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Winter tires: Tread material test innovations

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Executive summary

This paper presents the development of winter tire tread formulations using a variety of material testing techniques.

Winter tire tread compounds have to perform adequately under conditions of ice and snow. Tread compound formulation strategies encompass several factors, such as microscopic analysis, dynamic characteristics, filler interactions, traction and friction testing, geometric conditions of tread design.

We have focused on obtaining the tread formulation that will provide adequate traction under ice and snow conditions using laboratory bench testing techniques developed in-house.

We present the development of the ARDL bench top traction tester to perform testing to duplicate traction at cold temperatures to exact laboratory conditions.

Additional testing on the dynamic characteristics of the material provides insight into the tread rubber formulations. The laboratory testing provides the basis for production of winter tires and testing under ice and snow conditions by Apollo Tyres, India.

Testing tires for ice and snow performance is done using maneuverability testing and braking performance in the field.

Eight tires were received at Akron Rubber Development Laboratory. Each of the tires is subjected to complete reverse engineering reconstruction using the techniques of dynamic characterization, modulus profiling and chemical deconstruction. All tests are data analyzed to understand the design philosophy with respect to the dynamic properties as well as the raw material composition.

Physical properties

Tensile testing

Dumbbell specimens were die-cut using an ASTM D 638 Type V dumbbell die and tested per ASTM D 412. Samples were tested at 2 inches per minute (50.08 cm/minute).

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Testing was done in a controlled environmental space maintained at 50-percent relative humidity and at 70°F. Test output includes elongation to break, stress at break, modulus at 25 percent, 50 percent, 100 percent, 200 percent, 300 percent and 400-percent elongation.

Pulsed proton Nuclear Magnetic Resonance

The ARDL NMR instrument is a Bruker Minispec mq 20 MHz Pulsed Proton Unit. This instrument has been used as a chemical structure probe tool.

The solid state NMR pulsed proton instrument is used for measuring the transversal relaxation decay curves to probe the changes in the chemical structure. This in principle can be used to identify the changes in the structures with aging as well as with changes in the formulations of rubber products.

ARDL Benchtop Traction Test

The traction tester is used to compare the traction properties of the materials that are used in the tread formulations. The inputs are 65 mph speed axial load that equates to the load based on foot print analysis.

Table I. The seven tires used to conduct a winter tire survey.

ID	COUNTRY	SIZE	LOAD	SPEED
A, B	GERMANY	225/50 R16	93	H
C	GERMANY	295/30 R19	100	V
G	CANADA	P235/75R15XL	108	S
N1	USA	LT235/85R16	120 (E)	-
N2	FINLAND	LT265/75R16	119 (D)	-
B	JAPAN	235/75R16	105	Q
M	JAPAN	205/65R15	94	Q

Discussion

As stated in the introduction, complete analysis of the winter tires used in the study provides us with a good understanding of the critical components, dimensions and formulations.

The study also provides a new trac-

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Fig.1 Two tires used in the winter tire survey as identified in Table I.

