Effect of molybdenum disulphide and graphite on tribological properties of vulcanizates of hydrogenated butadiene-acrylonitrile rubber

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Introduction

Friction of elastomers or, speaking more generally, tribological properties of elastomers, is a complex issue. It may be considered from the viewpoint of elastoplastic features, adhesion-cohesion mechanism or hysteresis mechanism [1÷3].

One of the important problems accounted in many applications of rubber products is the reduction of their frictional wear occurring as a result of friction against mating parts. Such products include, for instance, packing elements (glands), among them rotating shaft packing. In order to reduce rubber wear, the coefficient of kinetic friction should be decreased, reducing thereby the force acting in the friction area and the corresponding mechanical energy that is responsible for the increase of the temperature of materials in frictional contact.

One of the basic methods of lowering the friction coefficient is by modifying the surface (outer layer) of rubber products. This way the frictional properties of rubber products are improved and their life span is extended. A method often applied to lower the friction coefficient is the modification of products made of various rubbers by chlorination, chlorosulphonation, sulphonation, bromination, iodination or fluorination of the outer layer of rubber products [4÷9]. Products made of some types of rubber, e.g. fluorocarbon rubber or silicone rubber, cannot have their surfaces modified chemically. Products made of such materials (but also of those, which can be chemically modified) may be modified using physical methods. An interesting example of that is modification by radiation. Growing in use are high-energy X-rays, electron or ion beams (bremsstrahlung) [1, 9÷11]. Tribological properties of rubber vulcanizates can also be improved by adding carbon nanotubes and silica to the rubber compound [12].

A combination of several methods of improving frictional properties provides better results than applying these individual methods alone, particularly in the case of decreasing initial friction coefficient of NBR vulcanizates [13].

The diversity of methods applied to improve tribological properties indicates that the problem is complex and that one versatile, "good-for-all" method has not been invented yet. Perhaps a combination of many methods should be sought, as suggested in [13].

Another method of modifying a rubber compound is adding to it a substance, which will subsequently migrate towards the surface and form a layer that reduces the friction coefficient [1, 14]. The drawback of this method in the case of rubber packing is that the migrating substance may dissolve in the medium which is in contact with the packing.

One method of lowering the friction coefficient is the addition of graphite or molybdenum disulphide to the rubber compound. There is, however, little literature data on this subject, except for papers published in China [15, 16]. These publications indicate that graphite and molybdenum disulphide have little effect on the friction coefficient, but nevertheless they reduce frictional wear of parts made of NBR rubber and PU. On the other hand, it is known from [17], that only finely powdered graphite is able to confer good properties, including reduced friction coefficient, to vulcanizates.

The method of modifying HNBR rubber compound presented in this paper (addition of molybdenum disulphide and/or micronized graphite to the rubber compound) is part of a larger research project, wherein rubber compounds and vulcanizates were modified using various methods. The paper presents results of the study of the effect of micronized graphite and molybdenum sulphide on the tribological properties of HNBR vulcanizates used in the manufacture of special purpose packings. The study also included the determination of the areas of synergy between these two additives.

Experimental

Materials used in tests

The paper presents test results of a modified rubber compound, designated with the symbol IRP 1078M, which contains hydrogenated butadiene-acrylonitrile rubber vulcanized with organic peroxides. The modification consisted in replacing carbon black in the rubber compound with micronized graphite (up to 10 phr) or molybdenum disulphide (up to 5 phr). The tested rubber compounds included also those, where carbon black was replaced with both micronized graphite and molybdenum disulphide (total content up to 15 phr). Rubber compounds containing 0, 4, 6 and 10 phr of micronized graphite and 2, 3 and 5 phr of molybdenum disulphide were prepared. The manner of preparing these compounds was in all cases identical.

Table 1

Rubber compound curing characteristics and basic physical properties of vulcanizates for samples with no modifiers and with maximum content of modifiers.

Item	Property	Test method	IRP 1078M	IRP 1078M-M5*	IRP 1078M-G10**	IRP 1078M- G10-M5***
1	Mmax, dNm	PN-ISO 3417:1994	106	108	108	108
2	Mmin, dNm	PN-ISO 3417:1994	21	22	23	23
3	M90, dNm	PN-ISO 3417:1994	97,5	99,4	99,5	99,5
4	Del M, dNm	PN-ISO 3417:1994	85	86	85	85
5	T2, min	PN-ISO 3417:1994	4,2	4,9	4,2	4,3
6	T90, min	PN-ISO 3417:1994	10	10,2	11	10,9
7	Hardness, °Sh A	PN – 80/C-04238	81	77	82	81
8	Wytrzymałość na rozciągania, MPa	PN-ISO 37:2007	23,1	24,1	22,3	22,1
9	Ultimate elongation, %	PN-ISO 37:2007	175	255	172	227
10	Modulus @ 100% elongation, MPa	PN-ISO 37:2007	13	9,5	14,2	10,2

* 5 phr of molybdenum disulphide, ** 10 phr of micronized graphite, *** 5 phr of molybdenum disulphide and 10 phr of micronized graphite

The correctness of preparing these compounds was verified by checking curing characteristics and basic physical properties of the vulcanizates. Table 1 shows the results obtained for the compound containing no modifiers and for compounds with the maximum content of modifiers (used in this study). The data presented indicate that replacing carbon black with molybdenum disulphide and with micronized graphite does not alter in any significant degree the curing characteristics and physical properties of the vulcanizates. Results obtained for the other rubber compounds (with intermediate content of molybdenum disulphide and/or micronized graphite) were similar to those above.

