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Effect of corn powder as filler in radial passenger tyre tread compound

S. L. Agrawal · S. K. Mandot · N. Mandal · S. Bandyopadhyay · R. Mukhopadhyay · A. S. Deuri · R. Mallik · A. K. Bhowmick

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Abstract The present context of technological scenario, requirement of developing low rolling resistance passenger radial tyres with naturally occurring environmental friendly materials is inevitable. Several studies have been reported by using silica filler in place of carbon black for improving the rolling resistance property. In the present study, an attempt has been made to investigate the effect of biodegradable Indian corn powder in tyre tread compound as filler. The effect of corn powder in gum and filled compound of both natural rubber (NR) and styrene butadiene rubber (SBR) based compound has been studied. It was found that corn powder of 200-mesh size increased thermal stability of NR compound and acted as a non-reinforcing filler. It also affected the fatigue properties and abrasion loss when the carbon black was partially replaced with corn powder. However, an improvement in the temperature build up (TBU) and tan δ at 60 °C (a representative of rolling resistance property of tyre) was observed.

S. L. Agrawal · S. K. Mandot · N. Mandal ·
S. Bandyopadhyay (✉) · R. Mukhopadhyay
Hari Shankar Singhania Elastomer and Tyre Research Institute (HASETRI), P.O. Tyre Factory, Jaykaygram, Dt. Rajsamand, Kankroli, Rajasthan 313342, India
e-mail: sbanerjee@ktp.jkmail.com

A. S. Deuri
R & D Centre, J. K. Tyre, Kankroli, India

R. Mallik · A. K. Bhowmick
Rubber Technology Centre, I.I.T. Kharagpur, Kharagpur, WB 721302, India

Abbreviations

NR	Natural rubber
SBR	Styrene butadiene rubber
RMA #4	Natural rubber, sheet, classified as per Rubber Manufacturers Association, Malaysia
ISNR	Natural rubber, block, classified as per Indian Standard Natural Rubber
PCTP	Pentachloro pthio phenol
RPO	Rubber process oil
ZnO	Zinc oxide
6PPD	*N*-(1,3-Dimethyl butyl)-*N*′-phenyl para phenylene diamine
DPPD	*N*,*N*′-Di-phenyl para phenylene diamine
TMQ	Polymerised 2,2,4-trimethyl, 1,2-di hydro, quinoline
CTP	*N*-Cyclo hexyl pthio pthalimide
ASTM	American Society for Testing and Materials
MV	Mooney viscometer
MDR	Moving die rheometer
VA	Viscoanalyser
TGA	Thermo gravimetric analyser
DTG	Differential thermo gravimetric analysis
DSC	Differential scanning calorimeter
FTIR	Fourier transformed infrared spectrophotometer
SEM	Scanning electron microscope
Tq	Torque
M50%, M100%, M300%	Modulus at 50%, 100% and 300% elongation level

TS	Tensile strength
EB	Elongation at break
FTFT	Flex to fatigue test
TBU	Temperature build up
V_r	Volume fraction of insoluble rubber in swollen gel
V_{r0}	Volume fraction of gum rubber compound
V_{rf}	Volume fraction of corn filled rubber compound
ϕ	Volume fraction of filler

Introduction

Tyre manufacturers are continuously looking for developing energy efficient, low rolling resistance tyres using more and more naturally occurring materials with minimum possible depletion of petroleum/natural resources. Out of all the components of a typical tyre, the tread component is contributing the major share to rolling resistance properties. So continuous efforts are in progress round the globe to develop the suitable tread compound in order to fulfil the above criteria.

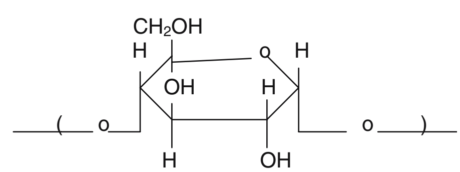
Use of special grades of polymers like solution grade styrene butadiene rubber, high performance black, silica, silane coupling agents and other processing aids have already been reported in development of suitable low rolling resistance tyres [1–7]. Use of starch-based product in plastics is well known and reported [8]. Starch originates from fleshy parts of plants especially the seeds, roots, and stems. Common commercial sources include corn, wheat, potatoes, rice, and sorghum. In nature starch serves as a food reserve. It provides the energy that starts young seedlings until they are ready to begin photosynthesis. Although starch is mostly used as food, large quantities are used in industry as a water-soluble polymer [9] e.g., in paper industry. Starch is recovered from plant as a granule ca. 50 μm in diameter. Native starch granules are insoluble in water until broken-down by heat and alkali. Starch is a mixture of linear and branched polymers of 1,4 α-D-glucopyranosyl (anhydroglucose) units [10]. By contrast cellulose exhibits the linear 1,4-β structure; both hydrolysed to glucose. Amylopectine, the branched component of starches, forms its major constituent with a molecular weight of several millions [11]. Branching occurs on C-6 on ca. 4% of the Amylopectine monomer units. The linear starch polymer amylase has a molecular weight of the order of several 100–1,000 [12]. Its linearity enables it to crystallise. Amylase crystallises from dilute aqueous solutions, whereas Amylopectine forms stable dispersion.

