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Research Article

Study on the Relationship Between the Laboratory Abrasion Tester and Industrial Tyre Performance Predictors on Passenger Car Tyre Tread Compounds

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Abstract

Over the last few decades, the demand for improving the tyre performance parameters such as mileage, traction, handling, and rolling resistance is increasing with high pressure on tyre industries. The behavior of the tyre tread compound is very complex and difficult to correlate with the performance in the field. There are performance predictors in the tyre industry like data from Dynamic Mechanical Analyzer. The requirement for the enhanced performance of Passenger Car Radial (PCR) Tyres is increasing from car makers' side day by day. In this study, an attempt is made to relate the data between the industry tyre performance predictors with the Laboratory Abrasion Tester (LAT 100).

Keywords: Parameters; Dynamic mechanical analyzer; Passenger car radial

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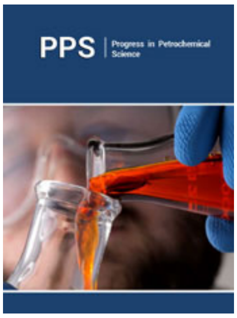

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Introduction

The tire is a highly engineered product and even with of years of research, the tyre is still not fully understood. The testing of the tyres in the field to understand the performance is costly and there is the time involved. Most of the Industry performance predictors provide little information without the scope of its validity during the real-time application. The Tread portion of the tyre is the major contributor to the abrasion, traction [1], and rolling resistance [2]. Traction, rolling resistance, and abrasion properties should be optimized to get the best performance out of the tread compound, frequently denoted as a magic triangle [3]. The essential properties of the tyre tread compound such as Abrasion, Traction, Handling, and Rolling Resistance can be measured by using Laboratory Abrasion Tester (LAT 100) [4].

Experimental

Materials

Styrene Butadiene Rubber (s-SBR) was supplied by Zeon, India Pvt. Ltd and Butadiene rubber by Lanxess International, USA. The other ingredients were N134, N234, and N339 carbon black (Birla Carbon Black India Pvt. Ltd., India), Oil of low polycyclic aromatic grade (Raj Petro, Chennai, India), Silica VN3 and 7000GR (Degussa Insilica. Ltd, India) zinc oxide (rubber grade; Zinc-o-India, India), stearic acid (Godrej Industries Ltd., India), N-phenyl-N'-(1,3-dimethylbutyl) p-phenylene-diamine (6PPD; National Organic Chemicals Industries Ltd., India), microcrystalline wax (Gujrat Paraffins Pvt. Ltd., India), 2,2,4-Trimethyl-1,2-dihydroquinoline (TMQ; NOCIL, India), soluble sulfur (Jain Chemicals Ltd., India), N-Cyclohexyl-2-benzothiazolesulfenamide (CBS, National Organic Chemicals India Ltd., India), diphenyl guanidine (DPG; National Organic Chemicals, India Ltd., India) and Pilgard PVI (NOCIL, India) used for the compound preparation. All the ingredients used for mixing in used as obtained only without any kind of further treatments.

The formulations of all the compounds used in this experiment are given in Table 1. The formulations used in this study are typical candidates for the Passenger Tyre Tread compounds for different applications such as Mileage (R1), Handling (R2), Traction (R3), and Rolling Resistance (R4). The mixing of rubber compounds was carried out in a 1.5L volume Banbury mixer (Stewart Bowling, USA) in three stages i.e master batch, repass, and final batch stage. Masterbatch mixing of compounds was carried out by setting the rotor speed at 60 Revolutions Per Minute (rpm) and the Temperature Control Unit (TCU) at 90 °C. Primarily, the rubber was added into the mixer and masticated for the 30s. Followed by carbon black, process oil, silica, zinc oxide, stearic acid, process aids, and anti-degradants were added to the mixer. The master batch was dumped after a total of 360s. The display dump temperature of the master batch compounds was found to be between 140 and 145 °C except for the batch R3 and R4 where the silanization of 120s was given in extra at 135 °C. Repass batch mixing of the compound was carried out at TCU temperature 70 °C and a rotor speed of 45rpm Final batch stage mixing of the compound was carried out at TCU temperature 70 °C and a rotor speed of 25rpm. The repass batch compound along with the curative package, viz, sulfur, CBS, DPG, and PVI were added into the mixer at 0s and dumped after 180s. The observed display dumb temperature of the final batch compound was found to be between 95-100 °C. The mixing sequence of the Master, Repass, and Final Batch is given in Table 2.