Study of tribological properties

Tribology is the science of processes occurring on interacting surfaces of solid bodies in relative motion. It includes the study of friction, wear and lubrication of moving assemblies. The main focuses of the paper are the friction coefficients and their consequences, i.e. temperature increase. As "friction" is not an unambiguous term (it may refer to the physical phenomenon, as well as to the rubbing of bodies against each other) its definitions are cited here followed by the description of methods of friction measurement with the use of an instrument acquired for the purposes of this project.

According to [1], friction is defined as "the resistance encountered when attempting to move one body on the surface of another body. Usually between the elements of a friction pair there is a lubricating substance. Even in the case of the so-called dry friction (with no lubricant used) the friction zones may contain products of wear and contaminants. In most cases friction is accompanied by wear of material."

The forces occurring in a system of interacting bodies with a horizontal contact plane are shown in the drawing. Fig. 1 [4].

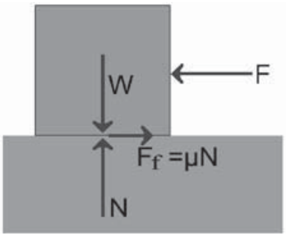

Fig. 1. Forces (vectors) acting in the case of friction between a block and ground: W - weight of bodies, N - normal force (perpendicular to the surface of contact) created in response to force W, force F setting the body in motion, F_f - force of kinetic friction, equal to the coefficient of friction times the normal force [4]

When the values of the force of friction and of the normal force are known, the friction coefficient can be calculated from the formula:

$$\mu = F_f/N$$

In the case of elastomers, friction is a complex phenomenon because of the viscoelastic nature of elastomers and because of the various other phenomena that accompany friction. It is not only the effect of uneven surface of the bodies in contact, but it is associated with adhesion and other phenomena that occur during the deformation and wear of an elastomer. It has both an adhesive and hysteretic nature [1]. During friction a "Schallmach wave" is formed in the outer layer of elastomer. This wave travels in the area of contact between the bodies at a speed higher than the relative speed of the bodies in contact [1]. In effect the value of force F_f changes rapidly, sometimes in a wide range (e.g. ca. 50% of its initial value), and the surface becomes uneven upon friction.

The friction coefficient is determined empirically, and in the case of elastomers it depends not only on the materials in contact and lubrication, but also on the force applied, movement speed, area of contact and temperature.

The friction coefficient was determined using a T-11 device (pin-on-disk apparatus), fabricated by the Institute for Sustainable Technologies (ITeE) in Radom. A steel ball, ñ of an inch in diameter, served as the counter-sample. The material tested was fixed in a special holder on a table rotating at a controlled speed. The instrument measures continuously the force of friction F_f, linear displacement, temperature inside the chamber and temperature of the ball.

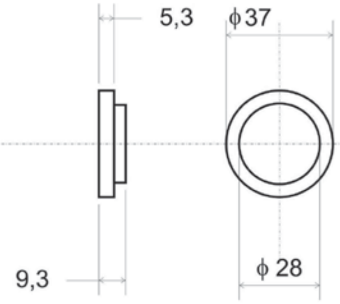

Fig. 2. Shape and dimensions of sample used in tribological tests

The sample used in the tests was of the shape shown in Fig 2.

Upon initial measurements the following test conditions were adopted:

- linear velocity of ball relative to sample - 0.03 m/s and 0.1 m/s
- force applied - 5 N
- ball diameter - 1/4 inch (counter-sample)
- ball movement radius - 6 mm and 10 mm
- test duration - 300 s
- ambient temperature

The following quantities were measured (recorded) during the test:

- force of friction
- ball displacement
- temperature of the ball

The results of measurements were used to calculate:

- coefficient of friction at the start of test (initial friction coefficient) and after 60 s and 300 s from the start of test,
- ball temperature increase (corresponding approximately to the increase of sample temperature)

Molybdenum disulphide - test results

Test results for vulcanizates containing molybdenum disulphide are shown in figures 3 and 4, and those for vulcanizates containing micronized graphite are shown in Fig. 5 and Fig. 6.

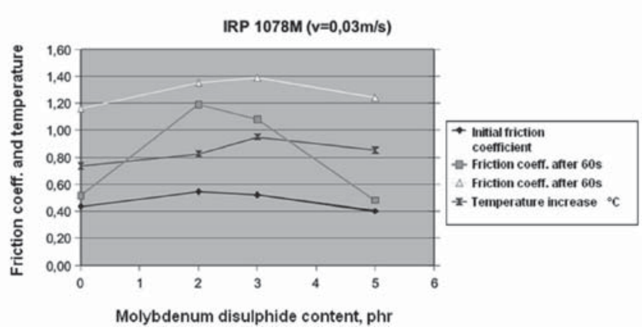

Fig. 3. Tribological properties of IRP 1078M vulcanizates at friction velocity 0.03 m/s for samples of various molybdenum disulphide content

The recorded value of the force of friction alters rapidly ("vibrates"), often forming a wide band on the chart. For this reason mean values were calculated for a number of measurement points at the start of the chart, after 60 seconds of test duration and near the end of the test (after 300 seconds).

