The typical construction of a hose is illustrated in Fig. 1. The first layer is an inner tube that carries the material being transported. The inner tube material, either a rubber or plastic resin, must be compatible with and able to contain the material being conveyed. The material used and the thickness of the tube depends on the intended service.

The next layer toward the outside is the reinforcement layer, which consists of metal (mesh or wire), synthetic polymer and/or textile covering (or combinations of these materials) that enable the hose to withstand internal and external pressure and abuse. Reinforcement fabrics commonly used include glass fiber, aramid fibers, nylon, polyester and rayon.

The cover is the outer layer that protects the reinforcement from damage caused by exposure to the environment, fluid contamination, and physical abuse. It is commonly made of plastic, rubber or textile materials. The cover also can serve as the medium for the reinforcement in some hoses; several synthetic rubbers that resist abrasion can be both reinforcement and cover materials. A hose must be flexible to accommodate misalignment, ease of routing and installation, mobility, portability, thermal expansion and vibration.

According to the Hose Handbook and Polymeric Flexible Hose & Tubing report, thermoplast elastomers (rubbers) offer far more superior physical properties than their counterparts, such as thermoplastic resins (non-elasticomer) and thermoplastic elastomers in flexible hose applications. Therefore, thermoset elastomers (rubbers) find wide spread use in hose applications.

EPDM offers one of the best balances of cost/performance profiles of any elastomer, and remains the largest-used synthetic thermosetting rubber in hose and tubing.

Automotive EPDM coolant hose

The internal combustion engine cooling system is illustrated in Fig. 2. A third of the heat energy produced by an internal combustion engine ends up as waste heat dissipated in the cooling system. EPDM coolant hoses are used to transfer aqueous coolant under pressure conditions at continuous temperatures ranging from -40°C to 150°C. Therefore EPDM coolant hoses (i.e., upper radiator hose, lower radiator hose, and heater hoses) are essential parts of the entire engine cooling system.

The EPDM thermal oxidation/degradation mechanism was systematically studied. The EPDM thermal oxidation/degradation mechanism was proposed and discussed. In addition, the effects of EPDM molecular architecture, antioxidants and EPDM compound formulations on long-term heat aging properties were investigated. Finally, a superior high heat resistant EPDM solution had been successfully developed for automotive coolant hose applications to provide optimized product performance before and after long-term heat aging.

among all the thermoset rubbers, EPDM offers one of the best balances of cost/performance profiles of any elastomer, and remains the largest-used synthetic thermosetting rubber in hose and tubing.1

By Greg Li, Ray Laakso, Yuming Lai, Wenzhao Yang, Sharon Wu and Lena Nguyen

The authors

Greg Li is a research scientist in North America Packaging & Specialty Plastics Technical Service & Development at Dow Chemical Co. His responsibilities include the development of Nordic-brand EPDM products, formulations, and applications for food processing developments.

Li joined Dow Elastomers R&D in 2011. Prior to joining Dow, he worked at Veeco Technical Foams Division of Armacell L.L.C. for three years as a researcher scientist and plant process chemist, where he developed elastomeric closed cell and open cell foams for the automotive industry.

He received a bachelor’s in engineering from Tianjun University, a master’s from the Institute of Chemistry (Beijing), Chinese Academy of Sciences, and a doctorate from the University of Toronto in Toronto. Li performed post-doctoral research at Case Western Reserve University.

Sharon Wu is a research scientist at Dow. She is currently responsible for driving the Nordic EPDM product and technology innovation pipeline for various thermoplastic applications. Wu joined Dow Elastomers product research group in 2005. In 2009, she received her doctorate in polymer materials and engineering from Georgia Institute of Technology. Her areas of focus are structure-property relationships of polyolefin elastomer products, and new processes and methods to produce unique elastomer products with differentiated properties.

Yuming Lai is an associate engineer in the core R&D analytical sciences at Dow. His work is primarily on accelerated thermal and ultraviolet degradation of polymeric materials. He currently serves on the Technical Advisory Board for the Service Life Prediction conference organized by the National Institute of Standards and Technology. Lai obtained his doctorate from the University of Pennsylvania in electrical and systems engineering, where he focused on improving charge transport characteristic of colloidal nanocrystal assembled thin film devices and realizing large area flexible integrated circuits.

Wenzhao Yang is a statistician in the North America Core Research & Development unit at Dow. Yang’s key responsibilities include supporting, enhancing and promoting sound experimental design strategies and statistical data analysis techniques within Dow.

