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Evaluation of stability of elastomer packing exposed to influence of various biofuels

M. Müller[1], V. Šleger[2], M. Pexa[3,*], J. Mařík[3] and Č. Mizera[2]

[1]Czech University of Life Sciences Prague, Faculty of Engineering, Department of Material Science and Manufacturing Technology, Kamýcká 129, CZ16521 Prague 6, Czech Republic
[2]Czech University of Life Sciences Prague, Faculty of Engineering, Department of Mechanical Engineering, Kamýcká 129, CZ16521 Prague 6, Czech Republic
[3]Czech University of Life Sciences Prague, Faculty of Engineering, Department for Quality and Dependability of Machines, Kamýcká 129, CZ16521 Prague 6, Czech Republic; [*]Correspondence: pexa@tf.czu.cz

Abstract. The aim of the European Union Member States is to reduce dependence on fuels derived from oil. For this reason, significant attention is paid to the use of organic products as a substitute or an additive in the fuel of petroleum origin. The usage of biofuels in conventional combustion engines is not easy due to the different properties of the products. The aim of the research was to determine the effect of biofuels on mechanical properties of O-rings type ACM (polyacrylate elastomer). The research was evaluated by the change of density, Shore A hardness, permanent deformation CS, tensile strength and deformation after exposure in the test environment for a period of 15 months. Comparing the O-rings immersed in standard diesel fuel it is clear that similar behaviour of the hardness shows are sunflower oil and canola oil. RME – Rapeseed Methyl Ester 20% and oil from Jatropha has a negative effect on the increase in hardness. Comparing the O-rings immersed in standard diesel fuel it is evident that except RME – Rapeseed Methyl Ester 20% other fuels have negative influence on permanent deformation CS.

Key words: biofuels, O-ring, compression and tensile properties.

INTRODUCTION

To reduce the dependence of the Member States on fuels derived from oil is an effort of the European Union. Significant attention is devoted to the use of organic products as substitutes or as an additive to petroleum based fuel for this reason. The usage of biofuels in conventional internal combustion engines is not easy due to the different properties of the products. It is necessary to deal in particular with a lower calorific value, the higher the density and viscosity of these biofuels and reflect their effect on components of combustion engines, especially sealing elements. (Soo-Young, 2011; Imran et al., 2013; Pexa et al., 2013; Barrios et al., 2014; Pexa & Mařík, 2014).

One of the main groups of materials used for manufacturing gaskets are elastomers. Elastomers exhibit good flexibility and chemical resistance.

The decisive factor is reliability - to reduce maintenance costs. One of the basic and most commonly used sealing elements is an O-ring (Bafna, 2013). An appropriate proposal of a suitable material to be used for this application is a very important issue.

The O-ring is a double-acting sealing element. The compression during installation acting in the radial or axial direction of the O-ring provides the initial sealing capability. This force increased by the power of imparting a pressure in the system represents the final sealing force. This capability can be eliminated by the liquid contaminants e.g. biofuels.

In the automotive industry, the O-rings of the type ACM (polyacrylate elastomer) are mainly used. It is a durable elastomer. Essential characteristics of the long-term ability to meet the sealing function are compression and hardness (Richter, 2014; Bafna, 2013). It is problematic to reproduce operating conditions in the case of the O-rings testing. O-rings have different sizes (Richter, 2014). When testing. Different results might be achieved (Bafna, 2013). As examples can be used the results of hardness tests at which Bafna (Bafna, 2013) demonstrates the significance of the shape factor of the test samples.

The aim of the research was to determine the effect of biofuels on mechanical properties of the sealing O-rings of the type ACM. The particular object of the experiments was the O-ring 13 x 1.9 mm (this dimension of O-rings was chosen on the base of the requirements of prominent Czech manufacturer of agricultural equipment within the grant support). There are sealing rings under the injectors of a diesel engine.