In one of the recent development made by the tyre giant, Goodyear [13, 14], is using modified starch derived from corn by partially replacing the carbon black filler. However, no systematic study has been reported regarding the effect of corn powder, specifically, the Indian corn, on rubber vulcanisate either as a sole filler or as a partial replacement of carbon black. In the present study, the effect of corn powder on natural rubber and styrene butadiene rubber has been studied. Physico-chemical characterisation, processing characteristics through rheometric properties, different physical properties including retention of properties after air ageing, temperature build up, dynamic mechanical property like tan ö and abrasion loss were studied in details.

Experimental

Material used

The Indian corn having the scientific name zea mays, was collected from standard Indian grocer's shop and grounded in flour mill. The chemical structure of 1,4 α-D-glucopyranosyl (anhydroglucose) units is as follows:



Constituents of corn [11] is as follows;

Starch	61.0%
Protein and fibre	19.2%
Corn oil	3.8%
Water	16.0%

The suppliers of other material used in this study are given in Table 1.

Physico-chemical characterisation

The moisture content of the corn powder was determined using a infrared moisture balance. Subsequently the corn powder was screened using different sieves after removing the surface moisture by drying it at 70 °C for 1 h under vacuum.

Corn powder was further characterised by using thermogravimetric analyser, TGA 7, differential scanning calorimeter, DSC 7 and system 2000 Fourier

Table 1 Materials used in the study

Sl. No.	Material	Supplier
1.	Sheet natural rubber, RMA # 4	MARDEC International, Kualalumpur, Malaysia
2.	Block natural rubber, ISNR # 20	The Rubber Board, Kottayam, India
3.	Styrene butadiene rubber, SBR 1502	Korea Kumho Petrochemicals Ltd., Korea
4.	37.5 parts oil extended styrene butadiene rubber, SBR 1712	Korea Kumho Petrochemicals Ltd., Korea
5.	PCTP based peptiser, PEPTIZOL—7	Acmechem Limited, Ankeleshwar, India
6.	High abrasion furnace black (HAF, N330)	Cabot India Ltd., Mumbai, India
7.	Intermediate high abrasion furnace black (ISAF, N220)	Cabot India Ltd., Mumbai, India
8.	Aromatic oil, RPO 701	Sah Petroleum Limited, Daman, India
9.	Red seal zinc oxide	Zinc—O—India, Ltd., Alwar, Rajasthan, India
10.	Stearic acid	Godrej Industries Ltd., Mumbai, India
11.	Antiozonant—1,3-dimethyl butyl para phenylene diamine, 6PPD, PILFLEX 13	NOCIL, Thane, India
12.	Antiozonant—diaryl paraphenylene diamine, DPPD, PILFLEX 100	NOCIL, Thane, India
13.	Antioxidant—1,2-dihydro 2,2,4-trimethyl quinoline, TMQ, PILNOX TDQ	NOCIL, Thane, India
14.	Rubber makers sulfur (soluble sulfur)	Jain Chemicals, Kanpur, India
15.	Accelerator, *N*-cyclo hexyl-2-benzo-thiazyl sulfenamide (CBS), PILCURE CZ	NOCIL, Thane, India
16.	Accelerator, *n*-oxy diethylene benzo thiazyl sulfenamide, (NOBS), PILCURE MOR	NOCIL, Thane, India
17.	Accelerator, diphenyl guanidine, (DPG), PILCURE DPG	NOCIL, Thane, India
18.	Scorch Inhibitor, *N*-cyclo hexyl pthio pthalimide, CTP (Pre vulcanising inhibitor, PVI 100), ACCITARD RE	ICI, Rishra, India

transformed infrared spectrophotometer (FTIR), all from M/s Perkin Elmer, USA. Scanning electron microscopic study of the gold-coated corn powder samples were taken by using JEOL JSM 5800 scanning electron microscope (SEM).

Interaction of corn powder with accelerator (NOBS and DPG)

In order to understand the interaction between corn powder and accelerator, high performance liquid chromatographic (HPLC) study was attempted. Since the corn powder was found insoluble in most of the common solvents used for HPLC measurement the HPLC study could not be continued. Therefore, FTIR study was performed. At first the spectra of the individual accelerators and corn powder was taken. The corn was then separately mixed with NOBS and DPG and spectrum of the mixed samples was taken.