She joined Dow Core R&D in 2014. Yang has been involved in causal inference and optimization for formulation and product development. She holds a master’s degree in statistics and a doctorate in applied statistics and agriculture from Michigan State University.
Typical EPDM coolant hose compound consists of EPDM rubbers, fillers (black and non-black), plasticizers (oil, process aids), small rubber chemicals (zinc oxide, stearic acid, PEG, etc.) and curing package (sulfur/accelerators or peroxide/co-agent). With a proper cure system (peroxide cure system) and selection of other ingredients—such as antioxidant, fillers, and plasticizers—it is possible to achieve high heat resistance (for example 125°C) for EPDM peroxide cure compounds.

However, the higher heat resistance at 150°C (CUTR ≥150°C) remains a big challenge for many EPDM rubber coolant hose manufacturers. To cope with the increasing demand on coolant hose heat aging performance, the hose technology has been continuously evolving from sulfur cure EPDM technology to peroxide cure EPDM technology, and to even higher temperature formulations based on silicone rubber (VMQ), as illustrated in Fig. 4.

To better understand the critical performance requirements for automotive coolant hose, the key performance requirements from various automotive OEM coolant hose standards are summarized in Table 1. As shown in Table 1, currently Chrysler has established the highest long-term heat aging performance standards for coolant hose among all major automotive OEMs.

As described above, compact and sophisticated designs for automotive under-the-hood compartments have led to increased temperature environments. Consequently, long-term heat resistance has been a key requirement for many automotive under-the-hood applications. It is a challenging task for many of the rubber product manufacturers to meet the continuous upper temperature resistance of thermostat rubber in additional to other stringent design criteria for auto parts such as under-the-hood coolant hose, wire and cable, and other components.

Research objectives

In order to improve the CUTR of EPDM thermostat rubber, a well-designed, developed, and carefully formulated EPDM compound is the key to achieve such high heat resistance. A systematic study was focused on many of the EPDM polymer molecular structure characteristics, including EPDM ENB content, average molecular weight, molecular weight distribution (MWD) and polymer composition (ethylene content).

From the compound formulation perspective, antioxidant (AO) package (AO type and content), plasticizer, carbon black and other additives, are included in the study as well. The research objectives for this study are to understand the effect of EPDM molecular structures on EPDM compound heat aging properties and to study the effect of formulation variables on EPDM compound heat aging properties.

Experimental EPDM rubbers

A few grades of EPDM that are commonly used for automotive coolant hose application were chosen in this study. The characteristics of these EPDM rubbers are listed in Table 2. These EPDM rubbers were considered to have balanced molecular architectures (i.e. molecular weight and molecular weight distribution, or Mw/Mn, ethylene content, diene content etc.) which are critical for hose application.

The EPDM molecular weight is important for compound extendibility, compound extrusion characteristics and cured hose physical properties. The EPDM ethylene content is a critical factor for the hose compounder to balance the low temperature flexibility, and hose cold green strength; the EPDM diene content will affect compound cure speed and the state of cure; therefore many physical properties of the cured compound are affected by the molecular architecture.

Typically, high Mooney viscosity (60~85 MV), medium ethylene content (~60 percent wt), and low to medium Mw/Mn level (0.5 wt percent ~ 5 wt percent) are considered the proper EPDM structures for automotive coolant hose application.

EPDM thermal property by DSC

A TA instruments Q1000 Differential Scanning Calorimetry, equipped with a refrigerated cooling system was used to perform sample thermal property analysis. During testing, a nitrogen purge gas flow of 50 ml/min was used. The thermal behavior of the sample was determined by predetermined heating and cooling of the sample temperature to create a heat flow versus temperature profile.

First, the sample was rapidly heated to remove its thermal history. Next, the sample was cooled at 10°C/min cooling rate (first cooling scan). The sample was then heated (second heating scan) at a 10°C/min heating rate. The first cooling and second heating curves were recorded.

EPDM compound mixing procedures

All EPDM compounds were mixed...
with a rubber internal mixer, for example a Banbury-brand lab mixer with 1.6 liter net chamber volume. A standard “Upside Down” mix was used, with carbon black and other additives added first, followed by oil injection, with EPDM added last in the mixer.