The changes in the friction coefficient of the IRP 1078M compound measured at the friction speed of 0.3 m/s (Fig. 3) confirm the observations reported in the literature [15, 16]. Changes of the initial friction coefficient after 300 seconds are similar in characteristics (slight initial increase, then a drop near the value close to that obtained for an unmodified compound), whereas values of friction coefficients after 300 seconds are higher. The value of friction coefficient after 60 seconds of test duration of the sample with 2 phr carbon black replaced with molybdenum disulphide, increased twofold; of the sample with 3 phr replaced - decreased slightly, while of the sample with 5 phr replaced fell below the value for the sample with no molybdenum disulphide added.

Temperature increases, like the friction coefficients, instead of being lower, as would have been expected, show a tendency to rise with growing content of molybdenum disulphide in the rubber compound.

The friction coefficients in this case increase with the duration time of the test.

As was the case with the 0.03 m/s friction speed, the friction coefficients at the friction speed of 0.1 m/s at the start and after 300 seconds of test duration change only slightly with the change in molybdenum disulphide content in the rubber compound.

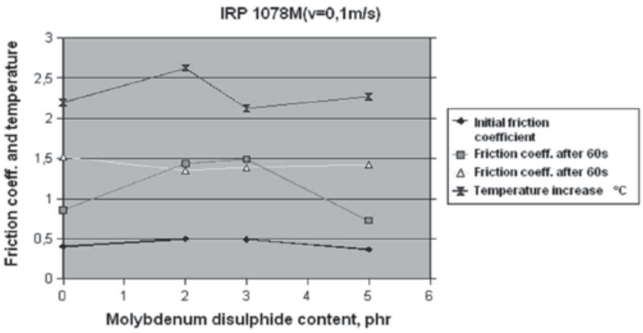

Fig. 4. Tribological properties of IRP 1078M vulcanizates at friction velocity 0.1 m/s for samples of various molybdenum disulphide content

However, the friction coefficient measured after 60 seconds of test duration indicates that the friction of these vulcanizates is a complex phenomenon. As was the case of test illustrated in Figure 3, the friction coefficient increases initially with growing content of molybdenum disulphide, and eventually at 5 phr decreases (quite rapidly) to below the initial value. The friction coefficient measured after 300 seconds of test duration decreases steadily with growing content of molybdenum disulphide. The friction coefficients measured at the friction speed of 0.1 m/s of samples containing 2 and 3 phr of molybdenum disulphide are higher after 60 seconds of test duration than those after 300 seconds. The last two observations are important, as they may suggest that the frictional properties of products made of these rubber compounds will improve with operation time.

Changes in temperature vary little with the change in molybdenum disulphide content, except for the 2 phr sample, where an increase is observed, which correlates with the increase in friction coefficient observed in the sample of same molybdenum disulphide content.

Micronized graphite

Replacing part of the carbon black in the IRP 1078M rubber compound with micronized graphite only slightly improves (lowers) the friction coefficients of the vulcanizates measured at the speed of 0.03 m/s, and has no significant effect on temperature increase of the ball in contact with the rubber surface during the test.

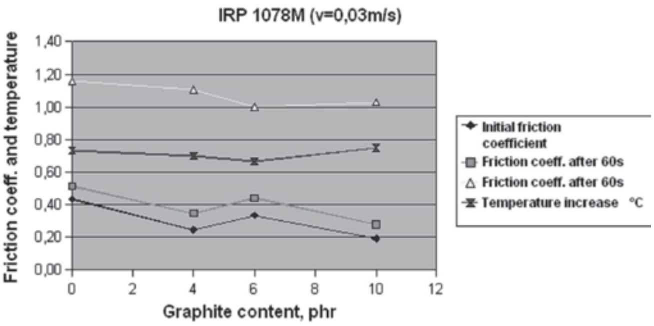

Fig. 5. Tribological properties of IRP 1078M vulcanizates at friction speed 0.03 m/s for samples of various micronized graphite content

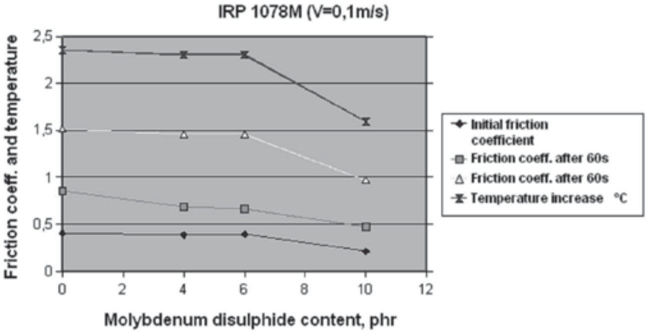

Fig. 6. Tribological properties of IRP 1078M vulcanizates at friction speed 0.1 m/s for samples of various micronized graphite content

The changes in the values of friction coefficients after the introduction of micronized graphite into the rubber compound are beneficial, although lower than expected. These changes, as was the case with molybdenum disulphide, are in line with literature reports [15, 16]. In this case the friction coefficients increase with increasing test duration time (the worn surface probably shows more resistance when the sample is in motion relative to the counter-sample).

