

Innovative specialty elastomers could bring a wind of change to A/C hose construction

Simplify your design with excellent adhesion to textile reinforcement



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Introduction

Advanced state of the art automotive air conditioning systems are highly complex and consists of multiple functional components, such as compressors, evaporators, fans, blowers, hoses, valves and several fittings.

To illustrate the complexity of the application, the schematic of an automotive air conditioning system is shown in **Figure 1**.¹ The refrigerant gas is pressurized by the compressor (1) and circulated into the condenser (3) thereby liquefying it.

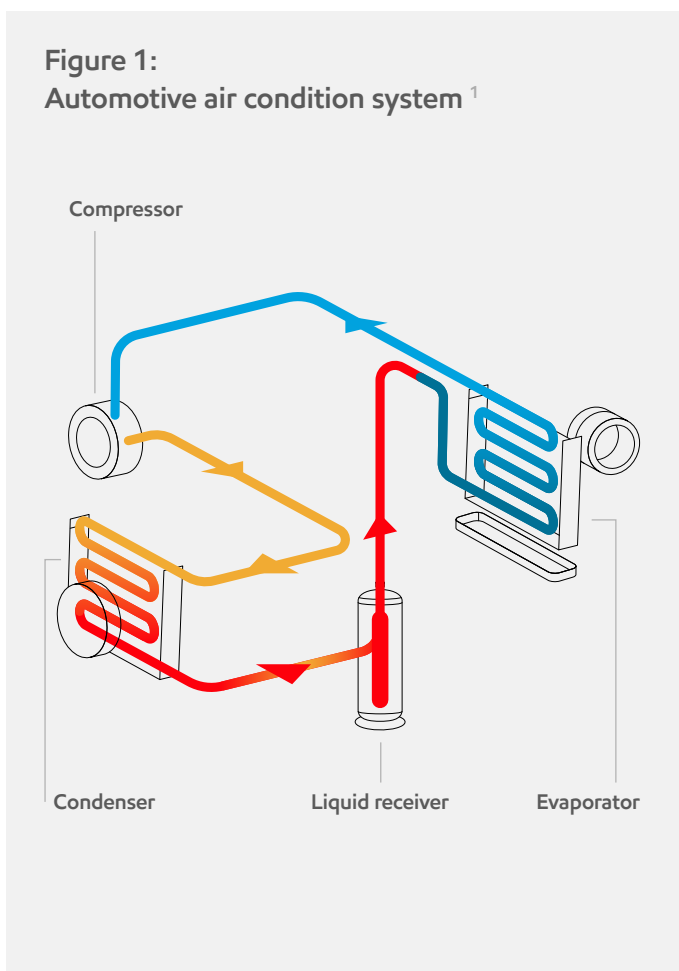
This high pressure/high temperature liquid then travels to an expansion valve (11), where it loses heat due to expansion. The cold refrigerant then enters the evaporator coils (8), absorbing heat from the blower air (9), thereby cooling the air.

The cold air is directed towards the cabin and the refrigerant enters the compressor again through the compressor suction inlet. In all cases, the transportation of the gaseous and liquid media is achieved via the use of specialized hoses and pipes.²

From the above illustration, it can be seen that in addition to containing and transporting the refrigerant, hose components have to be able to withstand high temperatures, pressures, shocks, dynamic flex fatigue, crack growth and chemical attack. Hoses used in these applications consists of several thermoplastics, elastomer blends and high strength textile or steel reinforcements.

New designs (for e.g. turbocharged engines in cars with smaller space) and evolving regulatory requirements (for e.g. use of more environmentally friendly fluid mediums in an automotive air conditioning hose) have stretched the operating temperatures and pressure requirements for hoses.

It is challenging to find elastomers that have the right balance of permeability, heat/UV/ozone resistance, adhesion strength and dynamic mechanical properties; key challenges being impermea-



bility and adhesion. Identification of such a polymer could enable reduction in construction complexity by the elimination of multiple layers and lead to significant weight reduction in these hoses (elimination of tie layers used for bonding purposes only).

In this article we will present an evaluation of brominated isobutylene - co paramethyl styrene based elastomers to achieve the above mentioned balance of properties - with a focus on the adhesion performance to textile reinforcements.

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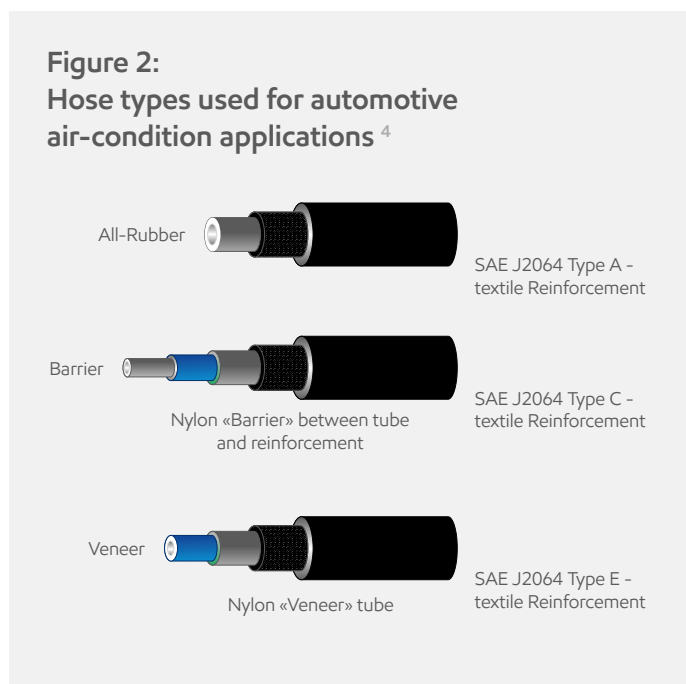
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The cross section of three different hoses used in automotive air conditioning applications is shown in **Figure 2**.⁴

In the SAE J2064 Type-A (all rubber) hoses, the innermost rubber layer needs to have very low permeability to refrigerant systems (such as R123A and R1234yf) in addition to excellent resistance to moisture ingress and heat resistance (such as halobutyl).

