Publication 1532

Oil-extended natural rubber in passenger tyre treads*

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Abstract

Technological innovations, consumer preferences and government legislation have maintained the tyre industry as the biggest consumer of natural rubber. Radialization, winter tyres and fuel economy are some of the developments which have increased the consumption of natural rubber in passenger car tyres.

The advent of the all-season tyre has improved the competitiveness of NR as a tread material. Partial replacement of OESBR by OENR leads to improvements in rolling resistance and ice traction, whilst maintaining wet traction.

Overall wear resistance in winter and summer months is shown to be comparable to an all synthetic tread.

Introduction

THE REQUIREMENTS of rubber consumers are determined by many variables and changes occur over a period of time in any country. Figure 1 illustrates the changes that can occur over a period of time in any country, in this case for passenger car tyre treads in Japan.[1] Wear resistance is no longer of prime importance because of the improvements in tyre design. The requirements of low rolling resistance took effect as a result of the oil crisis and subsequent legislation to conserve energy.

Figure 2 shows the world trend on tyre research.[2] The major demands[3,4] on passenger tyre technology are:

- Safety – tyre integrity, improved handling/traction
- Economy – rolling resistance and wear
- Comfort – acoustic and mechanical damping

In the past priorities have been given to wet grip and rolling resistance, particularly a good balance of these properties. However, recently, increased public demand for all-season tyres has highlighted the need for improved ice-traction in addition to good wet traction.

This paper describes the effect of the progressive replacement of OESBR by OENR in a passenger car tyre tread with particular reference to wet and ice traction, rolling resistance and wear.

Figure 1
Changing of passenger car tread compound requirements

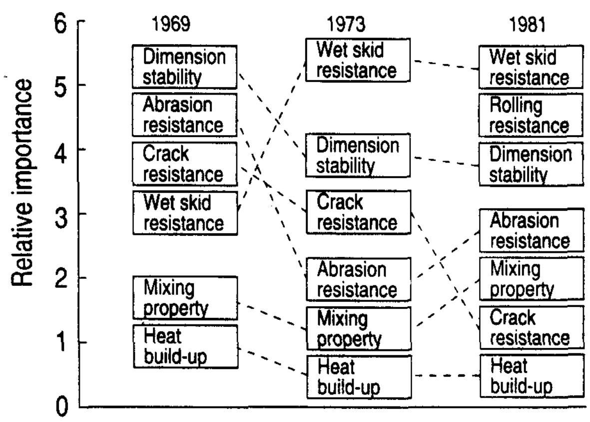

Figure 2
World trend – emphasis on tyre R&D

Fuel economy/rolling resistance
Convenience spare/no spare
High performance (improved handling/traction)
RCOT design
All-season tyres
Studless snow tyres
Super single radial truck
Minimum air loss
Run flat/self sealing systems
Integrated tyre – wheel suspension systems
Durability – long life
Down sizing
Automation/consistency/quality

Experimental

Tyre tread compounds for rolling resistance, wear and wet traction

Mixing. Mixing was carried out in a Shaw K2A Intermix (30kg) at 50rpm starting at 80°C, 100psi ram pressure and 9000l/h. Mixing cycle was as follows:

0min, add rubber, stearic acid, zinc oxide and antidegradant
0.5min, add filler and oil
2 and 4min, sweep
5.5min, discharge (temperature 125°C)

After maturation curatives were added in a final pass of 2.0min.

*Reprinted from the *Journal of Natural Rubber Research, 1994, 9(3), 143-154*

Retreading. The mixes were remilled prior to the finalization stage to ensure a Mooney viscosity of 45-50 necessary for processing on an AMF Orbitread tyre building machine (series 200C). New 165x13 steel radials, whose tread had been buffed off, were retreaded in a conventional bead to bead remoulding press at 150°C.

Rolling resistance testing. Rolling resistance was measured from the torque of the test tyres under load on a Heenan Froude test rig less the torque with the same tyre in skimming contact with the wheel [67.23" (1.71m) diameter]. Initially, all tyres were conditioned by subjection to a 60min run-in period at 50mph (80km/h) and 80% of the rated load. Inflation pressure was set at 36psi (248kPa) (cold) for the 165x13 tyres, which were run to equilibrium temperature conditions for 45min at 80% of the rated load for the two speeds of test, 30 and 50mph (48 and 80km/h). Three torque measurements per tyre were recorded at 15min intervals for each speed, and the relative ratings calculated from averaged torque readings.