The friction coefficient of the IRP 1078M compound measured at the speed of 0.1 m/s decreases distinctly with increasing content of micronized graphite, and the temperature increase caused by friction in the case of vulcanizate containing 10 phr of graphite is significantly lower than that of the compound with no graphite added. Replacing part of carbon black with micronized graphite in this compound improves its tribological properties. However, the effect of graphite addition on frictional properties, up to the content of 6 phr, is small; only at higher concentrations of graphite the lowering of friction coefficients and of temperature increases is significant.

Molybdenum disulphide and micronized graphite

The complex and substantially different interrelations of tribological properties in the case of micronized graphite and molybdenum disulphide suggest that the mechanisms of the improvement of tribological properties differ for each of these materials. It therefore seemed sensible to verify whether the use of both these substances together in

Table 2

The results of determining tribological properties of IRP 1078M compound vulcanizates containing micronized graphite and molybdenum disulphide at friction speed of 0.03 m/s

Item	Property	Content of graphite/molybdenum disulphide (phr)				
		2/4	4/3	6/2	8/1	10/5
1	Initial friction coefficient	0,28	0,30	0,31	0,29	0,26
2	Friction coefficient after 60 s	0,30	0,33	0,41	0,43	0,48
3	Friction coefficient after 300 s	1,12	0,73	1,05	1,14	0,93
4	Indentation, μm	-62	-48	-58	-68	-46,5
5	Temp. increase °C	0,65	0,45	0,65	0,68	0,53

Table 3

The results of determining tribological properties of IRP 1078M compound vulcanizates containing micronized graphite and molybdenum disulphide at friction speed of 0.1 m/s

Item	Property	Content of graphite/molybdenum disulphide (phr)				
		2/4	4/3	6/2	8/1	10/5
1	Initial friction coefficient	0,38	0,41	0,40	0,40	0,38
2	Friction coefficient after 60 s	0,76	1,05	1,35	1,17	1,26
3	Friction coefficient after 300 s	1,38	1,39	1,34	1,40	1,25
4	Temp. increase °C	2,15	2,28	2,58	2,30	2,0

the rubber compound would amplify the effect of enhancing tribological properties (synergy).

The results of determining tribological properties of IRP 1078M compound vulcanizates containing molybdenum disulphide and micronized graphite are shown in Tables 2 and 3.

The results presented indicate that some combinations of graphite/molybdenum content in the rubber compound confer advantageous values to friction coefficients and temperature increases. The evaluation of test results is not easy when dealing with two variables, particularly when at least one variable has nonlinear characteristics. For this reason an OPTY computer software was used to evaluate the results. OPTY makes use of an approximation method (a full second-degree polynomial) to process experimental data. The software enables plotting contour diagrams and calculation of content of components the determined property of which attains maximum or minimum values. Calculations were made on all experimental results obtained for compounds containing various quantities of graphite, molybdenum disulphide and both these components.

Contour diagrams, with lines joining points of the same values, enable assessing the effect of two variables on the property under study. These diagrams are shown in Figures 7 to 10 for properties measured at the friction speed of 0.03 m/s, and in Figures 11 to 14 for properties measured at the friction speed of 0.1 m/s.

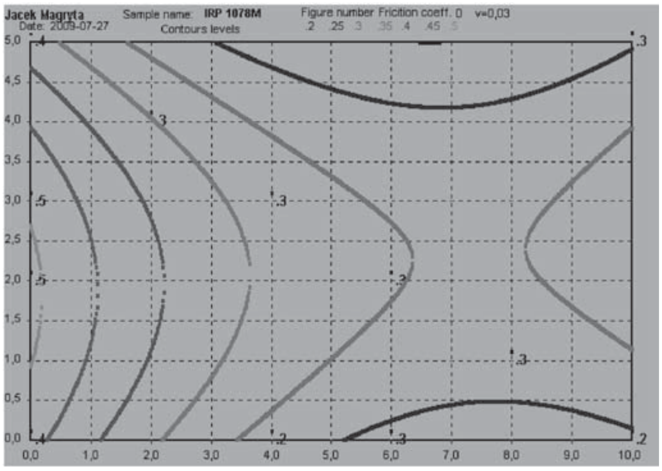

Fig. 7.Changes of the initial friction coefficient of IRP 1078M vulcanizates measured at the friction speed of 0.03 m/s vs. the content of graphite (0 to 10 phr, X axis) and molybdenum disulphide (0 to 5 phr, Y axis)