Whereas in the SAE J2064 Type-C & Type E (barrier, veneer) hoses, most of the impermeability is due to the nylon layer; hence the adjacent layer needs to have excellent resistance to moisture ingress with a lesser emphasis on impermeability requirements.

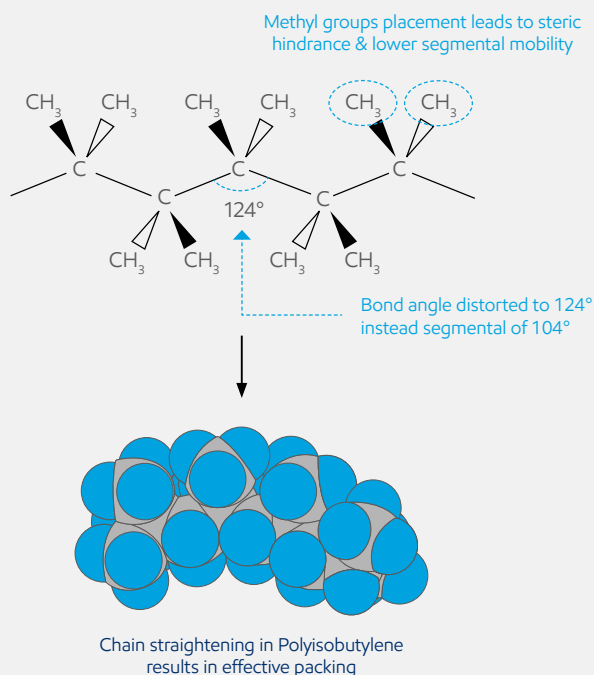
The elastomeric component calendared onto the textile reinforcement needs to have excellent bonding to the reinforcement system and also the elastomeric layers above and below it. In all cases, the cover compound needs to have excellent heat, ozone and UV resistance, in addition to low compression set, good mechanical properties and high flex fatigue, crack growth and crimp resistance.



Typical choices for the barrier layer include low molecular weight polyamide films or their blends (Nylon). Depending on the type and application of the hose, cover compounds could consist of EPDM, HNBR, NBR, CR CIIR, BIIR or NR/SBR blends (for less demanding applications). For the innertube, if permeation resistance is key, isobutylene based polymers such as BIIR or CIIR is a preferred choice (permeability is the aerial rate at which molecules pass through a material at a given pressure and temperature). Most elastomeric systems have all have carbon-carbon bonds at 104° (the classic tetrahedral bond angle).^{5,6} This hinders the amount of packing it can achieve. If the packing density is low, then molecules have more free spaces to pass through. In isobutylene based polymers, the presence of the dimethyl groups

forces the bond angle to 124° (more flat), which enables better packing (**Figure 3**). Ultra-low permeability of isobutylene chains could be attributed to its high packing density. However, if the polymer consists of only isobutylene, then it cannot be crosslinked into a hard rubber.

Figure 3:
Molecular Packing in Isobutylene



The presence of low amounts of isoprene in the main chain enables crosslinking to other unsaturated elastomers and to itself (i.e. can be cured). The halogen substitution (such as bromine or chlorine) enhances bonding to the adjacent tie layers facilitating manufacture of hose. Permeability of most elastomeric systems is an order of magnitude higher than those utilizing halobutyl polymers. However, halobutyl polymers have their limitations.

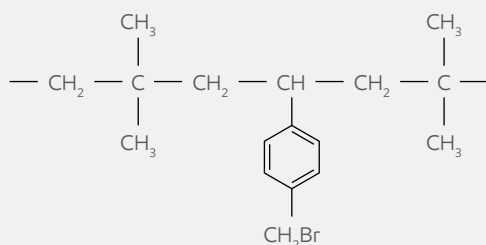
Due to unsaturation in the molecular backbone (i.e. carbon-carbon double bonds, due to isoprene in the backbone), halobutyl polymers are prone to oxidation via heat and ozone (due to cleavage of the double bonds); this could lead to cracking during operating conditions. Halobutyl polymers also have much lower adhesion to polymeric textile reinforcements than other elastomers.

In the early nineties, ExxonMobil Chemical Company (USA) developed a class of fully saturated specialty elastomer by the carbocationic polymerization of isobutylene and para-methyl styrene (pMS) followed by halogenation, thereby completely eliminating isoprene. These elastomers were known as brominated isobutylene-co-paramethylstyrene (BIMSM) and commercialized

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under the trade name Exxpro™ specialty elastomers (**Figure 4**). Exxpro™ specialty elastomers has several advantages over halobutyl polymers. Unlike halobutyl polymers (which has unsaturated backbone), these elastomers have a fully saturated backbone, thereby leading to exceptional chemical, oxidation and ozone stability.

Figure 4:
Exxpro™ specialty polymers



Not all the pMS groups are brominated

They also have an increased chain stiffness and better packing density with benzylic bromide groups in the chain. This facilitates a much more tortuous path for permeant molecules, thereby imparting the ability to achieve much lower permeability than halobutyl polymers. Since crosslinking occurs via substitution of the benzylic bromide groups, these systems can be cured sulfur-free, thus enabling clean cure systems.

Curing speeds can also be controlled very precisely so as to cure-in-sync with adjacent layers. Exxpro™ specialty elastomer

has found multiple industrial applications such as pharmaceutical stoppers, curing bladders, envelopes, high temperature resistant inner tubes, innerliners, adhesives, and some industrial rubber components.⁷⁻¹¹ The currently commercial Exxpro™ grade slate is shown in **Table 1**.