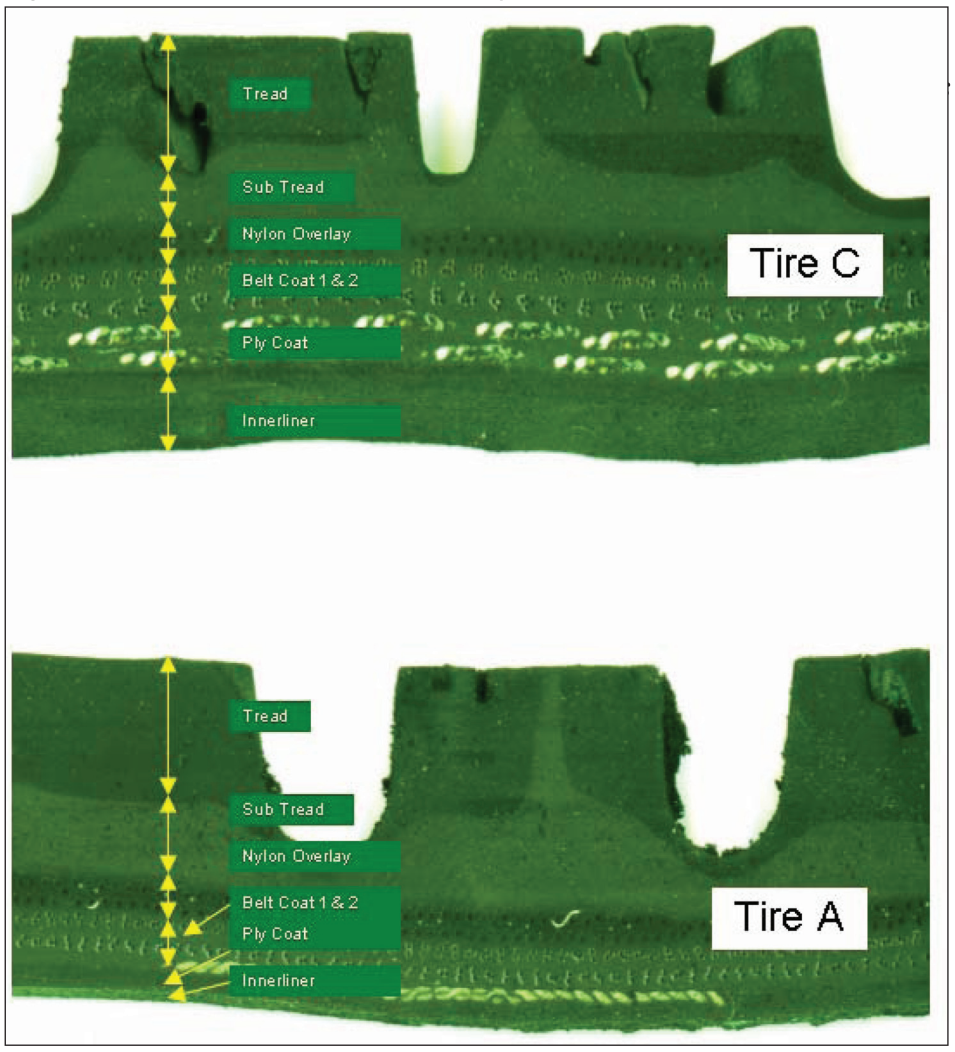

Fig 2. The remaining six tires used in the winter tire survey as per Table I.

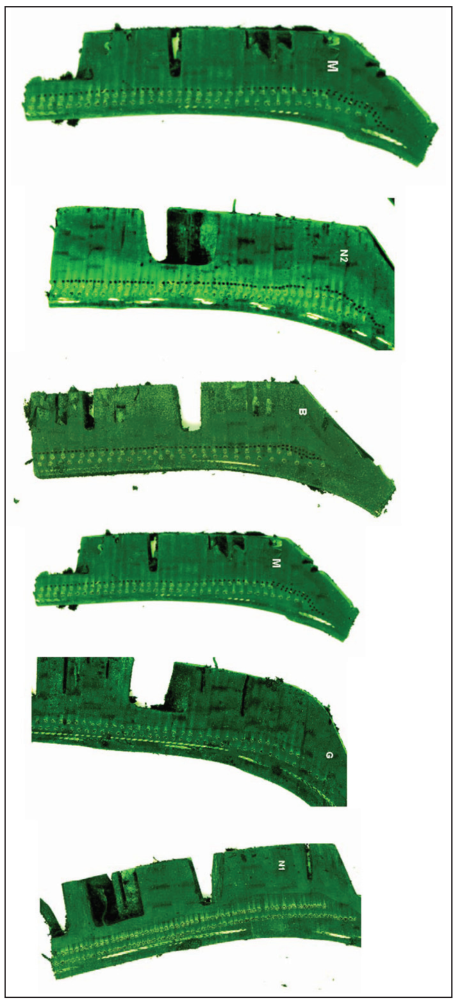

Fig 3. The dimensions of the different layers used in the tires.

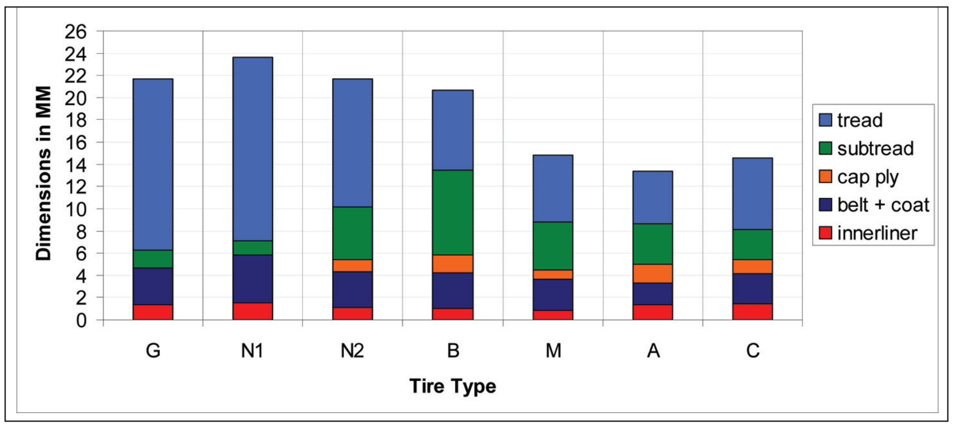

Table II. Data on three types of compounds formulated designated by letters A, B and C differentiating the level of antioxidants used 0.5, 1.25 and 2 phr. All slabs are compression molded to a uniform thickness of 40 thousandths of an inch.

