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RESEARCH

Tribological Properties of Silicone Rubber-Based Ceramizable Composites Destined for Wire Covers. Part II. Studies of Ball-on-Plate, Plate-on-Plate and Ring-on-Plate Friction Contact

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A B S T R A C T

Tribological properties of commercially available silicone-based ceramizable composites were studied. Friction forces of three different types of ceramizable composites were measured against three different-shape steel samples. Each friction pair contact was loaded with 15, 30, 45 or 60 N. Conducted studies reveal that tribological behavior of the composites vary considerably depending on the composite type and friction contact. However, friction force was increasing with an increase of the load, which mean that the composites behave accordingly to the classic friction theory.

1. INTRODUCTION

In our last paper we presented tribological properties of silicone rubber-based ceramizable composites tested against steel in block-on-ring friction contact [1]. In order to widen the knowledge concerning tribological behaviour of ceramizable silicone composites we have decided to complement these studies with new data obtained from ball-on-plate, plate-on-plate and ring-on-plate friction contact measurements. Since our last publication new papers describing ceramizable composites have surfaced. J. Wang et al. introduced properties of silicone composites filled with ceramic frit promoting formation of a ceramic layer of exceptional low softening point temperature – 400 °C [2]. Rybiński et al. proposed application of cenospheres or cenospheres covered with iron as new functional fillers for silicone rubber composites facilitating their higher thermal stability [3]. Recently, we also developed silicone composites, containing carbon fibers which significantly enhance their compression strength after ceramization [4]. Nowadays, ceramization process is more often applied to improve flame retardancy of organic polymers. E.E. Ferg et al. presented ceramizable composites on the base of EVA/PDMS blends [5], whereas H-W Di et al. developed ceramizable composites containing only EVA copolymer as a continuous phase [6]. Elastic composites generally exhibit high friction coefficient [7] due to considerable high hysteretic and microhysteretic components of their total friction force. Together with relatively low mechanical properties, this facilitates significant wear of elastic polymer composites, especially when they contain large amount of poorly compatibilized mineral fillers.

2. MATERIALS AND METHODS

Tribological tests were performed for three commercially available silicone rubber-based ceramizable composites: 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 – produced by Bluestar Silicones Ltd. (China), hereinafter referred to as “BLU”. Received mixes were cured with 1.8 % wt. of 2,4-dichlorobenzoyl peroxide (50 % wt. paste in silicone oil – produced by Novichem Sp. z o. o. (Poland)), incorporated by a two roll laboratory mill (Bridge – UK), operating with a friction of 1.13. Plates of the composites were cured and formed in a steel mould, using a laboratory heating press, at 120 °C during 15 min.

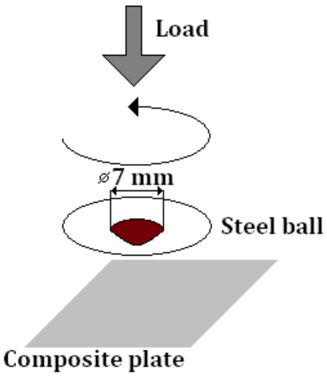

Fig. 1. Scheme of a ball-on-plate contact applied in a T-15 tribo-tester.

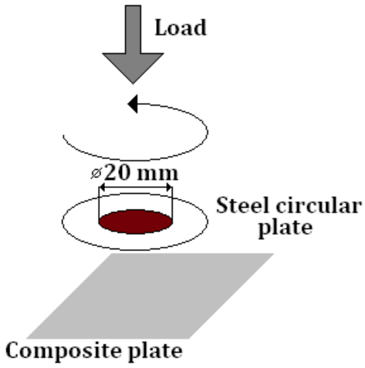

Fig. 2. Scheme of a plate-on-plate contact applied in a T-15 tribo-tester.