The dynamic mechanical advantages, permeation resistance, heat resistance and ozone resistance of Exxpro™ specialty elastomers have been studied extensively and shared in previous literatures and conference presentations.¹²⁻²² An area of extreme interest, which has not been previously studied in great detail is their adhesion to textile reinforcements used in the hose industry. One would not expect isobutylene based polymers to have very good wetting and adhesion strengths to reinforcements when compared to other elastomer systems. Improved adhesion is not only advantageous for product integrity and life; this could potentially also enable elimination of unwanted (and expensive) tie layers in certain layered hose constructions, thereby making the design more efficient and cost effective.

It is also worthwhile to understand what parameters of molecular design (pMS content, benzylic bromine content and molecular weight) would influence the adhesion and wetting behavior on textile reinforcements. Textile reinforcements are treated with adhesive systems and surface functionalities to enhance bonding – the adhesive formulation and type depends on the reinforcement and the type of rubber to be bonded. In order for a rubber to bond efficiently to a textile reinforcement, several criteria must be fulfilled. First, the rubber must efficiently wet out the adhesive coated textile surface (in the case of woven the fabric layers, efficient wetting could also increase adhesion due to interpenetrative networks). Secondly there has to be an interfa-

Table 1:
Exxpro™ specialty elastomer grade slate

Values are only targets and can differ from actual measured properties

Properties	CIIR 1066	BIIR 2222	Exxpro™ 3035	Exxpro™ 3563	Test Method
Mooney Viscosity _{ML(1+8)@125°C}	38	32	45	35	ASTM D1646 (mod)
Chlorine, Bromine or Bromine, Benzylic (mol%)	1.26 (Cl)	1.03 (Br)	0.47 (Br-pMS)	0.85 (Br-pMS)	ExxonMobil method
Calcium (wt%)	0.08	0.15	0.09	0.09	ExxonMobil method
Water (wt%)	0.3 max	0.3 max	0.3 max	0.3 max	ExxonMobil method
PMS Level* (wt. %) (Typical values - Internal Spec)	NA	NA	5	10	ExxonMobil method

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cial chemical bond formation at the two interfaces - the rubber - adhesive interface & the adhesive - fiber interface (additional hydrogen bonding and dipole forces are beneficial). Thirdly, since the primary function of the adhesive is to transfer load from the matrix (low modulus) to the fiber (high modulus) the interfacial (adhesive) layer must have a transitional modulus between the rubber & the fiber (typically ~ 0.5 - 1 GPa, **Figure 5**).²³⁻²⁵

Most reinforcements available commercially in the market today are sold with the adhesive treatment on the fiber (hence called dipped cord). Resorcinol formaldehyde latex (RFL) adhesives (aqueous dips) developed in 1938 by W. H. Charch & D. B. Maney (DuPont) has been the workhorse of the cord treatment industry for many decades.²⁶

Formulations vary slightly by manufacturers; however the central component of all formulations consist of a combination of resorcinol and formaldehyde (reacts to form a oligomeric resole structure shown in **Figure 6**;²⁷ in most cases, pre-condensates of the same are used and each component is used to adjust the molar ratio), a rubbery phase such as vinyl-pyridine latex and components to adjust the pH (sodium hydroxide, ammonia, ammonium hydroxide) in water.

Fibers (single cords or woven fabrics) are treated with these adhesive solutions using a dip coating process followed by drying.

Figure 5:
Illustration of the RFL treated yarn and cross linked network²³

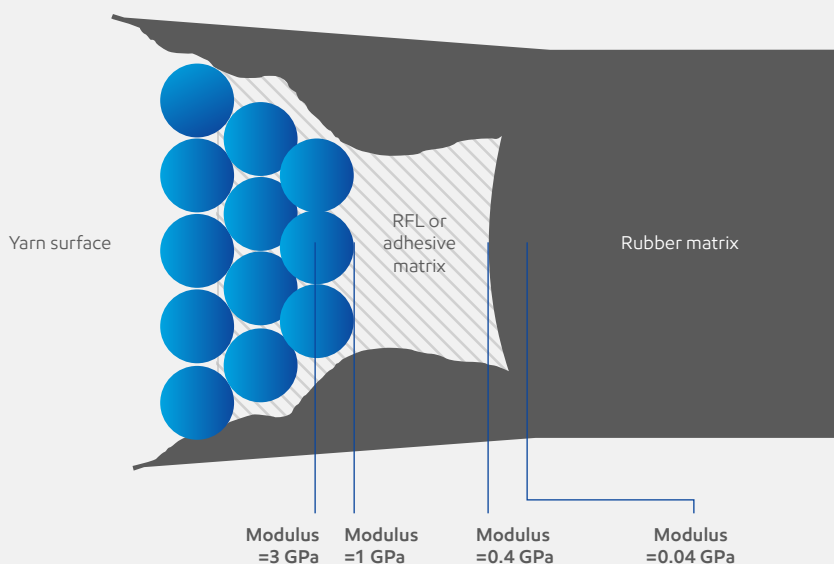
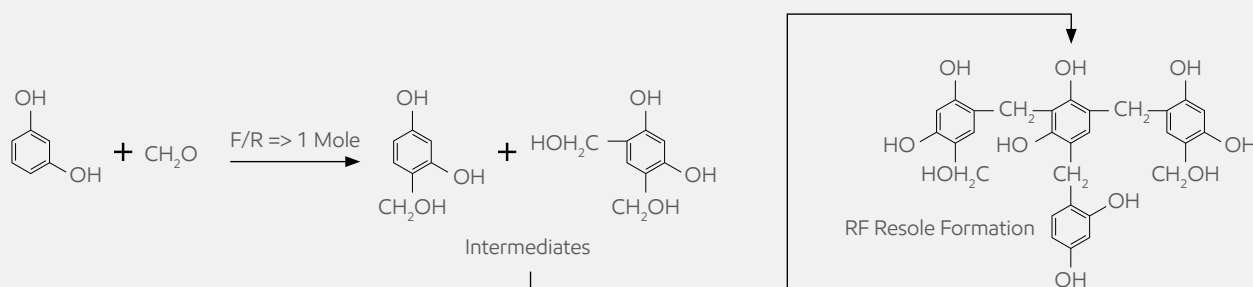


