Vol. 37, No. 2 (2015) 154-160

Tribology in Industry

www.tribology.fink.rs

RESEARCH

Tribological Properties of Silicone Rubber-Based Ceramizable Composites Destined for Wire Covers. Part I. Studies of Block-On-Ring Friction Contact

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Keywords:

Friction
Wear
Ceramization
Ceramification
Silicone rubber

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A B S T R A C T

Ceramizable composites of silicone rubber matrix become more and more popular materials destined for wire covers, what can enhance fire safety of building increasing operation time of important equipment or devices (eg fire sprinklers, elevators, alarms etc). Aim of the research was to examine tribological properties and wear of commercially available silicone rubber-based ceramizable composites against steel, in configuration – steel block on composite ring, under various load (5, 10, 15, 20, 25 and 30 N). Changes to friction force in time were monitored by a tribotester, whereas wear of the composite surfaces were determined using an optical microscope. Performed studies demonstrate, that tribological characteristics and wear of the composites depend significantly on the origin of material.

1. INTRODUCTION

Ceramizable (ceramifiable) silicone rubber-based elastic composites are commonly used in industry, being destined especially for wire covers, expected to maintain integrity for at least a half of an hour in case of fire. These composites are dispersion type of materials, where silicone rubber gives a continuous matrix, whereas mix of combined mineral fillers constitutes dispersion phase, which promotes creation of porous, ceramic protective layer at elevated temperature in the presence of flames. Mechanism of the ceramic structure creation involves specific chemical and physical interactions between components of the dispersed phase and silicone matrix, as well as silica and SiOC-ceramics, produced as a result of thermal decomposition of the matrix at elevated temperature [1-6]. Amount of fillers in the composites is generally high, typically over 50 wt%, what facilitates good mechanical and barrier properties of the ceramic layer. However, this can also adversely affect wear resistance of the composites, due to high difference in modulus of elasticity and poor interactions between silicone rubber and the fillers.

In our recent works we were studied an effect of the type of dispersed phase on processing, morphology and mechanical properties of ceramizable silicone rubber-based composites, before and after their ceramization [7-12]. Furthermore, extrudability, rheological and mechanical properties of commercially available ceramizable composites were also determined [13], but tribological properties and wear of the materials have never been published. However, we studied tribological properties of silicone composites filled with high amount of mineral powders and discovered that type of filler is very important form the point of view tribological properties and wear of silicone composites [14].

Because of high elasticity of rubber materials, their friction force consist of four components, what can be expressed by the following equation (1):

$$F_T = F_A + F_{Hs} + F_{Hb} + F_C,\ \mathrm{N} \qquad (1)$$

where:

F_T – total friction force,

F_A – adhesion forces between the surface of rubber and a paired material,

F_{Hs} – friction contribution form the surface deformation of rubber (microhysteresis),

F_{Hb} – friction contribution from bulk deformation of rubber (hysteresis),

F_C – cohesion loss component from wear of rubber.

The F_A, F_{Hb} and F_C components were defined by Kummer in 1966 [15], whereas existence of the last one remained unproved until 2008 [16,17]. Contribution of hysteretic components to the total friction force value is significant, therefore rubber materials do not follow the classic law of friction on a increase of friction force with an increasing load. Under higher load, elastic materials become stiffer and their hysteretic components decrease, making the total friction force decreased. This relationship can also stand for wear rate of rubber [18].

Tribological properties and wear of ceramizable composites in contact with steel are important during last stage of their extrusion, when pre-cured composite cover move fast through steel die. Moreover, it can be also crucial from the point of view of their potential application as fire resistant seals.

2. MATERIALS AND METHODS

Tribological tests were run for four commercially available silicone rubber-based ceramizable composites: Silplus 70 CW – originated from Momentive Inc. (USA), hereinafter referred to as “MOM”, MP 0097 NE 70 – produced by Mesgo S.p.A. (Italy), hereinafter referred to as “MES”, Elastosil R502/75 – produced by Wacker Chemie AG (Germany), hereinafter referred to as “WAC” and Rhodorsil MF 8465 U – originated from Bluestar Silicones Ltd. (China), hereinafter referred to as “BLU”. The mixes received required crosslinking, so 1.8 wt% of 2,4-dichlorobenzoyl peroxide (50 wt% paste in silicone oil – originated from Novichem Sp. z o. o. (Poland)) was incorporated using a two roll laboratory mill (Bridge – UK), operating with a friction of 1.13. After incorporation of curing agent, the mixes were vulcanized in a steel mould, using a laboratory heating press, at 120 °C during 15 min.

