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Investigation of Recycled Carbon Black and Carbon Black Coupling Agent on the Mechanical Properties of Rubber Track Compounds

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Abstract: Rubber tracks, which serve essential components in heavy-duty machinery, operate under high loads and in harsh terrains, thereby requiring superior abrasion resistance and enhanced mechanical properties. As the adoption of electrified heavy equipment expands, the battery-induced increase in machine weight has rendered reinforcement performance in rubber track compounds even more critical. Simultaneously, stringent environmental regulations in the rubber industry have made the use of environmentally friendly raw materials imperative. Recycled carbon black (rCB), a representative eco-friendly material, has attracted attention as a sustainable alternative reinforcing filler. However, compared with conventional carbon black, rCB generally exhibits a lower specific surface area and higher impurity and ash content, which reduces its reinforcement efficiency and limits its applicability in high-performance products. In this study, conventional carbon black was partially replaced with rCB, and a carbon black coupling agent was introduced to enhance the interfacial interaction with the rubber matrix. As a result, improved dispersion of carbon black and enhanced filler-rubber interaction (F-R interaction) led to superior abrasion resistance. Furthermore, the 100% modulus increased, and the dynamic viscoelastic properties improved. These results indicate that the reinforcement effect provided by the carbon black coupling agent can compensate for the intrinsic limitations of rCB.

Keywords: rubber track, recycled carbon black, carbon black coupling agent, abrasion resistance, filler-rubber interaction

Introduction

Rubber tracks are essential components for driving and braking heavy machinery in harsh environments and off-road such as construction sites, providing reduced noise, better road surface, and superior operability on soft ground compared with steel tracks. The images and characteristics of steel tracks and rubber tracks are presented in Figure 1 and Table 1. Recently, With the upsizing of heavy machinery and the expanding adoption of electrified excavators and tractors, added battery weight has substantially increased operating loads; accordingly, rubber track compounds require even higher abrasion resistance and mechanical performance.[1,2]

At the same time the global rubber industry is facing both the demand from the demand industry to secure sustainability and global regulations, and research on applying sustainable raw materials is actively underway to address these issues.[3,4,5,6] Especially, Recycled carbon black (rCB), recovered from end-of-life tires via pyrolysis, has attracted attention as an eco-friendly reinforcing filler due to its circular-resource advantage.[7,8,9] However, compared with conventional carbon black, rCB contains higher residual impurities and more irregular surface features, which lead to poorer dispersion, weakened filler-rubber (F-R) interaction, and reductions in mechanical strength.[10,11,12] Therefore, rCB is not yet a viable full substitute for conventional carbon black, and current efforts focus on partial replacement strategies.[13] In particular, for rubber track applications that demand high loads and durability, these poor performance are amplified, restricting the direct use of rCB.

From a compounding perspective, studies have explored the use of carbon black coupling agents (CCA) that promote chemical bonding between rubber chains and the carbon black surface to improve interfacial adhesion and dispersion. CCA has bifunctional terminal groups that react with oxygen-containing functional groups on the rCB/

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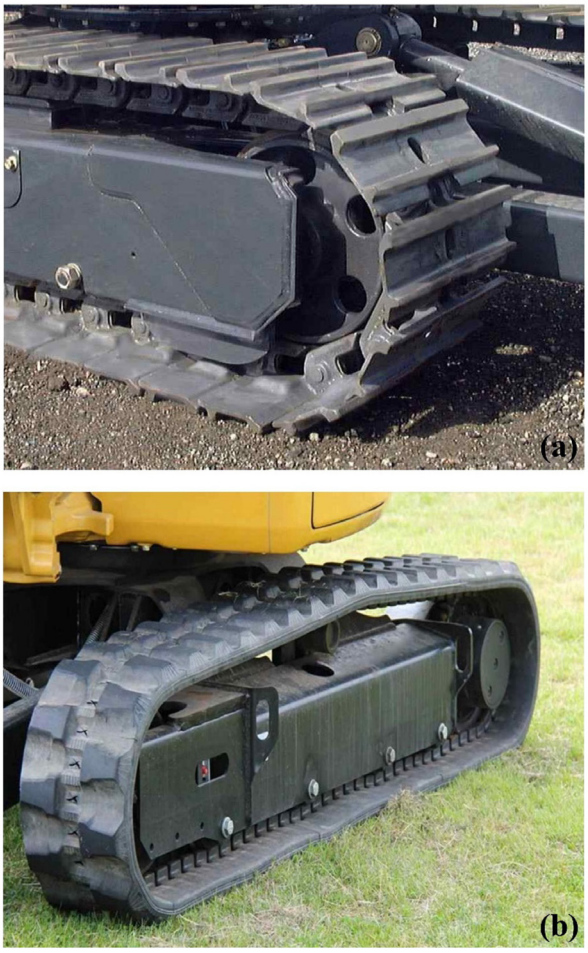

Figure 1. Tracks image; (a) steel track, and (b) rubber track.

