Mechanical Behavior of Carbon Nanotube Filled Styrene-Butadiene Rubber/Nitrile Butadiene Rubber Blends

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Abstract: This study evaluated the mechanical properties of styrene-butadiene rubber/nitrile butadiene rubber (1:1) blends reinforced with carbon nanotubes at 0–15 phr. Tests included resilience, tear resistance, abrasion resistance, hardness, tensile strength, and elongation per ASTM standards. At 10 phr carbon nanotubes, the blend showed a tensile strength of 27.77 kgf/cm², elongation at break of 288%, and rebound resilience of 60.39% outperforming other ratios. Above 10 phr, performance plateaued or declined, suggesting an optimal loading limit. The 10 phr composition is suitable for high-strength, high-toughness applications in automotive and industrial sectors.

Keywords: Styrene-Butadiene Rubber/ Nitrile Butadiene Rubber Blends; Synthetic Rubbers; Carbon Nanotubes; Mechanical Properties; Wear Resistance

1. Introduction

The rubber blending process mixes two or more rubber types to produce composite materials with excellent performance. In industrial and automotive applications, styrene-butadiene rubber (SBR) and nitrile butadiene rubber (NBR) are two of the most common choices. SBR is valued for its low cost and good abrasion resistance, which explains its common use in tire seals, treads, and hoses. However, the antioxidant and ultraviolet protection capabilities of pure SBR are relatively weak. This characteristic limits its use outdoors [1]. NBR, on the other hand, shows excellent resistance to oils and high temperatures and exhibits only limited swelling in oily environments, making it useful for fuel hoses and O-rings. However, its flexibility at low temperatures is suboptimal. To achieve both wear resistance and oil resistance while keeping good tensile strength and elongation at break. SBR and NBR are typically blended in a 1:1 ratio. Additionally, this helps shorten vulcanization time. Such a combination is suitable for products such as automotive sealing strips and industrial gaskets [2].

Although rubber blends provide some performance complementarity, fillers are still needed for more demanding applications. application scenarios. Fillers can improve specific properties, but their overall effect largely depends on their interaction with the rubber matrix. For example, adding montmorillonite to SBR/NBR blends improves their yield stress and toughness while stabilizing the glass transition temperature. In the rubber industry, in addition to the commonly used carbon black and silica fillers, various inorganic and emerging fillers are also employed. Commonly used inorganic fillers include carbonates and silicates; the former serves as an extender and enhances acid and alkali resistance. Emerging fillers include resins and starches [3]. The carbon nanotubes utilized in this experiment also fall into this category.

Beyond filler selection and compounding, the vulcanization process is pivotal in determining material performance. Vulcanization methods include cold and hot processes, with industrial applications classifying hot vulcanization into compression molding, injection molding, and steam curing depending on the medium. During vulcanization, cross-linking between rubber macromolecular chains forms a network structure, significantly enhancing the material's strength and elasticity. The required time, pressure, and temperature determine the quality of rubber products. Traditional high-temperature vulcanization techniques exhibit limited efficiency. Carbon nanotubes are widely studied in materials science and engineering. These unique properties—mechanical, electrical, and thermal—make it attractive for applications including composite materials, sensors, and nanoelectronic devices. Even small CNT additions during vulcanization can improve the performance of rubber compounds. Vennemann reported that good CNT dispersion and interfacial compatibility improved the mechanical performance of silicone rubber, SBR, and NBR composites [4]. Iqbal's team reported that CNTs incorporation accelerates vulcanization in nitrile rubber (NBR), emulsion-polymerized styrene-butadiene rubber, and solution-polymerized styrene-butadiene rubber systems [5]. Given CNTs' promising potential in rubber manufacturing, future research should explore their application across more specialized categories and product types, such as fluorocarbon or hydrogenated NBR.

To investigate the role of carbon nanotubes in the SBR/NBR blend system, five CNT loadings (1, 3, 5, 10, 15 phr) were added to SBR/NBR blends. An unfilled blend was used as the control. Testing followed ASTM standards for rebound resilience (D2632), tear strength (D624), abrasion resistance (D5963), hardness (D2240), and tensile strength (D412). The 10 phr CNTs blend outperformed all others: tensile strength reached 27.7 kgf/cm^2 (control: 22.6 kgf/cm^2); tear strength improved by ~22%; and both rebound resilience and elongation were the highest among the tested formulations. Overall, 10 phr CNT gave a good balance of strength, elasticity, and wear resistance. This provides a practical formulation option for oil- and wear-resistant materials used in automotive seals and industrial components.

