Soybean Oil-Based Additives for Low-Friction Rubber Compounds

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Summary

Poly(styrene-butadiene) (SBR) rubber is widely used for the manufacturing of rubber belts for agriculture harvesting equipment. SBR rubber possesses good mechanical strength and durability but has a high coefficient of friction (COF) which leads to overheating and damaging of the rubber belt. In this project, the feasibility of the use of modified soybean oils as additives for the reduction of COF of SBR rubber was studied.

After initial screening, two soybean oil-based additives were selected, namely commercially available partially hydrogenated soybean oil (PHSO) and soybean oil chemically modified with fluorinated acrylate (SOFA). SBR compounds were formulated with petroleum-based plasticizer, carbon black, and the addition of low-friction additives. The reference compound was of the same composition but formulated without additives. The compounds were vulcanized and tested for COF, tensile properties, and hardness.

The results demonstrate that PHSO reduces COF by up to 70% however the decrease of the surface friction is not stable. The rubber containing SOFA demonstrates the stable decrease of COF by 50%. The use of PHSO improves mechanical properties of rubber such as tensile strength and hardness while some decrease of mechanical strength was observed for SOFA-based rubber.

Objectives of the research

In this project, modified soybean oil was examined as an additive for poly(styrene-butadiene) (SBR) rubber compounds for reduction of coefficient of friction (COF) of the rubber. We explored soybean oil-based additives for compatibility with SBR rubber and to reduce the surface friction of vulcanized SBR rubber. The soy-based additives for reduction of surface friction of SBR rubber can be used for the formulation of SBR compounds for manufacturing of conveyor belts and rubber belts for harvesting equipment.

Completed work

- Initial screening of soy-based additives (SBA)
- The additive which provides the lowest surface friction selected

- Compounding of SBR rubbers with different content of SBA
- Testing of the coefficient of friction over time
- Mechanical properties testing

Technical report

The work on this project was started with the screening of different modified soybean oils (SBO) as additives for SBR rubber compounds and testing of static coefficient of friction (COF).

Two SBO-based additives were selected after initial screening, namely partially hydrogenated SBO (PHSO) and SBO modified with styrene and 1H,1H,11H-Pefluoroundecyl acrylate (PFUA). PHSO is a commercially available product with a low price. SBO modified with 15 wt.% of styrene and 5 wt.% of PFUA was synthesized by graft polymerization reaction developed for the synthesis of polystyrene-grafted soybean oil and described in our previous work. The monomer PFUA contains a fluoroalkyl group which, due to its low surface energy, can carry the additive toward the surface of the rubber providing a slippery layer while styrene functionality provides compatibility of modified SBO with SBR. Styrene-PFUA-modified SBO (SOFA) and PHSO were used as additives for rubber compounds formulated with carbon black, petroleum-based aromatic oil (AO), and a sulfur-based curative package. Two groups of SBR compounds were formulated, one group of compounds contains a high content of plasticizing oil (50 phr) and the second group is with low oil content (12 phr). In formulation with high oil content, the petroleum-based AO was partially or fully replaced with PHSO. In low-oil formulations, the petroleum-based AO was replaced with soy-based additives and no other plasticizer was added. The composition for high-oil compounds was agreed with engineers from WCCO Belting Inc. while the composition for low-oil compounds was found in the literature. The compositions of SBR compounds formulated for the testing of COF are presented in Table 1.