The area where molybdenum disulphide and micronized graphite act in concert and the tribological properties are improved can be seen in Figure 7. However, as the results presented above implies, the effect of the improvement of the tribological properties of HNBR vulcanizates (designated IRP 1078M) has complex characteristics (clearly nonlinear). At low content levels of graphite (up to ca. 3 phr), molybdenum disulphide has little effect on the initial friction coefficient at the friction speed of 0.03 m/s (friction coefficient dependant on graphite content: the higher the graphite content the lower the friction coefficient). At high levels of graphite content (above 5 phr) and ca. 2 phr content of molybdenum disulphide, the value of the initial friction coefficient basically does not depend on graphite content. Increasing or decreasing molybdenum disulphide content in this area causes reduction of the friction coefficient value. The most advantageous area, where the initial friction coefficient attains the lowest values, is at 6-7 phr graphite content and high molybdenum disulphide content.

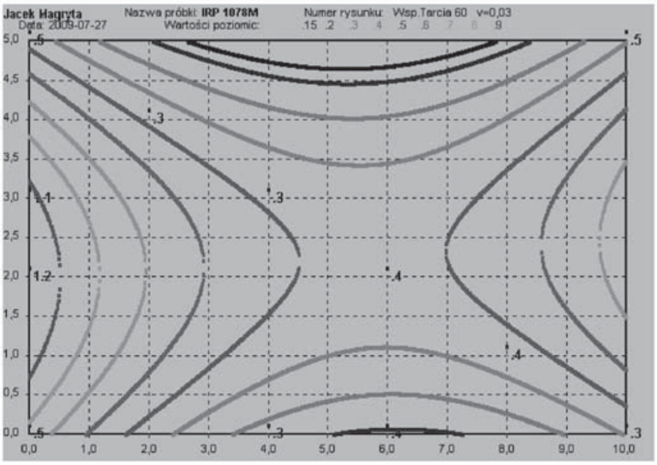

Fig. 8. Changes of the friction coefficient of IRP 1078M vulcanizates measured after 60 s at the friction speed of 0.03 m/s vs. the content of graphite (0 to 10 phr) and molybdenum disulphide (0 to 5 phr)

The area where molybdenum disulphide and micronized graphite act in concert shown in Figure 8 for friction coefficient measured after 60 s is even more distinct than that shown in Figure 7, and the changes of the friction coefficient are greater.

At 2-3 phr molybdenum disulphide content in the IRP 1078M compound the friction coefficient measured after 60 s attains the highest values. Addition of graphite, up to 6-7 phr, causes reduction of the friction coefficient value measured after 60 s. The most advantageous area, where graphite-molybdenum disulphide synergy is observed, is at 5-7 phr graphite content and high molybdenum disulphide content (above 3.5 phr). Optimum graphite content is lower than in the case of initial friction coefficient, and it has decreased from ca. 7-8 phr for the initial friction coefficient to 5-7 phr.

As was the case presented in Figures 7 and 8, at low graphite content levels in IRP 1078M compound, molybdenum disulphide has no significant effect on the value of friction coefficient. The coefficient decreases with increasing graphite content up to 3 phr (up to 4 phr in the case of friction coefficient measured after 300 s). At graphite content above 4 phr and high molybdenum disulphide content (above 3.5 phr), a clear synergetic effect appears and substantial decrease occurs in the value of friction coefficient measured after 300 s (Fig. 9).

The synergy of micronized graphite and molybdenum disulphide in IRP 1078M vulcanizates is also observed with regard to temperature increases measured at the speed of 0.03 m/s (Fig. 10) in the same area as for friction coefficients. The area of synergy confers to the improvement of tribological properties of the IRP 1078M compound.

The initial friction coefficient of the IRP 1078M vulcanizates measured at the friction speed of 0.1 m/s attains the lowest value when graphite content is ca. 5 phr and molybdenum disulphide content is above 4 phr (Fig. 11). However, synergy of graphite and molybdenum disulphide is observed only within a limited range: at low to medium graphite content (up to ca. 6 phr) and at medium to high molybdenum

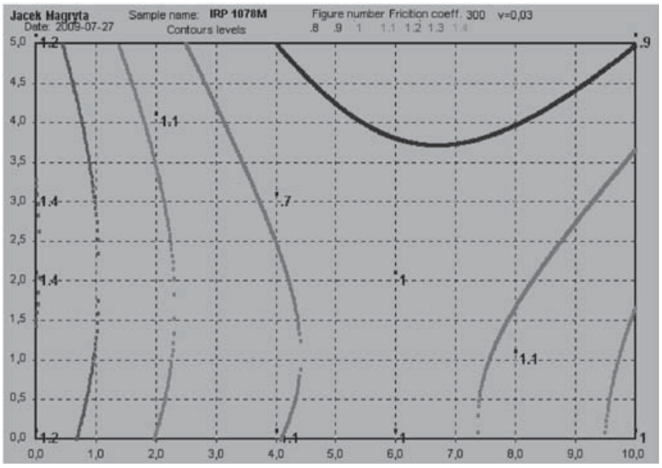

Fig. 9. Changes of the friction coefficient of IRP 1078M vulcanizates measured after 300 s at the friction speed of 0.03 m/s vs. the content of graphite (0 to 10 phr) and molybdenum disulphide (0 to 5 phr)

