

DESIGN AND PREPARATION OF FILLER-ELASTOMER MASTERBATCH SYSTEMS FOR HIGH-PERFORMANCE ELASTOMER COMPOSITES

Abstract

This thesis presents the development and optimization of advanced styrene–butadiene rubber (SBR)-based elastomer composites through surfactant-assisted latex-stage mixing, hybrid filler reinforcement, and graphene incorporation for high-performance tire tread applications. The research primarily focuses on improving filler dispersion, polymer–filler interaction, reinforcement efficiency, and dynamic performance while balancing rolling resistance, wet grip, and abrasion resistance.

Different classes of surfactants were explored to improve aqueous carbon black dispersion and colloidal stability. Among them, CTAB demonstrated superior colloidal stability with zeta potential reaching +49 mV. Wet-mixed composites exhibited approximately 13–26% reduction in Payne effect ($\Delta G'$), ~14.7% increase in bound rubber content, and ~9% increase in crosslink density. Mechanical performance showed up to 14.5% enhancement in modulus at 300% elongation, 4.7–6.9% improvement in tensile strength, and ~4.7% reduction in abrasion loss. Dynamic mechanical analysis further revealed 9.5–16.2% reduction in $\tan \delta$ at 70 °C, indicating improved rolling resistance behavior.

The influence of carbon black structure and surface characteristics was systematically investigated using different grades of carbon black. Wet-mixed systems demonstrated finer filler dispersion, reduced filler networking, improved viscoelastic behavior, enhanced abrasion resistance, and superior polymer–filler interaction compared to conventional dry-

mixed compounds. The study established the significance of balancing carbon black surface area and structure for optimizing reinforcement and dynamic performance in elastomer composites.

The effect of polymer microstructure and dual-filler reinforcement was further investigated using blends of ESBR and SSBR containing carbon black and silica fillers. Variations in bound styrene and vinyl content significantly influenced curing behavior, filler interaction, rolling resistance, wet grip, and abrasion resistance. An optimized ESBR–SSBR blend and silica–carbon black hybrid fillers achieved approximately 20% reduction in rolling resistance while improving traction and wear resistance relative to conventional ESBR–carbon black compounds. Reduced Payne effect and improved filler dispersion were confirmed through rheological and microscopic analyses.

In addition, graphene-SBR nanocomposites were developed using wet-stage masterbatch process and optimized through Box–Behnken response surface methodology. In the optimized formulation ~ 0.91 phr graphene successfully replaced ~ 8 phr carbon black while maintaining mechanical integrity. The optimized hybrid filler system achieved tensile strength of ~ 21 MPa, reduced $\tan \delta$ at 70°C (~ 0.268), improved processability, controlled DIN abrasion loss, and lower Payne effect. Multi-response optimization yielded a composite desirability value of ~ 0.731 .

Overall, the study demonstrates that latex-stage mixing, surfactant-assisted filler dispersion, hybrid reinforcement strategies, and graphene incorporation provide effective and scalable approaches for developing sustainable, high-performance elastomer composites with enhanced mechanical durability, lower hysteresis loss, improved rolling resistance, and superior dynamic efficiency for advanced tire tread applications.

Keywords Latex, Styrene–butadiene rubber (SBR), Carbon black, Graphene, Hybrid fillers, Polymer–filler interaction, Wet mixing, Payne effect, Rolling resistance, Abrasion resistance, Dynamic mechanical properties, Nanocomposites; Response surface methodology (RSM), Box–Behnken design (BBD), Reinforcement, Filler dispersion