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Experimental Investigation on Physico Mechanical and Cure Characteristics of Silica Reinforced SBR Tire Tread Component

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ABSTRACT: The ring-shaped component termed tire plays a vital role in the propulsion of a vehicle. It provides the required traction on the surface of the road to ascertain safe journey for the rider. The present work deals with the tire tread component, the one which wear more due to interaction with the terrain and the heat buildup on it. The tread is made up of styrene butadiene rubber (SBR 1502) of non-oil type along with butadiene rubber (BR). These polymers are taken in 80:20 proportions to incorporate the mechanical advantage of BR. The other ingredients include reinforcing material (silica, and carbon black in varying proportions), accelerator (DPG, and QP), anti-oxidants (TMG), vulcanizing agent (Sulphur), stearic acid, etc. The physico – mechanical properties like hardness, and tensile strength were evaluated for different variation of silica content of 10 to 90 phr (parts per hundreds of rubber) at the outset of reduced carbon black content. The silica was in white in colour and provides strength to the rubber material to withstand the abrasion during interaction with the surface of the road and also reduces the carcinogenic pollutants. The hardness value of silica reinforced tread shows higher value than carbon black incorporated component. This is because of higher interaction of rubber and filler particles and also the filler dispersion characteristics. The tensile strength, cure characteristics and specific gravity of the mixes made up of different proportions of carbon black and silica was evaluated and discussed in the present work. The proportion of 20:80 carbon black and silica were found to have better performance and can be taken for formulation of SBR – BR tire tread compound.

KEYWORD: SBR Tire Tread, Silica reinforcement, Carbon Black, Lemon Peel Oil.

I. INTRODUCTION

It is possible to quantify the modified silica and elastomers interactions predicted by thermogravimetry study Perkin Elmer TGAT analyzer with heating rate of 20c/min experimental analysis was carried out with a Carlo erbu instrument. The thermodynamic study indicates that a hardness decreases of hydrophilic character of silica surface is obtained.[1] SBR matrix and carbon black wear used a two-roll mill subjected to 160c under 10MPa pressure optimum curing time. After the tests are conducted, for investigation of the wear behavior at both conditions, the experiment called out by means of commercial block on ring friction testing machine. The tribological test were conducted on a commercial block friction testing machine. The friction is increases with increase in load at dry condition and decreases at wet condition.[2] Rubber components with the formulation were prepared using an internal mixer pretender plastic order 3508 by a 3-step mixing technique. Hardness, strength and wet grip efficiency were impaired whereas rolling resistance was improved with increasing BR properties. Increase in BR content, however provide the breed with the improved rolling resistance.[3] The silica silane filler system in passenger car tread components, instead of traditionally used carbon black. The silica influences both devulcanization and devulcanization. This process aims to reuse of the valuable material for new products. Modulus and tensile strength and elongation at break wear determined with Zwick tensile tester using dumbbell shaped samples. GTR contains an increasing amount of silica over recent times. As a result of the progressive use of these filler model tread components to improve tire performance. [4] The silica oxide and the aluminum oxide used as reinforced fillers. The different level of Phr composition is added and performed the test regarding to that of tensile test is performed by using UTM. Abrasive wear rate is reduced by addition aluminum oxide and silica oxide filler at 25Phr has tensile strength and modulus of rigidity as 67MPa,13MPa respectively [5] The vulcanizate structures at different cure temperature were categorized SSRN, CBBR are qualified. The analysis of the



vulcanizate structures revealed that CBBR, SSRN and CCDS all showed decreasing trends with increasing cure temperature.[6] The situ silica generated in NR solution using Sol gel technique. The rubber compound was prepared by conventional mixing on a two roll mills. The 65Phr silica content used in the starting of the test and the investigation takes place in various Phr composition. The hardness of the in-situ silica filled samples increased with increasing in situ silica contents.[7] A new mixing technique to improve the processability and dispersion of silica for enhanced abrasion resistance, mechanical properties, dynamic viscosity.[8] Orange peel oil and lemon peel oil are extracted from the peels of orange fruits and lemon fruits through any one of the following methods cold pressing method or steam distillation method. In cold pressed method, [9] the peels were shredded to a considerable range size of 0.3 – 2.0 cm. The extraction process is carried out at ambient temperature. The yields of the extraction are then centrifuged for a time period of 45 minutes at the standard temperature of 28° C to 30 ° C at a speed of 3000 r.p.m. After the centrifugation of the yield, it is separated in a separator and dried over anhydrous sodium sulphate to obtain the final yield of peel oil. In the steam distillation method, the heat source is used to extract oil from the shredded peels and later allowed to condense to form the desired output oil.