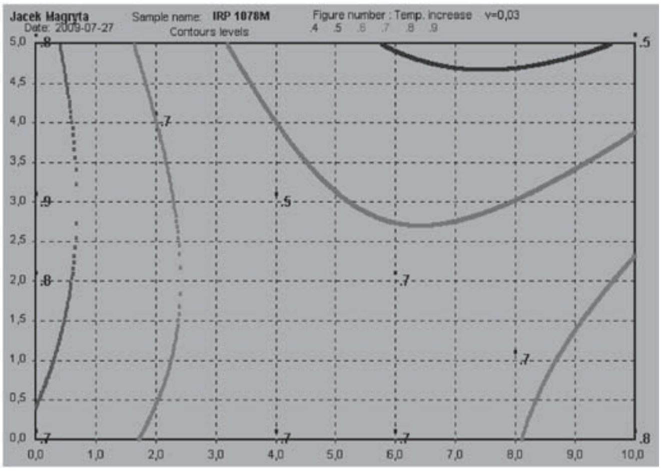

Fig. 10.Changes of the temperature increases of IRP 1078M vulcanizates measured at the friction speed of 0.03 m/s vs. the content of graphite (0 to 10 phr) and molybdenum disulphide (0 to 5 phr)

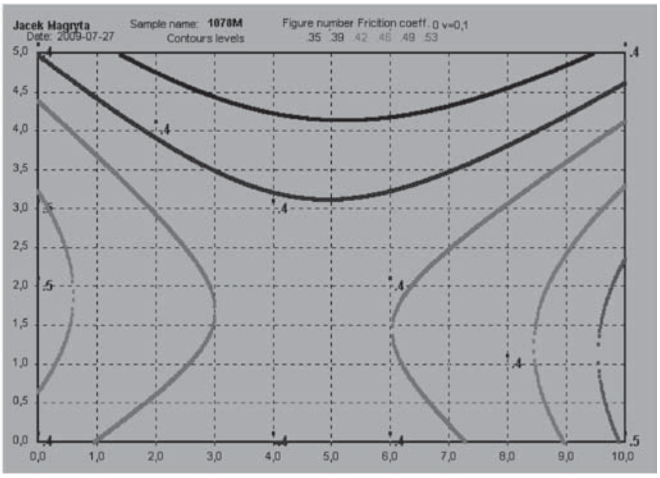

Fig. 11. Changes of the initial friction coefficient of IRP 1078M vulcanizates measured at the speed of 0.1 m/s vs. the content of graphite (from 0 to 10 phr, X axis) and molybdenum disulphide (0 to 5 phr, Y axis)

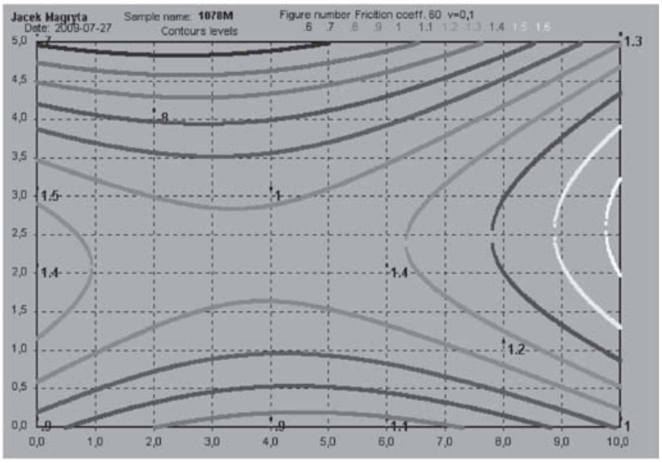

Fig. 12. Changes of the friction coefficient of IRP 1078M vulcanizates measured after 60 s at the friction speed of 0.1 m/s vs. the content of graphite (0 to 10 phr) and molybdenum disulphide (0 to 5 phr)

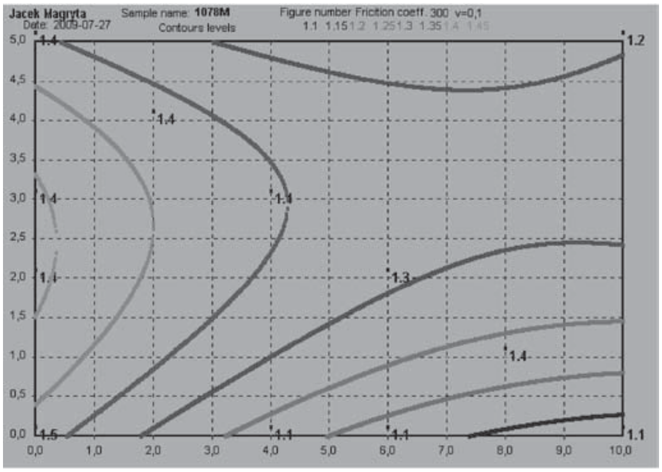

Fig. 13. Changes of the friction coefficient of IRP 1078M vulcanizates measured after 300 s at the friction speed of 0.1 m/s vs. the content of graphite (0 to 10 phr) and molybdenum disulphide (0 to 5 phr)

