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Rheological properties of NBR/CR blends as a function of silicon dioxide grain size gradation

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Abstract
This study focuses on the extent to which the rheological properties of acrylonitrile butadiene rubber (NBR)/chloroprene rubber (CR) blends are affected by the variation of silicon dioxide grain size. Silicon dioxide (SiO_2) as a nanopowder filler has been added with 50 wt.% and different grain size particles (0-150 nm), and studied the effect of these additives on viscosity, scorch time, cure time and max torque for NBR/CR blends. The results obtained from the rheological tests showed that viscosity and max torque increased with increasing of silicon dioxide grain size, while the result was inverse with scorch and cure time, where the larger grain size of silicon dioxide will lead to reduce both the scorch- and the cure time.
Keywords: NBR/CR, SiO_2 grain size, Rheological properties, Rubber blends
Kulcsszavak: NBR/CR, SiO_2 szemcseméret, Reológiai tulajdonságok, Gumi keverékek

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1. Introduction

It is widely thought that, "Rheology" as a science, only used for the applications of material science and engineering, but in fact it is widely applied in other scientific fields such as mathematics, physics, geology, chemistry, biology.., etc. [1-2]. In materials processing, the rheological properties have a considerable and important influence and through the stages of using material (rubber as example) for many industries, because of their impact on the development of the fabrication and stability to operate of the product and performance in the final form. Many scientific literatures were published about the effectiveness of fillers or working conditions and their relation to rheological properties of rubber [3-8]. Al-Maamori in his Ph.D thesis investigated the mechanical and rheological properties of rubber parts fabricated from NBR with silicon dioxide and rise husk powder additions [2]. Al-Maamori, Al-Mosawi and Abdulsada studied the effect of the novolac nanoparticle additives (0-40 wt.%) on viscosity, max torque, scorch time, and cure time of NBR/CR blends [9-10]. Al-Maamori and Al-Mosawi in a patent have been studied the mechanical and rheological properties of rubber parts with different amounts of cement and rise husk waste [11], Thomas et. al. investigated the effect of adding TiO_2, $Ca_3(PO_4)_2$ and layered silicate on the mechanical and rheological properties of the nitrile rubber, where, they indicated that particle geometry of additives have a clear effect on glass transition temperature values for the rubber blends [12].

2. Methodology

a. Materials: Acrylonitrile Butadiene Rubber (30% AN) and Chloroprene Rubber as a blend, silicon dioxide nanoparticles (10-150nm).

b. Mixing process and samples preparation: The two batches composition used in this article shown in *Table. 1*, and these two batches were prepared by roll milling process with Comerio Ercole Busto Arsizio roll mill machine. The samples were prepared as a disc shape with 6 mm in thickness and 40mm in diameter and 6mm in thickness by using hydraulic mould at 1.4 MPa pressure and temperature 150°C.

c. Calculating of rheological properties: Oscillating disc Rheometer (Rheometer ODR 2000E) was used calculating of rheological properties according to (ASTM D1646-68) standard and with operational conditions 0.35 MPa bar pressure and 185°C in 6 min [13].

d. Preparation of silicon dioxide and tests: The silica nanoparticles were prepared by precipitation method. Atomic force microscope (AFM) imaging was performed for checking the surface roughness and grains distribution (see *Fig. 1* and *Fig. 2*).

Compounding Ingredients	Parts per hundred rubber (pphr)
NBR/ CR	50/50
Silicon dioxide	0 and 50
Zinc oxide	3
Stearic acid	1
DOP	1
TMTD	1.5
6PPD	1.5
Sulfur	1.5