Tribological tests were performed using a T-05 block-on-ring tribo-tester (ITeE – PIB, Poland), operating with 60 rpm speed, under load of 5, 10, 15, 20, 25 and 30 N, for 30 min. The scheme of a block-on-ring contact and a picture of a T-05 tribo-trster are presented in Figs. 1 and 2 adequately.

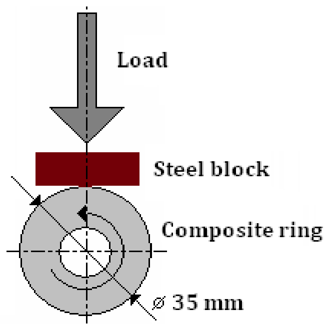

Fig. 1. Scheme of a block-on-ring contact applied in a T-05 tribo-tester.

Fig. 2. Photograph of a T-05 tribo-tester.

3. RESULTS AND DISCUSSION

Changes to friction force in time for the composites studied are presented in figures 3-8, whereas photographs of wear of their surface are shown in Figs. 9-16. Only MOM and BLU vulcanizates exhibited wear which was determinable under optical microscope. Surface of MES and WAC samples presented no optically visible changes.

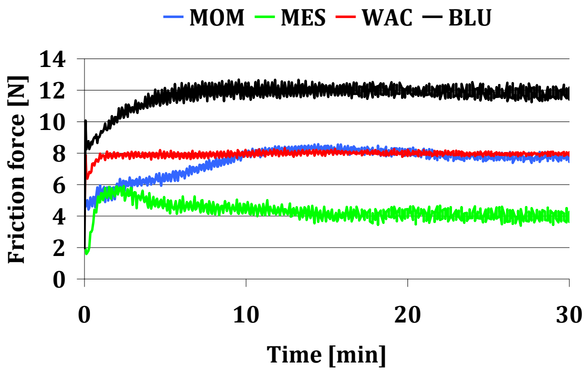

Fig. 3. Changes to the friction force in time for vulcanizates loaded with the force of 5 N.

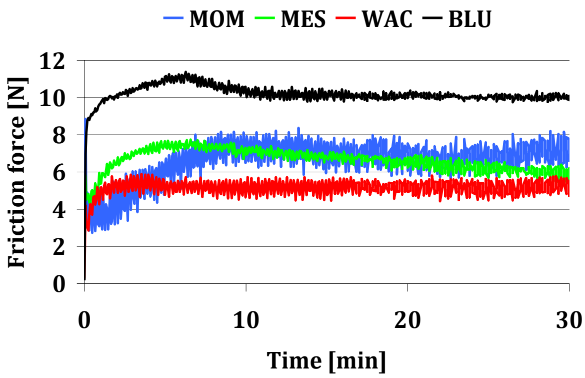

Fig. 4. Changes to the friction force in time for vulcanizates loaded with the force of 10 N.

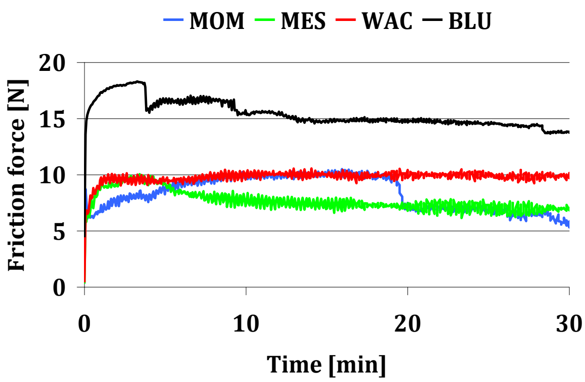

Fig. 5. Changes to the friction force in time for vulcanizates loaded with the force of 15 N.