The batch weight was sized to have 75 percent fill factor. The rotor speed was kept constant at 50 rpm before adding the curatives. The curatives were added to the compound when the compound temperature reached 80-90°C and subsequently the rotor speed reduced to 40 rpm. The final compound was dropped at 115°C. Mixing was completed on a 6-inch two roll mill at ambient conditions, a blanket was sheeted out to use for testing.

**EPDM compound testing**

The Mooney viscosity of each formulated composition was measured using an uncured blanket. Samples were conditioned for 24 hours at room temperature, prior to testing. Mooney viscosity (ML1+4 at 100°C) of the mixed compounds was measured in accordance with ASTM D1646, with a one minute preheat time and a four minute rotor operation time. The instrument is an Alpha Technologies Mooney Viscometer 2000.

The cure kinetic profiles of each formulation at 180°C were measured using an Alpha Technologies moving die rheometer (MDR) in accordance with ASTM D5289. The MDR test was carried out at 180°C over a period of 30 minutes. The rheology or curve of torque as a function of time for each formulated composition was measured from samples of uncured blanket, which was then cured during the MDR analysis.

Samples were conditioned for 24 hours at room temperature prior to testing. The viscoelastic properties, such as minimum S’ torque (ML), maximum S’ torque (MH), and time to reach a certain percentage of the cure state (for example, t95 corresponds to the time in minutes to reach the 95 percent state of cure), were measured during the cure cycle.

**Compound curing**

A sample from the uncured blankets was cut, heated and cured in a compression molder to make test specimens in accordance with ASTM D3182, using a PHI (100 ton press). To vulcanize the samples, the samples were cured under pressure at 180°C using t95 data plus 15 minutes for plaques, and using t95 data plus 15 minutes for compression set buttons. When cure time ended, the samples were removed from the press and immediately placed in cold water to stop the curing. Cured samples (plaques and buttons) were then conditioned for 24 hours at room temperature, prior to testing. The physical properties of the formulations were measured from Vulcanized plaques and buttons.

**Heat aging**

The test specimen were first die cut from the cured plaques using the “dumbbell” shaped tensile die described in ASTM D412. Those fabricated test specimens were then aged in an air ventilated oven at 150°C, at the desired aging hours. The heat aged physical properties were then measured using those heat aged samples.

### Table 3: Formulations for Compounds 1, 2, 3 and 4.

<table>
<thead>
<tr>
<th>Compound</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionomer</td>
<td>100</td>
<td>70</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>Polyol</td>
<td>55</td>
<td>55</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>Salicylic Acid</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Carbon Black</td>
<td>84</td>
<td>84</td>
<td>84</td>
<td>84</td>
</tr>
<tr>
<td>Peroxide Cross Linker</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Seignat</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Plasticator 1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Plasticator 2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>275.5</td>
<td>275.5</td>
<td>275.5</td>
<td>275.5</td>
</tr>
</tbody>
</table>

### Table 4: Mooney viscosities and MDR results for Compounds 1, 2, 3 and 4.

<table>
<thead>
<tr>
<th>Compound</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mooney Viscosity (ML1+4)</td>
<td>51.7</td>
<td>56.6</td>
<td>71.8</td>
<td></td>
</tr>
<tr>
<td>MDR</td>
<td>180°C</td>
<td>180°C</td>
<td>180°C</td>
<td>180°C</td>
</tr>
<tr>
<td>100%</td>
<td>1.5</td>
<td>1.6</td>
<td>1.6</td>
<td>1.9</td>
</tr>
<tr>
<td>95%</td>
<td>1.7</td>
<td>1.6</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>50%</td>
<td>0.9</td>
<td>0.8</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>25%</td>
<td>1.4</td>
<td>1.3</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>10%</td>
<td>4.8</td>
<td>4.7</td>
<td>2.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

---

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EPDMs

Continued from page 15

aged test specimens. All physical property tests were conducted not less than 16 hours nor more than 96 hours after specimens were removed from the hot air oven.

Physical properties testing

Tensile properties were measured per ASTM D-412. Three specimens were tested for each sample. Shore A hardness properties were measured using a stack of three die cut specimens. Shore A hardness properties were measured at room temperature, following the method ASTM D-2240.

FTIR

Infrared spectra were acquired with a Thermo Scientific Nicolet iS50 FTIR and its built-in ATR (Attenuated Total Reflection) accessory at a resolution of 4 cm⁻¹. Sixteen scans (47-second acquisition time) were collected for each specimen. The ATR accessory was equipped with a single bounce Germanium ATR crystal. The use of Ge ATR crystal rather than traditional diamond crystal is critical because of the presence of carbon black in the formulation.