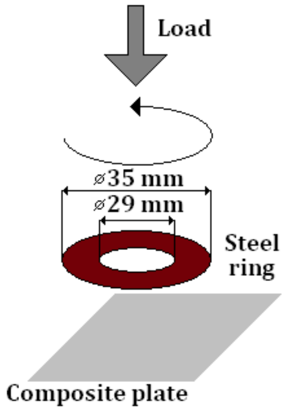

Fig. 3. Scheme of a ring-on-plate contact applied in a T-15 tribo-tester.

Tribological tests were performed by means of T-15 tribo-tester (ITeE – PIB, Poland) equipped with replaceable measuring heads allowing ball-on-plate, plate-on-plate or ring-on-plate friction configurations application. Tribo-tester was operating with 60 rpm speed, under load of 15, 30, 45 and 60 N, for 30 min. The scheme of ball-on-plate, plate-on-plate and ring-on-plate friction contacts are presented in Figs. 1-3 respectively.

3. RESULTS AND DISCUSSION

Changes to the friction force in time for the composites tested in ball-on-plate, plate-on-plate or ring-on-plate friction contacts are presented in Figs. 4-7, 8-11 and 12-15 respectively. Maximal friction force value (F_M) and friction force value after stabilization (F_s) of the samples are placed in Tables 1-3. If the stabilization of a sample friction force is not achieved, the force changing trend is described (increasing – incr. or decreasing – decr.).

3.1 Ball-on-plate friction contact

Friction force changes of the WAC, MES and BLU samples tested in ball-on-plate contact loaded with 15, 30, 45 and 60 N are showed in figures 4, 5, 6 and 7 respectively.

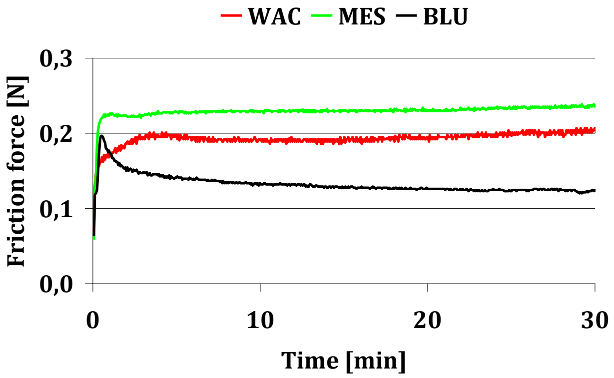

Fig. 4. Changes to the friction force in time for vulcanizates loaded with the force of 15 N in the ball-on-plate contact.

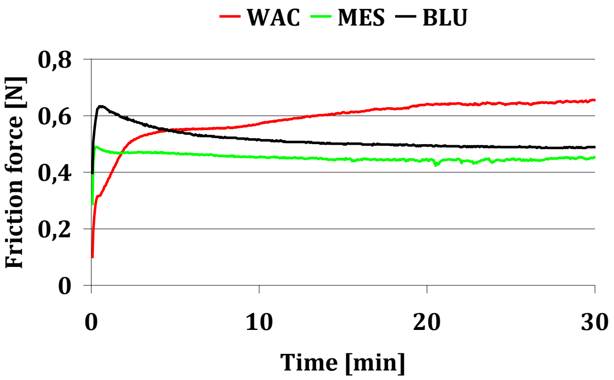

Fig. 5. Changes to the friction force in time for vulcanizates loaded with the force of 30 N in the ball-on-plate contact.

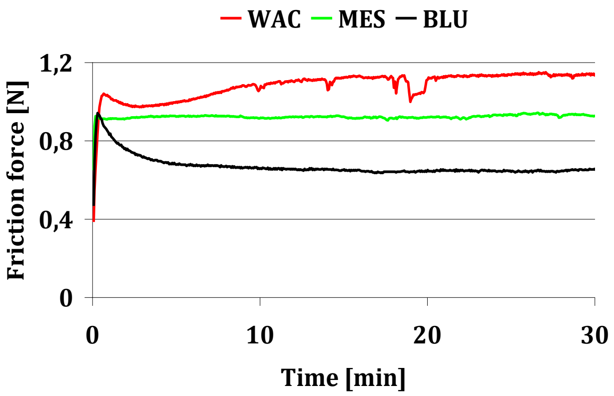

Fig. 6. Changes to the friction force in time for vulcanizates loaded with the force of 45 N in the ball-on-plate contact.