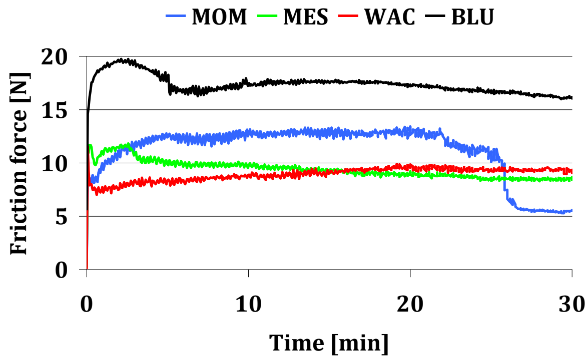

Fig. 6. Changes to the friction force in time for vulcanizates loaded with the force of 20 N.

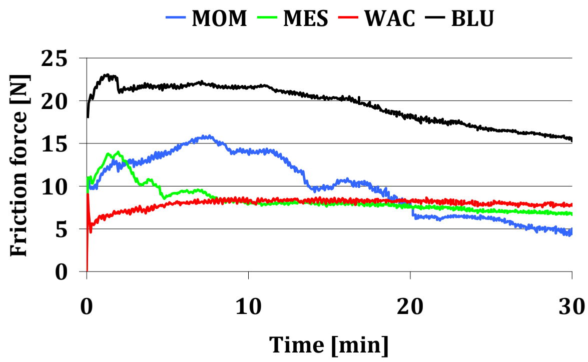

Fig. 7. Changes to the friction force in time for vulcanizates loaded with the force of 25 N.

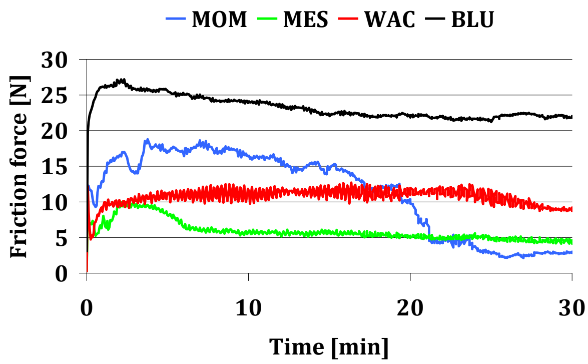

Fig. 8. Changes to the friction force in time for vulcanizates loaded with the force of 30 N.

Friction force for a WAC sample against steel under 5 N of load, stabilizes very quickly on 8 N (after ca. 1.5 min.). Friction force for a BLU sample stabilizes after ca. 6 min. on 12 N, whereas for MOM and MES ones after ca. 14 min. on 4 N (MES) and on 8 N (MOM) respectively, Fig. 3.

Similarly as under 5 N of load, friction force for a WAC sample under 10 N, stabilizes the fastest (ca. 1.5 min), but on a lower value – 5 N. Friction force for MOM and BLU ones stabilize after ca. 8

min. on 7 N and on 10 N, respectively. Friction force for a MES sample against steel reaches a peak after ca. 5 min. and then slightly decreases to stabilize on ca. 6 N after over 25 min.

Under the load of 15 N surfaces of MOM and BLU samples undergo strong wear, creating relatively large debris, Figs. 9 and 10. Time to the beginning of wear is clearly visible from a friction force graph, indicated as a rapid drop of friction force value. Wear process of BLU and MOM samples begins after 4 and 19 min. respectively. Wear products are larger for MOM than for BLU vulcanizates. Their friction force value remains unstable within 30 min. of a tribological test. The best tribological performance under the load of 15 N exhibits a WAC sample for which the friction force stabilizes on 10 N already after 1.5 min. Friction force for a MES vulcanizate stabilizes after 7 min. on 7 N.

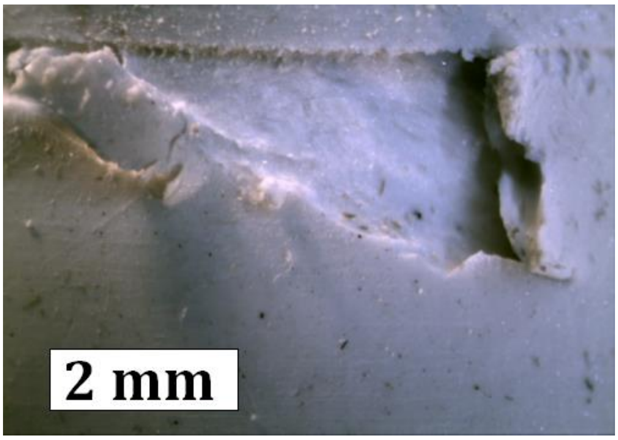

Fig. 9. Wear of the surface of MOM vulcanizate after tribological test under the load of 15 N.

