Technical

Preparation of SEBS beads for introduction of elastic properties in magnetic smart materials

By Sandhiya Thiagarajan, Aubrey Dettman and Amanda Koh
University of Alabama

Executive summary

This paper develops elastic styrene-ethylene-butylene-styrene (SEBS) beads to be used as additives in magnetorheological fluids (MRFs). With their ability to control physical properties in the presence of a magnetic field, MRFs are used for several energy-dampening applications. However, lack of elasticity limits MRF applications in energy dissipation.

This study developed SEBS (synthetic rubber) beads for the first time as MRF additives to enhance elasticity and recovery. Optimal SEBS and surfactant concentration for bead formation and enhanced viscosity was determined.

Future work will focus on how synthetic rubber composition and processing can be tuned to further enhance MRF performance. It is expected that MRFs with enhanced elasticity will enable tunable, dynamic, energy efficient industrial and automotive vibration dampening for improved comfort, equipment resiliency and product consistency.

Magnetic smart liquids, specifically magnetorheological fluids (MRFs), are smart materials whose rheological or flow properties can be controlled in the presence of a magnetic field. MRFs are non-colloidal mixtures of micron-sized magnetic particles in a non-magnetic carrier liquid.

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In the absence of a magnetic field, these liquids exhibit low viscosity based on the properties of the carrier liquid. Upon the application of a magnetic field, the magnetic particles attract to form chain-like structures inside the liquid that exhibit an increase in viscosity resulting in a solid-like state. The transition between the liquid and the solid-like state is fast and reversible, i.e., on removal of the magnetic field, the chain-like structures disaggregate.

The strength of the chain-like structures depends on the intensity of the applied magnetic field, magnetic particle concentration, and the saturation magnetization of the magnetic particles. An additional way of improving performance is by manipulating viscosity. A high viscosity liquid is often desired as the carrier fluid to enhance overall the resultant viscosity as well as sedimentation stability of the MRFs in the presence of a magnetic field.

Motivation

MRF-based applications include magnetic brakes, earthquake dampers, shock absorbers, smart robots and polishing liquids. In shock-absorbing devices, MRFs disperse excess energy absorbed in a collision through heat. In such cases, reusability of MRFs is often limited due to a lack of elasticity in conventional MRFs.

Non-elasticity of MRFs leads to irreversible MRF chain deformations and device failure. The study discussed here involves the introduction of elasticity to an MRF to overcome jamming and irreversible loss of function in piston-based applications and an enhancement of the overall MRF viscoelastic behavior.

Introduction

Styrene-ethylene-butylene-styrene (SEBS), commonly referred to as synthetic rubber, is a thermoplastic elastomer with applications such as self-healing, footwear and ballistics under compressive stress. Attempting to disperse SEBS elastomers in bulk throughout an MRF results in settling of SEBS powders and results in a non-homogenous MRF mixture.

To address this challenge, stable SEBS beads were prepared by mixing molten SEBS with water and a surfactant to form a stable emulsion, which forms elastic beads upon cooling and drying. Beads were analyzed through microscopy and rheological study to determine the most desirable bead mixture composition that can be used as an MRF additive.

SEBS elastomer formulation

The SEBS elastomer was prepared by a previously established method used in the Koh Lab. Briefly, SEBS powder is dissolved in light mineral oil in the ratio 90:10 (mineral oil:SEBS) vol/vol.

The 90:10 SEBS/oil formulation was chosen due to its low modulus relative to other formulations as reported by Koh's lab previously in "Mechanical Characterization of the Effects of Paraffinic Oil on the Thermoplastic Elastomer, Styrene-Ethylene-Butylene-Styrene" by Bury, E.

The 90:10 SEBS/oil formulation was kept at 80°C for five hours and mixed at 30-minute intervals until all of the SEBS solid dissolved into the oil and formed a clear, homogenous mixture. The resulting elastomer solution solidifies when the mixture is returned to room temperature.