Wear testing. Accelerated wear testing was carried out employing a Schallamach trailer (weight 2227 lbs) with the wheels set at a slip angle of 1.5°. For each run a test and control tyre were fitted to the trailer, and wear determined from the weight loss of the tyres after deflation. The same 150km route was used in all tests with the position of the tyres reversed for the return leg.

Wear testing was also carried out using staff cars. These tyres were dual compound, dual section, using the control compound (OESBR/BR) as one constant section on all tyres.

Wet traction testing. The tyres under test were fitted to the two-wheel Schallamach trailer. For these tests, the wheels were set at zero slip angle. A compressed air cylinder provided power to the brakes on the trailer, which were operated electrically and were independent from the brakes of the towing vehicle. The testing was carried out at the Motor Industry Research Association (MIRA) wet grip straight line braking facility where the surfaces were watered with a spray or spray and weir system. Skid path lengths were recorded after applying the brakes on the trailer using a distance counter located at the towing vehicle.

Tyre tread compounds for ice traction

Both the mixing of compounds and new tyre production were carried out in conjunction with Nivis Dack Sverige AB.

Mixing. Mixing was carried out in a No.11 Banbury at 40rpm starting at 80°C. A two stage mixing cycle was employed. Discharge temperatures for the masterbatch stage varied from 160°C (OESBR/BR) to 143°C (OENR/BR). After maturation curatives were added in a final pass of 2.0min.

Tyre production. New 185/65R15 tyres were produced of the Viking Stop 3000 winter tyre type.

Ice traction testing. Ice traction testing was carried out on a frozen lake in Northern Sweden. The traction of the tyres was assessed by timing cars fitted with the various test tyres around a fixed circuit on the frozen lake. Three identical cars were used, one a 'control' car having the same tyres fitted throughout, and the other two 'test' cars to which the various tyres to be assessed were fitted. The method of testing has the advantage that the track conditions are continuously monitored by the control tyre. The temperature of testing varied between -21°C and -11°C.

Results and discussion

All-season tyres require good grip on winter roads and summer roads, *ie* snow, ice or wet surfaces. Grip is a function of construction, tread pattern and tread compound, and this paper is concerned only with the tread compound and its effect on wet or icy surfaces and with the comparison between oil-extended natural rubber and the principal car tyre tread rubber OESBR.

In addition to grip, all-season tyres require adequate wear throughout the whole year. In fact, in cold weather natural rubber wears better than synthetic. Groove cracking resistance must also be adequate, though the advent of radial tyres reduced the problem to some extent.

That natural rubber has superior grip on ice has been well known for many years. The use of OENR in winter tyres became widespread in both Europe and North America in the 1970s.

The introduction of the all-season tyre with associated low rolling resistance requirements indicates that OENR is a viable candidate for all-season treads where improved snow and ice traction, and low rolling resistance are essential properties (Figure 3).

The replacement of OESBR by OENR and the effects of such replacements on tyre performance has been examined with specific reference to the above properties. Using an 80(OE)SBR/20BR compound as a control, OENR replaced OESBR at 25, 50, 75 and 100% levels. Carbon black and oil levels were maintained at 65 parts phr and 45 parts phr respectively (Table 1). Formulations were compounded to give equivalent tyre hardnesses. Rheological and physical property data are shown in Tables 2 and 3 respectively.

Rolling resistance. Fuel economy has become an important issue in recent years. Although tyre construction is a major factor in determining rolling resistance, the rubber compound in a tyre is also a very important consideration. For a medium-sized car at a constant speed of 80km/h, about 30% of the available mechanical energy is dissipated by the tyres[5] (Figure 4). For radial tyres, 61% of the energy loss is in the tread region[5] (Figure 5). The rubber compound used in the tread has therefore assumed great importance and particularly the tread polymer.