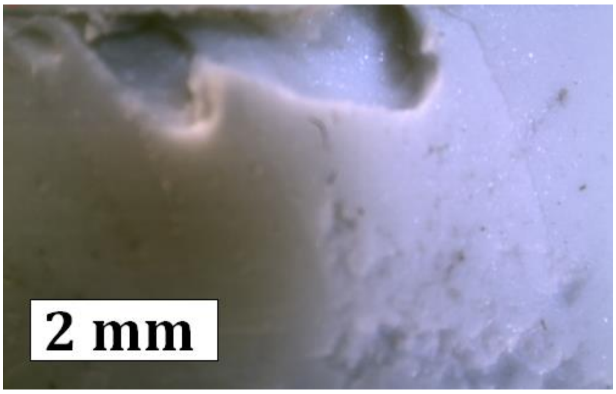

Fig. 10. Wear of the surface of BLU vulcanizate after tribological test under the load of 15 N.

Similarly as during previous test, under the load of 20 N, BLU and MOM samples both exhibit an intensive wear, Figs. 11 and 12. Wear of the samples begins after 5 and 25 min., respectively, significantly later than for a previous measurement under 15 N of load. Under applied conditions the friction force for a WAC vulcanizate stabilizes slowly, rising slightly after ca. 18 min, reaching 8 N. A MES sample reaches quickly a maximum friction force, then slightly decreases, stabilizing eventually on 8 N.

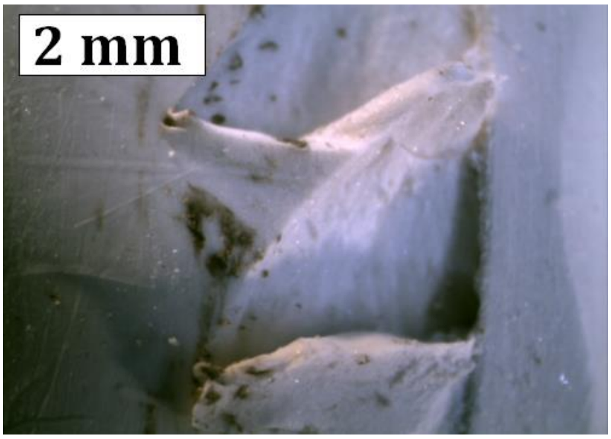

Fig. 11. Wear of the surface of MOM vulcanizate after tribological test under the load of 20 N.

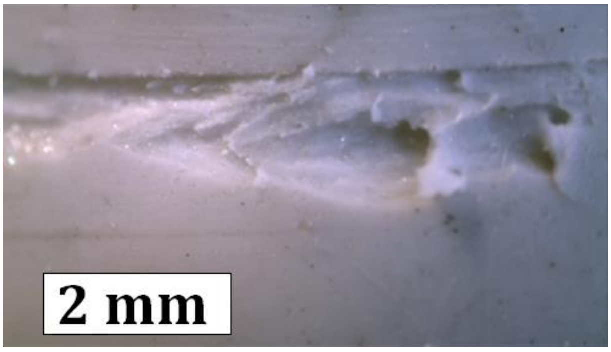

Fig. 12. Wear of the surface of BLU vulcanizate after tribological test under the load of 20 N.

Under the load of 25 N MOM and BLU samples behave tribologically very unstable. Wear of their surface is rough and visible optically, Figs. 13 and 14. Also the figure presenting changes to their friction force in time shows unstable curves, indicating on the beginning of wear, Fig. 11. Friction force of WAC and MES vulcanizates stabilizes after ca. 8 min. on 8 N and on 7 N, respectively.

Regardless of considerable wear, BLU vulcanizate exhibits stabilization of the friction force after ca. 15 min under 30 N of load. Probably, high amount of wear debris produced and present in friction contact decreases and stabilizes friction force for this sample on the level of ca. 22 N, Fig. 8. Under the same load WAC and MOM samples do not achieve stabilization of the friction force, but MES vulcanizate stabilizes on ca. 5 N after ca. 25 min. BLU and MOM samples exhibit a high wear under these conditions, Figs. 15 and 16, whereas surface of WAC and MES samples show no visible defect, Figs. 17 and 18.