Incorporation of such natural bio-oil is termed under Green Engineering or Technology. The green technology replaces the existing carbon content by silica content. Silica content is the major non-black reinforcing filler widely available in the market and is replenishable. The main mechanical advantage of using silica over carbon black is that it possesses higher tear strength, better abrasion resistance and lower rolling resistance . The silica is widely available in white in color, but it can be produced in colored article. The other major reasons for incorporating silica content are that it has good filler dispersion and highly interactive with rubber compounds. The study on use of rice husk , revealed that the silica surface is highly dense with the presence of siloxane and silanol groups thus making the silica filler polar in nature.

The tire tread components mainly consist of Styrene Butadiene Rubber (SBR), this hydrocarbon rubber has the problem of dispersion with silica due to the filler particle size which are highly aggregated because of greater filler interactions and reduction in mechanical properties of the tire tread compounds. This is taken care by introducing the coupling agent for silica, the silane which enhances the interaction between silica and the rubber matrix. In the past decade, silica filler becomes an active, better performing additive for rubber, with the concern over the dispersion of silica particles for improvement in the rubber matrices . The reinforcing filler (silica), coupling agent (silane) along with the processing oil (orange peel and lemon peel oil) tries to fill the research gap existing due to highly carcinogenic aromatic oil. The physical and chemical properties of the lemon peel and orange peel oils

II. EXPERIMENTAL WORK

2.1. MATERIALS:

The composition of rubber compound formulation is SBR 1502 (Non – oil Styrene Butadiene Rubber) has Mooney Viscosity of 48, 0.954 density and BR (Butadiene Rubber) has Mooney Viscosity of 45 and 0.91 density were procured from Bhargave

Rubber Private Limited, Madurai, Tamilnadu, India. The reinforcing filler used in this experiment is silica (particle size 63 µm,) and silane is used as the coupling agent. The N330 HAF carbon black of 1.8 density, CBS (Cyclohexyl Benzothiazole Sulphenamide), DPG (Diphenyl Guanidine), TQ (Trimethyl Quinoline), Sulphur and processing oil such as lemon peel oil, orange peel oil are obtained from Katyani Exports, India and aromatic oil (controlling component) from Bhargave Rubber Private Limited are used in this experimental work.



Figure 1. Styrene Butadiene Rubber 1502



Figure 2. Butadiene Rubber



Figure3 . Lemon Peel Oil



Figure 4. Silicareinforcing material

2.2.PREPARATION OF LEMON PEEL OIL:

The lemon peel oil prepared through steam distillation method is obtained from Katyani Exports, India and its physical and chemical properties ^[10] are summarized below in table.1

Table 1. Physical and chemical properties of Lemon peel oil

Specifications	Lemon peel oil
Specific gravity at 20°C	0.85
Refractive index at 25°C	1.474
Viscosity at 28°C, cP	5.9
Acid value	0.31 mg / 100 g of oil
Peroxide value, meq/kg	3.2

The principal components found in lemon peel oil are as follows, γ – terpinene, terpinolene, d – limonene. Its chemical structure is represented in Figure 5. The extracted peel oil is found as a suitable alternative for conventional aromatic oil.