MATERIALS AND METHODS

Sealing O-rings of the ACM type (polyacrylate elastomer) were used in the study. O-rings of the ACM type are resistant to fuels, lubricants and various other ingredients. The research focused on assessing the impact of various types of biofuels on behavioural change of the O-rings used as sealing elements in the fuel system of cars. O-rings were deposited in the environment for a period of 15 months.

The gaskets provided by a manufacturer that were not exposed to the environment degradation (ethalon, marked 1) were also tested. The following fuels and biofuels were tested (Table 1):

Table 1. Tested variants – ethalon, fuels and biofuels

Tested variants	Marked
Ethalon	1
Rapeseed Methyl Ester 20% – RME	2
Sunfloweroil	3
Diesel fuel	4
Jatropha oil	5
Rapeseed oil	6

The oil from jatropha was extracted by pressing ripe seeds, imported from Indonesia (Ružbarský, J. et al., 2014a; Ružbarský, R. et al., 2014b). Within the frame of the research the changes in density, Shore A hardness, permanent deformation CS, tensile strength and deformation were evaluated.

An important parameter for determining the sealing properties is the permanent deformation CS (Compression Set). The reason for this is the fact that it doesn't only cause the compression of the elastic deformation but also plastic deformation. Permanent deformation CS was measured with respect to a modified standard ISO 815. The modification of the standard considered the use of standard real sealing rings as well as the time of loading.

Measurements were performed on electromechanical testing machine MPTest 5,050 manufactured by the Czech company LaborTech. The equipment complies with the EN 7500-1 requirements for Class 0.1. The precision the heightof the load cell used is 0.1 N, the crosshead position is detected with an accuracy of 0.001 mm. The experiment was carried out as follows:

The O-ring 13 x 1.9 was firstly compressed by a speed of 0.03 mm s^{-1}, the height of h_1 = 1.425 mm. This compression corresponds to about 25% of strain. During this deformation of the O-ring was left loaded for 30 min and then again the load was relieved by a speed of 0.03 mm s^{-1}.

The height h0 O-ring was determined by crosshead position before the steep increase of the deformation force. The speed of the deformation force was 1 $N.mm^{-1}$. The reason for this was more moderate force increase, which appeared in some O-rings when a touch of the platen did appear. This situation was caused by a non-planar shape of O-rings which was caused by exposure biofuels to O-rings. The height h_2 was determined by crosshead position when the loading force has fallen to zero. Then it is possible to calculate the value CS (1):

$$CS = \frac{h_0 - h_2}{h_0 - h_1}.100\% \qquad (1)$$

where: CS – permanent deformation – compression set (%); h_0 – initial height of the O ring (mm); h_1 – the height in the state of compression (mm); h_2 – the height after release (mm).

Measurement of the compression set of the O-rings is shown in Fig. 1.

Measurement of the density

Density was determined by determining the proportion of the weight and volume. The weight was determined by weighting on an analytical balance (Analytical balance BBC-22 from the German company BOEC) with a resolution of 0.01 mg which was rounded to the units of milligrams. To determine the volume, a container with an exact volume (pycnometer) was used. Measurements of mass and volume were carried out in line with CSN 621405: 1992 Rubber – Determination Standard for density.

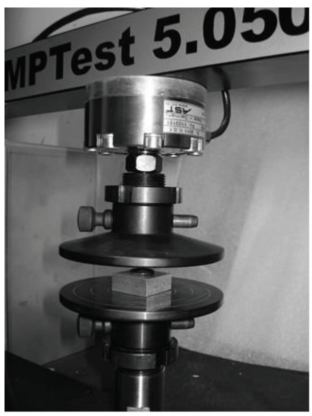

Figure 1. Measurement Compression set.

The tensile properties of rubber were determined by a modified standard ISO 37: 2012 Rubber, vulcanized or thermoplastic – Determination of Tensile Properties. The modification consisted in testing of already produced O-rings.