SEBS elastomeric beads

SEBS beads were developed by weighing melting aqueous solutions of 10-60 volume-percent SEBS elastomer at 70°C (above the melting temperature of the mixture as reported by Bury et al.) Triton X-100 (a common hydrophilic surfactant) was added to the molten SEBS elastomer aqueous solution concentrations in 20, 30 and 40 volume-percent to stabilize the emulsion. The entire mixture was mixed at 70°C with an overhead mixer for 20 minutes at 1,200 rpm. The resulting mixture was then cooled to room temperature resulting in SEBS elastic beads.

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Fig. 1: Schematic representation of magnetorheological fluids.

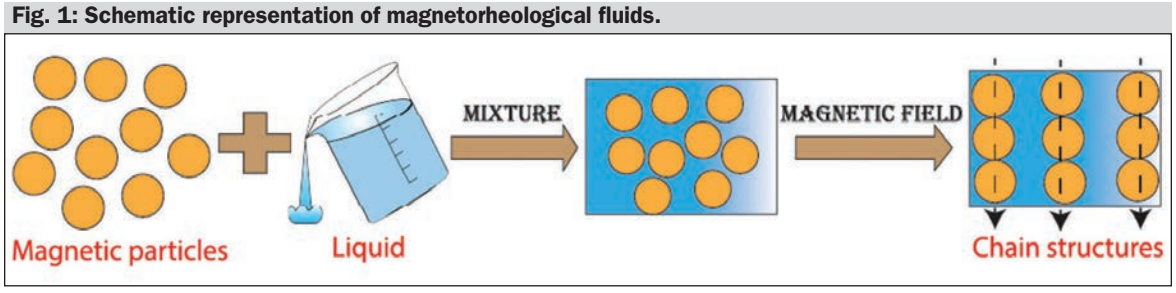


Fig. 2: A hypothetical representation of elastic SEBS beads as additives in magnetorheological fluids.

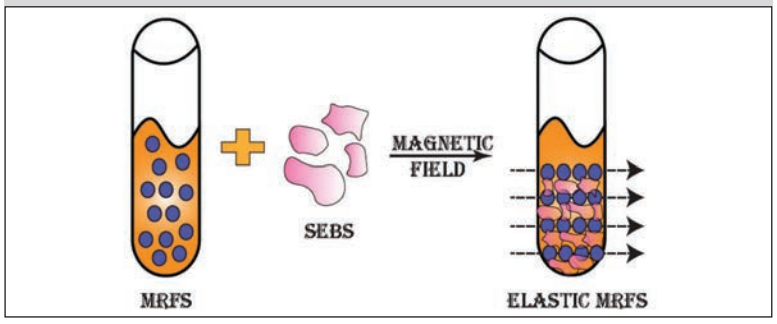


Fig. 3: Procedure for preparation of SEBS elastomers.

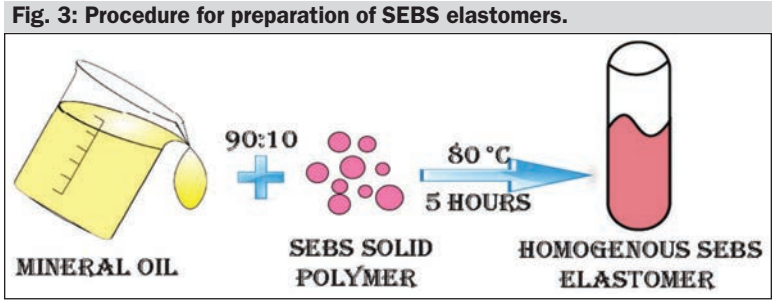
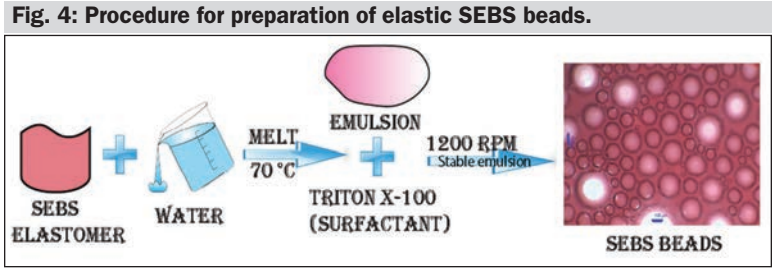


Fig. 4: Procedure for preparation of elastic SEBS beads.