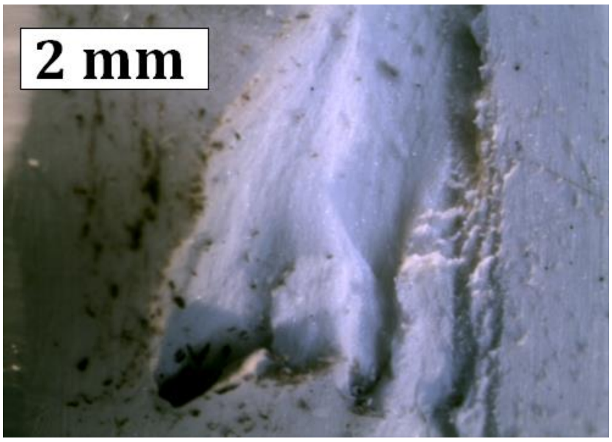

Fig. 13. Wear of the surface of MOM vulcanizate after tribological test under the load of 25 N.

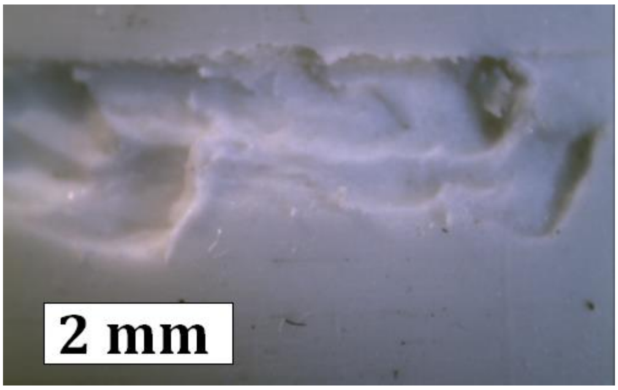

Fig. 14. Wear of the surface of BLU vulcanizate after tribological test under the load of 25 N.

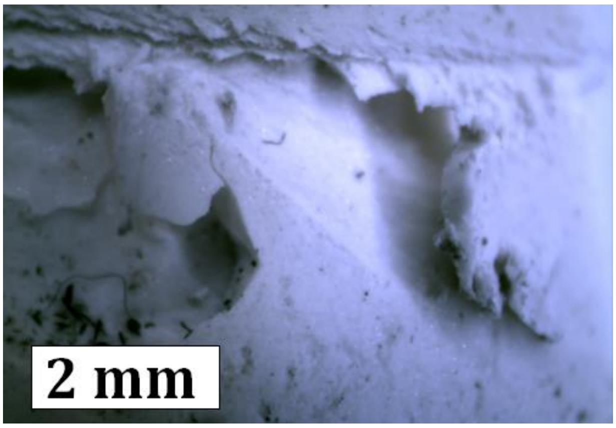

Fig. 15. Wear of the surface of MOM vulcanizate after tribological test under the load of 30 N.

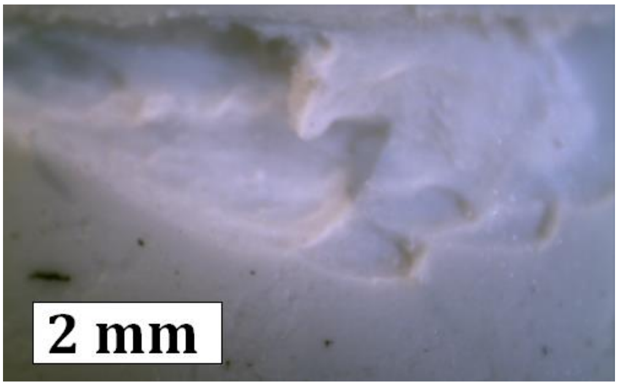

Fig. 16. Wear of the surface of BLU vulcanizate after tribological test under the load of 30 N.