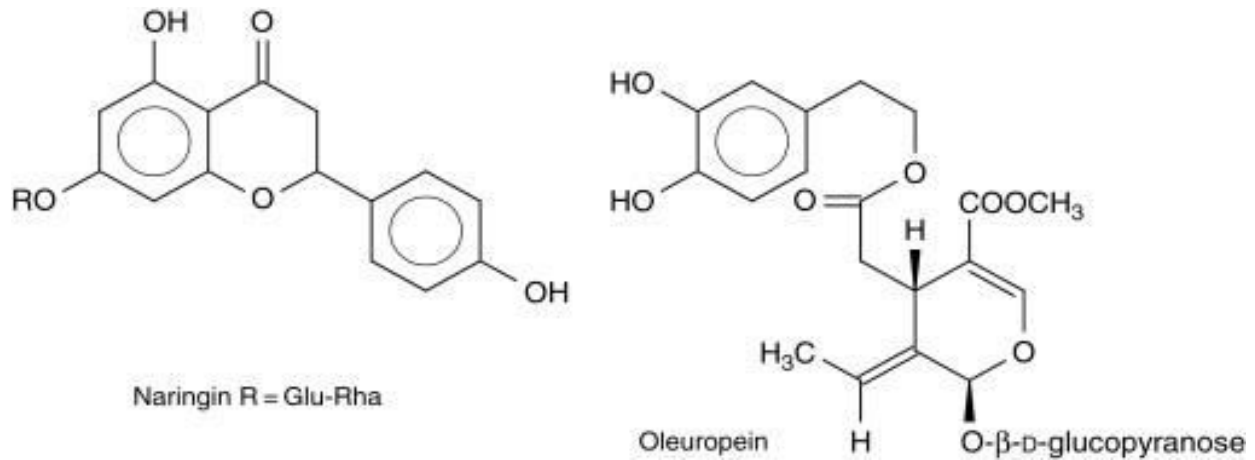


Figure 5. Chemical Structure of Lemon Peel oil

2.3. COMPOUND FORMULATION

The compound formulation was carried out by incorporating carbon black and silica in the following proportions as shown in Table 2.

Table 2. Compound Formulation with Carbon black and Silica

	Reference	CB ↑ SI ↓				CB ↔ SI				CB ↓ SI ↑
Compound No	1	2	3	4	5	6	7	8	9	10
SBR 1502	80	80	80	80	80	80	80	80	80	80
BR	20	20	20	20	20	20	20	20	20	20
Carbon Blank(N330)	100	90	80	70	60	50	40	30	20	10
Silica	0	10	20	30	40	50	60	70	80	90
Silane	0	0.8	1.6	2.4	3.2	4	4.8	5.6	6.4	7.2
Zinc Oxide	3	3	3	3	3	3	3	3	3	3
Stectric Oxide	2	2	2	2	2	2	2	2	2	2
CBS	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
DPG	1	1	1	1	1	1	1	1	1	1
TQ	1	1	1	1	1	1	1	1	1	1
Sulphur	2	2	2	2	2	2	2	2	2	2
Lemon Peel Oil	10	10	10	10	10	10	10	10	10	10

2.4. PREPARATION OF RUBBER MATRIX

The formulation for rubber compound preparation as a base formulation is shown in the table. In this formulation atomic oil is the controlling component. The tire tread was prepared through a three-step mixing method. In the first step, the SBR matrix, fillers and silane supported on a carbon black, when necessary were mixed at 60 rpm and the temperature at 111°C for 6 minutes. In the second step Zinc oxide, stearic acid were added to the mixture previously



prepared by mixing for 4 min at 60rpm at 100°C. In the final step, Sulphur and CBS were added at 60 rpm, 4 min at 67°C to prevent pre cross linking.

2.5. CURE CHARACTERIZATION:

The cure characteristic of the formulation is determined according to ASTM D2084 – 01 using Moving Die Rheometer made by Alpha Technologies. The measurements are carried out at 160 ± 1 °C. The ML (minimum torque), MH (maximum torque), T_{c90} (optimum cure time), and T_{s2} (scorch time) are obtained through the experimentation which is done for 30 minutes of duration and data are tabulated in Table 3.

2.6. PHYSICO-MECHANICAL PROPERTIES

The physico – mechanical properties like hardness of the vulcanizates are measured using Wallace Shore A hardness tester. The hardness of the vulcanizates are found using Wallace Shore A hardness tester satisfying the ASTM D – 2440 - 05. The tensile property of the SBR 1502 vulcanizates are evaluated following the standards of ASTM D 412 – 06 A on Ektron TS2000 equipment and the specimen of dumb bell shaped fabricated and subjected to test. The width and average thickness of the material was around 6 mm and 2.21 mm respectively. Five measurements were performed for each sample. The properties were determined for different proportions of carbon black and silica.

III. RESULTS AND DISCUSSION

3.1. CURE CHARACTERISTICS OF SILICA REINFORCED SBR TIRE TREAD

The cure characteristics curves for different mixes of carbon black and silica incorporated SBR 1502 – BR formulations are shown in Figure 9 and the cure characteristics are illustrated in Table 3.