Nokian signs rCB deal with Enviro joint venture

Rubber News Staff

NOKIA, Finland—In an effort to reach a key sustainability target, Nokian Tyres P.L.C. has entered a long-term purchase agreement for recovered carbon black with a tire recycling joint venture.

Nokian said in a Feb. 8 press release that the deal, signed with the Antin Infrastructure Partners and Scandinavian Enviro A.B. JV, will help the tire maker increase the share of recycled and renewable raw materials in tires to 50 percent by 2030.

The JV is establishing end-of-life tire recycling plants across Europe, seeking a total capacity to recycle up to 1 million metric tons of ELT annually by 2030.

The first plant located in Sweden—construction broke ground last month—is expected to be fully operational by 2025. Deliveries for Nokian will begin in 2026, the tire maker said, noting it has been using rCB in a commercial product line since 2022.

"As virgin carbon blacks are fossil-based, replacing them partly with recovered carbon black decreases the environmental burden of tires' raw materials," Nokian said. "It also accelerates the circular economy of the tire industry, as the recovered carbon black is made with pyrolysis from end-of-life tires."

Juha Hietalahti, vice president of procurement at Nokian Tyres, said using rCB will also help reduce emissions along the supply chain the tires.

"The emissions from manufacturing recovered carbon black are over 90 percent lower than those from virgin carbon blacks. On a larger scale, use of recovered carbon black also increases circularity and sustainability in the tire industry," Hietalahti said.

The rCB that Nokian will receive as part of this agreement "is an important step in creating even more sustainable premium tires that provide safety in all driving conditions," he said, noting Nokian must find the right balance between raw material selection and tire properties, "as the use of recycled or renewable materials must not impair a tire's safety characteristics."

European Rubber Journal contributed to this report.

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The authors

Amanda Koh is an assistant professor in the Chemical and Biological Engineering Department at the University of Alabama in Tuscaloosa.

She was an ORAU post-doctoral fellow with the U.S. Army Research Laboratory in Aberdeen, Md, after receiving her Ph.D. in chemical engineering from Rensselaer Polytechnic Institute in 2016 and her bachelor's in chemical engineering from the Massachusetts Institute of Technology in 2011.

Koh's lab focuses on harnessing the potential of material interfaces for improved soft, functional, responsive composites with applications in soft robotics, stretchable electronics, complex fluids and water treatment.

Sandhiya Thiagarajan is a doctoral student under Koh's guidance at the University of Alabama. She earned her bachelor's in chemical engineering in 2019 from SASTRA Deemed to be University in Thanjavur, India.

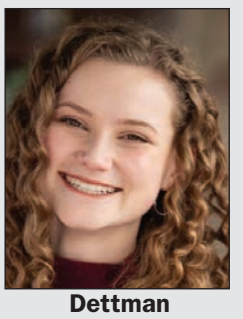
Her research interests include smart, functional and improved materials with applications in soft robotics and dampers with special focus on magnetorheological fluids (MRFs and their stability).

Aubrey Dettman attends the University of Alabama, where she is majoring in mechanical engineering and art history. She joined Koh's lab in the fall of 2021 and is studying the behavior and application of MRFs.

On campus, she is a member of the UA Astrobotics student design team, is a research ambassador for the Office of Undergraduate Research, and is the treasurer for the Society of Art History Students.


Koh


Thiagarajan


Dettman

SEBS

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Results

The developed beads were stable (no bead aggregation and/or phase separation) after the mixture was cooled to room temperature. The resulting bead size was a function of both SEBS elastomer and surfactant concentrations. The SEBS bead size increased with increasing SEBS concentration up to 40 volume-percent SEBS at 10 volume-percent surfactant.