Figure 3
OENR in all-season passenger tyre treads

Property requirements for all-season passenger tyres

1. ***All-season traction – rain, snow ice***
2. ***Low rolling resistance***
3. ***Ride, comfort, handling***
4. ***All-season wear performance***

Table 1
Tread compounds for all-season passenger tyres

Formulation	SBR/BR 80/20	SBR/BR/NR 60/20/20	SBR/BR/NR 40/20/40	SBR/BR/NR 20/20/60	SBR/BR/NR -/20/80
SBR 1712	110	82.5	55	27.5	-
SMR 20	-	20	40	60	80
High CIS 1.4 BR	20	20	20	20	20
N-234	65	65	65	65	65
HA Oil	15	22.5	30	37.5	45
Zinc oxide	4	4	4	4	4
Stearic acid	2	2	2	2	2
IPPD	1.5	1.5	1.5	1.5	1.5
M/C wax	1.0	1.0	1.0	1.0	1.0
Sulphur	1.8	2.0	2.06	2.13	2.2
TBBS	1.2	1.2	1.26	1.33	1.4
TMTD-80	0.2	0.15	0.1	0.05	-
PVI	-	-	0.03	0.07	0.1

Table 2
Rheological properties for all-season tyres

Property	SBR/BR 80/20	SBR/BR/NR 60/20/20	SBR/BR/NR 40/20/40	SBR/BR/NR 20/20/60	SBR/BR/NR -/20/80
M_L (1+4), 100°C	65	59	53	45	42
Rheometer, 150°C, ±1° arc					
M_LdN.M	8.0	7.1	6.4	5.6	5.2
M_HdN.M	49.0	49.5	54.5	49.5	46.0
t_{s2}, min	8.5	8.5	7.5	8.5	7.5
t_{90}, min	18.0	17.0	14.5	15.5	14.0
t_{95}, min	20.0	19.5	17.0	17.0	15.5
t_{max}, min	40.0	35.0	30.0	28.0	22.0

Table 3
Physical property data for all-season tyres (cure 20mins at 150°C)

Property	SBR/BR 80/20	SBR/BR/NR 60/20/20	SBR/BR/NR 40/20/40	SBR/BR/NR 20/20/60	SBR/BR/NR -/20/80
Hardness, IRHD	60	61	61	60	59
M100, MPa	1.3	1.3	1.3	1.4	1.4
M300, MPa	6.8	6.8	7.0	7.3	7.0
TS, MPa	21.5	20.0	20.5	21.5	21.3
EB, %	630	615	638	620	626
Resilience (Dunlop), % at 23°C	45.5	46.2	47.4	50.6	54.0
Goodrich *Flexometer*, static stress 24lb, stroke 0.225, start 23°C, 30min duration					
Temp. rise, °C	84	80	76	72	67

Figure 4
Energy losses in a medium-sized car

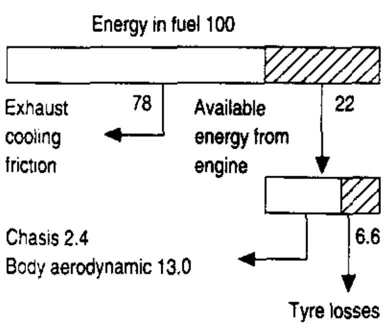

Figure 5
Distribution of energy losses in radial tyres

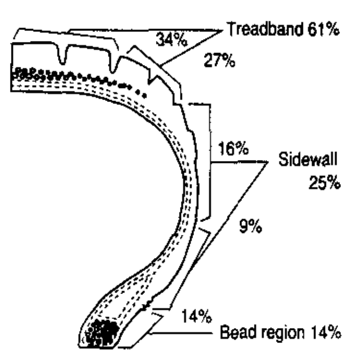

Figure 6 shows the results of rolling resistance tests conducted on our tyre test rig. Not unexpectedly, as the OENR content increases, rolling resistance decreases, by 8.0% for the 25% OENR level, 9.0% for the 50% level and 12% for the 75% level. On total substitution of the OESBR, the rolling resistance is lowered by a startling 25%. It has been estimated that this improvement could improve fuel economy by 5%.[7]