CB surfaces (e.g., carboxyl, phenolic, and carbonyl/ketone groups) while simultaneously interacting with the carbon-carbon double bonds of the rubber chains, thereby enhancing the F-R interaction.[14,15] SUMILINK®100 (Figure 2), used in this study, is a CCA that has amine (-NH_2) and sulfonic acid (-SO_3H) terminal groups; The amine group interacts with phenolic hydroxyl (-OH) and carboxyl (-COOH) groups on the carbon black surface through hydrogen bonding, covalent bonding, and acid-base neutralization, whereas the sulfonic acid group reacts with the C=C bonds of the rubber chains to form crosslinks. As a consequence of this mechanism, the strengthened F-R interactions lead to improved filler dispersion and enhanced mechanical properties in carbon black filled rubber compounds. In this study, a portion of conventional carbon black was replaced with rCB in NR/SBR blended rubber-track compounds and the effects of rCB loading and the introduction of a CCA on dispersion behavior, F-R interaction, abrasion resistance, and mechanical properties were evaluated. These results demonstrate the feasibility of a sustainable compound suitable for high-load, high-durability rubber-track applications.

Experimental

1. Materials

Natural rubber (NR) was used Standard Vietnamese Rubber

Table 1. Comparison of the Properties of Steel Tracks and Rubber Tracks

Properties	Steel Tracks	Rubber Tracks
Advantage	1. High durability 2. Excellent off-road performance 3. Long service life	1. Low noise 2. Excellent road surface protection 3. Excellent performance on soft ground 4. High fuel efficiency
Disadvantage	1. Poor road surface protection 2. High noise 3. Low fuel efficiency	1. Poor durability for abrasion 2. Low tear resistance

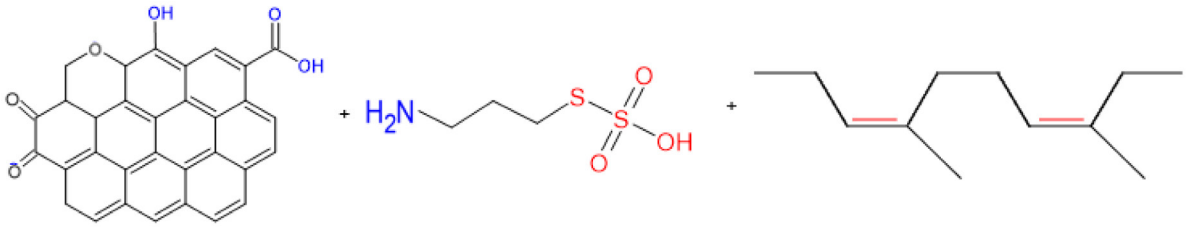

Figure 2. Structure of CB, Sumilink 100, Rubber.

(SVR-3L). Emulsion Styrene-butadiene rubber (ESBR) was used SBR 1502 (23.5% styrene; Kumho Petrochemical Co., Ltd.). Conventional carbon black was used N330 (BET surface area 74.1 m^2/g, Ash contents 0.22%, OCI Co., Ltd.) and the rCB was GCB 774G (BET surface area 62.4 m^2/g, Ash contents 17.82%, LD Carbon). CCA was used SUMILINK® 100 (Sumitomo Chemical Co., Ltd.). The processing oil was A-2 oil, and the processing aids were resin and wax.

Zinc oxide and stearic acid were used as vulcanization activators. Antioxidants were 2,2,4-trimethyl-1,2-dihydroquinoline (TMQ) and N-(1,3-dimethylbutyl)-N′-phenyl-p-phenylenediamine (6PPD). Sulfur was used as a vulcanizing agent. The accelerators were N-tert-butyl-2-benzothiazole sulfenamide (TBBS) and N,N′-1,3-phenylene dimaleimide (PDM). Solvents for the bound rubber and crosslink density experiments were toluene (≥99.80%, Samchun Chmeical co., Ltd.), tetrahydrofuran (THF, ≥99.5%, Samchun Chmeical co., Ltd.), n-Hexane (≥96.0%, Samchun Chmeical co., Ltd.), and Acetone (≥99.5%, Samchun Chmeical co., Ltd.).

2. Preparation of CB/rCB filled rubber track compounds

The rubber compounds were prepared using a 300 cc internal mixer (Brabender, GmbH & Co. KG) according to the formulation presented in Table 2. The mixing start temperature was set to 110°C, and the dump temperature was controlled at 140-150°C. Fill factor was 0.7, and the mixing time was 7 min 40 s. Subsequently, the carbon masterbatch (CMB) was compounded on an 8-inch two-roll mill with the vulcanizing agent sulfur and the accelerators TBBS and PDM at 50°C for 5 min to produce the final masterbatch (FMB), which was then sheeted. The mixing procedure for the compounds is shown in Table 3.