Table 1: Formulation of compounds.

Ingredients, phr[a]	R1	R2	R3	R4
SBR	100	100	80	80
BR	-	-	20	20
Carbon black[b]	70	50	-	-
Carbon black[c]	-	-	20	-
Carbon black[d]	-	80	-	10
Oil	-	20	14	-
Silica[e]	-	-	50	50
Silica[f]	-	10	-	-
Zinc oxide	4.0	2.0	3.0	3.0
6PPD[g]	3.0	1.0	2.0	2.0
Microcrystalline wax	2.5	2.5	1.5	1.5
Stearic acid	2.5	1.0	2.0	2.0
TMQ[h]	1	-	-	-
Sulfur	1.5	2.0	1.8	1.8
CBS[i]	1.5	1.5	1.5	1.5
DPG[j]	-	0.5	2.0	1.5
PVI	-	0.1	0.1	0.1

[a] phr, parts per hundred rubbers by weight.

[b] Carbon black grade N134

[c] Carbon black grade N234

[d] Carbon black grade N339

[e] Silica grade Ultrasil 7000 GR

[f] Silica grade Ultrasil VN3

[g] N,N’-diphenyl-p-phenylenediamine

[h] 2,2,4-Trimethyl-1,2-dihydroquinoline

[i] N-Cyclohexyl-2-benzothiazolesulfenamide

[j] Diphenyl guanidine.

Table 2: Mixing sequence.

Master Batch Mixing	
Mixing Speed (rpm)	60
Initial temperature (°C)	55
At 0 Second	Add Styrene Butadiene rubber/ Butadiene rubber into the Mixer
After 30 seconds	Add Dry Carbon black/Silica into the mixer

After 240 seconds	Ram sweep (20secs.)
Silica Silanization (R3&R4)	120 seconds
After completion of 360 Seconds	Dump the Masterbatch
Dump Temperature (°C)	140-145
Repass Batch Mixing	
Mixing Speed (rpm)	45
Initial temperature (°C)	60
At 0 Second	Add the Master Batch to the mixer
After completion of 180 seconds	Dump the batch
Dump Temperature (°C)	95-100
Final Batch Mixing	
Mixing Speed (rpm)	30
Initial temperature (°C)	55
At 0 Second	Add Repass Batch along with curatives (Sulfur, TBBS, and DPG) into the mixer
After completion of 180 seconds	Dump the Final batch
Dump Temperature (°C)	95 - 100

Characterization

Cure properties were studied by using Moving Die Rheometer (MDR 2000E from Alpha Technologies, USA) as per the test standard ASTM D5289. The Rheometric test was carried out at 160 °C for 30min. Mooney viscosity was carried out by using Mooney Viscometer (MV 2000E from Alpha Technologies, USA) as per ISO 289-1. Mooney viscosity test was performed at the condition ML [1+4]@100 °C. Hardness (Shore-A) measurements were performed by using Multi-Unit Hardness Tester (Gibitre Instruments, Italy) by following ISO 48-4. Tensile properties were carried out by using Universal Testing Machine (Z010 Model, Zwick Roell, Germany) according to the standard ISO 37. Rebound Resilience properties were carried out by using a Rebound Resilience Tester (Zwick Roell, Germany) according to the standard ISO 4662. Density measurements were carried out by using Densicom (Myung Ji, Korea). Dynamic Mechanical properties were carried out by using a Dynamic Mechanical Analyzer (DMA+2000 from ACOEM, France). Wear Analysis and side force measurements were carried out by using Laboratory Abrasion Tester (LAT100, VMI Holland). A photographic view of the Laboratory Abrasion Tester (LAT 100) working cabinet is shown in Figure 1. The test sample is molded at 141 °C for 60 minutes. The dimensions of the sample specimen used for testing are with an Outside Diameter (OD) of 84mm, an Inside Diameter (ID) of 35mm, and with a thickness of 18mm. The Image of the sample wheel is shown in Figure 2. R1 compound is selected as a reference against all other compounds and repeated one specimen of R1_R at the end of the measurements in each run to ensure the repeatability of the experiment. The rating of the reference sample is taken as 100, Sample with a rating higher than 100 is superior to the property, and with a less than the rating of 100 is inferior to the property concerning the reference sample.