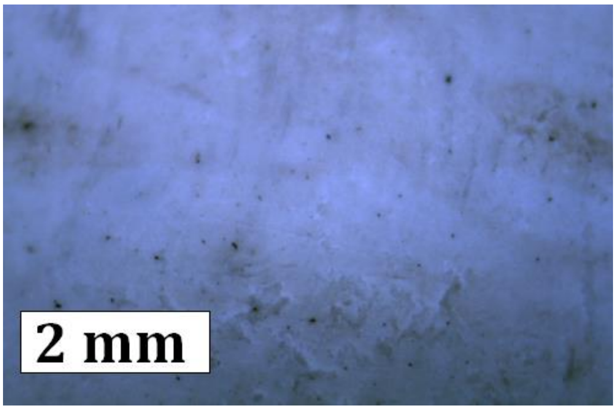

Fig. 17. The surface of WAC vulcanizate after tribological test under the load of 30 N.

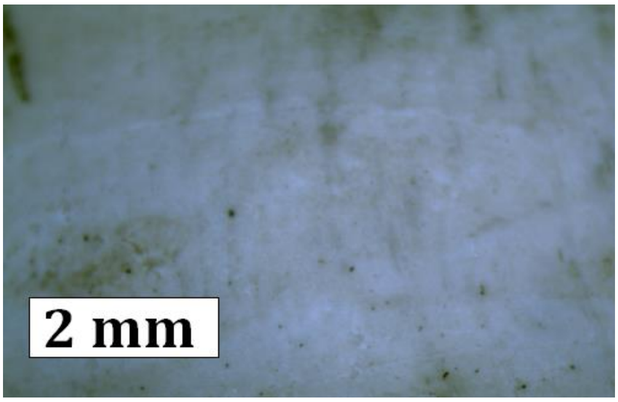

Fig. 18. The surface of MES vulcanizate after tribological test under the load of 30 N.

Regardless of a value of load, wear mechanism of BLU and MOM samples was similar from the load of 15 N. The so-called rolling mechanism of friction is very characteristic for rubber materials working in configuration against stiff materials like metals or ceramics [19].

Values of the maximum friction force (F_m) and the force after stabilization of friction (F_s) (if it happens), measured have been collected in Tab. 1.

Table 1. Values of the maximum friction force (F_m) and the friction force after stabilization (F_s) for the vulcanizates studied.

Load [N]	MOM		MES		WAC		BLU	
	F_m	F_s	F_m	F_s	F_m	F_s	F_m	F_s
5	8.6	8	5.9	4	8.1	8	12.7	12
10	8.4	7	7.7	6	5.9	5	11.4	10
15	10.4	-	10.0	7	10.5	10	18.3	-
20	13.0	-	11.8	8	9.9	9	19.8	-
25	7.7	-	13.7	7	9.0	8	23.1	-
30	18.4	-	9.9	5	12.4	-	27.2	22

The lowest values of the maximum friction force exhibit MES sample (under the load of 5 N) and WAC sample (under the load of 10 N), whereas the highest BLU vulcanizate (under the load of 30 N). The lowest value of the friction force after stabilization shows MES sample (under the load of 5 N), whereas the highest again BLU vulcanizate (under the load of 30 N). Changes to the F_m parameter with load were the lowest for WAC sample (6.5 N) and the highest for BLU one (15.8 N). None of the vulcanizates exhibit changes to the friction force under increasing load, being consistent with the classical law of friction, expecting an increase of the friction force with an increase of load.

4. CONCLUSION

Performed studies show that tribological properties and wear of silicone rubber-based ceramizable composites vary significantly. The most stable tribological performance exhibit WAC wulcanizates for which stabilization of the friction force against steel block is the fastest, and the surface of samples show no optically visible wear. Also MES vulcanizates exhibit good tribological performance and no visible wear, however, stabilization of their friction force takes longer than for WAC samples. Properties of MOM and BLU samples were far worse. Wear of their surface started already under the load of 15 N, destabilizing friction of materials. However, debris of a composite created as an effect of wear of a MOM samples were significantly larger than for BLU vulcanizates. Moreover MOM and BLU samples undergo the so-called rolling mechanism of friction, based on pulling off characteristic strip of tongue pieces, which wind further into a roll and decrease the friction force. Probably due to high dispersed phase content the nature of different wear of the samples is correlated with an interaction between dispersed ceramic and continuous silicone phases.

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