Table 2 Formulation of NR and SBR raw rubbers only with corn powder (phr)

Mix Id./ingredients	GN	GN5	GN10	GN15	GS	GS5	GS10	GS15
RMA 4	50	50	50	50	–	–	–	–
ISNR 20	50	50	50	50	–	–	–	–
SBR 1502	–	–	–	–	50	50	50	50
SBR 1712	–	–	–	–	68.75	68.75	68.75	68.75
Corn powder	0	5	10	15	0	5	10	15

Rubber compound mixing and characterisation

Mixing of raw natural rubber (NR) and styrene butadiene rubber (SBR) with corn powder only (Formulation given in Table 2) and gum compound (without carbon black filler, formulation given in Table 3a, b) was carried out in a 75×10^{-6} m^3 capacity Brabender Plasticorder PL2000-3 mixer. A two stage (master batch and final batch) mixing was followed for the gum compound.

Table 3 Formulation of (a) NR gum, (b) SBR gum (without carbon black) compound (phr)

Mix Id./ingredients	N	N5	N10	N15
(a) NR gum[A]				
RMA 4	50	50	50	50
ISNR 20	50	50	50	50
Corn powder	0	5	10	15
Mix Id./ingredients	S	S5	S10	S15
(b) SBR gum[B]				
SBR 1502	50	50	50	50
SBR 1712	68.75	68.75	68.75	68.75
Corn powder	0	5	10	15

[A]Other ingredients used in the above formulation and kept constant: PCTP, 0.2; ZnO, 5.0; Stearic acid, 3.0; 6PPD, 2.37; TMQ, 0.75; Aromatic oil, 6.0; Soluble sulfur, 2.25; NOBS, 0.50 and PVI 100, 0.20

[B]Other ingredients used in the above formulation and kept constant: ZnO, 2.0; Stearic acid, 1.0; 6PPD, 0.7; DPPD, 0.3; Aromatic oil, 18.0; Soluble sulfur, 1.9; CBS, 1.1; PVI 100, 0.10; and DPG, 0.3

Table 4 Formulation of (a) NR black (b) SBR black filled compound (phr)

Mix Id./ingredients	A	B5	B10	C5	C10	C15	
(a) NR black[A]							
RMA 4	50	50	50	50	50	50	
ISNR 20	50	50	50	50	50	50	
HAF Black	47	42	42	37	37	37	
Corn powder	0	5	10	5	10	15	
Mix Id./ingredients	D	E5	E10	E15	F5	F10	F15
(b) SBR black[B]							
SBR 1502	50	50	50	50	50	50	50
SBR 1712	68.75	68.75	68.75	68.75	68.75	68.75	68.75
ISAF Black	78	73	73	73	68	68	68
Corn powder	0	5	10	15	5	10	15

[A]Other ingredients used in the above formulation and kept constant: PCTP, 0.2; ZnO, 5.0; Stearic acid, 3.0; 6PPD, 2.37; TMQ, 0.75; Aromatic oil, 6.0; Soluble sulfur, 2.25; NOBS, 0.50; and PVI 100, 0.20

[B]Other ingredients used in the above formulation and kept constant: ZnO, 2.0; Stearic acid, 1.0; 6PPD, 0.7; DPPD, 0.3; Aromatic oil, 18.0; Soluble sulfur, 1.9; CBS, 1.1; PVI 100, 0.10; and DPG, 0.3

Mixing of carbon black filled compound was carried out using a two-wing rotor laboratory Banbury mixer of 15×10^{-4} m^3 capacity (M/s Stewart Bolling, USA) in two stages (master batch and final batch, formulation given in Table 4a, b). All the mixed compounds were sheeted out passing through a laboratory two-roll mill from M/s Santosh Industries, New Delhi, India.

Thermogravimetric study was also conducted for compound batches containing raw NR and SBR mixed with corn powder only, using TGA 7.

Mooney Viscosity, ML (1 + 4) at 100° C, was measured in a Mooney viscometer, MV 2000E, M/s Alpha Technologies, USA, in accordance with ASTM D 1646. The rheometric characteristics were checked in MDR 2000E, also from M/s Alpha Technologies, USA following ASTM D 5289.

The green rubber compounds were cured following ASTM D 3182 in an electrically heated hydraulic curing press using compression moulding. The moulding conditions followed for different compounds were for curing optimum cure time, tc_{90} at 141 °C (for NR based compounds) and at 160 °C (for SBR based compounds).

The tensile properties (including tear strength) were measured using a Zwick UTM 1445 in accordance with ASTM D 412 and ASTM D 624. The hardness was measured with a Shore A durometer, M/s Prolific Engineers, New Delhi in accordance with ASTM D 2240. The fatigue to failure test (FTFT) was performed in a Monsanto FTFT machine in accordance with ASTM D 4482. The abrasion loss was measured in a Zwick DIN Abrader in accordance with ASTM D 5963 using 10 N load. The temperature build up (TBU) was measured in a Goodrich Flexometer in accordance with ASTM D 623, the dynamic mechanical properties, tan δ at 60° C was measured in a Metravib dynamic mechanical analyser, VA4000 in accordance with ASTM D 5992.