Sample ID	Sample ID	PPO 2	Anti oxid ant level phr	Tem pera ture in C	Actual Aging time in days	Average Traction t = 4 to 9 seconds in lbf	Peak Tractio n force in Lbf	Sample Weight Loss in mg in 5 seconds	Traction in lbf per mg loss in weight	Average Elongatio n to break in %	Average Modulus at 100% psi 5SS/5OS	NMR %/gm at 50%
C-1-50-50	2AO-1PPO-50C-50D	1	2.00	50.00	49.00	5.12	7.86	0.05	102.32	573.36	659.69	0.6034
C3-50-50	2AO-21PPO-50C-50D	21	2.00	50.00	49.00	4.72	7.03	0.04	112.46	526.90	729.84	0.5409
C3-50-5	2AO-21PPO-50C-7D	21	2.00	50.00	6.88	5.56	7.81	0.05	103.00	561.68	610.43	0.6124
A2-70-50	.5AO-21PPO-70C-50D	21	0.50	70.00	49.00	4.27	9.42	0.08	54.11	157.22	868.26	0.4174
C2-70-50	2AO-21PPO-70C-50D	21	2.00	70.00	49.00	4.31	8.50	0.06	71.83	179.27	907.85	0.4744
C4-70-50	2AO-1PPO-50C-50D	1	2.00	70.00	49.00	4.82	10.40	0.03	166.29	339.11	970.60	0.4999
A1-50-50	.5AO-1PPO-50C-50D	1	0.50	50.00	49.00	5.21	6.49	0.03	162.76	556.30	756.81	0.5054
A3-50-50	.5AO-21PPO-50C-50D	21	0.50	50.00	49.00	4.66	10.35	0.02	194.18	496.06	803.41	0.4754

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tion test that helps with the understanding of the traction capabilities of the compounds under dynamic conditions. Tire component testing and research can be a very effective tool in developing tire durability tests as well as tire properties to help develop a winter tire with superior properties.

Winter Tire treads compounds have to perform adequately under conditions of ice and snow. Tire traction as well as the tire wear is important to a winter tire tread formulation. Understanding of tire traction and the transfer of forces on low coefficient of friction material as well as regular concrete is important for tread formulations.

Tread compound formulation strategies encompass several factors, such as microscopic analysis, dynamic characteristics, filler interactions, traction and friction testing and geometric conditions of tread design.

This task was divided into three steps: 1) winter tire survey, 2) traction and wear and 3) tire prototyping. The first step was conducted on eight tires as shown in **Table I**.

Dimensional analysis, dynamic testing and chemical deconstruction were performed to understand the existing ranges of material and sizes used in the winter tires.

All tests are data analyzed to understand the design philosophy with respect to the dynamic properties as well as the raw material composition.

Figs. 1 and **2** indicate the different layers in the tires. The different tires have varying thicknesses as well as construction characteristics depending on the usage and application. Five of the seven tires have cap ply overlays.

Detailed cross sectional microscopy is essential to accurate measurement of the thicknesses. Tire A and C indicate a subtread and tread interface that is only visible with color shaded optical microscopy images assisted with fresh cross section visual observations.

Tire A has a subtread that in the centerline has a physical connection to the road surface.

The second step was to conduct a track able traction and wear test on a laboratory materials scale. We focused on obtaining the tread formulation that will provide adequate traction under ice and snow conditions using laboratory bench testing techniques developed in house. **Figs. 4** and **5** shows the development of the ARDL Traction and Wear Tester.

A survey of the existing techniques such as Tabor abrasion ASTM 3389, DIN 53576, ISO 4649, ASTM 5963, PICO Index abrasion ASTM D2228, NBS abrasion test 1630, Slip and camber wear testing, flat track testing indicated a need for a simultaneous measurement of traction and wear on a laboratory scale.

The ARDL test equipment consists of a mechanism to apply a known axial force to the "donut" specimen against a known frictional surface at a known rotational speed. Footprint analysis of a typical tire used in service is conducted as a basis for the load.

Polished basalt tiles are used to simulate very slick icy conditions. All the test parameters are fed to a lab view program that allows accurate and high scan rate monitoring of the torsional force, axial load as well as temperature of the specimen.