Table 1. Compositions of SBR compounds for surface friction testing. Each compound contained 5phr of ZnO, 1 phr of stearic acid, 1.5 phr of sulfur and 1.5 phr of activator TBBS

	High-oil compounds			*Low-oil compounds*		
Compound ID	**AO-50**	**PHSO-10**	**PHSO-50**	**AO-12**	**PHSO-12**	**SOFA-12**
SBR	100	100	100	100	100	100
Carbon black	75	75	75	70	70	70
Aromatic oil	50	40	0	12	0	0

Soy-based additives						
PHSBO	0	10	50	0	12	0
SOFA	0	0	0	0	0	12

For surface friction testing, the ice-slip machine SHIMPO available in the department was adopted. For the testing, a steel block with the dimensions of 40 x 40 x 10 mm was pushed to move at a constant rate over the surface of the rubber sample. The value of COF_{SR} which is the COF for steel on the rubber was calculated by equation $COF_{SR} = N / 9.8 M$, where N is the measured force and M is the mass of the steel block. COF_{MR} was tested every 2 weeks in the first 2 months after vulcanization then in 3 months after vulcanization. The results of COF_{SR} testing are given in Table 2.

As it can be seen from Table 2, COF_{SR} decreases overtime for all rubbers, probably because the curing of rubber completes. For all rubbers, COF was not changed sufficiently after 4 weeks however some deviation was observed for each rubber sample. For the rubbers with high oil content, the replacement 10 parts of plasticizer with PHSO reduces COF_{SR} by 25% (PHSO-10 rubber). The complete replacement of plasticizer with PHSO (PHSO-50 rubber) reduces COF_{SR} by 40%. For the rubber PHSO-12, where all plasticizer was replaced with PHSO, COF_{SR} was reduced by 35%. For the rubber SOFA-12, where plasticizer was replaced with PFUA-modified SBO, the lowest COF_{SR} was observed, which is 60% lower than COF_{SR} for the reference rubber (Table 2).

Table 2. COF_{SR} for different rubbers tested with different time after vulcanization.

Compound ID	**AO-50**	**PHSO-10**	**PHSO-50**	**AO-12**	**PHSO-12**	**SOFA-12**
Days after vulcanization	**COF_{SR}**					
2	1.65	1.13	0.70	2.04	1.13	0.91
14	1.20	0.75	0.59	1.56	1.02	0.48
28	1.34	0.85	0.64	1.26	0.97	0.43
42	1.23	1.07	0.64	1.18	0.81	0.43
60	1.23	0.96	0.70	1.18	0.64	0.43
90	1.18	0.91	0.64	1.07	0.81	0.40

For the rubbers formulated with PHSO we observed some bloom after 12 weeks of storage. The bloom is a white solid layer on the surface of the rubber and can be an issue for some applications, however, if the material is in constant use the bloom will be worn away. For the reference rubbers and for rubbers formulated with SOFA, no bloom was observed.

Mechanical properties of vulcanized rubber compounds formulated with PHSO and SOFA were examined. Table 3 gives the results of tensile testing and hardness data for the tested rubbers.

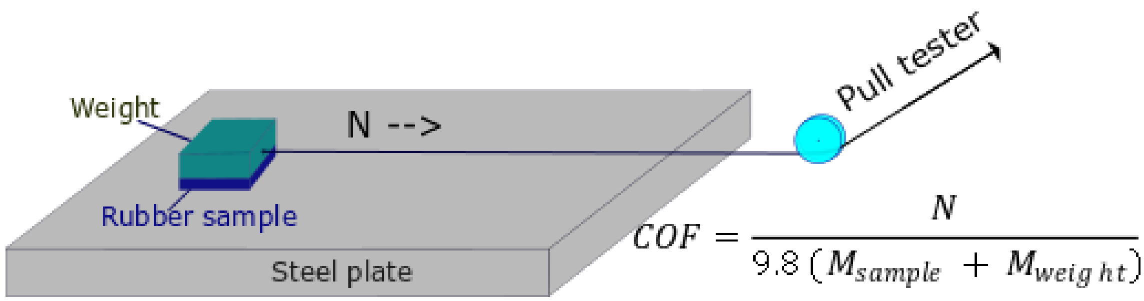
Table 3. Physical properties of different rubbers with the composition as given in Table 1.