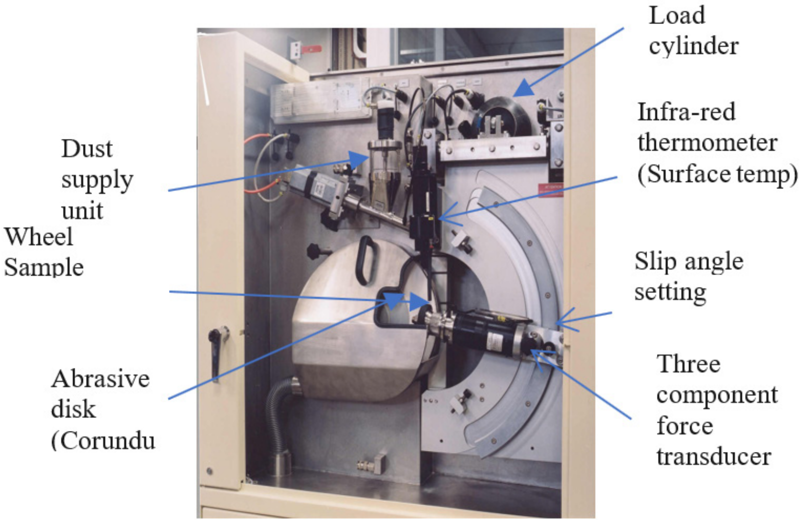

Figure 1: LAT 100 working cabinet.

Figure 2: LAT 100 sample wheel.

Results and Discussion

Table 3 illustrates the Mooney viscosities of the studied rubber compounds. It is visible from the Mooney viscosity results that all the compounds are processable and there would not be any process issues while handling these compounds under study. Table 4 illustrates the rheometric properties of the studied rubber compounds. The behavior of the compounds is similar to the typical curing of PCR Tyre Tread compounds. The physical properties of the compounds are shown in Table 5. The hardness of all the experimental compounds is maintained at 70±2 Shore A. R1 shows a high reinforcement with greater Tensile strength and Breaking Elongation. The compound with higher reinforcement has better wear characteristics [5]. Rebound Resilience properties of the studied compounds are outlined in Table 6. At 70 °C, a higher rebound resilience value indicates the elastic nature of the compound (lower hysteresis), which reflects the lower rolling resistance [6]. R4 compound showed the highest rebound resilience value in this study. Dynamic Mechanical Properties of the compounds were captured by performing a Temperature sweep from 0-70 °C at a constant frequency of 10Hz and a constant dynamic strain of 1%. Dynamic Mechanical properties studied at a Temperature of 0 °C outlined in Table 7. The higher the tangent delta, the higher the wet grip properties [7]. R3 is superior to other compounds in wet grip properties. Dynamic Mechanical properties studied at a Temperature of 30 °C outlined in Table 8. A higher tangent delta at 30 °C indicates better dry traction properties. R2 shows superior dry traction compared to other compounds. High storage modulus is the reflection of better-handling properties and wears [8]. R1 shows better wear properties and handling followed by R2.

Table 3: Mooney viscosity.

Test Parameter	R1	R2	R3	R4
Mooney Viscosity	74	70	58	62

Table 4: Rheometric properties.

Test Parameter	R1	R2	R3	R4
Minimum Torque (lb-in)	3.13	2.31	2.73	1.66
Maximum Torque (lb-in)	18.63	14.31	18.25	17.66
tS2 (min)	3.31	4.43	2.46	3.86
tC10 (min)	3.16	3.97	2.28	3.62
tC40 (min)	3.99	5.40	3.43	5.07
tC50 (min)	4.24	5.86	3.78	5.51
tC90 (min)	6.99	10.06	8.88	11.51

Table 5: Physical properties.