Table 3. Compound Mixing Procedure

Step	Time(min)	Action
CMB mixing	0:00	Add rubber
	0:40	Add Carbon Black + Oil +Resin
	5:40	Add ZnO + StA+ 6PPD +TMQ Wax
	7:40	Dump (140~150°C)
FMB mixing	0:00	Add CMB
	0:20	Add sulfur, TBBS, PDM
	5:00	Dump

3. Experimental methods

3.1 Bound rubber content

To comparatively evaluate the F-R interaction between carbon black and rubber, the bound rubber content was measured. For the measurement, 0.2 g of the CMB was wrapped in tissue and placed in a vial containing 100 mL of toluene. The sample was kept for 3 days, after which the toluene was replaced once, and the sample was kept

Table 2. Compound Formulation of the T-1 to T-10 Compounds

Unit :phr	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	T-10
	Ref.	rCB 5	rCB 10	rCB 15	rCB 20	Ref.+ CCA	rCB 5+ CCA	rCB 10+ CCA	rCB 15+ CCA	rCB 20+ CCA
NR (SVR-3L)	30									
ESBR (SBR 1502)	70									
Carbon Black (N330)	56.5	51.5	46.5	41.5	36.5	56.5	51.5	46.5	41.5	36.5
rCB (GCB 774G)	-	5	10	15	20	-	5	10	15	20
CCA (Sumilink 100)	-					1.13				
A-2 Oil	3									
Resin	4.5									
Zinc oxide	5									
Stearic acid	1									
Wax	2									
TMQ	1									
6PPD	2									
Sulfur	1.6									
TBBS	1									
PDM	0.5									

for an additional 3 days. The solvent was then changed to acetone to remove residual toluene, and the sample was left for 24 hours. Afterward, the sample was dried in an oven at 105°C for 24 hours and subsequently weighed. The measured weight was substituted into Equation (1) to calculate the bound rubber content.

$$R_B(\%) = \frac{W_{fg} - W_t[m_f/(m_f + m_r)]}{W_t[m_r/(m_f + m_r)]} \times 100 \quad (1)$$

R_B: bound rubber content (%)
W_{fg}: the weight of the filler and gel
W_t: the weight of the sample before immersion
m_f: the weight fraction of the filler in the compound
m_r: the weight fraction of rubber in the compound

3.2 Cure characteristics

The cure characteristics of the CB/rCB filled compounds were evaluated using FMB specimens with a moving die rheometer (MDR, Nichigo Shoji Co., Ltd.) at a vibration angle of ±1°, 155°C, for 20 minutes. Torque and the optimum cure time (t_{90}) were determined from the rheometer curves. For specimen preparation, vulcanization was carried out at 155°C using a hydraulic hot press, applying 1.2 times the measured optimum cure time.

3.3 Mooney viscosity

Mooney viscosity, an indicator used to evaluate the processability of rubber compounds, was measured using a Mooney viscometer (DMV-200C, Daekyung Engineering Co., Ltd.), a type of rotational viscometer. The measurement was conducted in accordance with ASTM D1646. The specimen was preheated at 100°C for 1 minute and then rotated at 2 rpm for 4 minutes to obtain the Mooney viscosity value (ML_{1+4}@100°C).

3.4 Crosslink density

The vulcanized specimens were cut into approximately 10 mm × 10 mm pieces and placed in vials containing 50 mL of THF for 24 hours. The specimens were then transferred to vials containing 50 mL of n-hexane and stored for an additional 24 hours to remove residual organics. Afterward, the specimens were dried at 40°C for 24 hours, and the dry weight was recorded. The dried specimens were subsequently immersed in toluene and allowed to swell for 24 hours, after which the swollen weight was measured. The crosslink density was calculated by substituting the measured mass values into the Flory-Rehner equation (Equation 2)

$$\nu = 2\frac{1}{2M_c} = -\frac{\ln(1 - V_1)1 - V_1) + V_1 + \chi V_1^2}{2\rho_r V_0\left(V_1^{\frac{1}{3}} - \frac{V_1}{2}\right)} \quad (2)$$

ν: Crosslink density (mol/g)
$_c$: Average molecular weight between crosslink points (g/mol)
V_1: The volume fraction of rubber in the swollen gel at equilibrium
V_0: The molar volume of solvent (cm /mol)
ρ_r: The density of the rubber sample (g/cm^3)
χ: The polymer-solvent interaction parameter (0.34)

3.5 Mechanical properties

For the measurement of mechanical properties, test specimens were prepared in accordance with KS M 6518. Tensile and tear tests were performed using a universal testing machine (UTM, DUT-500CM, Daekyung Engineering Co., Ltd.). The crosshead speed was set to 500 mm/min for the tensile test and 50 mm/min for the tear test. To evaluate thermal aging properties, the specimens were aged in an oven at 105°C for 24 hours, cooled at room temperature for 1 hour, and then tested under the same conditions.

3.6 Abrasion loss

Abrasion resistance was evaluated in accordance with ASTM D5963 using a DIN abrasion tester (WL210D, WITHLAB Co., Ltd.). Test specimens were prepared in a cylindrical shape with a diameter of 16 mm and a thickness of 8 mm. The specimens were pressed against a rotating drum covered with abrasive paper under a vertical load of 10 N and abraded over a distance of 40 m. The amount of abrasion was calculated by measuring the weight difference of the specimens before and after the test.

3.7 Dispersion grade value

The filler dispersion of the compound was evaluated in accordance with KS M ISO 11345 using a dispersion analyzer (DISPERGADER alphaview, Alpha Technologies). Surface images of the specimens were captured and compared with reference images, and the dispersion grade was determined based on the x-value.