Carbon black has strong absorption in IR, therefore other signals of interest might not be readily seen. With respect to diamond, Ge has higher refractive index, which reduces penetration depth during ATR mode data collection. Although the overall signal intensity is lowered, the carbon black absorption is greatly reduced, leaving behind more meaningful data for analysis.

Results and discussion

Effect of polymer structure on hot air heat aging properties

Compounds 1 through 4 (Table 3) were prepared according to the procedures described in the experimental passage. Each compound was tested for Mooney viscosity and MDR curing curve. The results are listed in Table 4.

Vulcanized plaques for each compound were cured according to the procedures described above. After curing, the tensile properties and hardness were measured and the results are listed in Table 5.

With the proposed formulation, all compound Mooney viscosity values were lower than the gum EPDM rubber Mooney viscosity. Typically, the broader MWD or higher LCB (long chain branching) of gum EPDM, the more Mooney viscosity reduction was observed for the mixed compound. Compound 4 had the highest compound Mooney viscosity, possibly because of Polymer 5 having the highest polymer Mooney and relatively narrow MWD structure.

Because the peroxide curing system was used in the formulations, all compounds exhibited very similar curing characteristics (cure speed, i.e., ts2 and t50). Compound 2 had the highest MH value indicating that Compound 2 had the highest state of cure. It is believed the higher diene content in Polymer 2 and Polymer 3 helped Compound 2 reach higher crosslinking density and higher level of state of cure. It remains unclear why Compound 3 did not reach a higher crosslinking density even though Polymer 4 has high diene content (5.7 percent wt).

The original physical properties for all the cured compounds are listed in Table 5. All compounds except Compound 3 had a statistically similar hardness (Shore A 60-65). Compound 4 showed slightly higher hardness and higher compression set at room temperature than the other three compounds because of the higher crystallinity in Polymer 5 (shown in Fig. 5). Original tensile strength of all compounds followed the state of cure of these compounds. Compound 2 had the highest tensile strength due to its highest state of cure contributed by the higher diene content.

The hot air heat aging properties at 150°C of EPDM were measured over a period of six weeks. All the heat aging results are compared and summarized in Table 6 and Fig. 6.

There are distinct differences among all of the compounds elongation retention property after heat aging at 150°C. Compound 2 and Compound 3 were very similar in terms of elongation retention drop rate. Both Compound 2 and Compound 3 quickly lost their elasticity and became very brittle in less than two weeks. Compound 4 exhibited the best elongation retention among all four compounds. After three weeks, Compound 4 with Polymer 5 still remained rubbery/elastic and retained 50 percent of its original elongation.

However all compounds became completely brittle after six weeks. The compound hardness change after six weeks (Hardness A) is another indication how these compounds thermally aged. Shore A hardness of both Compound 2 and Compound 3 increased more than 30 points after six weeks, while Compound 4 produced with Polymer 5 exhibited the lowest Shore A hardness increase (16 points increase). The results indicated that the EPDM polymer diene content significantly affects compound long-term heat aging properties. For example, low diene content yielded better compound long-term heat aging properties with high elongation retention and low hardness changes.

Effect of compound formulation

In order to further improve the high heat resistance and compound physical properties suitable for automotive components, see EPDMs, page 18.

Table 5: Original physical properties.

<table>
<thead>
<tr>
<th>Property</th>
<th>Compound 1</th>
<th>Compound 2</th>
<th>Compound 3</th>
<th>Compound 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress @ 50% Strain (MPa)</td>
<td>1.2</td>
<td>1.2</td>
<td>1.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Stress @ 100% Strain (MPa)</td>
<td>2.0</td>
<td>2.3</td>
<td>2.1</td>
<td>2.2</td>
</tr>
<tr>
<td>Stress @ 200% Strain (MPa)</td>
<td>4.3</td>
<td>5.3</td>
<td>4.7</td>
<td>4.4</td>
</tr>
<tr>
<td>Stress @ 300% Strain (MPa)</td>
<td>6.7</td>
<td>8.1</td>
<td>7.1</td>
<td>6.6</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>11.2</td>
<td>12.4</td>
<td>10.9</td>
<td>9.5</td>
</tr>
<tr>
<td>Elongation at break (%)</td>
<td>510</td>
<td>424</td>
<td>422</td>
<td>406</td>
</tr>
<tr>
<td>Compression Set (22 hr at 72°F)</td>
<td>15.2</td>
<td>12.3</td>
<td>12.0</td>
<td>20.5</td>
</tr>
<tr>
<td>Shore A</td>
<td>62</td>
<td>61</td>
<td>59</td>
<td>65</td>
</tr>
</tbody>
</table>

Table 6: Physical properties after hot air heat aging at 150°C.

