The effect of modified carbon black on filler dispersion and dynamic properties of natural rubber nano compounds

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Abstract
In this research, the effect of a modified carbon black on the morphology and dynamic properties of nano-silica/Natural rubber nanocomposites was studied. The results revealed that the modification process influenced curing properties. The ΔTorque increased to the value of 13.6 dN.m after surface modification. Scanning electron microscopy (SEM) analysis indicated better dispersion of the modified CB in NR nanocomposites. The dynamic-mechanical analysis (DMA) showed that modified CB reduced rolling resistance and improved wet grip potential. Also, utilization of modified CB decreased glass transition from -56 °C to -65 °C. Overall, selecting modification approaches is crucial for achieving optimal results in the performance and application of rubber compounds.
Keywords: Polymer nanocomposites, Carbon black, Natural rubber, Modification, DMA

Introduction
Polymer nanocomposites are receiving significant attention due to their valuable practical uses. Natural rubber, also known as cis-1,4-poly(isoprene), is primarily obtained from the latex of Hevea brasiliensis trees [1]. It has excellent resilience, high tensile strength, and good tear and wear resistance. However, challenges include susceptibility to aging, poor resistance to oils and solvents, and limited temperature range. NR is reinforced with different types of fillers to improve its properties. Tire treads are commonly reinforced with either silica or carbon black. These two fillers play a crucial role in determining tire performance. Nano-silica offers several advantages, including lower rolling resistance (improved fuel efficiency) and enhanced wet grip (enhanced safety). Carbon black has been conventionally used as a reinforcing filler in tire treads. Carbon black significantly improves tensile strength, modulus, tear strength, and abrasion resistance. A current trend in rubber technology involves utilizing hybrid fillers, which consist of combinations of two or more distinct types of fillers [2]. Based on our previous work [3], modified CB demonstrates significant potential for application as a filler in rubber compounding. Therefore, silane-modified-CB in nano-silica-reinforced NR nanocomposites aiming to enhance tire performance have been studied. Understanding natural rubber compounds' dispersion and dynamic-mechanical properties is essential for realizing their optimal design and applications. The present study aims to investigate the effect of modified CB on the morphology and dynamic properties of nano-silica-filled natural rubber nano compounds.

Experimental
As explained in our previous work [3], carbon black was initially oxidized by citric acid monohydrate and the material obtained was modified by TESPT. Finally, the TESPT-functionalized CB was dried at 50 °C and was labeled as "Modified-CB". Table 1 presents the composition of the NR compounds prepared in this study. A two-roll mill was used to mix the ingredients, and then the rubber compounds were cured in a compression mold at 160 °C and a pressure of 150 bar.

Table 1: Formulation of natural rubber nanocomposites.

Samples / Ingredients*	CB/Nano-Silica/NR	Modified-CB/Nano-Silica/NR
NR (phr)	100	100
CB (phr)	15	0
Modified-CB (phr)	0	15

*Amounts of other components in both nano compounds:
Nano-Silica, 5, Nano-ZnO, 6, Stearic acid, 2, S, 3, and TBBS, 4 phr.

Results and discussion
Figure 1 shows the cure curve (torque vs time) of NR nano compounds obtained by MDR at 160 °C. ΔTorque represents the variation between the maximum and minimum torque observed in the cured sample, indicating alterations in the cross-link density (CLD) of the vulcanized rubber. According to Figure 1, the Modified-CB/Nano-Silica/NR compound revealed higher ΔTorque (13.6 dN.m) and, as a result, a higher CLD value (202.1 mol/m^3). The obtained results conformed with the other report [4].

Figure 2 presents a comparison of SEM images (at the magnitude of 2 μm) showing the cross-sectional surfaces of cured NR nano compounds with CB and Modified-CB fillers. The addition of TESPT coupling agents improves the interaction between the fillers and rubber, reducing their tendency to aggregate. As a result, modified-CB is better dispersed within the NR matrix, leading to improved dynamic-mechanical properties. The results of SEM images were consistent with the results of dynamic properties [5].