3.8 Dynamic viscoelastic properties

The glass transition temperature (T_g) and dynamic viscoelastic properties of the compounds were evaluated using a rheometer (ARES-G2, TA Instruments). The temperature sweep conditions were performed in torsion mode from -60°C to 80°C at a heating rate of 5°C/min, with a frequency of 2 Hz and a strain of 0.5%. From this test, T_g and tan δ at 70°C were determined. The strain sweep conditions were conducted in torsion mode at 70°C, over a strain range of 0.5-16% at a frequency of 2 Hz, and tan δ at 70°C was measured at 5% strain.

Results and Discussion

1. Mooney viscosity, Bound rubber content

Figure 3, and Table 4 show the Mooney viscosity and bound rubber content measurement results. According to Mooney viscosity measurements, Mooney viscosity tended to increase gradually with increasing rCB content. This result is attributed to the poor dispersibility of rCB particles, which have a non-uniform particle morphology distribution and contain more impurities and higher ash content compared to conventional carbon black.[16] As a result, the flowability of the rubber matrix is restricted.[17] Additionally, the compound containing CCA showed a slight increase in Mooney viscosity. This can be attributed to the enhanced F-R interaction induced by CCA, which restricts the mobility of rubber chains within the matrix.

Bound rubber content show to decrease as the rCB loading increased. This is attributed to the lower specific surface area of rCB compared to that of conventional carbon black (N330), resulting in a reduced number of active sites available for adsorption and bonding with rubber chains, and consequently, a weaker F-R interaction. In contrast, the compound containing CCA exhibited an increased bound rubber content. This result suggests that CCA enhances the interaction between carbon black and rubber chains, thereby strengthening the F-R interaction and promoting the formation of bound rubber.

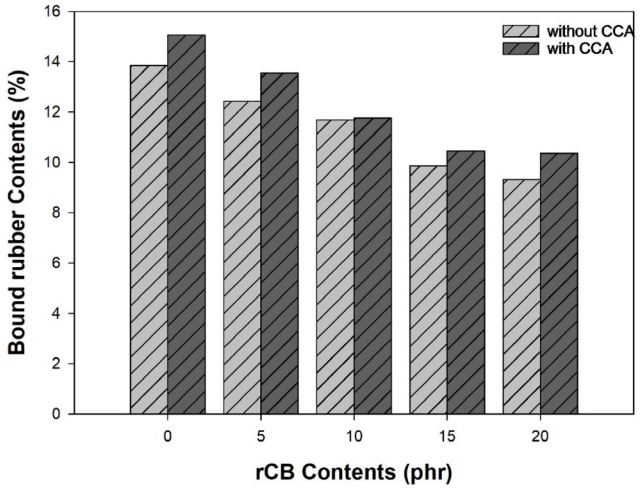

Figure 3. Bound rubber contents graph.

2. Cure characteristics

The results of the cure characteristics are presented in Figure 4 and Table 5. As the rCB content increased, both scorch time (t_{10}) and optimum cure time (t_{90}) showed a tendency to increase. This behavior is attributed to the difference in surface chemistry between N330 CB and rCB. Conventional carbon black possesses oxygen-containing functional groups, such as hydroxyl and carboxyl groups, on its surface, which promote interaction with the rubber matrix.

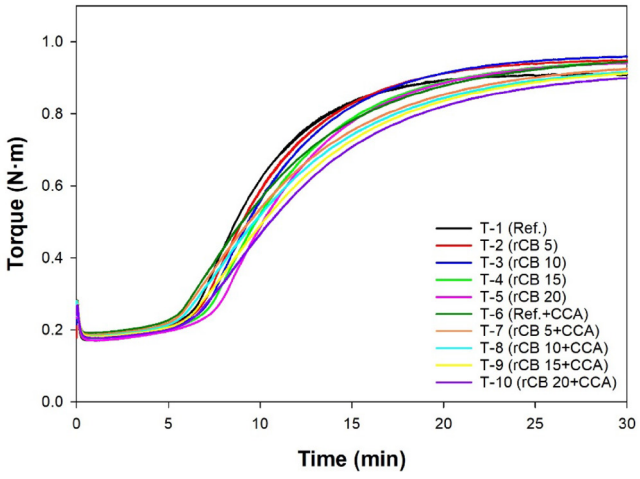

Figure 4. Cure characteristics graph.

Table 4. Results of Mooney Viscosity and Bound Rubber Contents

Compound	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	T-10
Mooney viscosity (MU)	50.3	52.9	53.7	54.7	55.7	56.1	55.6	55.9	56.9	57.4
Bound rubber contents (%)	13.8	12.4	11.7	9.9	9.3	15.1	13.6	11.8	10.5	10.4

Table 5. Cure Characteristics of the T-1 to T-10 Vulcanizates

Compound	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	T-10
T_{min} (N·m)	0.17	0.18	0.18	0.17	0.17	0.19	0.19	0.18	0.18	0.18
T_{max} (N·m)	0.91	0.95	0.96	0.94	0.94	0.95	0.93	0.92	0.91	0.90
T_{max} - T_{min} (N·m)	0.74	0.77	0.79	0.77	0.77	0.75	0.74	0.73	0.73	0.72
t_{10} (min)	6.17	6.53	6.83	6.97	7.35	5.93	5.96	6.10	6.48	6.67
t_{90} (min)	15.20	16.93	17.67	18.45	18.51	19.35	19.85	19.86	20.25	20.39

