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A COMPARATIVE ANALYSIS OF RECOVERED AND COMMERCIAL CARBON BLACK IN NATURAL RUBBER COMPOSITES: INFLUENCE OF PARTICLE DISPERSION AND ASH CONTENT ON MECHANICAL PROPERTIES

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ABSTRACT: This study compares recovered carbon black (RCB) and commercial carbon black (CCB) as reinforcing fillers in natural rubber composites, focusing on how their physical and chemical properties affect mechanical performance. RCB, derived from pyrolyzed end-of-life tires, supports circular economy goals but shows inconsistent reinforcement compared to CCB. Experimental analyses— including FTIR, particle size and ash content characterization, rheometry, abrasion, and mechanical tests—were conducted to explore these differences. While RCB and CCB have similar mean particle sizes, RCB exhibits a higher z-average diameter and polydispersity index, indicating more aggregation and poorer dispersion. RCB's significantly higher ash content reduces its reinforcing effectiveness. Mechanical testing showed that CCB-filled composites outperformed RCB filled composites in tensile strength, 300% modulus, and tear resistance, especially at higher loadings (20–25 phr). In contrast, RCB-filled composites matched or exceeded tensile strength at low loadings (5–10 phr) and showed greater elongation and resilience, suggesting higher elasticity but lower rigidity. At higher loadings, RCB performance declined due to filler–filler interactions and inert residues. Tear strength characteristics also worsened under these conditions. FTIR confirmed the presence of polar functional groups on both fillers, but RCB's structural limitations offset their potential reinforcing effect.

Keywords: recovered carbon black, mechanical properties, sustainable composite, natural rubber, rubber-filler interaction

1 INTRODUCTION

Natural rubber (NR) composites rely on reinforcing fillers to enhance their mechanical properties and durability in industrial applications. Among the most widely used fillers, commercial carbon black (CCB) plays a central role in improving tensile strength, elasticity, abrasion resistance, and overall product lifespan (Donnet & Bansal, 2013). Produced through highly controlled furnace processes, CCB provides uniform particle morphology and reliable reinforcement, making it a standard material in the manufacture of tires, belts, gaskets, and other rubber products subjected to mechanical stress (Mooney, 2015).

In recent years, the drive for environmental sustainability and resource efficiency has intensified interest in alternative fillers derived from waste materials. One such material is recovered carbon black (RCB), produced from the pyrolysis of discarded tires. The concept aligns well with circular economy goals by reducing waste, recovering valuable materials, and promoting cleaner production practices (Wang et al,2018; Karger-Kocsis & Hancox, 2019). However, despite its positive environmental impact, RCB has seen limited use in commercial rubber products (Ma & Zhao, 2020).

This study aims to assess the mechanical performance of natural rubber composites filled with either RCB or CCB. Through experimental evaluation of key mechanical and processing characteristics including hardness, abrasion resistance, rebound resilience, and curing behaviour, this research investigates the extent to which RCB can serve as a viable replacement for CCB in rubber reinforcement. The goal is to identify the root causes of any performance disparities between the two fillers and to derive insights that can guide future improvements in the production and application of RCB.

2 METHODOLOGY

Rubber composites were prepared by incorporating natural rubber with zinc oxide, stearic acid, and antioxidant agents using an internal mixer. Carbon black fillers—either recovered (RCB) or N330 commercial (CCB) served as the variable component and were added at different loadings of 5, 10, 15, 20, and 25 parts per hundred rubber (phr), followed by further mixing. Sulfur and accelerators were subsequently added using a two-roll mill to complete the compounding process. The mixtures were then vulcanized at 150°C under 15 MPa pressure using a hydraulic press. Vulcanization times were determined by rheometric analysis, specifically based on the optimum cure time (t90). Mechanical properties of the vulcanized sheets including tensile strength, elongation at break, 300% modulus, rebound resilience, and hardness were evaluated according to ISO 37:2024 and ISO 34-1:2022 protocols.

3 RESULTS AND DISCUSSION

The comparative analysis between recovered and commercial carbon black revealed several distinct differences in structural and performance behavior. Although both fillers displayed similar mean particle sizes in the range of 204 to 208 nm, RCB exhibited a significantly higher z-average diameter of 752.3 nanometers compared to 249.0 nanometers for CCB (Table 1).
This disparity suggests a greater tendency toward aggregation in RCB, resulting in larger secondary particle structures that reduce effective surface interaction with the rubber matrix. The polydispersity index (PDI) further confirmed this difference, with RCB showing broader particle size distribution than CCB, indicating less uniform dispersion.