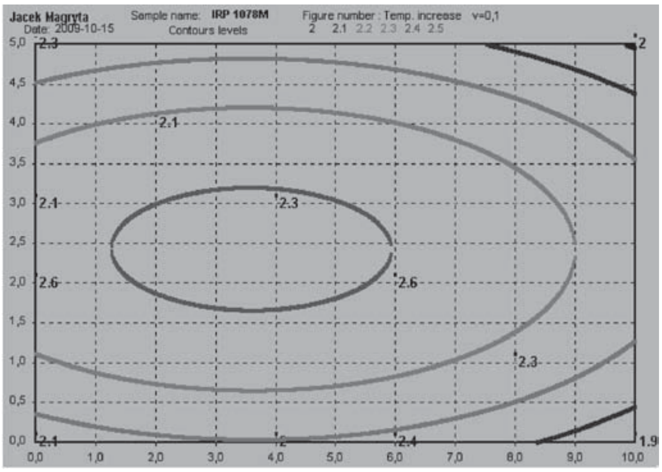

Fig. 14. Changes of temperature increases of IRP 1078M vulcanizates measured at the friction speed of 0.13 m/s vs. the content of graphite (0 to 10 phr) and molybdenum disulphide (0 to 5 phr)

disulphide content. This is similar to the behaviour of the initial friction coefficient measured at friction speed 0.03 m/s. Unexpectedly, at low molybdenum disulphide content (below 2.5 phr), the initial friction coefficient increases with growing graphite content. This increase, however, is not large.

The data shown in Figure 12 indicate that the highest values of the friction coefficient measured at the speed of 0.1 m/s after 60 seconds are attained in samples containing 2 to 2.5 phr of molybdenum disulphide. The changes in the friction coefficient measured after 60 s are surprising, as the addition of graphite in excess of 7 phr aggravates the situation, and the friction coefficient is even higher. The lowest values of the friction coefficient are attained at high molybdenum disulphide content levels (ca. 5 phr) and graphite content within the range of 0-5 phr. The area of low friction coefficients measured after 60 s is similar to that of initial friction coefficient, with a slight shift towards lower graphite content values.

The value of the friction coefficient of the IRP 1087M vulcanizates measured after 300 s at the friction speed of 0.1 m/s depends mostly on the graphite content. The friction coefficient attains the lowest values when graphite content is above 8 phr with low molybdenum disulphide content. The optimum additive content range for this friction coefficient differs from the optimum ranges determined for the initial

Table 4

Micronized graphite and molybdenum disulphide content at which minimum test values were obtained at friction speed of 0.03 m/s for IRP 1078M vulcanizates

Item	Property Friction coefficient	Additive content corresponding to minimum test value		
		Graphite	Molybdenum disulphide	Measurement result
1	Initial friction coefficient	6,6	5	0,2
2	**after 60 s**	5,2	5	0,05
3	**after 300 s**	7	5	0,82
4	**Temperature increase (°C)**	7,6	5	0,48

Table 5

Micronized graphite and molybdenum disulphide content at which minimum test values were obtained at friction speed of 0.1 m/s for IRP 1078M vulcanizates

Item	Property	Additive content corresponding to minimum test value		
		Graphite	Molybdenum disulphide	Measurement result
1	**Initial friction coefficient**	5,4	5	0,3
2	**Friction coefficient after 60 s**	2,4	5	0,63
3	**Friction coefficient after 300 s**	10	0	1,12
4	**Temp. increase (°C)**	10	5	1,99

friction coefficient and that measured after 60 s. The determination of optimum ranges of additive (graphite/molybdenum) content in the IRP 1078 compound is not easy, as these ranges vary depending on the measurement time.

It was found (Fig. 14) that the optimum (with regard to temperature increase due to friction) range of graphite and molybdenum disulphide content differs from the optimum range determined for friction coefficient measured at friction speed of 0.1 m/s. In this case there is a maximum in the temperature increase of the IRP 1078M vulcanizates (measured at the friction speed of 0.3 m/s) within the graphite content range of 2-5 phr (at molybdenum disulphide content within the range of 2-3 phr).

Increasing the graphite content to above ca. 2.5 phr lowers the temperature increases due to friction, and the most advantageous result (lowest temperature increase) is expected at high graphite (10 phr) and molybdenum disulphide (5 phr) content.

Summary

The tests performed and analysis thereof with the use of contour diagrams enabled the assessment of the effect of rubber compound components on the tribological properties of the IRP 1078M rubber compound vulcanizates. Despite the complex nature of interrelations, this method enables the determination of the ranges of additive content, where the synergetic effect of molybdenum disulphide and micronized graphite improves the tribological properties of the vulcanizates.

It was also found that the ranges of molybdenum disulphide and micronized graphite content, where the synergetic effect is observed, do not cover the entire range studied, but only include small areas, with high (above 5 phr) graphite content.