Figure 6:
Condensation reaction between resorcinol and formaldehyde to create resole - novolak structure²⁷



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During heat treatment, several reactions take place at the adhesive - fiber interface, depending on the functional groups available on the fiber. In the case of polyamide, the amide groups establish a primary chemical bond with the resoles through condensation reactions and additional hydrogen bonds, thereby increasing the adhesion at the interface (Figure 7 a, b).²⁷

Polyester fibers do not have much surface groups to bond to, hence they must be pre-treated with aromatic isocyanates which can react with carboxylic end groups creates an amide that can then bond with resoles. Additionally the isocyanates can also react with the aliphatic alcohol groups on the surface, forming urethane functionalities (Figure 8 a, b).²⁷

Figure 7:
(a) Primary chemical bond between amide group and RF resole
(b) additional hydrogen bonding²⁷

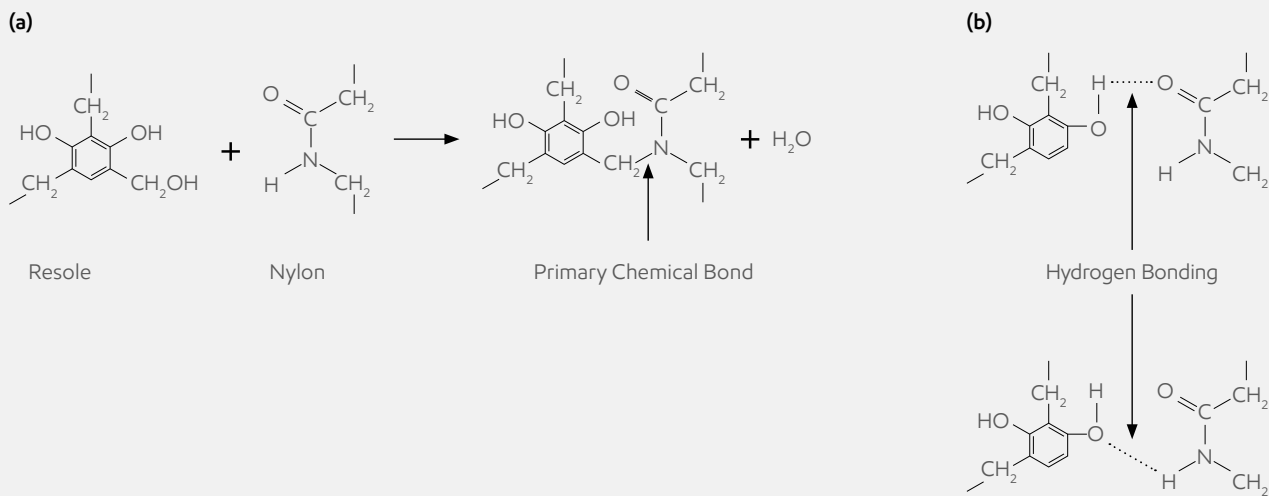
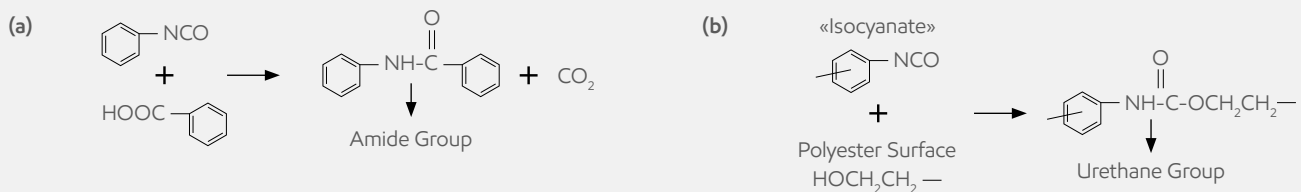


Figure 8:
(a) Amide group formation in polyester
(b) urethane group formation in polyester²⁷



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During curing of the rubber onto the adhesive treated fibers, several reactions take place at the rubber - adhesive interface.

Dehydration reaction of the resole structure to a quinone methide structure, which in turn forms a methylene bridge and/or a chroman ring link with the vinyl pyridine polymer as well as the primary rubber layer (**Figure 9 a, b**). Formation of the resole structures also increases the modulus of the vinyl pyridine thereby achieving the required translational modulus of 0.5 – 1 GPa. Sulfur diffusion from the rubber compound establishes crosslinks with the vinyl pyridine latex in the adhesive layer as well.²⁷⁻²⁹

Continuously evolving environmental regulations have driven manufacturers to innovate “greener” adhesive alternatives to RFL systems. Some of these advancements include the use of other aldehydes (except formaldehyde) along with resorcinol and vinyl pyridine latex; elimination of both resorcinol and formaldehyde via the use of water based epoxy and amine hardeners along with vinyl pyridine latex; polyacrylic acid copolymers and alkanol amine hardeners with modified styrene butadiene latex; and acrylic dispersion along with suitable cross-linkers with vinyl pyridine latex.

More recent innovation adhesive systems are based on polyurethane with resins and appropriate plasticizers/hardeners which yield the same or improved performance as the RFL systems. Since the discovery in the 1930's of the basic diisocyanate polyaddition process by Dr. Otto Bayer, polyurethanes have made their way into our everyday life. Since the 1950's, polyurethanes have been used in coatings, elastomers, rigid foams and adhesives.