Volume fraction of insoluble rubber in swollen gel [15–17] and Kraus Plot for rubber to filler interaction was determined by following the method described earlier [18].

Treatment of the corn powder with yeast and silane coupling agent-Si69

In order to understand the effect above chemicals on corn powder, the authors had done a separate study and reported the result [19]. In the same study the authors have reported that treatment of corn with a silane coupling agent improved the rubber compound temperature build up, tan δ at 60° C and modulus properties. There was no improvement in abrasion resistance, which clearly indicates that treatment of silane coupling agent did not improve the interaction between corn powder–rubber and corn powder–carbon black. The authors also reported that treatment of corn with yeast improved the modulus, temperature build up, tan δ at 60° C as well as the abrasion resistance considerably. The improvement in abrasion resistance indicates that the interaction between corn powder and rubber and between corn powder and carbon black improved after yeast treatment.

Result and discussion

Physico-chemical characterisation of corn powder

The moisture content and weight loss values of corn powder are reported in Table 5. The moisture data

Table 5 Moisture content and weight loss

Test parameter	Value
Moisture content at 70° C, 1 h (%)	2.95
Moisture content at 105° C, 1 h (%)	6.95
Weight loss at 141° C, 1 h (%)	9.05
Weight loss at 160° C, 20 min (%)	9.30

Table 6 Sieve analysis of corn powder

Test parameter	Value
40 mesh residue (%)	10.9
80 mesh residue (%)	26.7
120 mesh residue (%)	12.6
200 mesh residue (%)	10.5
200 mesh pass out (%)	39.8

Note: The reported values are average of three measurements

Table 7 Characterisation of corn powder by (a) TGA at 40 °C/min, (b) DSC at 10 °C/min heating rate in nitrogen atmosphere

Decomposition initiation temperature (°C)	Decomposition termination temperature (°C)	T_{max} (°C)	Carbonaceous residue (%)	Ash (%)	Volatile content (%)
(a) TGA					
284	445	362	15.68	1.1	5.39
DSC Peak 1 (°C)	DSC Peak 2 (°C)	DSC Peak 3, onset (°C)			
(b) DSC					
105.7	231.5	271.3			

determined at 70° C gives an idea of the volatile matters present in corn powder whereas, the data at 105° C indicates about the percentage moisture. The weight loss values determined at 141° C and 160° C are the indications of weight loss of corn powder at different processing operations of tyre manufacturing. The sieve analysis of corn powder is reported in Table 6. It was found that the 80 mesh residue being the predominant one, whereas, the 40, 120 and 200 mesh residues were found to be almost same. The thermogravimetric analysis of corn powder is reported in Table 7a. The TGA curve is also shown in Fig. 1. The corn powder started decomposing at 284° C and it was completed at 445° C, the T_{max} was found to be at 362° C. The carbonaceous residue found in the corn powder may be due the presence of some cyclic groups. The FTIR spectrum of the corn powder is shown in Fig. 2. The peak at 1010 cm^{-1} is due to –C–O– stretching vibration of primary alcoholic group (–CH_2OH) and the peak at 1140 cm^{-1} is due to symmetric –C–O– stretching of –C–O–C– linkage. The characterisation by DSC is reported in Table 7b. The DSC thermogram is shown in Fig. 3. The corn powder was found to have two softening peaks at 105.7° C and 231.7° C, whereas the peak 3 at 271.7° C is indicating about the initiation of decomposition of the corn powder. The SEM photographs of the corn powder are shown in Fig. 4. The micrograph of corn powder indicates the presence of particles having dimensions 10–30 μm and the particles are existing as coalesced together (Fig. 5).

