>
</tr>
<tr>
<td>Vanox CDPA</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Stearic Acid</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Struktol WB222</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Vanfre VAM</td>
<td>0.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Armeen 18D</td>
<td>0.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhenogran XLA-60</td>
<td>2.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diak #1</td>
<td>0.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HyTemp NS-70</td>
<td></td>
<td>6.00</td>
<td>6.00</td>
<td>6.00</td>
<td></td>
</tr>
<tr>
<td>HyTemp NPC-50</td>
<td>2.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HyTemp SR-50</td>
<td>2.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diuron 80</td>
<td></td>
<td></td>
<td>2.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spider Sulfur</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.30</td>
</tr>
<tr>
<td>Ethyl Zimate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.50</td>
</tr>
<tr>
<td>Zisnet F-PT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.50</td>
</tr>
<tr>
<td>Retarder Safe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.30</td>
</tr>
<tr>
<td>TOTAL</td>
<td>161.60</td>
<td>180.00</td>
<td>178.00</td>
<td>171.30</td>
<td>167.30</td>
</tr>
</tbody>
</table>

Mooney Stress Relaxation, ML1+4+4 @ 100°C

<table>
<thead>
<tr>
<th></th>
<th>HT-ACM</th>
<th>DC/NPC</th>
<th>DC/DMU</th>
<th>CC/S-S</th>
<th>CC/TMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Viscosity</td>
<td></td>
<td>45.7</td>
<td>55.8</td>
<td>55.2</td>
<td>51.0</td>
</tr>
<tr>
<td>Slope</td>
<td></td>
<td>-0.49</td>
<td>-0.31</td>
<td>-0.35</td>
<td>-0.28</td>
</tr>
</tbody>
</table>

ODR Rheology, 30 Min @ 190°C, 100 CPM @ 3°Arc

<table>
<thead>
<tr>
<th></th>
<th>HT-ACM</th>
<th>DC/NPC</th>
<th>DC/DMU</th>
<th>CC/S-S</th>
<th>CC/TMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ML, (dN·m)</td>
<td>6.5</td>
<td>8.1</td>
<td>6.4</td>
<td>5.8</td>
<td>5.7</td>
</tr>
<tr>
<td>MH, (dN·m)</td>
<td>41.2</td>
<td>34.9</td>
<td>25.7</td>
<td>43.3</td>
<td>41.1</td>
</tr>
<tr>
<td>Ts2, (min)</td>
<td>0.9</td>
<td>0.6</td>
<td>2.0</td>
<td>1.8</td>
<td>1.7</td>
</tr>
<tr>
<td>Tc90, (min)</td>
<td>10.5</td>
<td>3.5</td>
<td>16.4</td>
<td>12.5</td>
<td>6.9</td>
</tr>
</tbody>
</table>

Original Vulcanized, Post Cured

<table>
<thead>
<tr>
<th></th>
<th>HT-ACM</th>
<th>DC/NPC</th>
<th>DC/DMU</th>
<th>CC/S-S</th>
<th>CC/TMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness Shore A, (pts)</td>
<td>67</td>
<td>67</td>
<td>69</td>
<td>64</td>
<td>70</td>
</tr>
<tr>
<td>Modulus @ 100 %, (MPa)</td>
<td>5.05</td>
<td>5.08</td>
<td>5.35</td>
<td>4.63</td>
<td>4.75</td>
</tr>
<tr>
<td>Tensile Strength, (MPa)</td>
<td>11.5</td>
<td>12.2</td>
<td>12.2</td>
<td>11.5</td>
<td>11.5</td>
</tr>
<tr>
<td>Elongation, (%)</td>
<td>224</td>
<td>225</td>
<td>232</td>
<td>262</td>
<td>264</td>
</tr>
</tbody>
</table>

Figure 6 – Low-Temperature Performance, Gehman T100
Figure 7 - Chlorine Curesite Family, Original Physical Properties and Rheology
Figure 8 - Chlorine Curesite Family, Compression Set Performance
Figure 9 - Chlorine Curesite Family, 175°C Air Aging Performance
Figure 10 - Chlorine Curesite Family, 190°C Air Aging Performance
Figure 11 - Dual Curesite Family, Original Physical Properties and Rheology
Figure 12 - Dual Curesite Family, Compression Set Performance
Figure 13 - Dual Curesite Family, 175°C Air Aging Performance
Figure 14 - Dual Curesite Family, 190°C Air Aging Performance
Figure 15 - HT-ACM Comparison, Original Physical Properties and Rheology
Figure 16 - HT-ACM Comparison, Fluid Aged Volume Change
Figure 17 - HT-ACM Comparison, Fluid Aged Elongation Change
Figure 18 - HT-ACM Comparison, 175°C Air Aging Performance
Figure 19 - HT-ACM Comparison, 190°C Air Aging Performance
Figure 20 - HT-ACM Comparison, Compression Set Performance
Compressive Stress Relaxation (CSR), 150°C in SF-105 Oil

Figure 21 - Compressive Stress Relaxation (CSR), Aged at 150°C in SF-105 Oil

REFERENCES


ACKNOWLEDGEMENTS

The authors wish to thank and recognize the Zeon Chemicals L.P. Elastomer Laboratory
personnel for the mixing and testing of the numerous compounds required for the studies that culminated in the writing of this paper.

FOR MORE INFORMATION
The authors of this paper can be contacted at Zeon Chemicals L.P. Tel: 800-735-3388.