Compound	**Tensile strength, MPa**	**Elongation at break, %**	**Modulus at 100% Elongation**	**Modulus at 300% Elongation**	**Hardness**
	High-oil compounds				
AO-50	13.7 ± 0.9	705 ± 56	1.96 ± 0.04	5.91 ± 0.07	50
PHSO-10	13.9 ± 0.3	661± 19	2.21 ± 0.03	6.49 ± 0.09	56
PHSO-50	14.2 ± 0.3	546 ± 17	3.02 ± 0.06	8.06 ± 0.19	61
	Low-oil compounds				
AO-12	21.0 ± 1.0	465 ± 12	4.12 ± 0.12	14.62 ± 0.36	70
PHSO-12	22.0 ± 0.6	453 ± 12	4.26 ± 0.09	15.24 ± 0.14	71
SOFA-12	20.0 ± 0.9	468 ± 30	4.00 ± 0.04	13.56 ± 0.12	69
Target properties*	>13.8	>400			

*Target properties found in literature

For the PHSO-containing compounds, the partial and whole replacement of AO with PHSO leads to an increase of hardness, tensile strength, and tensile moduli (samples PHSO-10 and PHSO-50), compared to the reference AO-50 and AO-12 rubbers. The replacement of AO with SOFA slightly reduces tensile strength and moduli (sample SOFA-12).

A testing device for determining COF for the rubber over the surface of steel was developed (Schema 1). For the testing, the MTS Insight® Electromechanical testing system was used. The rubber sample with the dimension 1 in x 1 in was attached to the bottom of the metal block with a weight of 80g. The sample was tightening with the line to the top grip of the MTS machine. The grip of the MTS machine, which is connected to the dynamometer was moved with the constant speed of 304.8 mm/min. The moving force N was recorded by MTS tester, and the COF was calculated as an average force in the moving distance range from 6 cm to 10 cm divided by the weight of the sample with the top load. The range for the distance 6-10 cm was chosen as the force was stabilized after 4 cm of moving distance but starting from 12 cm, the force was increased in all experiments with the increase of the high of moving grip.



Schema 1. Testing of COF for the samples of rubber with the use of mechanical testing machine.

Table 4 shows the results of COF for the different samples of rubber tested on MTS machine while Figure 1 and Figure 2 shows the results of COF testing.

Table 4. COF for different rubbers tested with MTS Insight® Electromechanical testing system.

	High-oil compounds			*Low-oil compounds*			
Compound ID	**AO-50**	**PHSO-10**	**PHSO-50**	**AO-12**	**PHSO-12**	**SOFA-12**	**SOFA12-PTFE**
COF	1.12±0.03	0.75±0.05	1.05±0.12	1.03±0.07	0.30±0.06	0.53±0.05	0.24±0.03
COF reduction		33%	6%		71%	48%	77%

From Table 4 and Fig. 1 it can be seen that the rubber PHSO-10 has lower COF than the reference AO-50 rubber, but the difference is not sufficient. For the rubbers with low content of plasticizer (Fig.2) both samples PHSO-12 and SOFA-12 show sufficiently lower COF than the reference rubber AO-12. Both PHSO-12 and PHSO-50 rubbers show unstable surface friction. The reason for unstable COF for PHSO-containing rubbers can be the surface bloom that impacts the surface properties of rubber.

The sample SOFA12-PTFE was made by vulcanizing the sheet of SOFA-12 compound with the thin polytetrafluorethylene (PTFE) film on the surface. PTFE is known as a polymer with the lowest COF but has pure adhesion to the rubber. Since SOFA-12 compound contains fluor-modified SBO, we were able to vulcanize the SOFA-12 compound with the PTFE (Teflon) film on the surface. This sample shows the lowest COF (Fig.2) however, both samples PHSO-12 and SOFA-12 show much lower COF that the reference rubber AO-12.