Wear. It is well known that running conditions affect the relative tyre wear rating of one rubber compound with respect to another and that changes in speed, manner of driving and ambient conditions can reverse the rankings of two compounds. Grosch showed that the effect of all these factors could be compounded into the effect of the temperature of the surface of the tyres.[8,9] Figure 7 shows the relative wear rating of the natural rubber tread compound versus an SBR compound. Tests covered a wide range of speed, ambient conditions and slip angle. Below a tyre surface temperature of about 35°C, natural rubber is superior to SBR. Above 35°C the reverse is the case. Similar behaviour is shown by oil-extended NR/BR blends tested against oil-extended SBR/BR blends, except that the temperature below which natural rubber is superior is shifted upwards to 40°C-45°C. The tyre surface temperature of 40°C is broadly equivalent in normal running cars to an ambient temperature of about 10°C-15°C. That is, under true winter conditions, OENR would be expected to wear better than OESBR.

The accelerated wear testing has the advantage that the ambient conditions can be monitored continuously during each test run. The results in Figures 8 and 9 show the relative wear ratings of the compounds during the winter and summer months. The effect of temperature is very evident. The performance of natural rubber is clearly dependent on the ambient conditions. With the exception of the 80/20, (OE)NR/BR compound the overall performance of the OENR compounds versus the synthetic control is broadly similar.

Figure 10 shows the results of the testing on staff cars. The results quoted are the overall mean ratings during the winter and summer months. The unusually mild winters

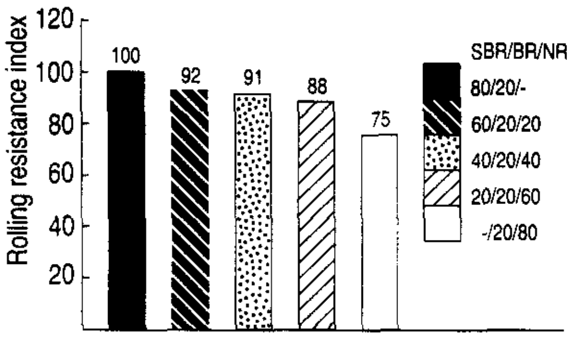

Figure 6
Rolling resistance – all-season tyres

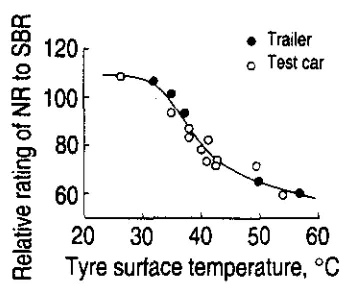

Figure 7
Relative wear rating of NR and SBR-treaded tyres as a function of the tyre surface temperature for trailer and test car

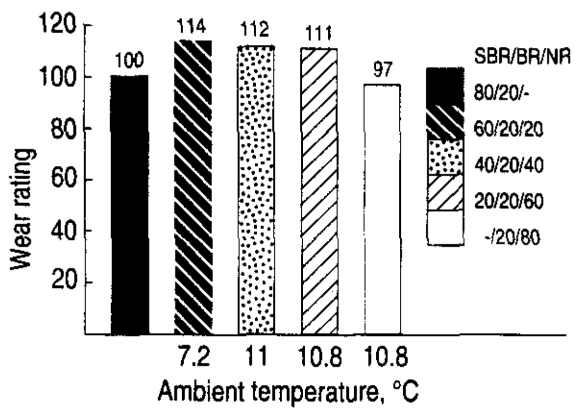

Figure 8
Wear performance in winter – all-season tyres (trailer testing)

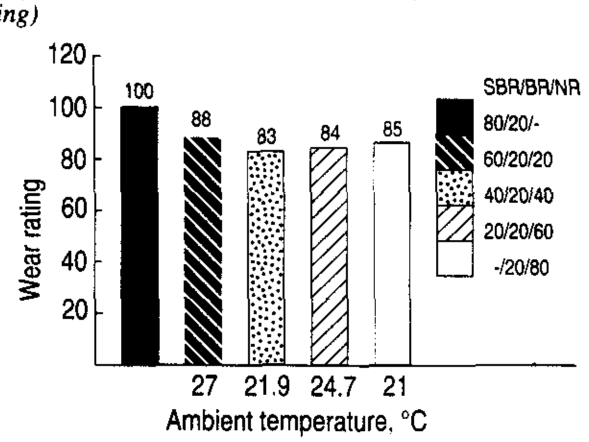

Figure 9
Wear performance in summer – all-season tyres (trailer testing)