The tensile strength TS was calculated according to the formula (2). The maximum tensile strength Fm was detected from the record tensile tests performed on the test machine MPTest 5050. The feed speed crosshead was 100 mm min^{-1}. For clamping of the O-rings the wire hooks with a diameter of 2.9 mm were used.

$$TS = \frac{F_m}{(\frac{2\pi \cdot h_0^2}{4})} \tag{2}$$

where: TS – Tensile strength (MPa); F_m – the maximum tensile force (N); h_0 – initial height of the O ring (mm).

The Elongation E_b was calculated by the formula (3):

$$E_b = \frac{(C_b - C_{j)}}{C_j} .100\% \tag{3}$$

where: E_b – elongation (%); C_b – end inner circumference of the O-ring (mm); C_j – initial internal perimeter of the O-ring (mm).

The initial inner circumference of the O-ring was calculated from the inner diameter of the O-ring, which was determined from a distance of the hooks in a tensile test in the moment when the measured force began to grow. The final inner circumference of the O-ring C_b may be calculated using the formula (4), where the diameter of the wire hook is 2.9 mm:

$$C_b = \pi \cdot 2.9 + 2 \cdot 2.9 + 2 \cdot L_b \tag{4}$$

where: C_b – end inner circumference of the O-ring (mm); L_b – distance of the hooks when breaking the O-ring (mm).

Measurement of the tensile properties of the O-rings is shown in Fig. 2. The hardness SHORE A was measured according to the standard CSN EN ISO 868. Material hardness was measured by the Shore A i.e. by pressing the tip of the instrument durometer Shito HT. Hardness measurements according to the EN ISO 868 Shore A method requires the test specimens at least 4 mm high. The O-rings failed to meet this size limit. The height of the O-ring was measured 1.91 ± 0.02 mm. This fact led to the composition of four O-rings in a special fixture for hardness measurement (Fig. 3). This procedure is allowed by the standard.

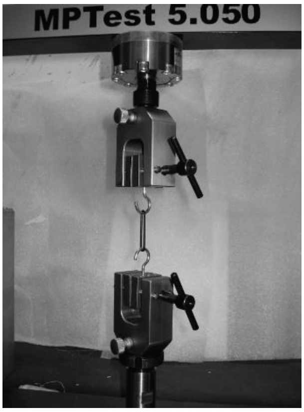

Figure 2. Measurement of tensile properties.

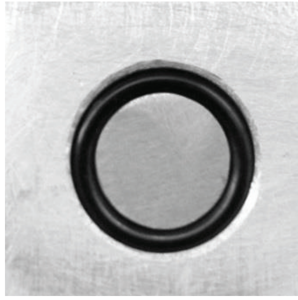

Figure 3. Preparation for measurement of Shore A hardness of O-rings.

For statistical comparison of the measured data the F-test was used. The zero hypothesis H_0 presents the state when there is no statistically significant difference in their mean values ($p > 0.05$) among tested sets of data.

RESULTS AND DISCUSSION

The results of tests aimed at assessing the density are shown in Fig. 4. It is evident that different fuels do change the density of O-rings. Different proportion of variance of results is alos obvious. The coefficient of variation was in the interval 0.45 to 4.67%. From the viewpoint of the impact of the various fuels on the density of the O-rings the F-test results can be summarized as follows: H_0 hypothesis was not confirmed ($p = 0.0158$), i.e. the difference in the 0.05 level of significance among the tested variants can be detected.