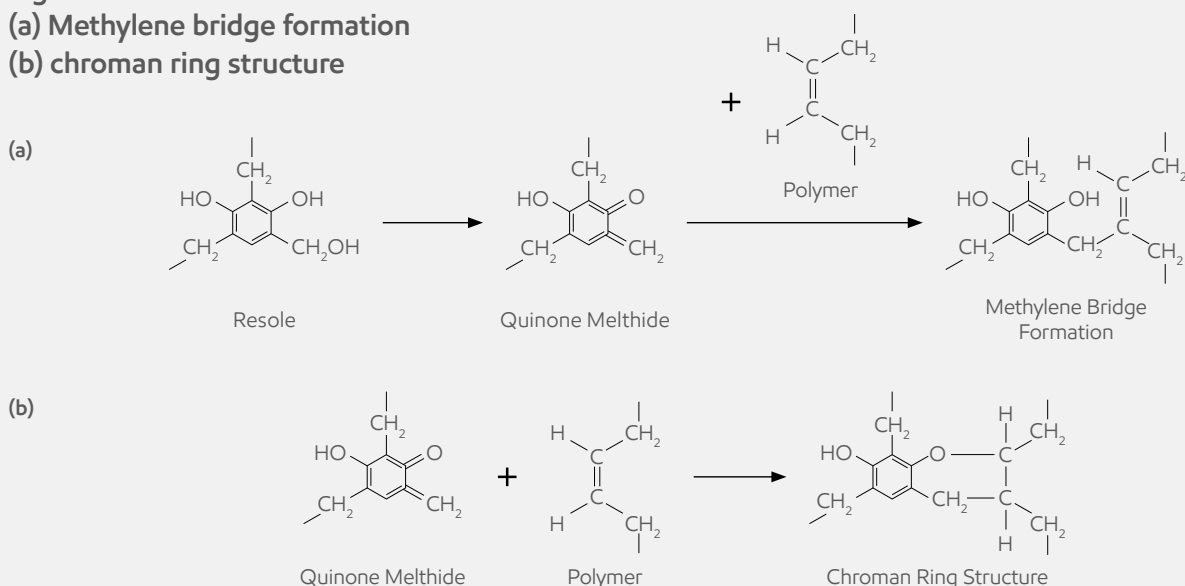
Today, polyurethanes are used in everything from coatings for our clothing, footwear and accessories to our home appliances,

furniture, insulation and roofing to our car sealants, seating, interior panels and adhesives. Beaver Manufacturing Company's line of BEAVERLOC® fibers employ proprietary isocyanate and urethane adhesive technology using polyunsaturated polymers and resins to bond during vulcanization and react with fillers and other loading materials.³⁰

The BEAVERLOC® adhesive products are also formulated to assist in precision winding, improve processing during braiding and aid with the rigors of shipping and handling. BEAVERLOC® adhesive treated fibers are designed to adhere to the wide variety of rubber compounds used in both automotive and industrial hoses and other mechanical rubber goods applications. BEAVERLOC® adhesive fibers are free flowing and process clean without tacky or sticky residue build-up. In this study we have evaluated the following: (a) adhesion of various halobutyl & Exxpro™ grades to 2 different fiber types, namely, polyvinyl alcohol and polyester fibers treated with similar adhesive systems; (b) and adhesion of various halobutyl & Exxpro™ grades to polyester fibers treated with two different adhesive systems. BEAVERLOC® 102 and BEAVERLOC® 108 fibers were designed to adhere to EPDM and other low polarity rubber compounds.

BEAVERLOC® 304 was developed particularly for butyl and halobutyl rubber compounds. BEAVERLOC® 102, 108 and 304 work well with a wide variety of rubber compounds from IIR to EPDM to CPE to ACM. All three product lines are used many applications and in particular automotive air conditioning hose.

Figure 9:
(a) Methylene bridge formation
(b) chroman ring structure



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Materials & methods

All compounds were prepared in a 4310 cc Banbury mixer. Typically, the industry uses a non-productive (NP) master batch fill factor of around ~ 70 – 80 % and a rotor speed of 40 – 60 rpm. In our studies, we tried to keep the fill factor at around ~ 70 - 75 % and a rotor speed of 70 rpm.

Conventional masterbatch densities are ~ 1.12 to 1.14 g/cc. Hence, the actual NP masterbatch weights were around 3500 grams for almost studies. Formulations used in the study are shown in **Table 2**. It should be noted that in all cases, the compound ingredients & type were kept constant, with the exception of the polymer system being studied. A 3-step mixing process was used: (Step 1) NP masterbatch (Step 2) NP masterbatch + dry bonding system (Step 3) final batch. The details of the mixing procedure are shown in **Table 3**. The total NP mixing time was approximately 5 – 7 minutes (this is the typical mix time for 2 wing mixers; for 4 wing mixers, the mix time could be as low as 3.5 minutes).

Table 2:
Formulations used in study

Ingredient	Compound Id >>>	CIIR 1066	BIIR 2222	EXXPRO™ 3035	EXXPRO™ 3563
Exxon™ Chlorobutyl 1066 rubber		100	/	/	/
Exxon™ Bromobutyl 2222 rubber		/	100	/	/
Exxpro™ 3035 specialty elastomer		/	/	100	/
Exxpro™ 3563 specialty elastomer		/	/	/	100
Carbon Black N774		65	65	65	65
Hi Sil 233		5	5	5	5
Stearic Acid		1	1	1	1
MgO (Maglite K)		0.2	0.2	0.2	0.2
Stage 2 Mixing					
Totals (Master 1) pphr		171.1	171.1	171.1	171.1
PENACOLITE Resin (B-19-SC)		2	2	2	2
Finalization					
Zinc Oxide		2	2	2w	2
Vultac 710		1.5	1.5	1.5	1.5
HMMM (CYREZ® 964; 65% Active)		3	3	3	3
Sulfur		0.5	0.5	0.5	0.5
Total pphr		180.2	180.2	180.2	180.2

Table 3:
Mixing sequence/steps

Compound mixing guideline		
1 st (NP)	0 (sec)	Kuraray Add polymer
	30 - 45 (sec)	Add black + stearic acid and oil
	~140°C	Dump (Mixing time max 5 Minute)
2 nd (Stage)	0 (sec)	Add polymer + Resorcinol Formaldehyde Resin
	~130°C	Dump (Mixing time max 3 Minute)
3 rd stage	0 (sec)	Add ½ NP + ZnO + Accelerator + ½ NP
	~ 105°C	Dump (Mixing time max 2.5 Minute)

Mixing in three stage with similar mixing conditions
Mixing Test method: ExxonMobil Test Method; Data source: Enterprise No. 9012020009)

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Please note that in all cases, the material dumping was temperature controlled and not time controlled. For the final batch, the fill factors were kept at ~ 70 - 80 % and the rotor speed was kept at 40 rpm.