Table 1. Particle size analysis of CCB and RCB

	CCB	**RCB**
Mean particle size (nm)	204.2	208
Z-average (nm)	249	752.3
PDI	0.323	0.455

Chemical composition analysis uncovered another notable distinction. The ash content of RCB was measured at 0.083%, substantially higher than CCB's 0.0013% (Table 2). This ash consists of inorganic residues that do not contribute to reinforcement and can interfere with the dispersion and bonding of filler particles within the rubber matrix. As a result, the active reinforcing surface of RCB is effectively reduced, weakening its contribution to mechanical strength.

Table 2. Ash content of CCB and RCB

Filler Type	Ash content,%
CCB	0.0013
RCB	0.083

Mechanical testing reflected these structural and compositional differences. Both CCB and RCB increased hardness with increasing filler loading (Figure 1). At low concentrations (5– 10 phr), RCB achieved hardness values comparable to or slightly exceeding CCB. However, at higher loadings (15–25 phr), CCB provided more effective reinforcement, achieving greater hardness values. Rebound resilience showed an opposite trend: CCB-filled composites demonstrated decreasing resilience as stiffness increased, while RCB-filled composites maintained or even improved resilience at higher phr (Figure 1). This suggests that RCB forms a more elastic and flexible matrix, but with reduced rigidity.

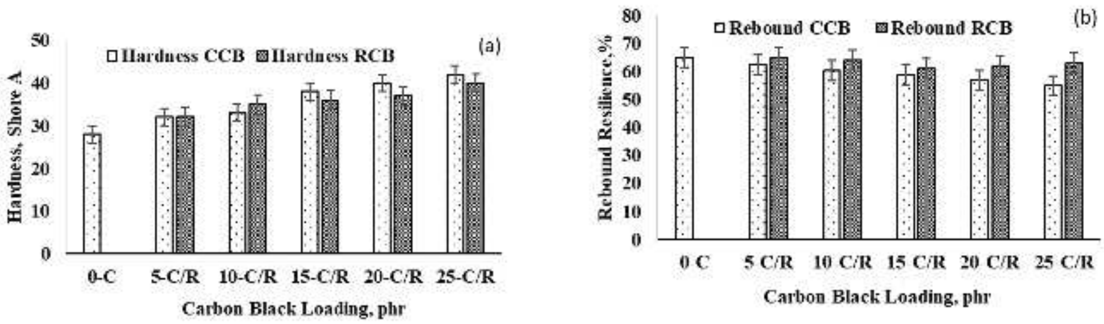

Figure 1. Hardness (a) and Rebound Resilience (b) of Rubber Vulcanizate

Tensile strength and elongation at break (Figure 2) provided further insight into the reinforcement effectiveness of each filler. The unfilled control sample exhibited a tensile strength of 15.02 MPa and an elongation at break of 1524%. CCB-filled composites showed consistent improvement in tensile strength with increasing filler content, reaching 19.9 MPa at 25 phr. RCB-filled samples initially outperformed CCB at 5–10 phr, peaking at 20.12 MPa, but exhibited a substantial drop to 10.75 MPa at 25 phr. This decline at higher RCB loadings suggests that particle aggregation and ash interference limit the effective reinforcement of the rubber matrix.

Elongation at break decreased with increasing filler loading in all cases, consistent with the expected stiffening effect. However, RCB-filled rubbers generally maintained higher elongation values than CCB-filled counterparts, indicating greater elasticity and flexibility due to weaker filler–matrix interactions. For example, at 10 phr, RCB-filled samples retained 1384% elongation versus 1342% for CCB-filled samples.