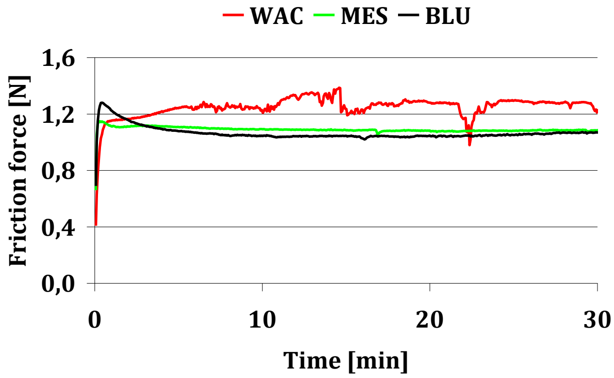

Fig. 7. Changes to the friction force in time for vulcanizates loaded with the force of 60 N in the ball-on-plate contact.

Friction force of all vulcanizates against steel ball increases with an increase of friction contact load, which has been expected in terms of classic friction theory. MES vulcanizate exhibits the most stable run during all measurements, whereas friction force of BLU vulcanizate always reaches a maximum peak directly after start of the measurement and then after ca. 5 min generally stabilizes. WAC vulcanizate exhibits the most unstable run of friction force under this contact, which is surprising taking into account results presented in our last publication, where WAC composite presented the most balanced tribological properties [1].

Table 1. Values of the maximal friction force (F_m) and the friction force after stabilization (F_s), or the trend of friction force changes, for the vulcanizates studied in the ball-on-plate contact.

Load	WAC		MES		BLU	
[N]	F_m	F_s	F_m	F_s	F_m	F_s
15	0.20	incr.	0.24	incr.	0.19	decr.
30	0.65	incr.	0.49	0.45	0.63	0.49
45	1.15	incr.	0.93	0.93	0.94	0.65
60	1.39	1.28	1.15	1.09	1.28	1.18

Maximal friction force values grow most significantly with an increase of load for WAC composite, whereas the slightest increase of this parameter is noticed for MES composite. None of the vulcanizates achieve stabilization of its friction force after 30 min test, under 15 N load. This is probably caused by their inability to creation of stable friction surface between contact pair, under such low load. Under the highest load all of the composites achieved stabilization of the friction force.

3.2 Plate-on-plate friction contact

Friction force changes of the WAC, MES and BLU samples tested in plate-on-plate contact loaded with 15, 30, 45 and 60 N are showed in figures 8, 9, 10 and 11 respectively.

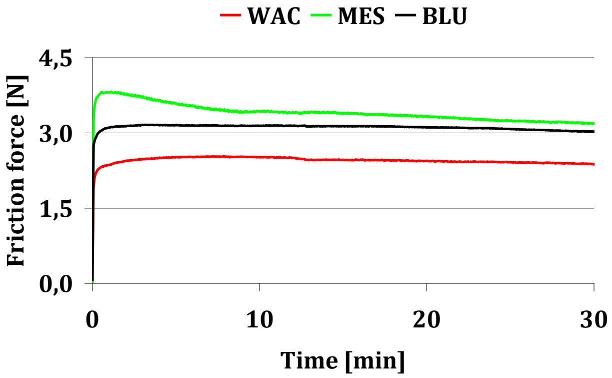

Fig. 8. Changes to the friction force in time for vulcanizates loaded with the force of 15 N in the plate-on-plate contact.

