INTRODUCTION

• Styrene-butadiene rubber (SBR) is a synthetic copolymer of styrene and butadiene
• It is commonly used in the tire industry
• Star-shaped vs. linear SBR
  • Improvements in wet traction, rolling resistance, rubber-filler interactions, abrasion loss, hysteresis
• Silica is a popular reinforcing filler
• Commonly used to reinforce tires
  • Rolling resistance, traction, wet-sliding friction

Derived from thermodynamic approach

The Leonov model is a constitutive model for predicting rheological behavior

The three highest surface area compounds exhibited a plateau in G(t) increase with filler surface area in the linear viscoelastic regime

ABSTRACT

The rheological behavior of star-shaped SBR/silica 60 phr compounds with different filler surface areas was experimentally studied and simulated using constitutive modeling. Rheological behavior was characterized in small amplitude oscillatory shear (SAOS) and stress relaxation after a small step shear. Unfilled SBR and SBR filled with four different silica grades with BET surface areas of 55, 135, 160, and 195 m²/g were used. A clear trend in rheological behavior was observed with surface area. A frequency sweep in the SAOS regime indicated an increase in dynamic properties with surface area. Strain sweeps indicated an increase in Payne effect with filler surface area. Additionally, linear stress relaxation tests at a strain level of 0.05 showed an increase in relaxation modulus with surface area and the presence of a plateau in the relaxation modulus at large times in compounds containing silica with high surface areas. The Leonov and Simhambhatla-Leonov models, modified to incorporate multiparticle particle network relaxation, were successfully used to simulate the frequency dependence of the storage modulus and the time evolution of the linear relaxation modulus for all samples. However, simulations of the frequency dependence of the loss modulus showed poor results in comparison with experimental data for the filled compounds.

MATERIALS AND METHODS

Duradene 739, a solution polymerized, 4-arm star SBR, provided by Firestone Polymers was used. Four different silica grades with varying BET surfaces areas were used: Hi-Sil 532EP, Hi-Sil 210, Hi-Sil HDP-320G, and Hi-Sil HDP-190G provided by PPG Industries. Their respective BET surface areas are 55, 135, 160, and 195 m²/g. The compounds were mixed in a Brabender mixer manufactured by C.W. Brabender Instruments, Inc. The mixing time was 7 minutes for all compounds. The compounds were then passed through a two-rolloff mill (Dependable Rubber Machinery Co.) to form rubber sheets. Rheological tests were carried out using a RPA 2000 (Alpha Technologies). Strain amplitude sweep: 0.3-200% at 1 rad/s and 90 °C. Frequency sweep: 0.1-200 rad/s at 1% strain amplitude and 90 °C. Stress relaxation after step strain: 5% at 90 °C.

RESULTS AND DISCUSSION

For stress relaxation after a step shear, the system of ODEs is solved with the following initial conditions:

For SAOS:

REFERENCES

8. Firestone Polymers Datasheet of Duradene 739

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