Test Parameter	R1	R2	R3	R4
Stress @ 100% E(MPa)	2.3	2.5	3.1	2.7
Stress @ 200% E(MPa)	5.8	6.6	8.1	6.4
Stress @ 300% E(MPa)	11.2	11.2	13.8	10.7
T.S. (MPa)	22.0	17.1	20.4	16.4
Breaking Elongation (%)	492	459	417	422
Hardness (SH-A)	70	69	70	68
Density (g/cc)	1.144	1.165	1.193	1.168

Table 6: Rebound resilience properties.

Test Parameter	R1	R2	R3	R4
RR @ RT	32.1	30.8	31.4	33.7
RR @ 70 °C (%)	46.3	43.8	55.1	59.6

Table 7: Dynamic mechanical properties @ 0 °C.

Test Parameter	R1	R2	R3	R4
Storage Modulus (MPa)	29.12	24.43	26.45	23.49
Loss Modulus (MPa)	12.37	10.73	14.36	12.46
tan delta	0.42	0.44	0.54	0.53

Table 8: Dynamic mechanical properties @ 30 °C.

Test Parameter	R1	R2	R3	R4
Storage Modulus (MPa)	18.75	15.64	15.55	13.43
Loss Modulus (MPa)	6.59	5.92	4.82	3.64
tan delta	0.35	0.38	0.31	0.27

Dynamic Mechanical properties studied at a Temperature of 70 °C outlined in Table 9. A lower tangent delta at 70 °C indicates lower rolling resistance [5]. R4 showed the lower tangent delta and agrees with the results of Rebound resilience. Glass Temperature study by DMA was carried out by running a Temperature sweep from -70-0 °C at a constant frequency of 10Hz and a constant dynamic strain of 0.25%. Dynamic Mechanical properties studied at a Temperature of -60 °C outlined in Table 10. The higher the tangent delta at -60 °C, the higher would be the mileage properties. R1 is superior to other compounds in mileage property. Glass transition temperature study data of the subjected compounds are shown in Table 11 and the tan delta vs temperature is shown in Figure 3. Wet traction of tyre tread compound is related to Glass transition temperature (Tg). The compound showing higher Tg is an indication of higher wet traction properties [9]. R3 compound shows a higher Tg compared to all other compounds. In Laboratory Abrasion Tester (LAT 100), a wear test run is performed at medium severity. condition. In this severity, Speed the of the surface wheel is maintained at 20kmph, Load at 40N, slip angle at 6°, and Corundum 60 is used as the surface. The distance of the run was set for 500m. Ratings are calculated based on averaging the four runs' data. Wear ratings are shown in Table 12. From the LAT 100 Experimentation, R1 shows superior abrasion resistance compared to other compounds. Optical microscopic images in (Figure 4) show that the R1 compound has a finer pattern and thinner ridges compared to other compounds. The mechanism of wear is indicated by the formation of ridges [10] and the pattern formation is already well-known [11]. From the mechanical properties and the low-temperature Dynamic mechanical properties, it was observed that the R1 compound shows a higher reinforcement. This higher reinforcement leads to better abrasion resistance. Grosch et. al studied the filler loading effect on abrasion resistance and established that higher filler loading leads to superior abrasion resistance [12].

Table 9: Dynamic mechanical properties @ 70 °C.

Test Parameter	R1	R2	R3	R4
Storage Modulus (MPa)	10.56	8.89	10.05	8.94
Loss Modulus (MPa)	2.49	2.34	1.67	1.24
tan delta	0.24	0.26	0.17	0.14

Table 10: Dynamic mechanical properties @ -60 °C.

Test Parameter	R1	R2	R3	R4
Storage Modulus (MPa)	1138	2150	2245	2131
Loss Modulus (MPa)	112	145	185	180
tan delta	0.10	0.07	0.08	0.08

Table 11: Glass transition temperature.

Test Parameter	R1	R2	R3	R4
Glass Transition Temperature (Tg)	-12	-27	-1	-2

Table 12: Wear rating by LAT 100.