2. Materials and Methods

2.1 Materials and Composition

CNTs, NBR, and SBR were all provided by the Rubber Laboratory of Wuhan Institute of Technology. The model number for NBR is N41 (containing 28-30% acrylonitrile and 70-72% butadiene), and for SBR it is SBR-1500 (containing 22-25% styrene and 75-78% butadiene). Table 1 shows the materials and ingredients used during the experiment. SBR/NBR composite was made at a 1:1 weight ratio. Five different loading ratios of CNTs powder were added: 1 phr, 3 phr, 5 phr, 10 phr, and 15 phr. All raw materials and finished products should be stored at room temperature.

Table 1. Materials and Composition

Material	0S	1S	3S	5S	10S	15S
SBR	50	50	50	50	50	50
NBR	50	50	50	50	50	50
ZnO	4	4	4	4	4	4
Stearic acid	2	2	2	2	2	2
MBT	1	1	1	1	1	1
TMTD	0.2	0.2	0.2	0.2	0.2	0.2
Sulphur	2.5	2.5	2.5	2.5	2.5	2.5
CNTs	0	1	3	5	10	15

ZnO: Zinc Oxide, MBT: Mercaptobenzothiazole, TMTD: Tetramethylthiuram disulfide.

2.2 Experimental Procedure

The rubber samples were prepared through three main steps: grinding, mixing, and molding. First, the rubber was milled on a two-roll machine for 10 minutes to achieve uniform blending. Subsequently, curing agents were added and mixed for 30 minutes to promote cross-linking reactions. Finally, compression molding was performed after the addition of sulfur to form the required samples.

2.3 Testing and Characterization

Torque and curing time were measured using a moving die rheometer (MDR) to assess the progress of the curing reaction. Tensile properties were tested according to ASTM D412 using a universal testing machine (UTM) to determine the modulus at 100% elongation, thereby evaluating the material's elasticity. Tear strength testing was conducted following ASTM D624 on the same universal testing machine to assess the material's toughness and tear resistance. Wear resistance was evaluated using a DIN abrasion tester (according to ISO 4649), and the wear resistance index (ARI%) was calculated. Rebound resilience was measured using a Wallace Dunlop resilience tester following ISO 4662:1986. Hardness was measured using a Shore A durometer.

3. Result and Discussion

In polymer rubber, crosslinking is what happens when polymer chains get linked together by covalent bonds, building a network structure. NBR (acrylonitrile butadiene rubber) and SBR (styrene-butadiene rubber) are two common rubber materials that exhibit differences in their cross-linking characteristics. Studies have shown that the addition of fillers increases curing time, a phenomenon likely related to the rubber's crosslinking properties [6]. Table 2 presents the measurement characteristics of all samples. In this experiment, it was observed that the sample with 10 parts per hundred rubber (phr) of CNTs exhibited the longest curing time, indicating the highest crosslinking efficiency. NBR typically has a higher crosslink density, forming more covalent bonds, leading to excellent oil and chemical resistance suitable for applications requiring abrasion and corrosion resistance. On the other hand, SBR has a relatively lower crosslink density, providing good elasticity and flexibility.

Table 2. Properties of all Samples

Property, unit	0S	1S	3S	5S	10S	15S
Cure time, min	3.43	4.98	5.51	5.24	5.52	5.29
Hardness, Shore A	50.1	52.0	52.2	52.5	52.8	52.9
Tensile strength, kgf/cm^2	22.8	24.35	25.11	25.3	27.77	26.58
Elongation in tension, %	230	247	250	253	288	275
Tear strength, kgf/cm^2	130.8	150.2	180.3	175.0	176.0	182.0
Rebound resilience, %	40.75	48.75	50.66	55.28	60.39	57.27
Abrasion resistance index	70	75	72	72	64	63

3.1 Resilience

Figure 1 illustrates the resilience of all samples. The maximum elasticity, approximately 62.39%, was observed when rubber was combined with 10 phr of CNTs. A gradual increase in elasticity was noted upon the addition of 1 phr of CNTs. The trend of increasing elasticity continued from 3 phr to 10 phr. Following the inclusion of 15 phr of CNTs, there was a slight decrease in the CNTs content. The improvement in mechanical properties did not continue beyond 15 phr CNT; in fact, a slight decrease in elasticity was observed at this loading, suggesting an optimal concentration. This behavior can be explained by the load transfer mechanism. When the filler content is high, the distance between CNT particles becomes very small. While the resulting filler network can effectively bear external loads, it also restricts the mobility of the rubber chains. Material becomes stiffer but loses some of its ability to return to its original shape after deformation.