The cure characteristics curve indicates the time taken by the filler materials to get dispersed in the rubber matrix. The carbon black content was reduced from 100 phr for which the cure time was found to be 256 seconds. The cross linking time taken for silica constituents increases. For a slight increase in silica from 0 phr to 10 phr the cure time was found to be 364 seconds. With increase in the silica content the cure time was found high for 40 phr this is because of time taken for the reinforcing filler materials to get dispersed in the rubber matrix. Beyond 40 phr of silica content, the cure time gradually reduced to 272 seconds, the reason is that the white powder form of silica dispersed quickly in the composition with decrease in the content of carbon black.

Table 3 CURE CHARACTERISTICS OF SILICA REINFORCED SBR TIRE TREAD

Mix No.	Constituents (Carbon black : Silica)	Minimum Torque (dNm)	Maximum Torque (dNm)	Delta Torque (dNm)	Scorch time T _{s2} (in sec)	Optimum cure time T ₉₀ (in sec)
1	100 : 0	5.61	30.68	25.07	45.03	256.2
2	90:10	4.47	29.03	24.56	50.14	364.9
3	80:20	4.98	28.85	23.87	54.11	305.5
4	70:30	5.67	32.42	26.75	58.06	397.7
5	60:40	7.04	33.98	26.94	63.98	415.4
6	50:50	7.44	33.73	26.29	68.56	352.1
7	40:60	6.85	30.30	23.45	73.91	272.3
8	30:70	11.11	36.09	24.98	89.51	301.4
9	20:80	12.03	34.73	22.7	95.55	312.1
10	10:90	17.61	38.73	21.12	111.26	396.9

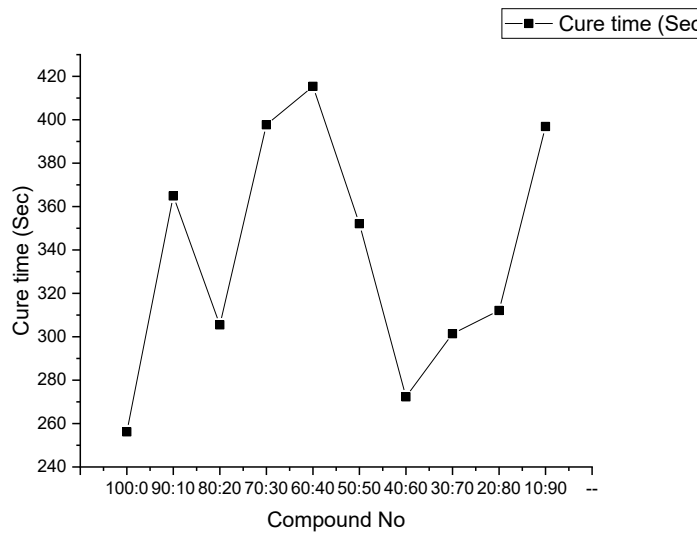


Figure 6 Cure time curve

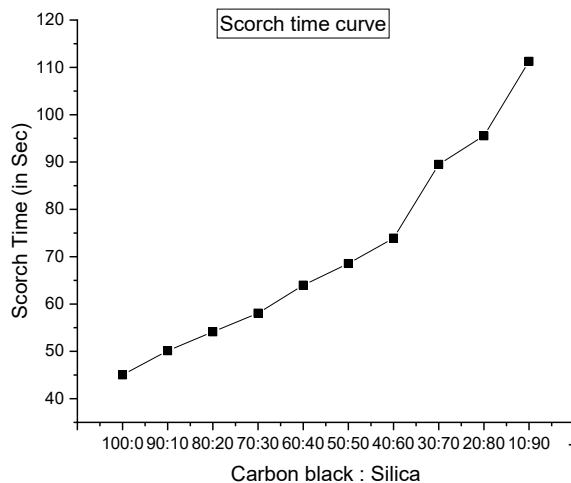


Figure 7 Scorch time curve

The scorch time is the time taken for onset of vulcanization at a temperature of 160°C. The controlling component of carbon black 100 phr shows a minimum time period for onset of vulcanization, this is due to the interaction of high abrasion furnace carbon black with rubber matrix. While the silica needs more time to get dispersed in the matrix to provide the required strength and hardness.