Table 1. Composition of batch
1. táblázat A keverék összetétele

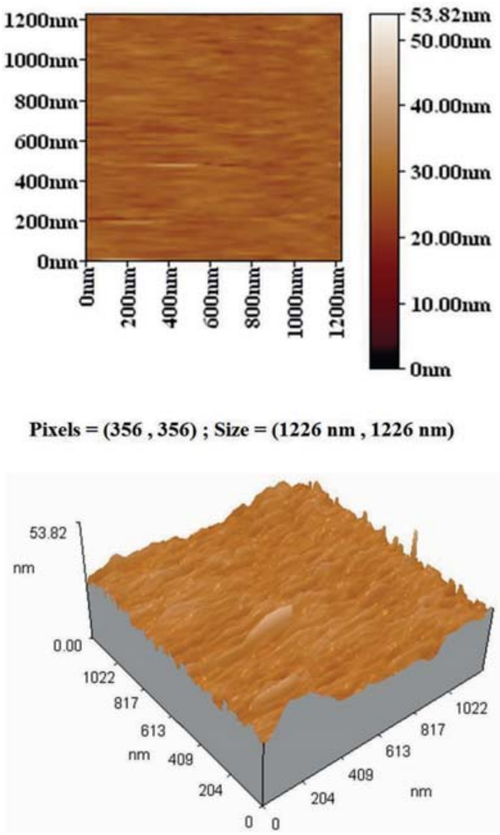

Fig. 1. *AFM imaging analysis for silicon dioxide grains*
1. ábra *A szilícium-dioxid szemcsék AFM analízise*

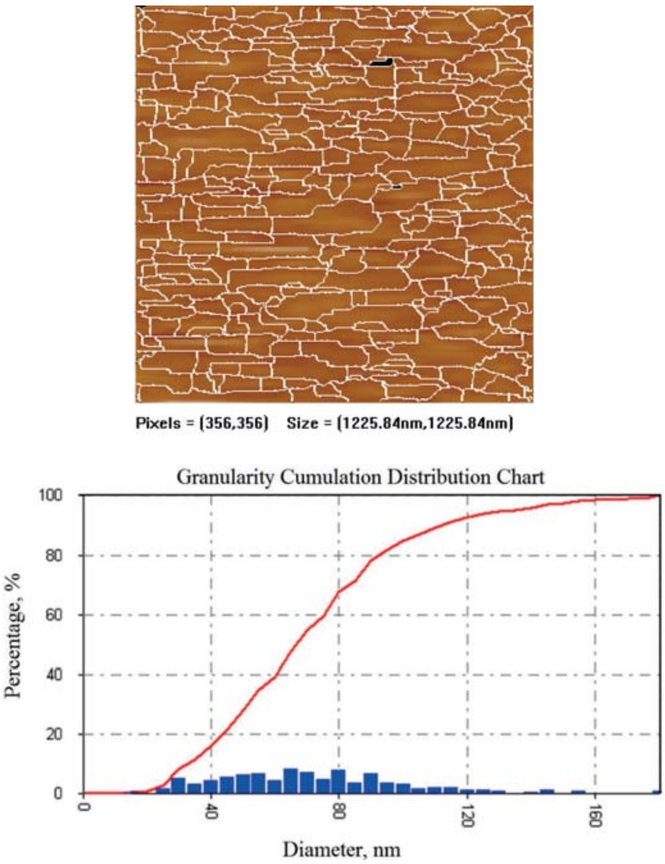

Fig. 2. *Granularity cumulative distribution for silicon dioxide grains*
2. ábra *A szilícium-dioxid szemcsék kumulatív eloszlása*

3. Reslults and discussion

Fig. 3 and *Fig. 4* represent the behavior of viscosity and max torque as a function of silicon dioxide grain size respectively. From these two figures we noted that viscosity and torque are increasing as silicon dioxide grain size increases, because the small grain size particles will diffuse more easily than large grain size particles through the chains of rubber, therefore the viscosity and torque will increase. On the other hand, the large grain size particles inhibit diffusion process and rubber chains movement. This means that the silicon dioxide is an active filler, no wonder the viscosity is about double with the same quantity as filler as rubber itself and triple with 100 pphr. The torque is more or less proportional to viscosity; therefore the torque increase can be taken as relative viscosity. The relative viscosity increase is higher than calculated from the Einstein's law ($\eta_{sp} = 2.5\Phi$, where Φ is the volume fraction of dispersed particles) therefore silicon dioxide has reinforcing effect.