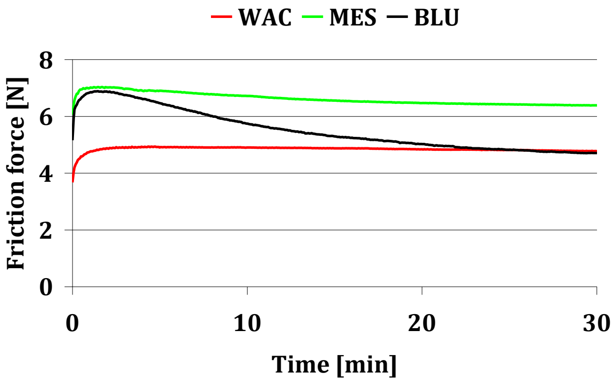

Fig. 9. Changes to the friction force in time for vulcanizates loaded with the force of 30 N in the plate-on-plate contact.

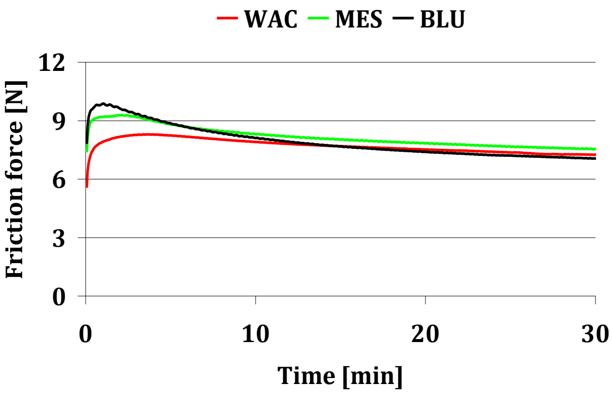

Fig. 10. Changes to the friction force in time for vulcanizates loaded with the force of 45 N in the plate-on-plate contact.

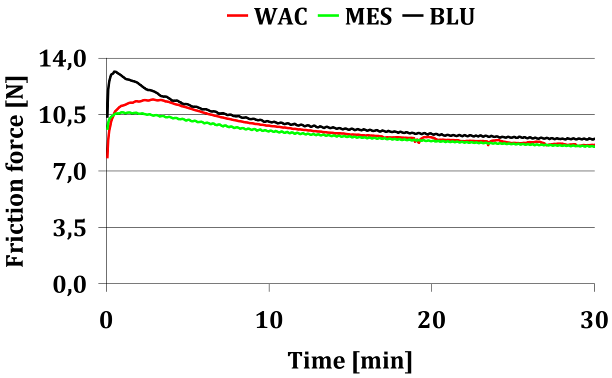

Fig. 11. Changes to the friction force in time for vulcanizates loaded with the force of 60 N in the plate-on-plate contact.

Similarly to previous friction configuration, samples tested in plate-on-plate configuration, exhibit increase of friction force with an increase of load value. Generally all samples exhibit very stable run during measurements, under lower load their friction force do not change very significantly. However, with an increase of load value the samples reach a noticeable pick of maximum friction force, which is decreasing afterwards in order to achieve equilibrated value.

Table 2. Values of the maximum friction force (F_m) and the friction force after stabilization (F_s), or the trend of friction force changes, for the vulcanizates studied in the plate-on-plate contact.

Load	WAC		MES		BLU	
[N]	F_m	F_s	F_m	F_s	F_m	F_s
15	2.53	decr.	3.82	decr.	3.16	decr.
30	4.93	4.78	7.03	decr.	6.89	decr.
45	8.30	decr.	9.29	decr.	9.88	decr.
60	11.44	8.59	10.63	8.52	13.16	8.95

In lower values of load (15, 30 N) the MES sample exhibits the highest F_m force values, whereas with an increase of the load (45, 60 N) the BLU sample reaches the highest values of F_m. Only under the highest load all the samples stabilize their friction force after 30 min of testing, in other cases value of friction force is slightly but constantly decreasing (Table 2).