For the preparation of the final batch, the masterbatch was charged to the mixer at time $t = 0$; at time, $t = 45$ seconds, the curing package was charged into the mixer. The final batch was dumped at 100 – 105°C.

The total final batch mixing times were ~ 2 – 3 minutes (this is the typical mix time for 2 wing mixers; for 4 wing mixers, the mix time could be as low as 1.5 minutes).

The final batch material dumping was also temperature controlled and not time controlled. The produced compounds were for several minutes on a 2 roll mill to prepare thick pads. Whenever required, these pads were then re-mixed on large 2 roll mills to achieve the desired thickness for certain molds.

Adhesion comparisons were made by using peel force adhesion testing. In preparing the fiber-rubber composites for evaluations, treated fibers were applied to high temperature masking tape to adjacently align fiber ends in parallel.

The tape backed fiber was laid onto a clean uncured rubber surface milled to 0.100-120" in thickness and the assemblies were cured in a heated hydraulic press at 320°F for 60 min at 50 psi.

Aluminum foil was used to provide an initial separation for the peel test and after the press cure the fiber-rubber composites were cut into 1" wide by 4" long strips.

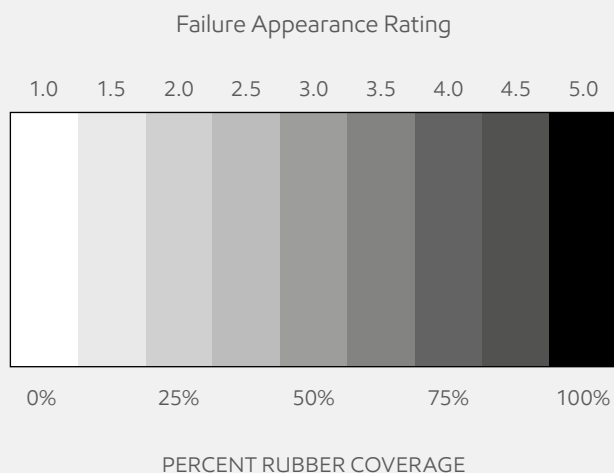
Using side action pneumatic peel force grips on a Lloyd LR5K Plus tensile tester the strips were tested with a 1" gauge length at 2 in/min jaw speed to 350% extension.

The fiber separation force was measured and in addition, a visual inspection and rating of the fiber surface appearance after pull separation was made.

The visual appearance was rated on a scale from 1.0 to 5.0 in 0.5 increments from little to no rubber coverage (1.0 rating) to complete rubber failure with no visible fiber (5.0 rating).

The visual appearance rating is related to percent rubber coverage as shown below in **Figure 10**

Figure 10:
Visual appearances for failure ratings



Results & discussion

The fibers used in the study are shown in **Table 4**. For comparison purposes, two controls (standard chlorobutyl grade CIIR 1066 - high mooney; and a standard bromobutyl grade BIIR 2222 - low mooney) and two Exxpro™ grades at the high mooney, low pMS end (Exxpro™ 3035) and low mooney, high pMS end (Exxpro™ 3563) were selected.

For properties, please refer to **Table 1**.

Table 4:
Fibers and adhesive systems used in study

Specification	Polymer	Manufacturer	Denier	Adhesive System
T-5501	PVA	Kuraray	1800/1	Beaverloc 102
T-16ST2	PET	Akra	1000/2	Beaverloc 108
T-16ST2	PET	Akra	1000/2	Beaverloc 304

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The rubber coverage of various elastomeric compounds to the fibers is shown in **Figure 11**. A quick visual examination shows that all elastomers have sufficient coverage.

The adhesion strengths of the various elastomeric compounds (halobutyl and Exxpro™) to PVA fibers is shown in **Figure 12**. Several observations can be inferred from this result.

The adhesion strengths of both the control compounds – CIIR 1066 and BIIR 2222 are statistically similar. One would expect the adhesion strengths of BIIR 2222 to be higher than CIIR 1066.

Figure 11:
Rubber coverage of various elastomer compounds on PVA fibers post peel

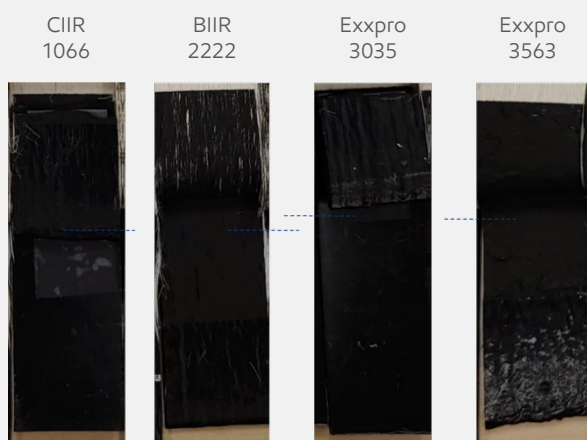
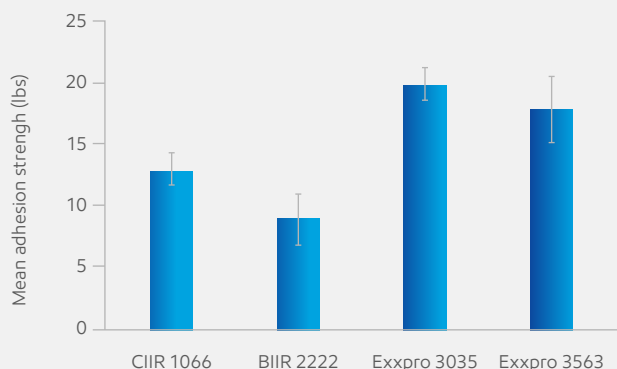


Figure 12:
Adhesion strength of various elastomer compounds to PVA fibers



This is because the C-Br bond energy is lower than the C-Cl bond energy; easier substitution reactions are facilitated with bromobutyl, thereby providing better adhesion to substrates.