In contrast, rCB undergoes thermal degradation during the pyrolysis process, resulting in the loss or reduction of these functional groups. As a result, the filler is more difficult to disperse uniformly within the rubber, which interferes with the crosslinking reaction and leads to delayed t_{10} and t_{90}.[18] In contrast, compounds containing CCA exhibited a decrease in t_{10}, which is interpreted as the result of the amine functional groups in the CCA acting in a manner like vulcanization accelerators, thereby promoting the onset of vulcanization.[14]

Meanwhile, when comparing the torque values of compounds containing CCA, it was observed that both the maximum torque (T_{max}) and ΔTorque (T_{max}−T_{min}) decreased with increasing rCB content. This result is attributed to the reduction in crosslink density.

3. Crosslink density

The results of crosslink density measurements are presented in Figure 5 and Table 6. Overall, the crosslink density tended to decrease as the rCB content increased. This result is attributed to the lower specific surface area of rCB compared to that of N330, F-R interaction and subsequently has a negative impact on crosslink formation between rubber chains.

In contrast, the vulcanizates containing CCA exhibited higher crosslink density than those without CCA. This can be explained by the enhanced interaction between carbon black and rubber chains induced by CCA, which promotes the formation of a more developed crosslink network.

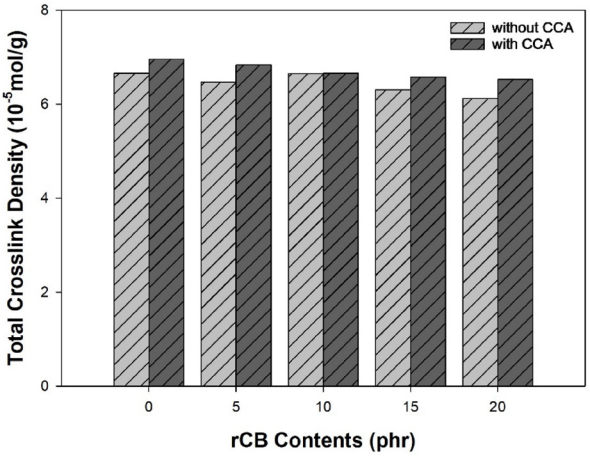

Figure 5. Crosslink density graph.

4. Mechanical properties

The results of mechanical property measurements are presented in Figure 6 and Table 7. Overall, the vulcanizates containing rCB exhibited lower tensile strength at room temperature compared to the reference compound (T-1), and this degradation in mechanical performance became more pronounced with increasing rCB content. Tensile strength and 100% modulus after thermal aging also showed a decreasing trend as the rCB content increased. This deterioration in mechanical properties is attributed to the reduced F-R interaction caused by the lower specific surface area and higher ash content of rCB. These characteristics interrupt the effective dispersion and interaction of the filler within the rubber matrix, thereby reducing the efficiency of stress transfer.

Furthermore, the vulcanizates containing CCA increased tear strength and 100% modulus at room temperature compared to those without CCA. 100% modulus also improved after thermal aging. These enhancements are attributed to the improved F-R interaction facilitated by CCA, which reinforces mechanical properties such as 100% modulus and tear strength.

Table 6. Crosslink Density of the T-1 to T-10 Vulcanizates

Compound	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	T-10
Crosslink density (10^{-5} mol/g)	6.66	6.47	6.65	6.31	6.12	6.96	6.84	6.66	6.58	6.53