3.3 Ring-on-plate friction contact

Friction force changes of the WAC, MES and BLU samples tested in ring-on-plate contact loaded with 15, 30, 45 and 60 N are showed in figures 12, 13, 14 and 15 respectively.

Similarly to the previous results, friction force value increases with an increase of the load. In this friction contact the highest value of maximum friction force (Fm) reaches MES composite. Surprisingly friction force of WAC composite under higher load starts to increase after ca. 20 min of measurement. This effect is noticed only for WAC sample on the contrary to two other composites which tribological behaviour is much more similar to the results obtained from plate-on-plate measurements, especially under higher load.

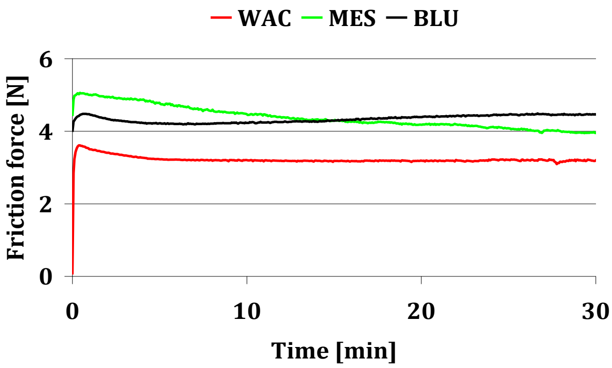

Fig. 12. Changes to the friction force in time for vulcanizates loaded with the force of 15 N in the ring-on-plate contact.

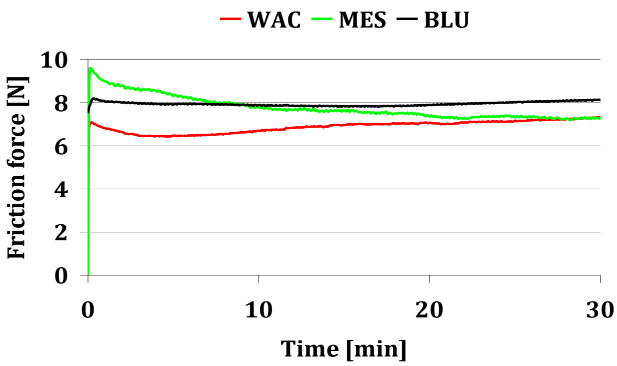

Fig. 13. Changes to the friction force in time for vulcanizates loaded with the force of 30 N in the ring-on-plate contact.

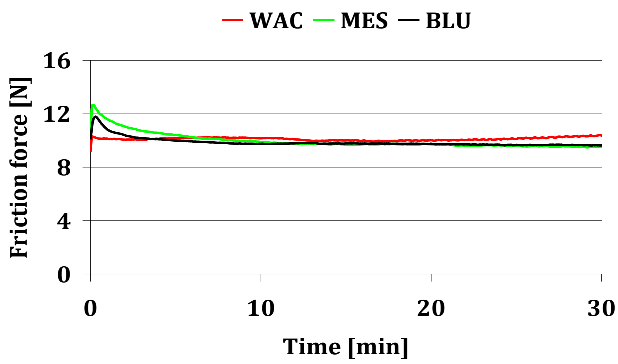

Fig. 14. Changes to the friction force in time for vulcanizates loaded with the force of 45 N in the ring-on-plate contact.

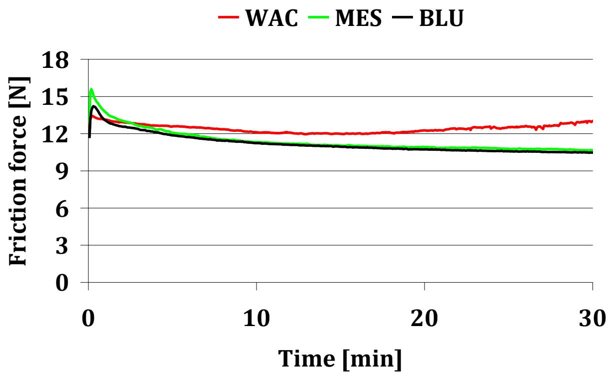

Fig. 15. Changes to the friction force in time for vulcanizates loaded with the force of 60 N in the ring-on-plate contact.