However, it has to be noted that chlorobutyl has a higher molecular weight (indicated by its viscosity) which could possibly render a higher interfacial tear strength and thereby a slightly higher adhesion strength in some cases.

It is possible that both these effects cross out any possible difference in the results. Exxpro™ 3035 and CIIR 1066 have similar viscosities and molecular weights; so does Exxpro™ 3563 and BIIR 2222. One would expect Exxpro™ 3035 and 3563 to have similar interfacial tear strength and adhesion strengths as that of CIIR 1066 and BIIR 2222. However Exxpro™ 3035 and 3563 have almost 100% higher (2X) adhesion strength than CIIR 1066 and BIIR 2222.

As discussed earlier, it is easier to bond rubber compounds to fibers such as PVA and polyamides, due to the presence of a large number of surface groups available. This is clearly not the case for fibers like PET, which lacks the presence of functional groups.

Hence even if these fibers are treated with adhesive activated solutions, the adhesion strengths are low. The rubber coverage of various elastomeric compounds to PET fibers is shown in **Figure 13**.

Visual examination shows poor rubber coverage on treated fibers in the case of both chlorobutyl (CIIR 1066) and bromobutyl (BIIR 2222) based samples – the treated polyester fiber color can be clearly seen (golden yellow). In the case of Exxpro™ 3035 and 3563, it can be seen that there is sufficient rubber coverage (fibers show black coated rubber layer).

Figure 13:
Rubber coverage of various elastomer compounds on PET fibers post peel

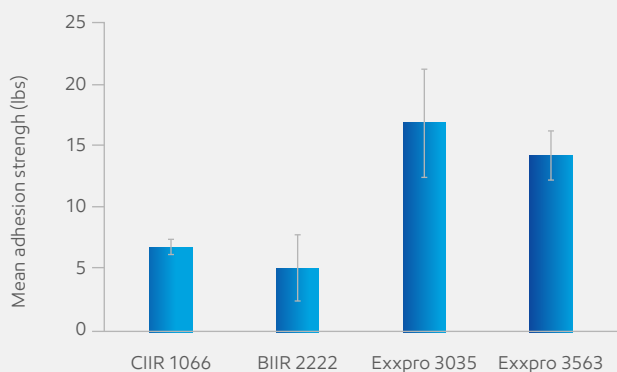


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The adhesion strengths of the various elastomeric compounds (halobutyl and Exxpro™) to adhesive activated PET fibers, with 2 different adhesive systems AS 108 and 304 is shown in **Figure 14** (AS 108 = AS 102). It can be seen that the adhesion strengths of both the control compounds – CIIR 1066 and BIIR 2222 are statistically similar, but much lower than those exhibited for PVA fibers (almost ~ 50% lower).

Interestingly, Exxpro™ 3035 and 3563 have almost 200% higher (3X) adhesion strength than CIIR 1066 and BIIR 2222. It should also be noted that unlike halobutyl compounds, Exxpro™ maintains almost similar adhesion strength levels to those seen on PVA fibers as well.

Figure 14:
Adhesion strength of various elastomer compounds to PET fibers



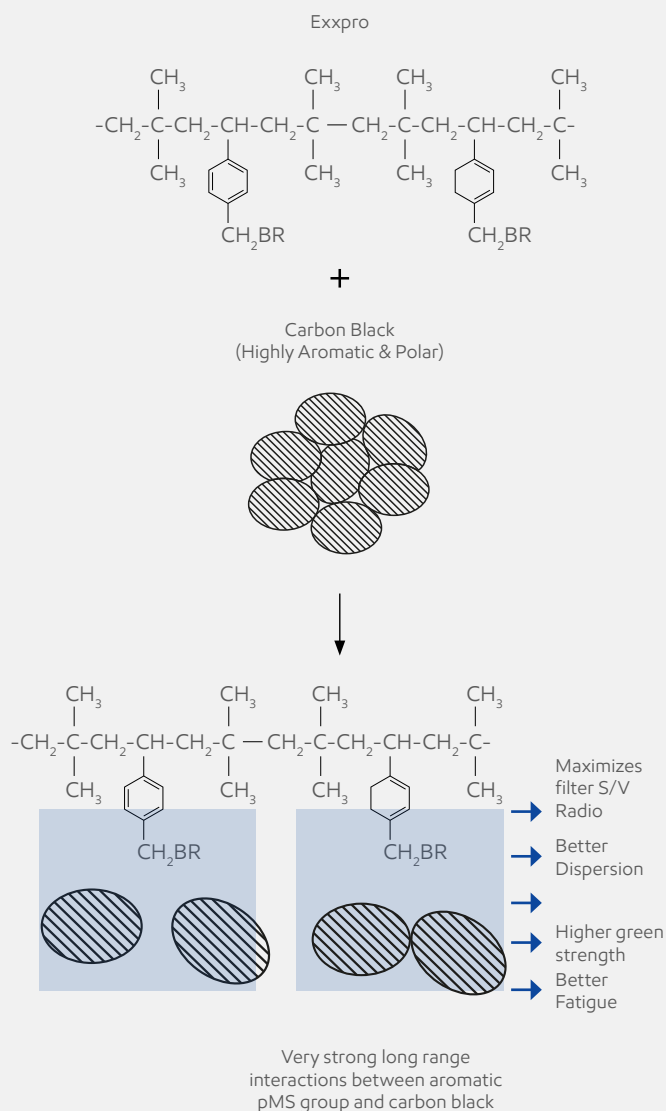
From earlier discussions it can be seen that the molecular architecture of Exxpro™ specialty elastomer is responsible for the improved gas impermeability and heat stability of Exxpro™ based compounds; specifically, the lower segmental mobility of the paramethylstyrene group (higher glass transition temperature) imparts superior impermeability and the fully saturated backbone (absence of double bonds) imparts exceptional heat stability. However, the significant difference in adhesion behavior of Exxpro™ specialty elastomers compared to conventional halobutyl polymers deserves explanation.