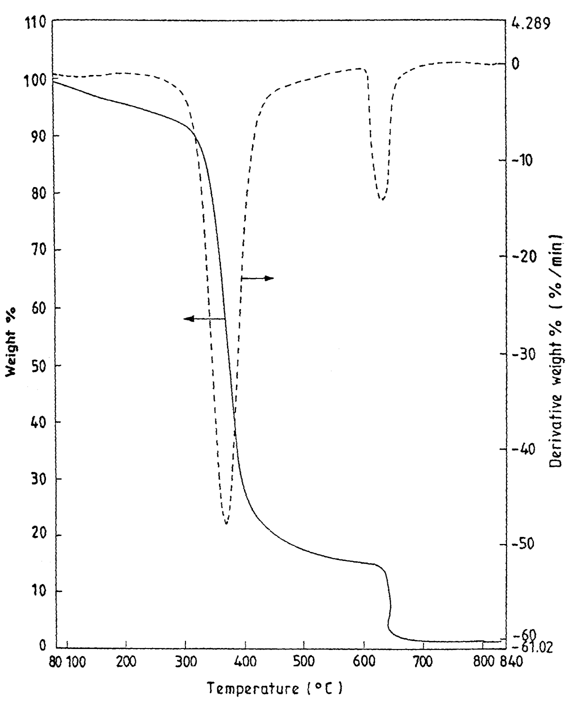


Fig. 1 TGA and DTG curves of corn powder at 40 °C/min heating rate

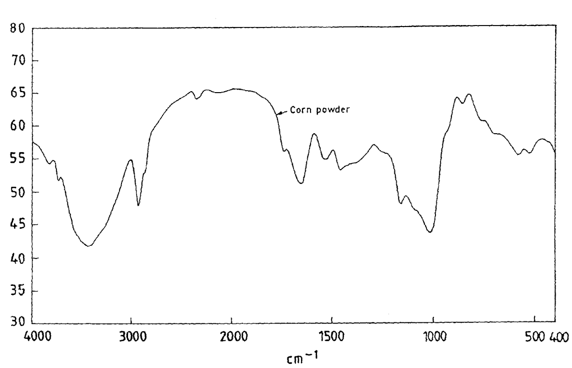


Fig. 2 FTIR spectrum of corn powder

Interaction of corn powder with accelerator (NOBS and DPG)

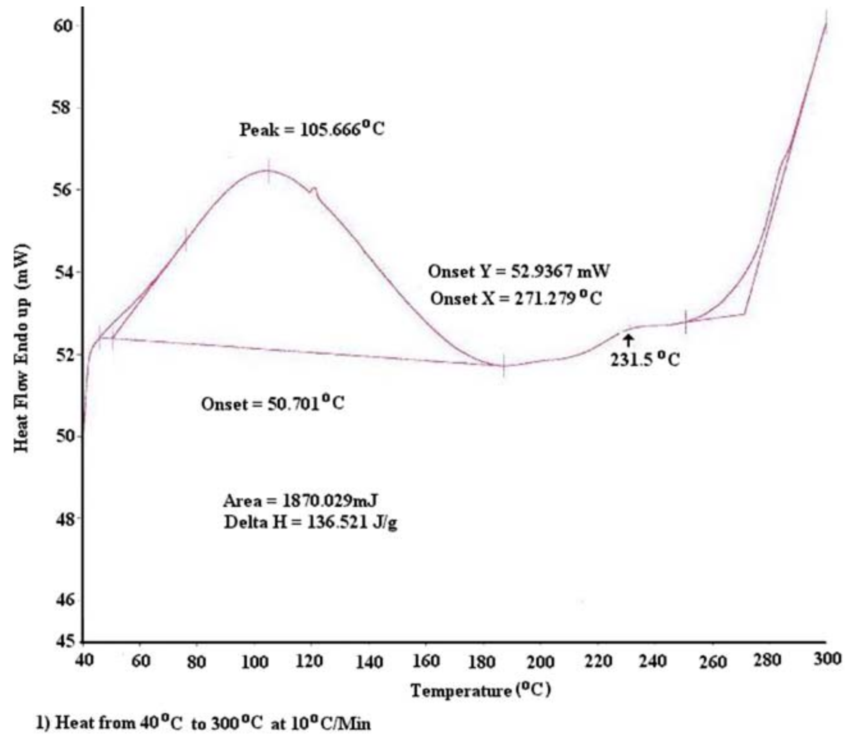
In case of the spectrum of mixed samples of corn and NOBS as well as corn and DPG, no shift of peaks from the original peak of corn, NOBS or DPG was noticed. This clearly indicates that corn powder is having no interaction with the accelerators used in the study.

Characterisation in rubber compound

Corn powder as an additive (sole filler) in NR and SBR

Thermogravimetric analysis results as shown in Table 8, indicates that though corn powder reduces initial decomposition temperature, it increases the

Fig. 3 Differential Scanning Calorimeter study of corn powder



temperature at which maximum decomposition occurs for NR. Increase in activation energy for decomposition of NR depicts that corn powder increases the thermal stability of the NR. However, a little difference was observed for SBR mix on addition of corn powder because of the inherent higher thermal stability of SBR.

Mooney viscosity and rheometric properties as shown in Table 9, depicts that both Mooney viscosity and maximum torque increases on addition of corn powder and compounds are having a tendency of reduced scorch safety and faster curing for both NR and SBR based compounds.

The physical properties as given in Table 10 indicates that the modulus and hardness showed incremental trend with corn filler loading for both NR and SBR gum vulcanisate, whereas, tensile strength and FTFT values followed a reverse trend with minor deviation at 5 phr loading. Ageing properties of corn filled compound were found to be comparable with that of the unfilled one. This clearly indicates that corn powder is hardly showing any reinforcing character particularly at higher loading.