3.2.TENSILE STRENGTH OF SILICA REINFORCED SBR TIRE TREAD

The tensile strength of the silica reinforced SBR – BR tire tread component was evaluated for different proportions of carbon black and silica. The range of phr of filler material was from 0 phr to 90 phr of silica, while the controlling component carbon black was gradually reduced from 100 phr to 10 phr. The results of the tensile test were tabulated in Table 4.



Table 4 Tensile Strength of silica reinforced SBR tire tread component

Significantly better tensile strength & elongation at break for the 20:80 sample

Batch No	Oil content (phr)	Tensile strength (MPa)	Elongation at break (%)	100% Modulus (MPa)
1	100 : 0	10.02	137.27	6.88
2	90:10	10.97	165.84	5.85
3	80:20	11.71	169.74	6.25
4	70:30	11.52	149.06	6.87
5	60:40	10.02	142.69	6.62
6	50:50	11.92	185.33	5.84
7	40:60	13.26	219.16	5.01
8	30:70	12.26	202.64	5.28
9	20:80	11.93	216.90	4.60
10	10:90	13.16	223.96	5.02

compared to the reference sample made up of 100:0 proportion of carbon black and silica. The rubber compound with increasing silica content samples is found to be stronger and more resilient than the reference sample.

The tensile strength of the controlling component carbon black 100 phr is around 10 MPa, while the increase in silica content increases the tensile strength of the vulcanizates, but 60:40 proportion resembles the strength obtained by the controlling component

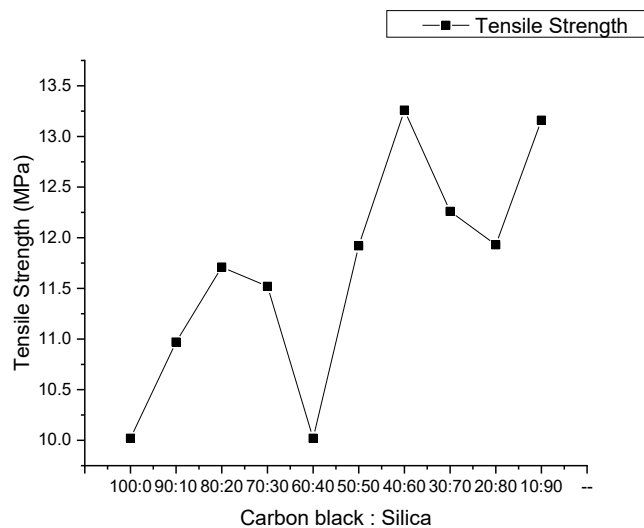


Figure 8 Tensile Strength curve



3.3.HARDNESS OF SILICA REINFORCED SBR TIRE TREAD

The hardness of the batches made up of different proportions of carbon black and silica was obtained and tabulated in Table 5

TABLE 5 SHORE A HARDNESS OF SILICA REINFORCED SBR TIRE TREAD COMPONENT

Batch No.	Constituents (Carbon black : Silica) (in phr)	Shore A Hardness
1	100 : 0	87.5
2	90:10	83.2
3	80:20	87.4
4	70:30	85.1
5	60:40	84.7
6	50:50	83.8
7	40:60	83.2
8	30:70	90.4
9	20:80	90.5
10	10:90	91.4

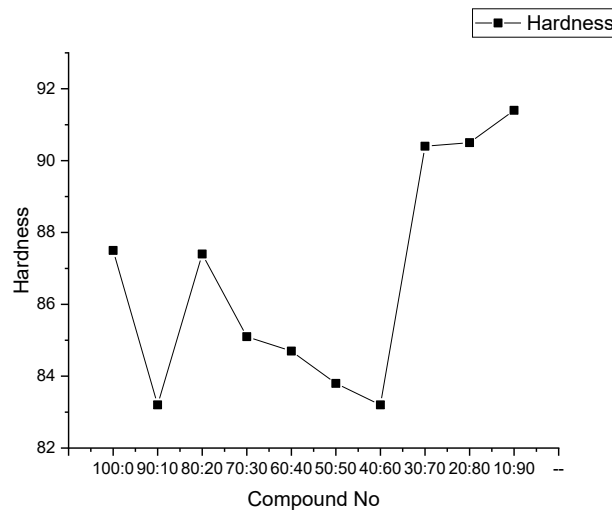


Figure 9 Hardness of Silica reinforced SBR tire tread component

From the Figure 12, the vulcanizates compounds of different loading obtained through variation of silica from 0 phr to 90 phr at the same time reduction in the carbon black phr value linearly. The hardness value of carbon black filled vulcanizates showed higher hardness value than compound made out from silica reinforced except in the case of 80:20 proportion of carbon black and silica. With increase in the silica content the hardness value was found to be greater than the value of control component carbon black.