<table>
<thead>
<tr>
<th>Property</th>
<th>Compound 1</th>
<th>Compound 2</th>
<th>Compound 3</th>
<th>Compound 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength retention</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Temperatures at break (%)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Elongation retention</td>
<td>99</td>
<td>96</td>
<td>98</td>
<td>94</td>
</tr>
<tr>
<td>Moisture absorption at 90% RH</td>
<td>91</td>
<td>91</td>
<td>95</td>
<td>96</td>
</tr>
<tr>
<td>Compression Set (22 hr at 72°F)</td>
<td>63%</td>
<td>55%</td>
<td>44%</td>
<td>71%</td>
</tr>
<tr>
<td>Shore A</td>
<td>37%</td>
<td>37%</td>
<td>37%</td>
<td>37%</td>
</tr>
<tr>
<td>Shore A</td>
<td>37%</td>
<td>37%</td>
<td>37%</td>
<td>37%</td>
</tr>
</tbody>
</table>

Fig. 6: Tensile elongation retention vs. heat aging time at 150°C (line was added to guide the eye only).

Table 7: Formulations for high heat resistant EPDM compounds.

<table>
<thead>
<tr>
<th>Compound 4</th>
<th>HHR Compound 1</th>
<th>HHR Compound 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPDM</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>Additive 1</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>Additive 2</td>
<td>84</td>
<td>84</td>
</tr>
<tr>
<td>Calcium Carbonate</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Carbox</td>
<td>58</td>
<td>58</td>
</tr>
<tr>
<td>Peroxide</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>275.5</td>
<td>295.5</td>
</tr>
</tbody>
</table>

Table 8: Mooney Viscosities and MDR results for HHR compounds.

<table>
<thead>
<tr>
<th>Property</th>
<th>Compound 4</th>
<th>HHR Compound 1</th>
<th>HHR Compound 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mooney Viscosity</td>
<td>71.8</td>
<td>81.4</td>
<td>89</td>
</tr>
<tr>
<td>MDR</td>
<td>1.9</td>
<td>2.3</td>
<td>2.7</td>
</tr>
<tr>
<td>MDR (50°C)</td>
<td>1.5</td>
<td>1.6</td>
<td>1.8</td>
</tr>
<tr>
<td>OD (50°C)</td>
<td>0.6</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>OD (90°C)</td>
<td>1.3</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>OD (90°C)</td>
<td>4.2</td>
<td>4.1</td>
<td>4.2</td>
</tr>
</tbody>
</table>
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Elastomer Team, R&D
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EPDMs

Continued from page 16

ant hose application, two high heat resis-
tant (HHR) EPDM compounds were de-
veloped with Polymer 5 which showed the
best heat aging performance among all
the EPDM polymers. The formula-
tions are listed in Table 7. In HHR Com-
-pound Mooney viscosity and MH.

As it was shown, both HHR com-
 pounds have excellent original physical
properties and superior heat aging
physical properties retention in compar-
ison to both Compound 4 and the com-
mercial hose compound. After six weeks
of heat aging at 150°C, HHR Compound
2 still had more than 250 percent elon-
gation at break and higher than 8 MPa
tensile strength, while the commercial
hose compound thermally degraded at a
much faster rate.

After heat aging at 150°C for 2 weeks,
the commercial EPDM hose compound
became completely brittle and lost its
elasticity. The new formulation, HHR
Compound 1 and HHR Compound 2,
which is enabled by a novel EPDM mo-
lecular structure (EPDM Polymer 5) and
new compound formulation, had
significantly improved the longevity of
EPDM coolant hose at higher aging
temperature (150°C).

This technology will definitely provide
the required flexibility to further im-
prove the combustion engine technology,
which requires higher temperature re-
sistance from under-the-hood compo-
nents and yield better gas mileage.