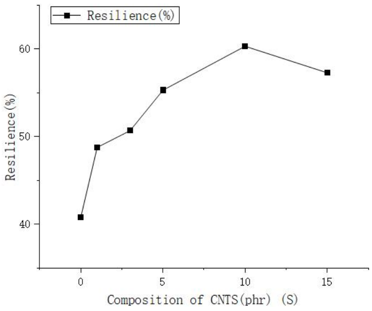

Figure1.Resilience Comparison of all Samples

3.2 Abrasion

Figure 2 demonstrates the wear resistance performance of all compounds expressed as percentages. When 1 pound of CNTs is incorporated into rubber, the highest resistance is achieved, approximately 72%. As the content of CNTs increases from 5 phr to 10 phr, there is a decreasing trend in resistance, indicating the impact of CNTs addition on resistance [7]. At 10 phr of CNTs content, the wear rate peaks at around 62% ARI, suggesting that within a certain range of additive amounts, an increase in CNTs may not necessarily result in improved wear resistance. The combined effect of aggregation defects induced by excessive CNTs and inhibited vulcanization. Furthermore, upon adding 15 phr the observed resistance level is approximately equivalent to 68% of ARI, demonstrating the influence of different hard phases on the performance of composite materials. Overall, the wear resistance of pure compounds surpasses that of composite forms, implying that the introduction of new hard phases may lead to an increase in wear rate, necessitating careful consideration in composite material design.

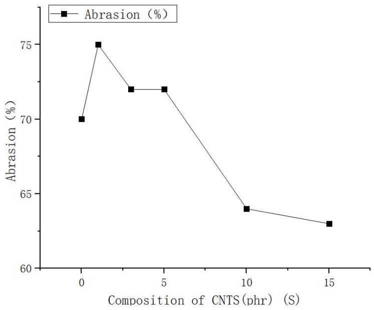

Figure 2. Comparison of Abrasion Resistance across all Samples

3.3 Tensile Strength and Elongation

Figure 3 shows the tensile strength characteristics of blends with different proportions of CNTs. As the CNTs increased from 0 phr to 5 phr, the tensile strength gradually increased; when the content reached 10 phr, the tensile strength rapidly rose to a peak of 27.77 kgf/cm². When the CNTs content increased to 15 phr, the tensile strength of the rubber matrix decreased. Figure 4 presents the tensile performance of these compounds. When rubber was mixed with 10 phr of CNTs, the maximum elongation, about 288%, was achieved; while when the CNTs content increased to 15 phr, the elongation slightly decreased to 275%.

The continuous increase in tensile strength confirms the reinforcing effect provided by CNT filler particles in the composite.

Excessive filler content induces a hardening effect in CNTs, which tend to aggregate into bundles within the rubber matrix, and reducing the mechanical properties of the material.

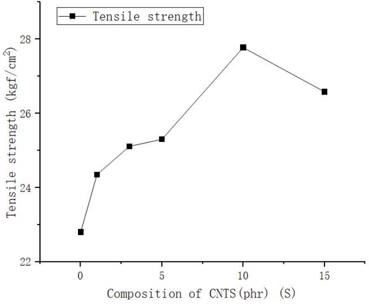

Figure 3. Tensile Strength of the Various Samples Compared

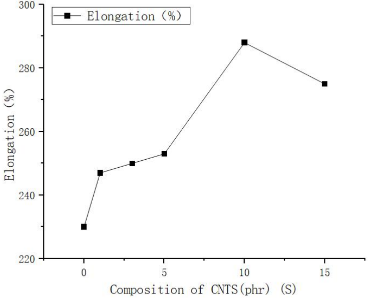

Figure 4. Tensile Elongation Measured for Each Sample

3.4 Hardness

Figure 5 shows that hardness increased steadily with CNT loading. The increase was moderate across the tested range, and the highest value (about 51.6 Shore A) was obtained at 15 phr CNT. Hardness responded more to higher CNT loadings than to lower ones. However, increasing filler content to raise hardness may come at the expense of other properties [8]. In addition to CNT content, hardness is governed by filler's dispersion state in the rubber [9]. Each final value represents the mean of three repeated and independent experiments.