The sprocket and the sample, the friction surface and the loading block, and the collection pan for wear particles are all accurately measured for weight before and after the 15-second test is complete.

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Fig. 4. The "ARDL Benchtop Traction Tester" and sample dimensions.

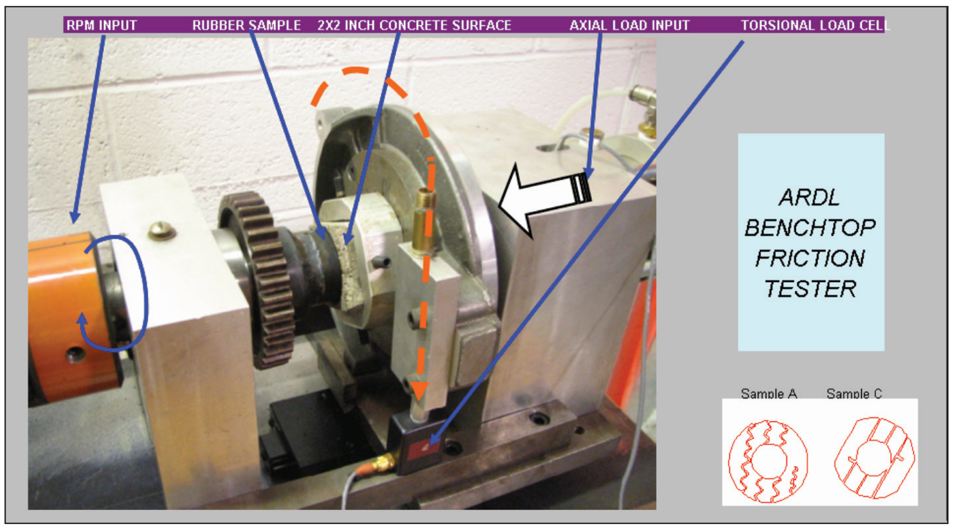


Fig 5. The comparative data between the tread formulations based on the winter survey and the two formulations developed. The data indicates an identical transfer of torque under dynamic conditions.

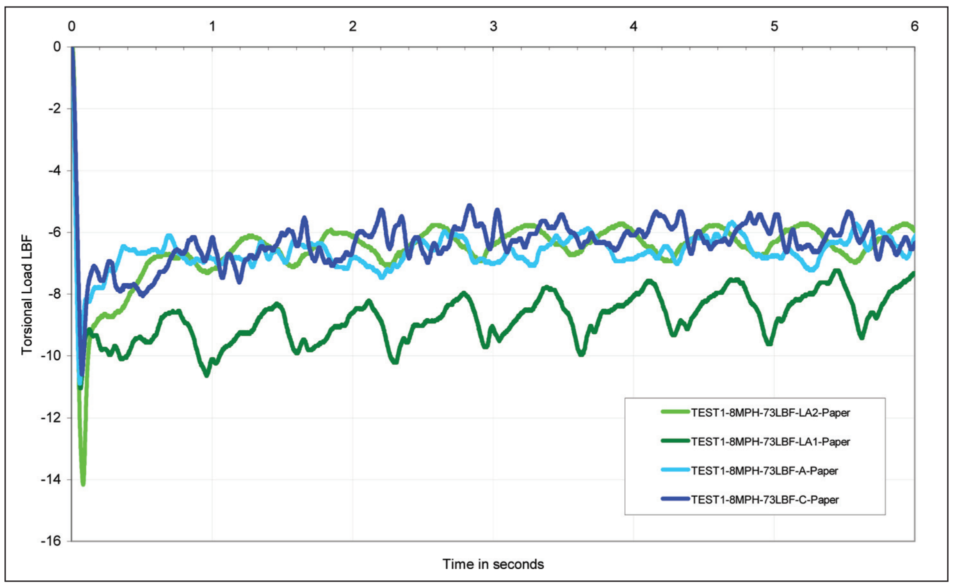


Fig 6. The data from NMR and traction transferred on the traction and wear tester. Generally the higher the crosslink density, the lower the traction.