The comparison between the results for fixed weight percent of silicon dioxide of various sizes shows that the higher grain size of silicon dioxide results in decreasing scorch and cure times as shown in *Fig. 5*. This is due to the grain size which resembles a measure for the specific surface area in contact with the rubber, where as this area decreased (i.e. more fine size contact area) results in decreasing in the physical bonds with the rubber chains and causes reduction in both scorch and cure times.

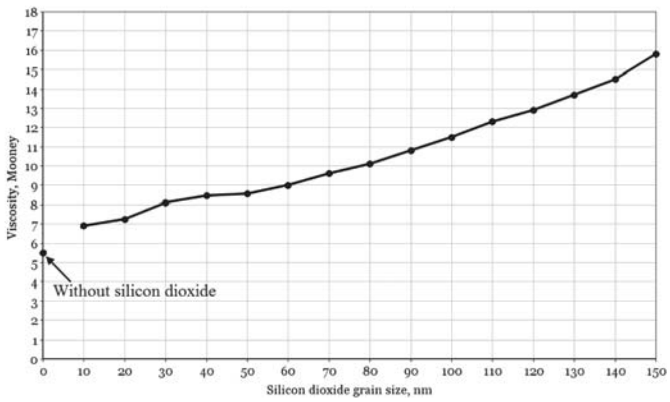

Fig. 3. *Viscosity vs. silicon dioxide grain size*
3. ábra *Viszkozitás a szilícium-dioxid szemcseméret függvényében*

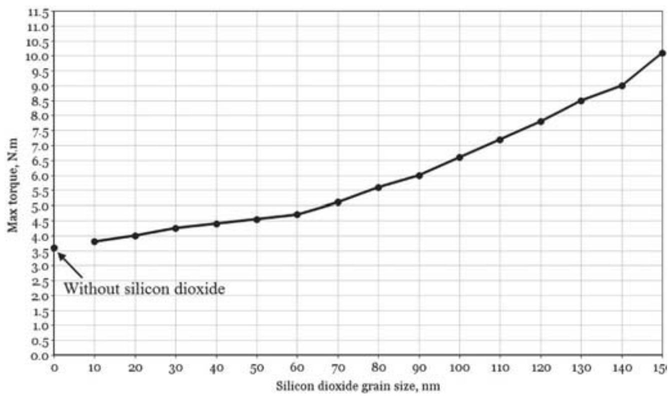

Fig. 4. *Max torque vs. silicon dioxide grain size*
4. ábra *Maximális nyomaték a szilícium-dioxid szemcseméret függvényében*

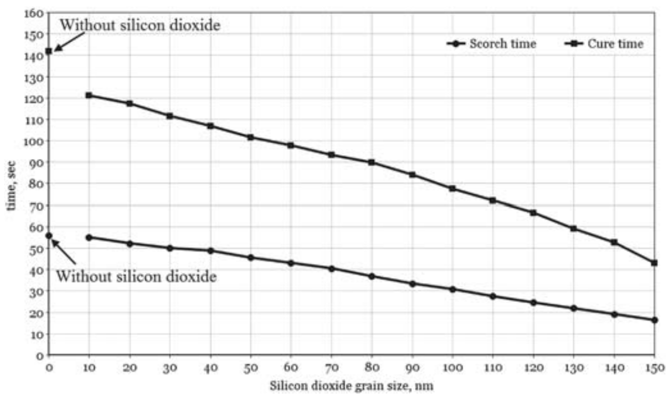

Fig. 5. Scorch and cure time vs. silicon dioxide grain size
5. ábra Scorch és keményedési idő a szilícium-dioxid szemcseméret függvényében

4. Conclusions

1. The practical results showed that silicon dioxide has an accelerating effect on the crosslinking reaction of rubber blends.
2. The crosslinking will increase due to the interaction between silicon dioxide and sulfur, where the scorch process is about 3.6 times faster and the difference is more than 40% if it is not present. Similarly, the cure time is also shorter about three times.
3. Increasing grain size of silicon dioxide particles resulted in higher viscosity and maximum torque.

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