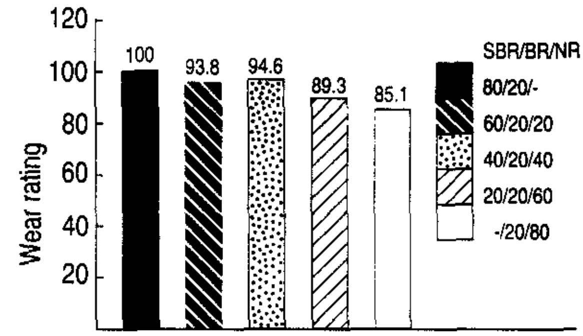

Figure 10
Wear performance – all-season tyres (staff cars)

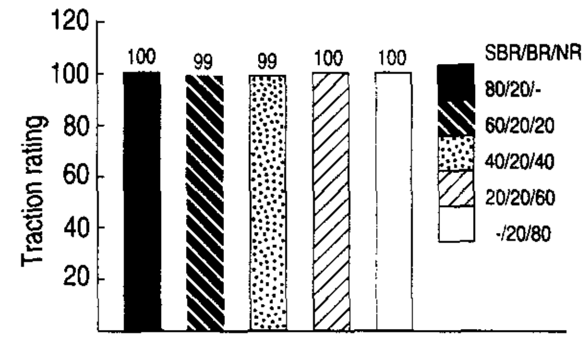

Figure 11
Wet traction – all-season compounds – Bridport pebble

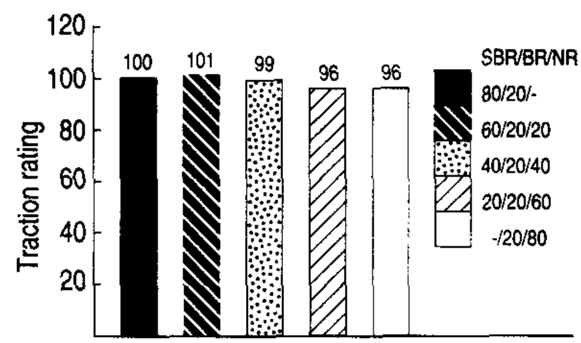

Figure 12
Wet traction – all-season compounds – Asphalt

experienced in the UK over the past few years have not been to natural rubber's advantage. Nevertheless at OENR levels of 25% and 50% there is only a small trade-off in wear. In climates of cool summers and cold winters the OENR compounds are likely to be superior.

Wet traction

It is well known that high hysteretic polymers such as SBR generally exhibit better wet traction than natural rubber. However, oil-extended natural rubber has been shown to be comparable to OESBR in wet traction.[10] Wet traction tests conducted at MIRA on Bridport pebble showed insignificant differences between any of the compounds including the OESBR/BR control (Figure 11). However, on the asphalt surface there was a trade-off in this property at the 75% and 100% OENR replacement levels (Figure 12).

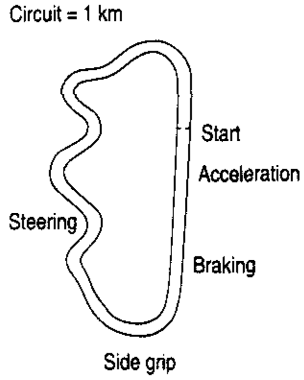

Figure 13
JOKKMOKK ice traction circuit

Table 4
Ice traction – vehicle response analysis

Performance	SBR/BR 80/20	SBR/BR/NR 60/20/20	SBR/BR/NR 40/20/40	SBR/BR/NR 20/20/60	SBR/BR/NR -/20/80	Winter tyre
Acceleration	6.0	6.0	6.5	7.5	7.5	7.0
Braking	6.0	6.5	7.0	7.0	8.0	7.0
Steering	6.0	6.5	7.0	7.0	7.5	7.0
Sidegrip	6.5	6.0	6.5	7.0	8.0	6.5
Driver analysis	Unsatisfactory	Below average	Good	Very Good	Outstanding	Good