Table 3. Values of the maximum friction force (F_m) and the friction force after stabilization (F_s), or the trend of friction force changes, for the vulcanizates studied in the ring-on-plate contact.

Load	WAC		MES		BLU	
[N]	F_m	F_s	F_m	F_s	F_m	F_s
15	3.61	3.19	5.04	decr.	4.48	4.46
30	7.33	incr.	9.51	7.27	8.19	incr.
45	10.39	incr.	12.55	9.53	11.73	9.65
60	13.44	incr.	15.59	decr.	14.10	decr.

The maximum values of friction force for the composites are slightly higher in comparison to the values from plate-on-plate measurements. This is quite surprising taking into account the fact that area of friction surface is higher for the plate-on-plate contact (314,00 mm^2) than for the ring-on-plate contact (301,44 mm^2). Probably the mechanism of friction changes with the distance from the middle of the steel plate where contact is concentrated to the edge of the plate where two surfaces move in opposite directions, similarly to the ring-on-plate contact. In opposition to previous friction contacts, even under the highest load, friction force of the composites does not stabilize.

4. CONCLUSION

Tribological properties of commercially available silicone rubber-based ceramizable composites vary significantly. This was expected based on our previous experience [1]. However, in comparison to previous results WAC composite exhibits very unstable run under ball-on-plate friction contact. On the other hand, under plate-on-plate friction contact its friction force is remarkably stable during the measurement, regardless of the load value. In all cases friction force increases with an increase of the load, which stays with accordance to the classic friction theory. In summary it should be state that tribological behaviour of silicone rubber ceramizable composites depends considerably on the type of the composite and friction contact. In order to avoid further wear or tribological problems a sample of each type of a composite should be tested in specific friction environment before its final application.

Acknowledgement

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REFERENCES

[1] R. Anyszka, D. M. Bieliński and D. Strzelecki, 'Tribological properties of silicone-rubber based ceramizable composites destined for wire covers. Part I. Studies of block-on-ring friction contact', *Tribology in Industry*, vol. 37, no. 2, pp. 154-160, 2015.

[2] J. Wang, C. Ji, Y. Yan, D. Zhao and L. Shi, 'Mechanical and ceramifiable properties of silicone rubber filled with different inorganic fillers', *Polymer Degradation and Stability*, vol. 121, pp. 149-156, 2015.

[3] P. Rybiński, W. Żukowski and D. Bradło, 'Influence of cenosphere particles on thermal properties composites of silicon rubber', *Journal of Thermal Analysis and Calorimetry*, vol. 122, no. 3, pp. 1307-1318, 2015.

[4] M. Imiela, R. Anyszka, D. M. Bieliński, Z. Pędzich, M. Zarzecka-Napierała and M. Szumera, 'Effect of carbon fibers on thermal properties and mechanical strength of ceramizable composites based on silicone rubber', *Journal of Thermal Analysis and Calorimetry*, vol. 124, no. 1, pp. 197-203, 2016.

[5] E. E. Ferg, S. P. Hlangothi and S. Bambalaza, 'An experimental design approach in formulating a ceramifiable EVA/PDMS composite coating for electric cable insulation', *Polymer Composites*, doi: 10.1002/pc.23595.

[6] H-W Di, C. Deng, R-M Li, L-P Dong and Y-Z Wang, 'A novel EVA composite with simultaneous flame retardation and ceramifiable capacity', *RSC Advances*, vol. 63, no. 5, pp. 51248-51257, 2015.

[7] N.K. Myshkin, S.S. Pesetskii and A.Ya. Grigoriev, 'Polymer tribology: current state and applications', *Tribology in Industry*, vol. 37, no. 3, pp. 284-290, 2015.