3.4.SPECIFIC GRAVITY OF SILICA REINFORCED SBR TIRE TREAD

The specific gravity of the mixes made up of different proportions of carbon black and silica was obtained and tabulated in Table 6.

Table 6 Specific Gravity of silica reinforced SBR tire tread component

Batch No.	Constituents (Carbon black : Silica)	Specific Gravity
1	100 : 0	1.232
2	90:10	1.216
3	80:20	1.237
4	70:30	1.24
5	60:40	1.246
6	50:50	1.249
7	40:60	1.238
8	30:70	1.264
9	20:80	1.258
10	10:90	1.274

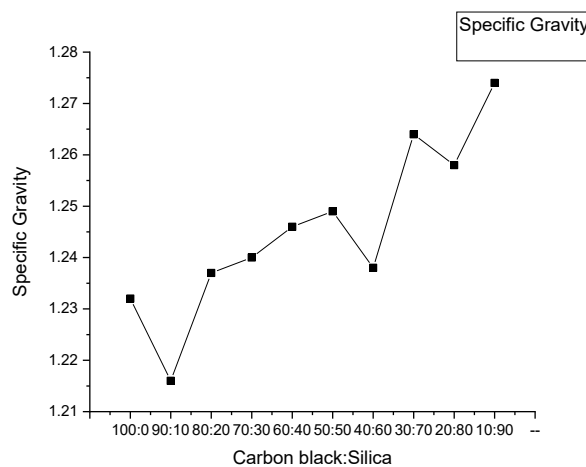


Figure 10 Specific Gravity of Silica reinforced SBR tire tread component

The specific gravity of controlling component carbon black (100:0 phr) has a value of 1.232. It indicates the processability of the compound during extrusion. Higher the specific gravity higher the density of the compound and more energy consumption during extrusion, calendaring etc. There is slight increase in specific gravity with increase in silica content this due to the fact that silica amorphous substance requires time to mix well with the rubber matrix. While the 40:60 carbon black and silica proportion resembles the required specific gravity of the controlling component and seems idle for the compound preparation.

IV. CONCLUSIONS

The need for replacement of conventional reinforcing carbon black with silica started with the greener tires eventually came out from reputed tire manufacturers.

The manufacturers claim that greener tires are more fuel economic and reduces the emission of CO2 into atmosphere. Also silica is highly versatile compound used in several industries. The characteristics study on different proportions of silica reinforced SBR vulcanizates along with the coupling agent silane revealed the following:



- The reinforcing material silica needs a coupling agent like silane for processability.
- The processability is understood by determining the specific gravity of the vulcanizates compound made up of silica – silane reinforced SBR tire tread component.
- The results of cure characteristics study reveal that the vulcanizates containing carbon black and silica in the proportion of 60:40 requires the maximum time for formation of cross link density. While the 40:60 proportions resemble the characteristics exhibited by the vulcanizates made from the controlling component 100:0 carbon black and silica.
- The scorch time of 10:90 carbon black and silica is maximum and requires around 2 minutes for the onset of vulcanization in the silica reinforced SBR vulcanizates. While the controlling component starts the vulcanization process within 50 seconds.
- The hardness value of 30:70 and 20:80 carbon black and silica combination reveals the characteristics exhibited by 100:0 proportion which is the controlling component in this work.
- The minimum torque and the maximum torque required for suitability of process oil are maintained by 70:30 carbon black and silica proportion based SBR vulcanizates.
- The physico – mechanical characteristics of silica reinforcement disclose its closeness in performance to the conventional carbon black and supports in determination of alternative to the latter.
- The experimental results showed the 20:80 carbon black and silica proportion has the most suitable proportion for compound preparation in the case of SBR – BR tire tread formulation.

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