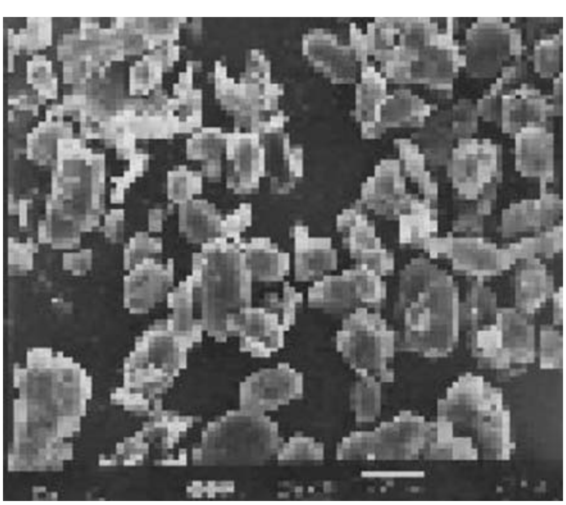


Fig. 4 SEM study of corn powder at 750 magnification

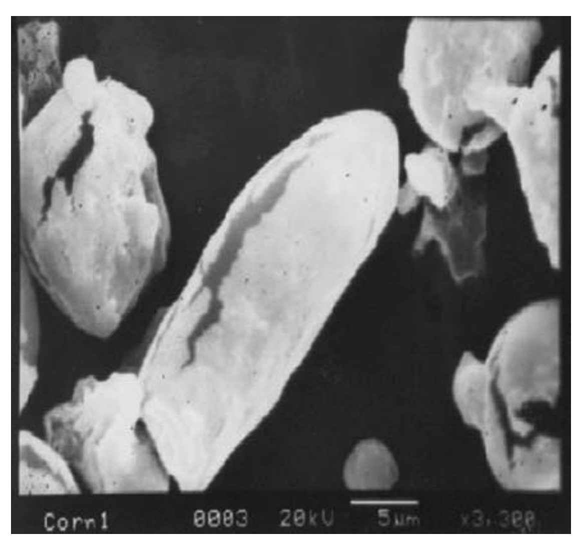


Fig. 5 SEM study of corn powder at 3,300 magnification

Table 8 TGA results for raw NR and SBR mixed with corn powder only

Mix Id.	Decomposition initiation temperature (°C)	Decomposition termination temperature (°C)	T_{max} (°C)	Activation energy (kJ/mol)
Corn powder	285	420	368	155
GN	330	499	414	138
GN5	297	505	414	151
GN10	305	519	418	159
GN15	297	500	418	167
GS	388	547	489	259
GS5	393	553	494	268
GS10	399	546	487	264
GS15	407	554	493	259

Table 9 Rheometric properties at 141 °C/60 min for NR and at 160 °C/30 min for SBR

Compound Id.	Minimum torque (dN m)	Maximum torque (dN m)	t_{s02} (min)	t_{c40} (min)	t_{c90} (min)	ML (1 + 4) at 100 °C
N	1.8	13.3	6.2	8.6	18.9	44
N5	2.1	13.8	6.3	8.8	19.2	47
N10	2.1	14.7	4.9	7.3	17.3	48
N15	2.0	15.0	3.4	5.8	16.2	48
S	0.6	6.0	7.6	7.5	11.7	37
S5	0.6	6.0	6.3	6.2	9.9	39
S10	0.7	6.5	5.8	5.8	9.5	38
S15	0.7	6.7	5.9	4.9	8.1	38

Note: The reported values are average of three measurements

Interaction of corn powder with rubber (NR, SBR)

In order to understand the interaction between rubber and corn powder, the volume fraction of insoluble rubber, V_r, at different loading of corn powder was measured and Kraus Plot was drawn (Fig. 6 for NR and Fig. 7 for SBR). A straight line parallel to the X-axis clearly indicates that corn powder is having non-reinforcing characteristics for both NR and SBR compounds and has got no interaction with NR and SBR.