Test Parameter	R1	R2	R3	R4	R1_R
Wear Rating	100	48	42	43	100

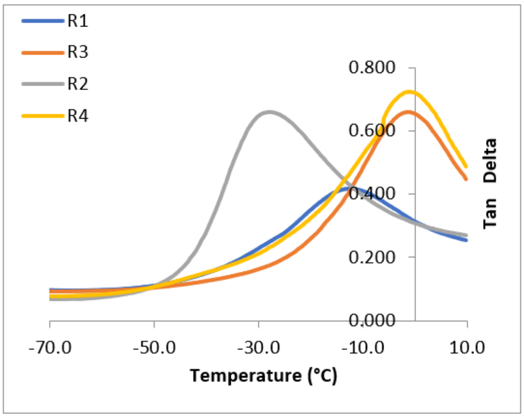

Figure 3: Tan delta Vs temperature.

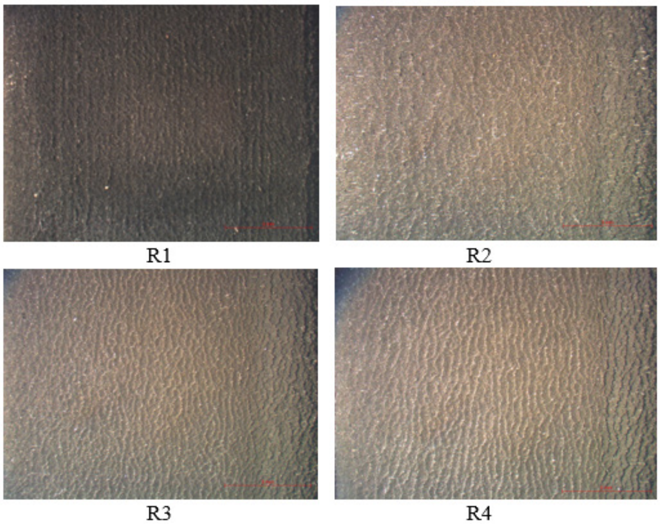

Figure 4: Optical microscopic images.

For the Dry Traction study, the Test condition chosen was the same as the condition used for wear analysis. The Side Force Coefficient (SFC) measured against the applied force is captured by using a three-point force transducer. Ratings are calculated based on averaging the four runs' data. SFC ratings are shown in Table 13. R3 compound is superior to other compounds in dry traction study and agrees with the Dynamic mechanical analysis for the handling study, the Speed of the surface wheel is maintained at 2.1kmph, Load at 75N, slip angle at a range of -3 to 33°, and Corundum 180 is used as a surface. The Side Force Coefficient (SFC) measured against the applied force is captured by using a three-point force transducer. Ratings are calculated based on average conditions. SFC ratings are shown in Table 14. R2 compound shows better handling properties compared to other compounds, whereas R2 was the second-best compound in the Dynamic mechanical study. For the wet traction study, the Speed of the surface wheel runs at a range of 0.06–6.0kmph, Load at 75N, slip angle at 15°, Temperature range at -2 to 40 °C, and Corundum 180 is used as a surface. The Side Force Coefficient (SFC) measured against the applied force is captured by using a three-point force transducer. Ratings are calculated based on average conditions. SFC ratings are shown in Table 15. R3 compound is superior to other compounds in wet traction study and supports the Dynamic mechanical properties.

Table 13: SFC rating by LAT 100 (dry traction).

Test Parameter	R1	R2	R3	R4	R1_R
SFC Rating	100	100	102	97	100

Table 14: SFC rating by LAT 100 (handling).

Test Parameter	R1	R2	R3	R4	R1_R
SFC Rating	100	102	101	99	101

Table 15: SFC rating by LAT 100 (wet traction).

Test Parameter	R1	R2	R3	R4	R1_R
SFC Rating	100	106	116	115	101

Conclusion

Laboratory Abrasion Tester is a machine designed to give a quick solution to the time taking field evaluation. It provides a good correlation with the industry tyre performance predictors in measuring wear characteristics, traction, and handling. The control parameters of LAT 100 are closer to the field and give a relatable prediction of the performance of the PCR Tread compounds.

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