Above 40 volume-percent SEBS and 10 volume-percent Triton X-100, beads were not observed, which can be attributed to an insufficient surfactant concentration to stabilize the large amount of generated interface (**Figs. 5(e) and (f)**). Conversely, the elastomeric SEBS bead size did not significantly change with increasing surfactant concentration, which may point to antagonistic adsorption to the interface (**Fig. 6**). Based on optical microscopy, the bead sizes varied between 2 and 100 μm

The viscosity of the SEBS bead solution was a function of SEBS elastomer concentration while the concentration of surfactant had a negligible effect. Viscosity of the SEBS bead solutions increased with increasing SEBS elastomer concentration up to 40 volume-percent.

Due to unsuccessful bead formation above 40 volume-percent SEBS elastomer, no further increase in viscosity was observed (**Fig. 7**). While surfactant concentration had a relatively lower impact on SEBS bead solution viscosity, 40 volume-percent SEBS elastomer and 30 volume-percent surfactant concentration exhibited a relatively higher viscosity among all the samples prepared (**Fig. 8**).

As a high viscosity mixture is desired for enhanced MRF performance, the 40 volume-percent SEBS 30 volume-percent surfactant formulation will be used as an additive for the MRF future work.

Conclusion

Elastomeric beads have been developed by a simple process using the thermoplastic polymer styrene-ethylene-butylene-styrene (SEBS), water, and Triton X-100 surfactant. The bead mixtures were stable after cooling down to room temperature from 70°C.

The beads can be used as additives to enhance viscoelasticity, and in particular it is envisioned that they will improve the flow properties of active fluid-based systems such as magnetorheological fluids (MRFs).

While the majority of existing work has focused on using SEBS to improve the elasticity of solids, the presented work is the first time that the focus is dispersing SEBS in such a way to refine viscoelastic properties of liquid systems.

Apart from MRF-based applications, SEBS beads pave the way for a new type of research focus on tunable liquid viscoelasticity. By enhancing the elastic recovery behavior of fluids, SEBS elastic beads can enhance active fluid recovery behavior, such as in piston-based applications.

Fig. 5: Microscopic images of elastomeric SEBS beads with increasing SEBS concentration, (a) 10vol% SEBS (avg. bead size=4.4 μm ± 1.78); (b) 20vol% SEBS(avg bead size=73.8μm ± 38.63); (c) 30vol% SEBS(avg bead size=57.97μm ± 39.87); (d) 40vol% SEBS(avg bead size=99.403μm ± 82.073); (e) 50vol% SEBS; and (f) 60vol% SEBS, at a 10vol% Triton X-100.