Despite the large differences in the characteristics of the influence of molybdenum disulphide and graphite on the measured tribological properties (Fig. 7–14), in most cases the optimum range could be determined. To facilitate the determination of this range, we determined the values of molybdenum disulphide and graphite content at which the tribological properties studied attained minimum values. (Tables 4 and 5)

On the basis of diagrams (Figs. 7÷14) and calculations of micronized graphite and molybdenum disulphide content corresponding to minimum friction coefficients and temperature increases, it was found that the best results for an IRP 1078M compound may be expected when 10 phr carbon black in the compound is replaced with 6 phr graphite and 4 phr molybdenum disulphide.

Conclusions

The effect of molybdenum disulphide and micronized graphite on tribological properties of IRP 1078M vulcanizates was found to be small. Only the addition of both these substances in appropriate proportions causes a synergetic effect and improves tribological properties of the vulcanizates.

The tests performed, and particularly analysis thereof with the use of contour diagrams, enables the assessment of the effect of rubber compound components on the tribological properties of the IRP 1078M rubber compound vulcanizates. This method enables the determination of the ranges of additives content, where the synergetic effect improves the tribological properties of the vulcanizates. The application of this method is sensible in the case of nonlinear effect produced by many factors (not only by the components of the rubber compound).

It was also found that the ranges of molybdenum disulphide and micronized graphite content, where the synergetic effect is observed, do not cover the entire range studied, but only include small areas, with high (above 5 phr) graphite content.

Bibliography

1. Bieliński D. M.: *Tribologia elastomerów i gumy z perspektywy inżynierii materiałowej*. Instytut Technologii Eksploatacji – Państwowy Instytut Badawczy w Radomiu, 2009.
2. Moore D. F.: *The friction and lubrication of elastomers.* Pergamon Press (Oxford, New York) 1972.
3. Bieliński D. M.: *Warstwa wierzchnia a tarcie elastomerów.* Polimery 2001, **46,** 10, 684-691.
4. http://en.wikipedia.org/wiki/Friction.
5. Barsamyan G., Sokolov B. V.: *Surface Fluorination of Polymers Using Xenon Difluoride"* in *Topics in Applied Chemistry. Fluoropolymers 1: Synthesis,* Springer U, 2002.
6. Padgurskas J., Rukuiza R., Votter M.,Wollesen V.: *New tribotechnical materials for the friction pair radial lip seal/shaft*. Industrial Lubrication and Tribology 1999, **51,** 5, 233-238.
7. Dedov A. V., Stolyarov V. P., Baranov V. A., Bablyuk E. B., Nazarov V. G.: *Investigation of the formation of a layer of fluorine-containing ingredients on the surface of a vulcanizate*. International Polymer Science and Technology 2005, **32, 7,** 25 – 27.
8. Stein G.: *Surface modification of elastomers to reduce friction.* Gummi Fasern Kunststoffe 2008, **61**, 306-315.
9. Khan M. S. Lehman D., Heinrich G. Gohs U. Franke R.: *Structure-property effect on mechanical, friction and wear properties of electron modified PTFE filled EPDM Composite*. Express Polymer Letters 2009, **3**, 1, 39-48.
10. Bieliński D. M., Pieczyńska D., Jagielski J.: *Modification of Elastomer Friction by Ion Bombardment*. Gummi Fasern Kunststoffe 2009, **62**, 4, 2001-2004.

11. Shalnov A., Bogdanovich B. Yu., Ignatiev A., Senyukov V.: *Application of accelerated electron beams for rubber and polymer modification.* Particle Accelerator Conference, Proceedings of the 1995, 1, **1-5** 125-127.
12. Felhos D., Karger- Kocsis J., Xu D.: *Tribological Testing of Peroxide Cured HNBR with Different MWCNT and Silica Contents Under Dry Sliding and Rolling Conditions against Steel*. Journal of Applide Polymer Science 2008, **108**, 5, 2840-2852.
13. Pyatov I. S., Vasil'eva S. N., Tikhonova S. V., Stolyarova V. P., Nazarova V. G.: *Combined method for modifying the friction properties*. International Polymer Science and Technology 2000, **27,**3.
14. Bieliński D. M., Głąb P., Chriściel J.: *Modyfikacja kauczuku butadienowo-styrenowego polimetylosiloksanami Cz. II Układy napełnione krzemionką*. Polimery 2007, **52**, 4, 268-273.
15. Hao-Jie Song, Zhao-Zhu Zhang, Zhuang-Zi Luo: *Investigation of the influence of* MoS_2 *and Graphite on the Tribological Properties of Poluflu Wax/Polyurethane Composites Coatings.* Polymer Materials Science and Engineering 2006, **22**, 6, 141-144.
16. Jun-Hong Shi, Jian Yang, Ming Tian, Li-Qua Zhang: *Study on properties of submicrometer- graphite/HNBR composite*. China Rubber Industry 2008, **55**, 3, 146-149.
17. Jian Yang, Ming Tian, Qing-Xiubn Jia, Li Quan Zhang, Xiao-lin Li: *Influence of Graphite Particle Size and Shape on the Properties of NBR.* Journal of Applied Polymer Science 2006, **102**, 4, 4007-4015.

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