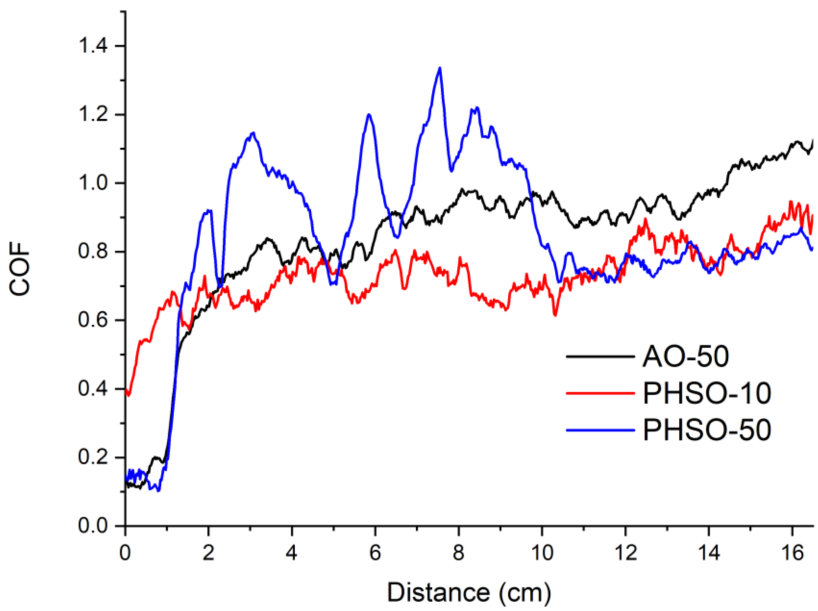


Fig. 1. Result of COF testing for the rubbers formulated with high oil content

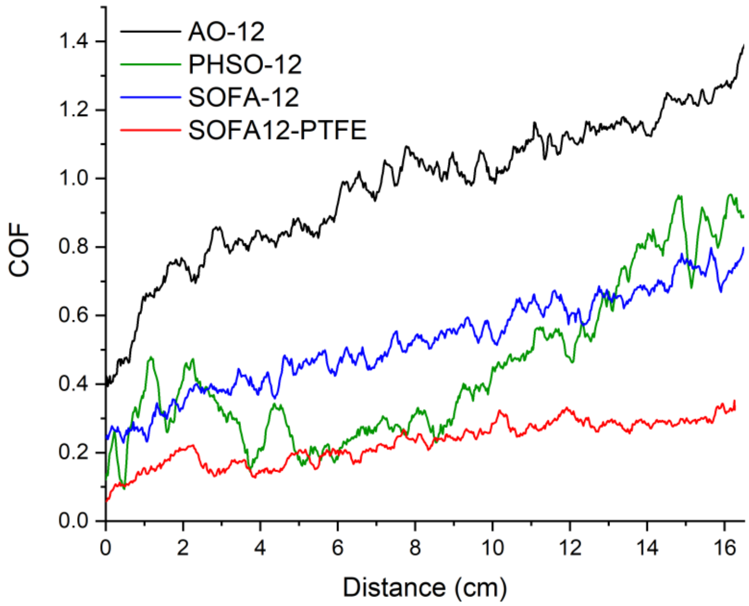


Fig. 2. Result of COF testing for the rubbers formulated with low oil content

Conclusions

Partially hydrogenated soybean oil (PHSO) and fluoroalkyl acrylate-modified SBO (SOFA) can be used as additives for SBR rubber compounds for reduction of surface friction of rubber. PHSO can be used in place of petroleum-based plasticizer, however, PHSO rubbers show some bloom after 12 weeks of storage. The use of SOFA in place of plasticizer in SBR compounds with low oil content reduces the COF and allows for the attachment of a PTFE film to the surface of rubber since SOFA improves compatibility of SBR rubber with PTFE.

Mechanical properties and hardness were improved for all PHSO-containing compounds while tensile properties for SOFA-based rubbers slightly deteriorated.

Soybean oil-based additives PHSO and SOFA can be used in SBR rubber formulation for reduction of surface friction of rubber. The amounts of additives for each compound can be estimated based on the application of rubber. The results obtained in this project will be used in our future studies for the use of soybean oil in rubber compounds with increased sustainable content and enhanced properties.