From **Figure 3**, it is evident that the key to improving the adhesion is by increasing the interfacial modulus between the rubber compound and adhesive system. One could envision several possible routes to achieve this. A simple way to obtain this would be to utilize a high molecular weight polymer; however high molecular weight polymers would also have a higher viscosity thereby making it more difficult to process and also lesser flow and wetting (thereby leading to very inconsistent flow patterns and variability).

Another way to obtain this is to increase filler loadings of the compound; however this could lead to fatigue issues. A creative way to achieve this would be to utilize a functional polymer with high affinity to filler to maximize the polymer filler interaction and increase interfacial modulus.

The brominated paramethylstyrene group (Br-pMS) in Exxpro™ specialty elastomer is polar and aromatic; which differentiates itself from chlorobutyl and bromobutyl. The reinforcing carbon blacks used in the mechanical rubber goods industry (N110 – N660) have a very thin layer of polycyclic aromatic hydrocarbons on its surface, which is a result of its manufacturing process. Due to surface structure and polarity, the Br-pMS group has a very high affinity (strong long range interactions) to the carbon black surface in comparison to regular halobutyl polymers (as shown in **Figure 15**).

Figure 15:
Schematic of filler polymer interaction and consequences in Exxpro™



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This phenomenon was confirmed in a separate series of work by observing the modulus increase in the compound with equally weighted increase in filler loadings (as shown in **Figure 10**). It can be seen that without any reinforcing fillers, the modulus of Exxpro™ specialty elastomers is very similar to bromobutyl.

As filler loading is increased, the compound modulus for both Exxpro™ and halobutyl increases (as shown in **Figure 16**), thereby displaying the reinforcing effect; but the increase in compound modulus of Exxpro™ based elastomers is much higher than that of bromobutyl showing the excellent filler polymer interaction.

This phenomenon is very similar to that seen in ideal composite systems, where the maximum compound modulus is obtained for those that have the best fiber and matrix adhesion (or compatibility). It should also be noted that the Br-pMS group is distributed along the main chain; in order to maximize the interaction with this group, the filler is forced to distribute itself, thereby improving dispersion (**Figure 17**).

The ability of Exxpro™ polymers to maximize interactions with the filler systems, thereby increasing the bulk and interfacial modulus could be responsible for the observed higher adhesion strength to textile based reinforcements.

As explained previously, utilizing the functional characteristics of the polymer and maximize the interaction to fillers is a much better way to increase interfacial modulus and hence maximize adhesion strengths to textile reinforcements; rather than using high molecular weight polymers or increased filler loadings which could lead to debits in processing, large variability in test results or performance debits in compound properties.

Superior compound properties of Exxpro™ specialty elastomers along with high adhesion strengths will enable hoses with reduced complexity of construction and design and exceptional performance and longevity

Conclusion

Exxpro™ polymers have several unique advantages with respect to hose applications. With respect to compound properties, it has exceptional permeability resistance in addition to heat, ozone fatigue and crack resistance when compared to halobutyl polymers.

As demonstrated in this paper, Exxpro™ specialty elastomers have higher adhesion strength and coverages to both PVA and PE fibers, as compared to halobutyl polymers. This added advantage opens up several avenues to reduce complex constructions of next generation of hoses by elimination of unwanted tie layers, which are typically used to overcome the shortcoming of halobutyl polymers. Reduced complexity of construction and design, along with superior compound properties will enable these hoses with exceptional performance and longevity.

Figure 16:
Modulus increase with filler loading – comparison between bromobutyl & Exxpro™

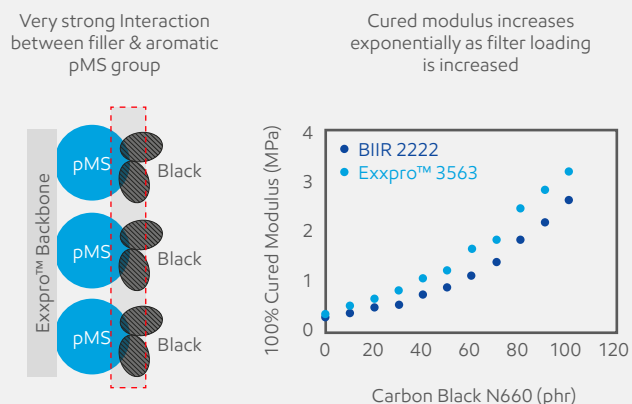
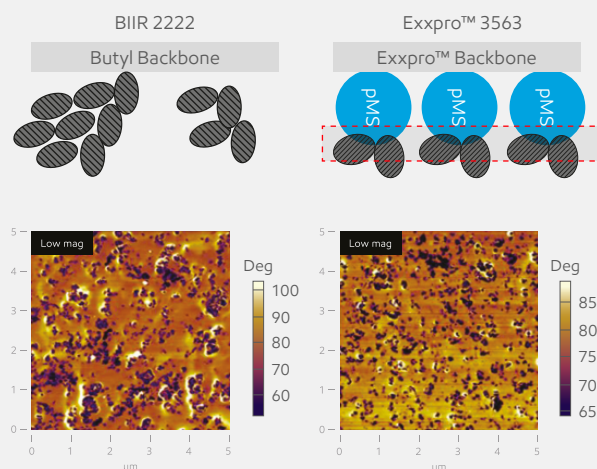


Figure 17:
Filler dispersion - comparison between bromobutyl & Exxpro™



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