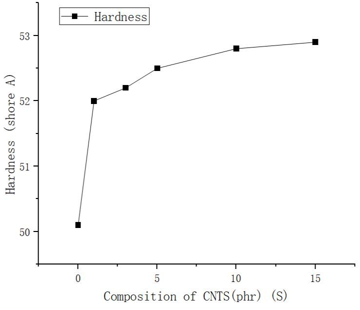

Figure 5. Hardness Comparison of all Samples

3.5 Tear Strength

Figure 6 shows the changes in tear strength with CNTs loading. Tear strength increased from 130.8 kgf/cm² (0 phr) to 180.3 kgf/cm² (3 phr). It decreased between 3 and 5 phr, and rose again from 5 to 15 phr and reached about 182.0 kgf/cm² at 15 phr. This behavior is related to changes in CNTs dispersion and interfacial stress transfer in the composite [10].

To sum up, the 10 phr CNTs filled SBR/NBR blend provided the most balanced performance. Relative to the unfilled blend, tensile strength increased by 22%, tear strength by 35%, toughness by 48%, and hardness by about 5%, while density changed only slightly. This results indicate CNT is an effective reinforcement level for improving mechanical performance without a significant density penalty.

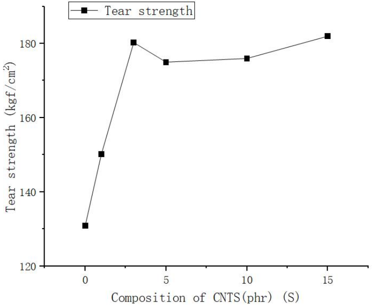

Figure 6. Tear Strength Comparison of all Samples

4. Conclusion

This study measured the effects of varying carbon nanotubes filler ratios on the physical properties of SBR/NBR blends. The optimal performance results were as follows: the tensile strength of the compound was 27.77 kgf/cm² (10 phr); the elongation at break was 288% (10 phr); the rebound resilience was 60.39% (10 phr); the tear strength was 182.0 kgf/cm² (15 phr); the abrasion resistance was 75% ARI (1 phr); and the hardness was 52.9 Shore A (15 phr). Overall, when carbon nanotubes were added to SBR/NBR (1:1) rubber, the 10 phr content exhibited the best mechanical properties, with only a slight reduction in abrasion resistance.

References

[1] GUO Y, TIAN H, ZHANG H, et al. High heat-and oil-resistant and gas barrier thermoplastic elastomers based on hydrogenated nitrile rubber and fluoro-copolymer. Industrial & Engineering Chemistry Research, 2023, 62(38): 15490-15498.

[2] ZHAO R P, YIN Z G, ZOU W, et al. Preparation of high-strength and excellent compatibility fluorine/silicone rubber composites under the synergistic effect of fillers. ACS Omega, 2023, 8(4): 3905-3916.
[3] HOU Q Q, XU F, DONG Y Z, et al. Preparation of fluorine certified reference material for fluoroether rubber. Journal of Physics: Conference Series, 2023, 2460(1): 012116.
[4] KUMMERLÖWE C, VENNEMANN N, YANKOVA E, et al. Preparation and properties of carbon nanotube composites with nitrile- and styrene-butadiene rubbers. Polymer Engineering & Science, 2013, 53(4): 849-856.
[5] IQBAL S S, ADREES M, AHMAD A, et al. Tuning of thermo-mechanical performance: modified multiwalled carbon nanotubes reinforced SBR/NBR/SR nanocomposites. Key Engineering Materials, 2018, 778: 71-78.
[6] YADAV S G, GUNTUR N P R, GOPALAN S. Effect of titanium carbide as a filler on the mechanical properties of styrene butadiene rubber. Materials Today: Proceedings, 2020, 24(4): 1552-1560.
[7] JIA Z, GUO B, JIA D. Advances in rubber/halloysite nanotubes nanocomposites. Journal of Nanoscience and Nanotechnology, 2014, 14(2): 1758-1771.
[8] ESSAWY H, EL-NASHAR D. The use of montmorillonite as a reinforcing and compatibilizing filler for NBR/SBR rubber blend. Polymer Testing, 2004, 23(7): 803-807.
[9] ESSAWY H A, TAWFIK M E, EL-SABBAGH S H. Rubber nanocomposites based on compatibilized NBR/SBR blends using a series of amphiphilic montmorillonites. Journal of Elastomers & Plastics, 2014, 46(2): 113-131.
[10] KHALF A I, NASHAR D E E, MAZIAD N A. Effect of grafting cellulose acetate and methylmethacrylate as compatibilizer onto NBR/SBR blends. Materials & Design, 2010, 31(5): 2592-2598.