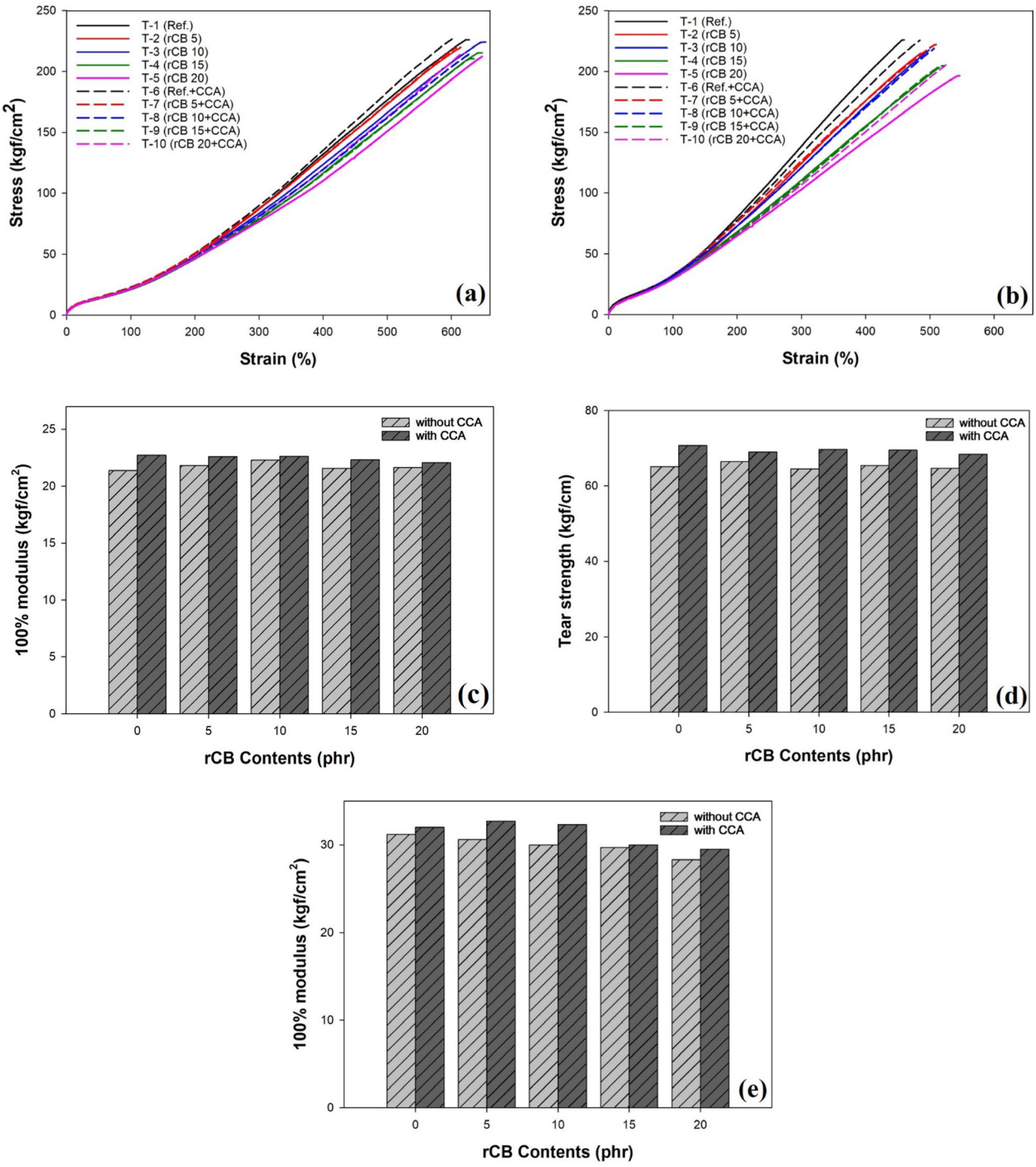

Figure 6. Mechanical properties of the T-1 to T-10 vulcanizates; (a) S-S curves at 25°C, (b) S-S curves after heat aging at the 105°C, 24hours condition, (c) 100% modulus at 25°C, (d) tear strength, and (e) 100% modulus after aging at the 105°C, 24 hours condition.

5. Carbon Black Dispersion Image Analysis (Dispersion Grade Evaluation)

Figure 7 and Table 8 show the dispersion grade measurements results. Overall, similar to the trends observed in Mooney viscosity and bound rubber content, the dispersion grade decreased with increasing rCB content, whereas the application of CCA improved the dispersion grade in the vulcanizates. This is attributed to the non-uniform particle morphology, more impurities and higher ash contents in rCB,

Table 7. Mechanical Properties of the T-1 to T-10 Vulcanizates

Compound	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	T-10
Tensile strength (kgf/cm^2)	225	218	224	215	209	231	219	225	211	209
Elongation at the break (%)	626	620	643	649	642	624	609	652	634	620
100% modulus (kgf/cm^2)	21.4	21.8	22.3	21.6	21.6	22.7	22.6	22.6	22.3	22.1
Tear strength (kgf/cm)	65.1	66.4	64.5	65.4	64.6	70.7	69.0	69.7	69.5	68.4
Tensile strength after aging (kgf/cm^2)	219	214	216	207	196	225	219	214	205	204
Elongation at the break after aging (%)	464	480	506	526	553	490	497	551	519	525
100% modulus after aging (kgf/cm^2)	31.2	30.6	30.0	29.7	28.3	32.0	32.7	32.3	30.0	29.5