The DMA test was conducted to investigate the dynamic-mechanical behavior of the cured nano compounds at a constant frequency of 1 Hz with a temperature sweep between -100 to 80 °C at a heating rate of 5 °C/min. Figure 3 (a) illustrates the comparison of the damping or loss factor (tan δ) versus temperature at 1 Hz for selected natural rubber nanocomposites. Figure 3 (b) shows Modified-CB-Oxi/Nano-Silica/NR represented a high wet grip (high tan δ at 0 °C). At the same time, it illustrates low rolling resistance and reduced fuel consumption and pollution (low tan δ at 60 °C) compared to the carbon black/Nano-Silica/NR sample due to the better filler dispersion in NR nanocomposite. Similar observations were reported in another report [4].

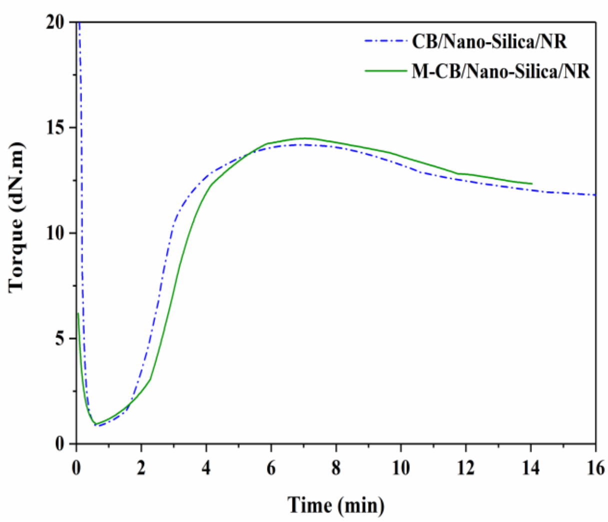

Figure 1. The curing curve of NR nanocomposites obtained by MDR at 160 °C.

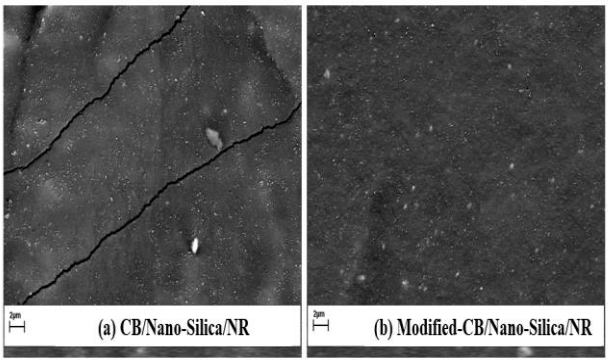

Figure 2. SEM images of Nano-Silica/NR nanocomposites with CB (a) and Modified-CB (b) at the magnitude of 2 μm.

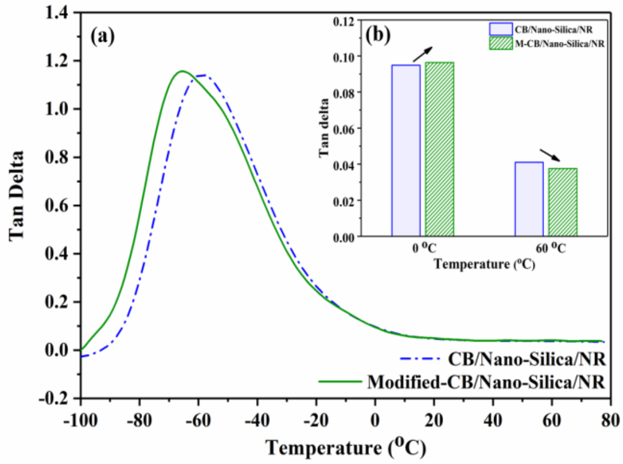

Figure 3. Damping factor (Tan δ) versus temperature for CB/Nano-Silica/NR and Modified-CB/Nano-Silica/NR compounds at 1 Hz.

Conclusions

NR nanocomposites were prepared via a two-roll mill with different types of filler. DMA and SEM analysis showed that the prepared NR nanocomposites with modified CB have lower T_g and rolling resistance and enhanced wet grip than CB fillers due to better filler dispersion. Moreover, the modified CB increased ΔTorque, which resulted in a higher CLD value.

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