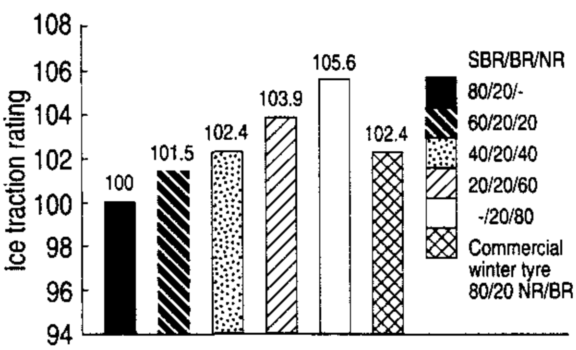

Figure 14
Ice traction – all season compounds

Ice traction

That natural rubber has better traction on ice compared to SBR is well documented. In one study non-studded OENR tyres exhibited superior ice grip to the studded OESBR tyres.[11]

The testing in Northern Sweden, largely of a confirmatory nature, was carried out on a special circuit shown in Figure 13. In addition to the 'timed circuit' testing, the test drivers each gave, independently, their own subjective assessment of the test tyres with particular reference to acceleration, braking, side-grip and steering capabilities.

Figure 14 shows the clear superiority of OENR over OESBR in the timed circuit trials. The performance of the 40/20/40 tri-blend of SBR/BR/NR was identical to that of a commercial winter tyre. In addition the driver analysis of the performance of the test tyres confirmed these results (Table 4).

Summary and discussion

Ice traction measurements have confirmed the superiority of OENR over OESBR. It has been demonstrated that the substitution of OESBR by OENR will lead to substantial improvements in fuel economy. Replacing OESBR by OENR at 25% and 50% levels leads to no adverse effect on wet traction. Some trade-off in wear is to be expected where hot summers and milder winters prevail, however in climates of cool summers and cold winters OENR will be superior.

OENR is thus confirmed as a premium material for all-season tyres.

Acknowledgements

The authors would like to thank the Board of the Malaysian Rubber Producers' Research Association for permission to publish this paper, and Nivis Tyre AB, Sweden for the manufacture of the tyres for ice traction testing. We also thank Nivis for the organization and implementation of the ice traction trials in Northern Sweden.

References

1. Komuro, K., Veda, A. and Watanabe, H., New synthetic rubbers for tire applications, Akron Rubber Group Meeting, January 25, 1985.
2. Walker, J. and Horne, S.E. Jr., History of speciality elastomers in tires, Akron Rubber Group Meeting, January 25, 1985.
3. Nordsiek, K.H., Model studies for development of an ideal tread rubber, 125th ACS Rubber Division Meeting, Indiana, May 1984, Paper 48.
4. Muller, E., Tire requirements from the car manufacturer's point of view, *Rubber World,* 1986, **194(3),** 19.
5. Krol, L.H., Synthetic rubbers: their outlook for the eighties, *Plast. Rubb. Int.,* 1981, **65**, 197.
6. Hill, S.W. Jr. and Moore, R.C., Tire rolling resistance, its effect on vehicle fuel economy and other performance areas, Akron Rubber Group Technical Seminar, October 27, 1978.
7. Schuring, D.J., The rolling loss of pneumatic tyres, *Rubb. Chem. Technol.*, 1980, **53(3)**.
8. Grosch, K.A. and Schallamach, A., The load dependence of laboratory abrasion and tyre wear, *Kautschuk Gummi Kunstoffe*, 1969, **22**, 288.
9. Grosch, K.A., The effect of tyre surface on the wear rating of tread compounds, *J. Inst. Rubb. Ind.*, 1967, **1**, 35.
10. Bateman, L., Recent developments bearing on NR's position as a tyre rubber, *Proc. Symp. Trends on Tyre Technology and Safety Standards and Implications for Rubbers*, Ottawa, 1971, September 21.
11. Grosch, K.A., Schallamach, A., Southern, E. and Swift, P.McL., Natural rubber in winter tyres and industrial tyres, *NR Technol.*, 1970. **2(9)**.