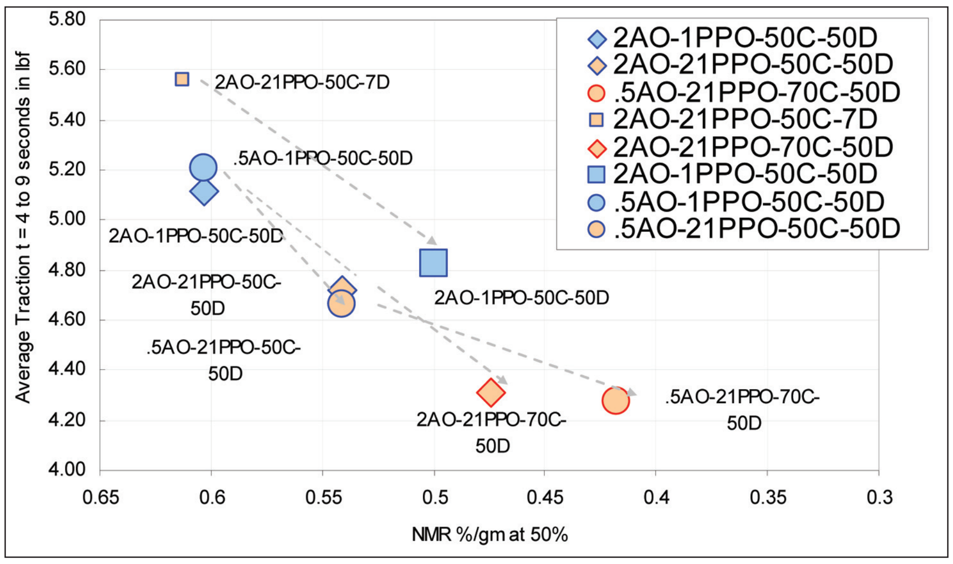
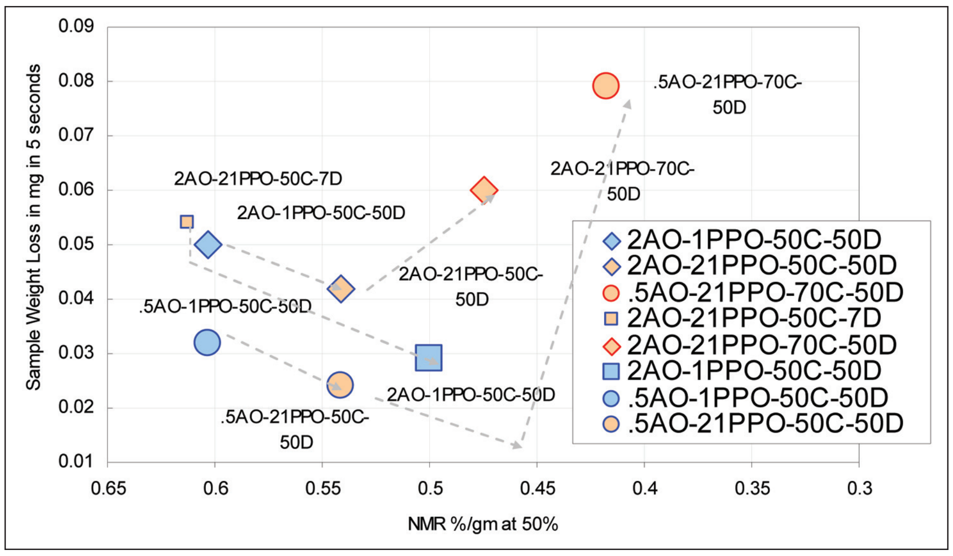


Fig 7. The simultaneous measurement of the wear rates indicates that the model compound aged at 70°C has a reversal in trend in comparison to the traction rates. This data demonstrates the capability of the test to differentiate the sample chemistry.



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Studies were conducted on compounded rubber samples aged in tire reactors under various conditions of thermo oxidative aging.

Table II shows the comparison of pulsed proton NMR data and traction. **Figs. 6** and **7** indicate the unusual phenomenon where the high temperature aged sample and a trend reversal between traction and wear compared to crosslink density.

The blue shaded symbols indicate samples aged in lower oxygen concentrations that the lower change in cross linking for these specimens also is matched by a lower drop in traction forces. The greater the thermo oxidative aging, the greater the loss of traction. The wear rate, however, depends on the temperature of aging. This might possibly be from the formation of certain sulfur linkages compared with others.

The third step of novel tire tread compound prototyping was started using the traction and wear tester. **Fig. 5** indicates comparison of the traction rates for two tires compared to two experimental tread formulations. A variety of techniques will be utilized for comparing the new formulations to existing tread formulations.

Conclusion

A new test method is under development at ARDL to measure traction forces transferred.

Testing of winter tire tread material formulations can be performed on molded model compounds as well as on samples from tires.

New winter tires are being developed with material testing

The ARDL Benchtop Traction tester can be used to measure information on traction and wear and to study wear particle morphology.

Detailed cross section analysis, dynamic testing and winter traction testing are used to develop a benchmarked winter tire formulation

The next phase of this study is to manufacture tires with this tread formulation and conduct on the road ice and snow testing for correlations

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