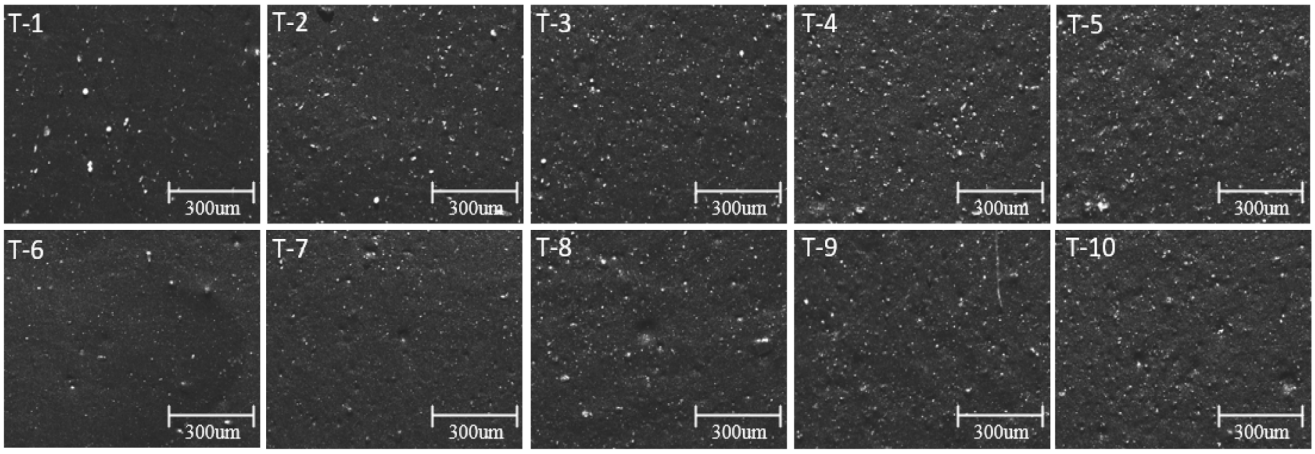

Figure 7. Dispersion images of compounds T-1 to T-10.

Table 8. Dispersion Grade Value (X-value)

Compound	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	T-10
Visual dispersion grade (X-value)	6.77	5.69	5.32	4.64	4.32	7.54	6.86	5.63	5.32	4.94

which interrupt the uniform dispersion of the filler within the rubber matrix. In contrast, the improved dispersion in the CCA-containing vulcanizates is interpreted as the result of enhanced F-R interaction promoted by CCA, which reduces carbon black agglomeration during vulcanization.

6. DIN Abrasion properties

The results of abrasion resistance measurements are presented in Figure 8 and Table 9. Overall, compared to the reference compound (T-1), the vulcanizates with higher rCB content (T-2 to T-5) showed a gradual decrease in abrasion resistance, which is attributed to the reduced F-R interaction caused by rCB. This reduction in F-R interaction is supported

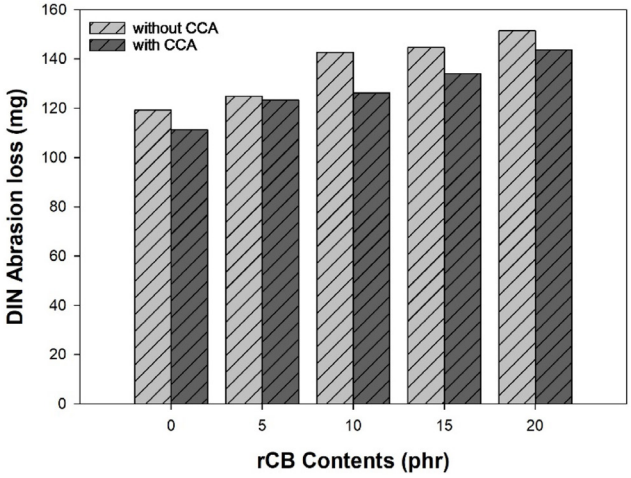

Figure 8. DIN Abrasion loss weight graph.

Table 9. DIN Abrasion Loss Weight

Compound	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	T-10
DIN Abrasion loss (mg)	119.3	124.9	142.7	144.8	151.5	112.2	123.4	126.3	134.0	143.7