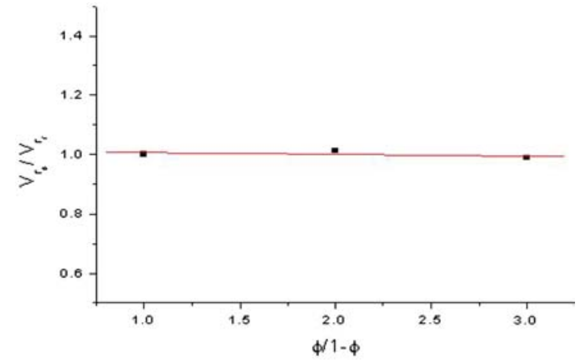


Fig. 6 Kraus plot for NR compound

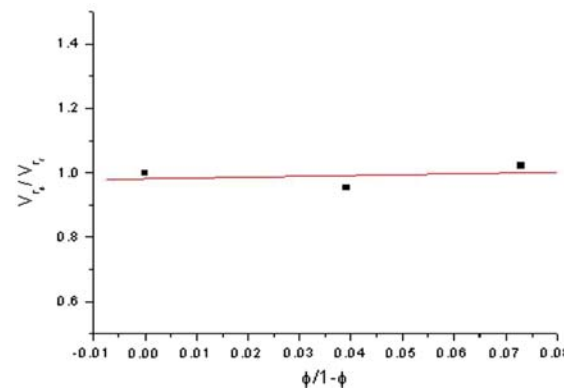


Fig. 7 Kraus plot for SBR compound

Corn powder as a partial replacement of reinforcing filler, carbon black

Rheometric properties of carbon black filled compound using corn powder as a partial replacement at different black loading are reported in Table 11. Minimum

Table 10 Physical properties of gum (without black) NR and SBR compounds

Compound Id.	M50% (MPa)	M100% (MPa)	M300% (MPa)	TS (MPa)	EB (%)	FTFT (kilo cycles)	Hardness (Shore A)
N	0.5 (120)	0.8 (112)	1.9 (142)	20.4 (94)	698 (88)	81	41 (+3)
N5	0.5 (120)	0.8 (112)	2.0 (135)	21.4 (82)	734 (83)	77	42 (+3)
N10	0.6 (117)	0.9 (133)	2.4 (133)	18.2 (93)	650 (87)	51	44 (+2)
N15	0.6 (117)	1.0 (110)	2.5 (116)	19.4 (87)	669 (88)	41	45 (+2)
S	0.4 (120)	0.7 (128)	2.0 (130)	2.0 (75)	316 (76)	4	38 (+6)
S5	0.5 (120)	0.7 (120)	2.1 (122)	2.2 (90)	334 (74)	8	38 (+6)
S10	0.5 (130)	0.8 (125)	2.0 (130)	2.6 (75)	390 (73)	6	39 (+5)
S15	0.6 (117)	0.9 (133)	2.4 (135)	3.0 (80)	382 (68)	4	41 (+4)

Results in the parentheses are the percentage retention in properties after ageing at 70 °C for 14 days for NR and at 105 °C for 3 days for SBR. The + values indicate increase in hardness after aging over the unaged hardness value. All the above results are average of five measurements

Table 11 Rheometric properties at 141 °C/60 min for NR and at 160 °C/30 min for SBR

Compound Id.	Minimum torque (dN m)	Maximum torque (dN m)	t_{s02} (min)	t_{c40} (min)	t_{c90} (min)	ML (1 + 4) at 100 °C
A	2.8	16.4	9.9	12.6	23.7	44
B5	2.6	15.8	7.9	10.3	21.2	41
B10	2.8	16.5	8.1	10.6	21.4	42
B15	2.8	16.4	8.3	10.8	21.6	42
C5	2.2	14.0	10.8	13.0	23.7	37
C10	2.4	14.6	8.9	11.2	22.2	39
C15	2.4	14.8	8.8	11.1	22.1	46
D	4.1	23.5	4.3	8.7	11.9	83
E5	3.6	20.5	3.9	8.2	11.1	72
E10	3.8	21.7	3.6	7.5	10.2	78
E15	3.8	21.5	3.8	7.5	10.2	78
F5	3.3	20.6	4.0	8.2	11.0	68
F10	3.4	20.5	3.9	8.0	10.9	68
F15	3.4	20.5	3.4	7.3	10.0	68

Note: The reported values are average of three measurements

torque, Mooney viscosity and maximum torque decreased when 5 and 10 phr of carbon black was replaced by 5 phr corn powder. This reduction is due to the reduction of high reinforcing carbon black filler dosage. However, further addition of corn powder caused an increase in these values with some deviation for SBR filled stock. Scorch time, ts_{02} and optimum cure time, tc_{90} of all corn powder filled compounds reduced with minor exception.

The results of physical and fatigue properties are reported in Table 12. For compounds based on NR, the modulus at different extensions, tensile strength, tear strength, elongation at break (%), hardness and fatigue property decreased when 5 and 10 phr of carbon black was replaced by 5 phr of corn powder. On further addition of corn powder these properties also showed decreasing trend. Change in properties after ageing of corn filled compounds is comparable with those of the control compound. Ageing properties did not show any regular trend.

For compounds based on SBR, modulus at different extensions and hardness decreased when 5 and 10 phr of carbon black were replaced by 5 phr of corn powder. On further addition of corn powder, the modulus at different extensions continued to reduce, while the hardness increased slightly. Tensile strength, tear strength, elongation at break and fatigue property increased when 5 and 10 phr of carbon black was replaced by 5 phr of corn powder. Further addition of corn powder caused a decrease in tensile strength, tear strength and elongation at break. Improvement in fatigue property of the corn filled compounds with replacing 5 phr black was more than that of the compounds with 10 phr replaced black. Retention of properties after air ageing of corn filled compounds was comparable with that of the control compound.