With respect to the significant high
heat resistance improvement of HHR
compounds, it is believed that EPDM
Polymer 5 enables this superior heat
aging performance because of its unique
polymer structure design with low diene
content. In addition, the formulation
polymer structural changes and for-
mulation optimization results in an out-
standing balance of physical properties
and new compound formulation, had
proved the combustion engine technology,
which requires higher temperature re-
sistance from under-the-hood compo-
nents and yield better gas mileage.

Table 9: The original physical properties of compounds.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Module</th>
<th>Mooney 100</th>
<th>Mooney 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compound</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Stress @ 50% Strain (MPa)</td>
<td>1.4</td>
<td>1.7</td>
<td>1.4</td>
</tr>
<tr>
<td>Stress @ 100% Strain (MPa)</td>
<td>2.2</td>
<td>2.5</td>
<td>2.3</td>
</tr>
<tr>
<td>Stress @ 200% Strain (MPa)</td>
<td>4.4</td>
<td>4.7</td>
<td>4.7</td>
</tr>
<tr>
<td>Stress @ 300% Strain (MPa)</td>
<td>6.4</td>
<td>6.9</td>
<td>7.4</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>9.5</td>
<td>8.6</td>
<td>10.9</td>
</tr>
<tr>
<td>Elongation At Break (%)</td>
<td>465</td>
<td>405</td>
<td>453</td>
</tr>
<tr>
<td>Compression Set (22 hr RT)</td>
<td>20.5</td>
<td>19.8</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Table 10: The physical properties retention after heat aging at 150°C.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Module</th>
<th>Mooney 100</th>
<th>Mooney 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compound</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Stress @ 50% Strain (MPa)</td>
<td>1.4</td>
<td>1.7</td>
<td>1.4</td>
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<tr>
<td>Stress @ 100% Strain (MPa)</td>
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<td>2.5</td>
<td>2.3</td>
</tr>
<tr>
<td>Stress @ 200% Strain (MPa)</td>
<td>4.4</td>
<td>4.7</td>
<td>4.7</td>
</tr>
<tr>
<td>Stress @ 300% Strain (MPa)</td>
<td>6.4</td>
<td>6.9</td>
<td>7.4</td>
</tr>
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<td>Compression Set (22 hr RT)</td>
<td>20.5</td>
<td>19.8</td>
<td>20.0</td>
</tr>
</tbody>
</table>

Table 10: The original physical properties of compounds.

Hose Manufacturing

Fig. 7: Elongation retention vs. heat aging time (line was added to guide the eye only).

Fig. 8: EPDM chemical composition change during thermal oxidation.

Fig. 9: Correlation between elongation at break retention and C=O formation after 150°C thermal aging for 6 weeks (line was added to guide the eye only).

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dation of EPDM. However, it is non-triv-
ial to the exact functional groups as it could be anything from al-
dehydes to carboxylic carboxylic acids as they all carry C=O signatures.

Nonetheless, it is important to point out that HHR Compound 1 and HHR Compound 2 exhibit not only the reduced growth in C=O, but also a broad band growing around the absorption bands of carboxylic acids as well.

During thermal oxidation, while undergoing the loss of elasticity, EPDM gradually oxidized and formed C=O containing spe-
cies, mostly carboxylic acid.

Conclusions
This study focused on automotive en-
gine coolant hose applications. It was
clearly identified that long-term heat aging properties are the most critical need for EPDM coolant hose to meet the demanding high heat resis-
tance requirement.

A superior high heat resistant EPDM solution was successfully developed to balance cured EPDM compound original physical properties and long-term heat aging properties. The results demonstrat-
ed that it is possible to achieve high heat resistance at 150°C (CUTR ±150°C) as
shown by HHR Compound 1 and HHR Compound 2 heating aging performance.

It was discovered that EPDM compound heat aging content is the most critical EPDM poly-
mer structural characteristic that af-
facts the long-term heat aging proper-
ties. Low EBN content in EPDM polymer significantly improved the cured EPDM heat aging properties with higher elon-
gation at break retention. It is believed that there is a strong inverse correlation be-
 tween the heat stability of the carbonyl group formation and carbonyl (carboxylic acid etc.) EPDM heat degradation process (oxidation/thermal degradation) and EPDM rubber compound heat degradation with pres-
ence of oxygen.

Acknowledgments
The authors would like to recognize Kristel Blackwell and the Dow EPDM rubber lab personnel for their support in getting all of the compounding and testing complete for this study.

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