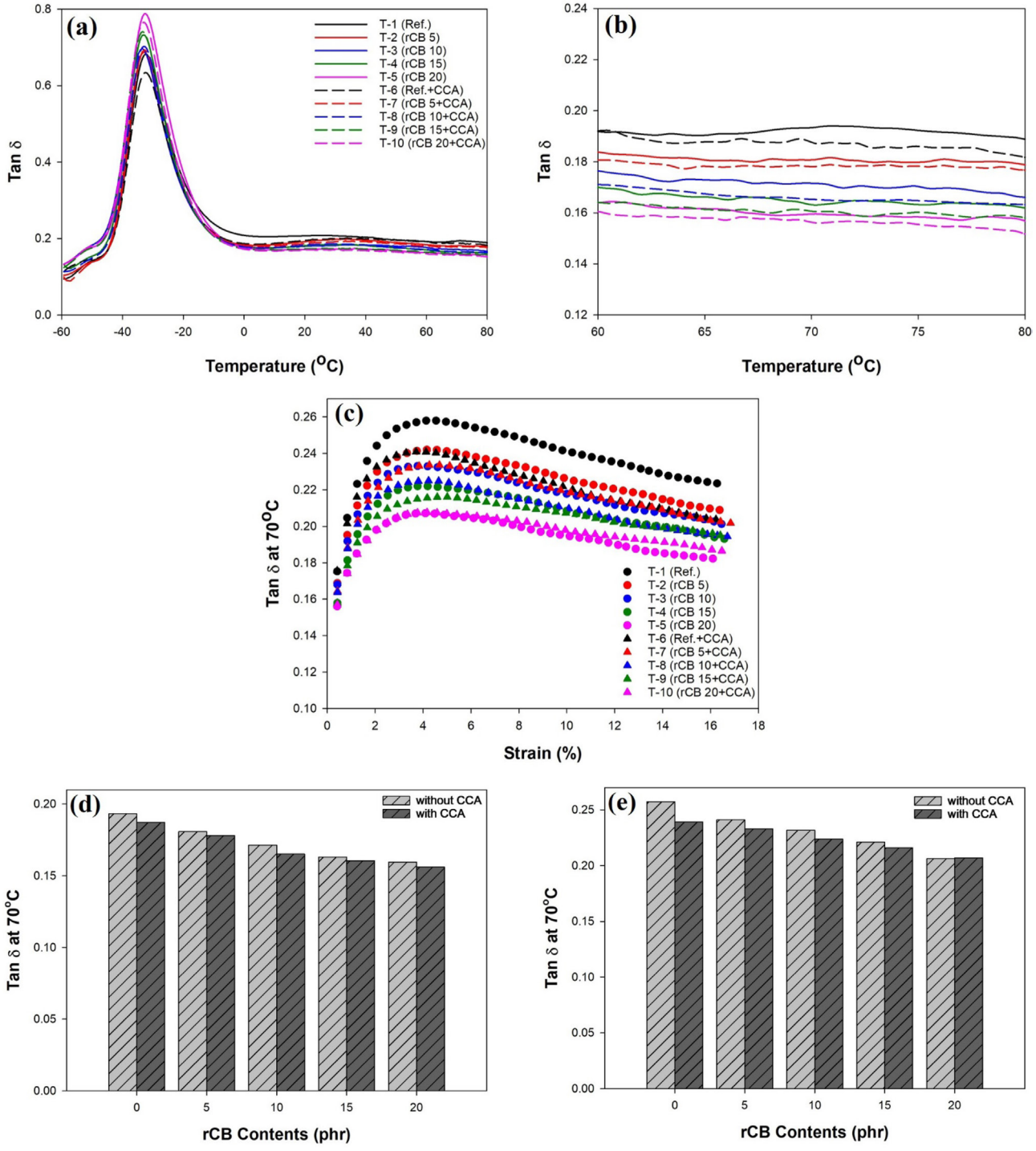

Figure 9. Viscoelastic properties of the T-1 to T-10 vulcanizates; (a) temperature sweep curves from -60°C to 80°C, (b) temperature sweep curves from 60°C to 80°C, (c) strain sweep curves from 0.5% to 16%, (d) tan δ at 70°C at 0.5% strain, and (e) tan δ at 70°C at 5% strain.

Table 10. Viscoelastic Properties by Temperature Sweep Condition

Compound	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	T-10
T_g (℃)	-32.1	-32.7	-33.4	-33.4	-32.7	-32.7	-32.7	-32.7	-33.4	-32.7
Tan δ at 70℃	0.193	0.181	0.172	0.163	0.160	0.187	0.178	0.165	0.161	0.156

Table 11. Viscoelastic Properties by Strain Sweep Condition at 5% Strain

Compound	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	T-10
Tan δ at 70℃	0.257	0.241	0.232	0.221	0.206	0.239	0.233	0.224	0.216	0.207

by the decrease in bound rubber content, which in turn leads to lower abrasion resistance.

In contrast, the CCA applied vulcanizates (T-6 to T-10) exhibited improved abrasion resistance compared to T-1 to T-5, despite having the same CB/rCB content. This improvement is interpreted as a result of enhanced F-R interaction promoted by CCA, which contributes to the improved abrasion performance of the vulcanizates.

7. Viscoelastic properties by temperature sweep and strain sweep

The results of dynamic viscoelastic property evaluations are presented in Figure 9 and Table 10, 11. As the rCB content increased, the tan δ values exhibited a decreasing trend. This behavior is attributed to the lower specific surface area of rCB compared to N330, which limits the formation of the filler-filler network (F-F network) and reduces the breakdown of the network and internal heat generation during deformation, thereby lowering the contribution to the loss modulus. Additionally, the weaker interaction between rCB and the rubber matrix leads to reduced hysteresis loss, and the irregular particle aggregation of rCB further hinders the development of a well-connected F-F network, both of which contribute to the decrease in tan δ.

Furthermore, the vulcanizates containing CCA showed a further reduction in tan δ. This result is interpreted as the effect of enhanced F-R interaction promoted by CCA, which facilitates bound rubber formation, suppresses carbon black agglomeration, and improves filler dispersion, ultimately reducing hysteresis loss.

Conclusions

In this study, the changes in rubber properties were evaluated when conventional carbon black (N330) was partially replaced with rCB. According to low specific surface area, particle size irregularity, and residual impurities, the use of rCB resulted in a decrease in bound rubber content, abrasion resistance, and dispersion quality, while the Mooney viscosity tended to increase. These deteriorations in material properties indicate that rCB alone has limitations in applications such as rubber track compounds, which require high load-bearing capacity and durability. To overcome these limitations, the CCA with bifunctional terminal groups was applied. The introduction of CCA enhanced the F-R interaction between carbon black and the rubber matrix, resulting in improvements in Mooney viscosity, bound rubber content, modulus, and abrasion resistance, along with a reduction in tan δ. In particular, the combined use of rCB and CCA improved the previously reduced properties such as abrasion resistance, dispersion, and modulus associated with rCB, enabling a performance level comparable to that of conventional carbon black-based compounds.

As a result, the T-7 compound (rCB 5 phr + CCA) exhibited the most comparable properties to the conventional T-1 compound, experimentally demonstrating the potential applicability of rCB as a partial replacement.

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Conflict of Interest: The authors declare that there is no conflict of interest.

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