Temperature build up (TBU), abrasion loss, volume fraction and tan δ values are reported in Table 13. For NR compounds, temperature build up showed decreasing trend compared to the control (compound without corn). The initial drop in temperature build up of compounds in which, 5 and 10 phr of carbon black was replaced by 5 phr of corn powder, might be due to reduction in dosage of carbon blacks. On further addition of corn powder there was a marginal increase in temperature build up.

Table 12 Physical and fatigue properties of black filled compounds

Compound Id.	M50% (MPa)	M100% (MPa)	M300% (MPa)	TS (MPa)	EB (%)	Hardness (Shore A)	Tear strength (N/mm)	FTFT (kilo cycles)
A	1.3 (115)	2.6 (135)	11.9 (126)	25.9 (85)	553 (88)	61 (+4)	107	71
B5	1.4 (119)	2.6 (131)	11.0 (124)	23.8 (88)	536 (85)	60 (+3)	83	52
B10	1.5 (116)	2.7 (124)	11.0 (123)	22.4 (82)	511 (88)	62 (+3)	84	45
B15	1.5 (122)	2.7 (126)	10.5 (126)	20.9 (89)	506 (90)	63 (+2)	65	39
C5	1.2 (121)	2.2 (132)	9.2 (135)	23.9 (81)	572 (82)	58 (+4)	68	45
C10	1.2 (113)	2.2 (124)	8.6 (129)	22.9 (76)	569 (80)	59 (+3)	64	47
C15	1.3 (114)	2.4 (121)	8.7 (121)	21.7 (81)	555 (84)	60 (+3)	55	32
D	1.3 (107)	2.2 (159)	10.4 (155)	18.0 (80)	483 (80)	73 (+5)	48	17
E5	1.1 (118)	1.8 (150)	8.4 (150)	18.4 (77)	566 (78)	68 (+3)	51	23
E10	1.1 (127)	1.8 (166)	8.1 (160)	16.9 (81)	542 (74)	69 (+2)	48	36
E15	1.2 (108)	1.8 (150)	7.8 (152)	16.4 (77)	544 (76)	71 (+2)	47	33
F5	1.1 (72)	1.7 (123)	7.9 (128)	18.2 (75)	562 (68)	65 (+2)	51	30
F10	1.0 (120)	1.6 (175)	7.2 (179)	17.5 (71)	585 (73)	67 (+2)	50	20
F15	1.0 (120)	1.6 (156)	6.5 (155)	16.3 (82)	583 (83)	67 (+5)	49	21

Results in the parentheses are the percentage retention of properties after ageing at 70 °C for 14 days for NR and at 105 °C for 3 days for SBR. In case of hardness, the + values indicate increase in hardness after aging over the unaged hardness value. All the above results are average of five measurements

Table 13 Temperature build up (TBU), abrasion loss, volume fraction, V_r and tan ö

Compound Id.	Tan δ at 60 °C by VA 4000	Temperature build up (°C)	Abrasion loss (mm^3)	Volume fraction, V_r
A	0.13	18	106	0.252
B5	0.13	16	129	0.241
B10	0.13	18	144	0.259
B15	0.13	19	159	0.249
C5	0.11	12	141	0.236
C10	0.12	14	152	0.239
C15	0.13	16	172	0.234
D	0.33	36	81	0.154
E5	0.31	35	95	0.136
E10	0.32	34	108	0.171
E15	0.32	36	127	0.145
F5	0.29	32	93	0.133
F10	0.30	32	121	0.142
F15	0.31	31	143	0.144

Note: The reported values are average of three measurements

Tan δ at 60 °C was decreased in each of the corn filled compounds compared to control one. Initial drop in tan δ of compounds in which 5 and 10 phr of carbon black was replaced by 5 phr of corn powder, might be due to reduction in dosage of carbon black.

For SBR compound, a similar trend was observed like that of NR compound. The abrasion loss of all corn filled samples was higher compared to control compound. The abrasion loss increased consistently with increase in corn powder loading. This is a clear indication of the poor interaction between corn powder–rubber or corn powder–carbon black. Volume fraction, V_r values also indicate poor interaction with corn powder and showed no definite trend.

Conclusion

From the above study, it can be concluded that corn powder alone as a filler can not give the adequate reinforcement required for tyre tread compound. It can also be concluded that Indian corn powder on partial replacement of carbon black acts as non-reinforcing filler. It affects physical properties like abrasion loss etc. However, there will be a definite improvement in the temperature build up and tan δ value, a laboratory predictor for tyre rolling resistance properties. This can be utilised in compound development with improved rolling resistance property particularly for passenger radial tyres.

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