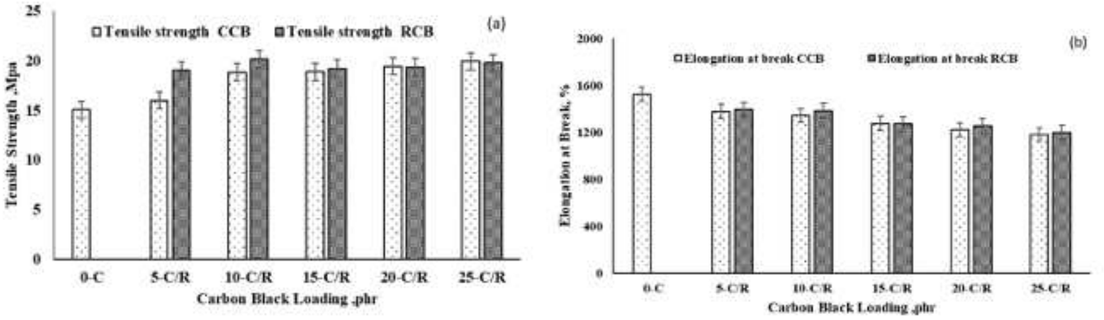

Figure 2. Tensile Strength (a) and Elongation at Break (b) of Rubber Vulcanizate

Modulus at 300% elongation further highlighted filler differences (Figure 3). CCB composites increased in modulus from 1.44 MPa at 5 phr to 2.03 MPa at 25 phr, reflecting greater stiffness and reinforcing efficiency. RCB also showed rising modulus values from 1.44 MPa at 5 phr to 2.10 at 25 phr. However, this increase did not correspond to improved tensile strength at higher loadings, indicating stress localization due to poor dispersion and filler–filler interactions. Tear strength data also revealed contrasting trends (Figure 3). CCB-filled composites improved steadily from 34.6 kN/m to 72.7 kN/m between 5 and 25 phr, attributed to robust filler–rubber networks that resisted crack propagation. In contrast, RCB-filled samples demonstrated minimal gains, increasing only from 31.0 to 39.6 kN/m across the same range. The performance plateau in RCB-filled composites at higher loadings reflects a failure to establish an integrated reinforcement phase, likely due to structural inhomogeneities and nonreinforcing ash content.

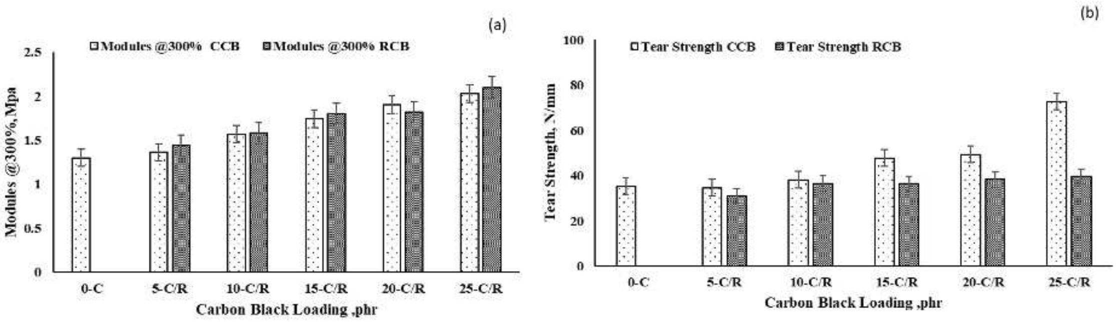

Figure 3. Modulus at 300% (a) and Tear Strength (b) of Rubber Vulcanizate

FTIR(Fourier Transform Infrared Spectroscopy) analysis revealed (Figure 4) the presence of similar functional groups on both carbon black types, including hydroxyl, carbonyl, and aliphatic bonds. RCB displayed stronger absorption peaks for polar groups, likely due to oxidation during pyrolysis. While these groups could theoretically enhance filler–rubber bonding, their positive effect is diminished by the previously discussed physical drawbacks of RCB.

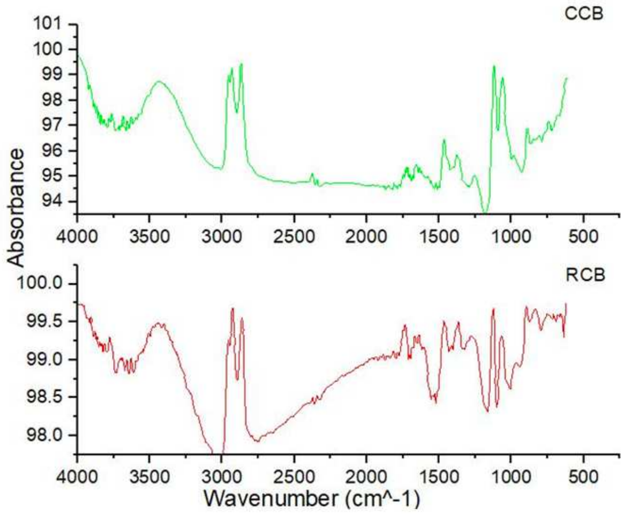

Figure 4. FTIR graph of CCB and RCB

4 CONCLUSION

Recovered carbon black (RCB) offers a sustainable alternative to commercial carbon black (CCB), but exhibits higher particle aggregation, greater ash content, and weaker dispersion, which limit its reinforcing efficiency. While RCB performs comparably at low loadings (5–10 phr) with higher resilience and elongation, CCB consistently delivers better mechanical strength at higher loadings. FTIR confirms similar surface chemistry in both fillers, but RCB's structural limitations outweigh its potential bonding advantages. Therefore, RCB is best suited for moderate-performance applications, while CCB remains preferable for demanding, high-load rubber products.

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