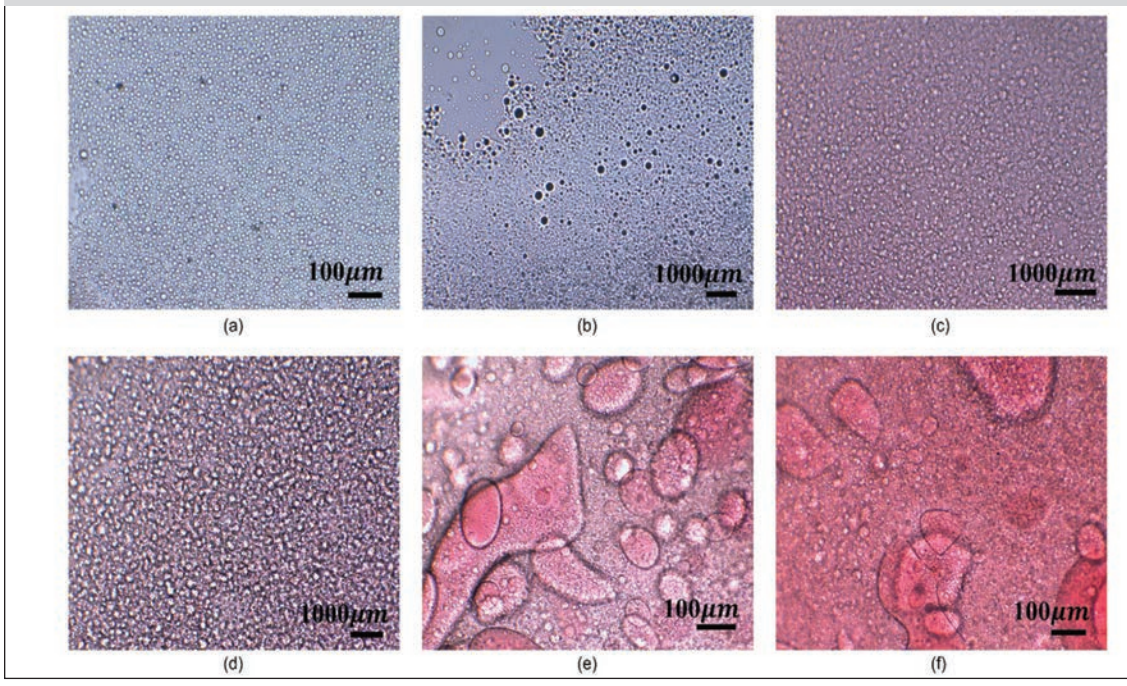

Fig. 6: Microscopy images of elastomeric SEBS beads with increasing Triton X-100 (surfactant) concentration, (a) 20vol% (avg SEBS bead size=2.96μm ± 2.07); (b) 30vol% (avg SEBS bead size=4.4μm ± 4.3); and (c) 40vol% (avg SEBS bead size=2.09μm ± 1.5), at 40vol% SEBS.

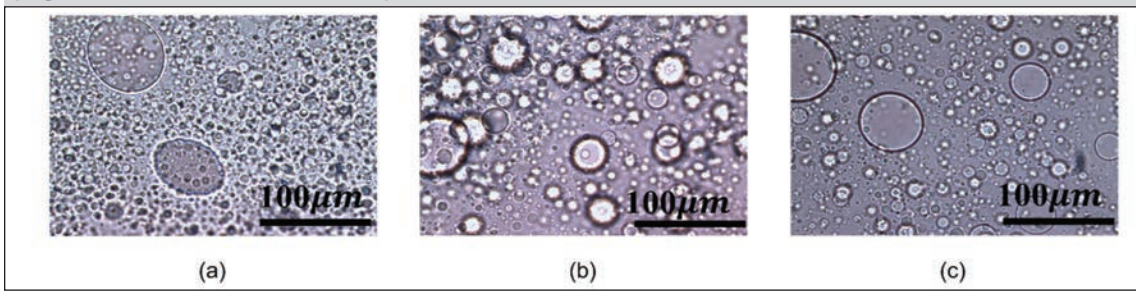

Fig. 7: Viscosity of the elastomeric SEBS bead mixture as a function of SEBS concentration relative to the neat SEBS elastomer.

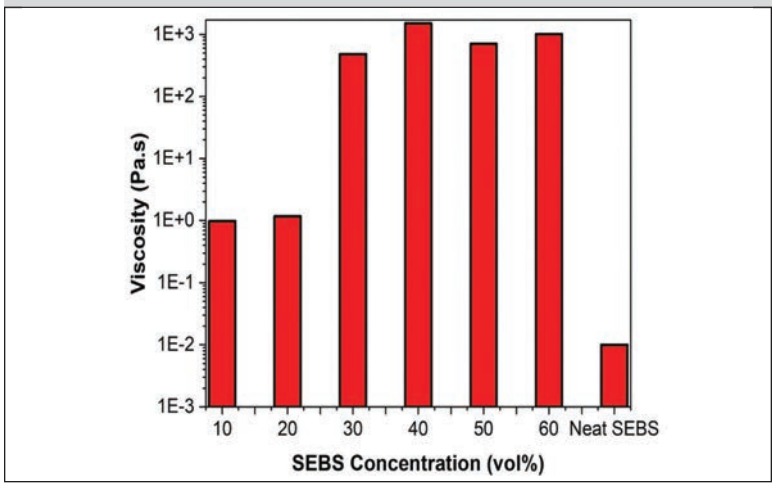

Fig. 8: Viscosity of the elastomeric SEBS bead mixture as a function of Triton X-100 concentration relative to the neat SEBS elastomer.