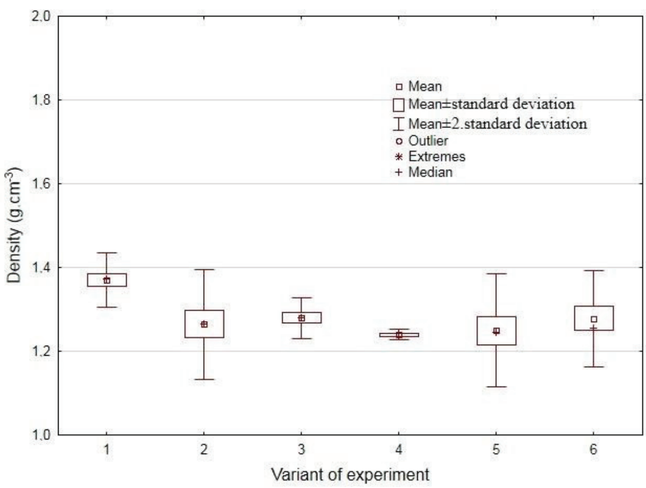

Figure 4. Results of density measurements: 1 – Ethalon; 2 – Rapeseed Methyl Ester 20%; 3 – Sunfloweroil; 4 – Diesel fuel; 5 – Jatropha oil; 6 – Rapeseed oil.

The results of tests aimed at assessing the Shore A hardness are shown in Fig. 5. From the results it is evident that the variants no. 2 (RME - Rapeseed Methyl Ester 20%) and no. 5 (Jatropha oil) do increase the hardness Shore A Hardness by 32.6 to 36.2%. The other variants are characterized by hardness stagnation with respect to the Comparative ethalon (variant no. 1).

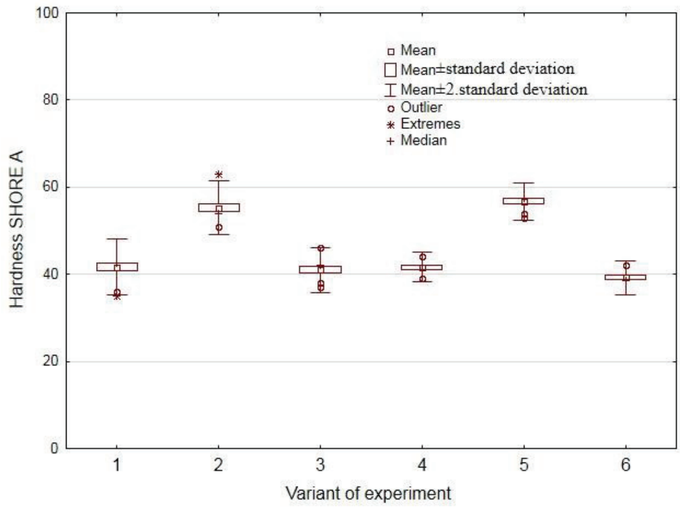

Figure 5. Results of hardness Shore A: 1 – Ethalon; 2 – Rapeseed Methyl Ester 20%; 3 – Sunfloweroil; 4 – Diesel fuel; 5 – Jatropha oil; 6 – Rapeseed oil.

From the viewpoint of the impact of the various fuels on the Shore A hardness of the O-rings the results of the F-test can be summarized as follows: H_0 hypothesis was not confirmed (p = 0.0000), i.e. the difference in the 0.05 level of significance among the tested variants was experimentally detected. When considering the F-tests of the variants 1, 3, 4 and 6 the hypothesis H_0 (p = 0.0591) was confirmed, i.e. there is no difference at the 0.05 significance level among the experimentally tested variants.

The results of the tests aimed at assessing the compression set are shown in Fig. 6. From the results it is evident that different fuels do change the compression set of O-rings.

The results show that the variant no. 3 (sunflower oil), no. 5 (Jatropha oil) and no. 6 (rapeseed oil) do increase the compression set. The higher values of the compression set are negative.

The compression set did increase by 16.7 to 29.4%. Other variants are characterized by the compression set to decrease in comparison to the Comparative etalon (variant no. 1). In variant no. 2 (RME - Rapeseed Methyl Ester 20%), the decrease was 41.5% and in the variants no. 4 (diesel) was 11.3%. From the viewpoint of the impact of the various fuels on the Compression set of the O-rings are the F-test results as follows: H_0 hypothesis was not confirmed (p = 0.0000), i.e. the difference in the 0.05 level of significance among the tested variants can be identified.

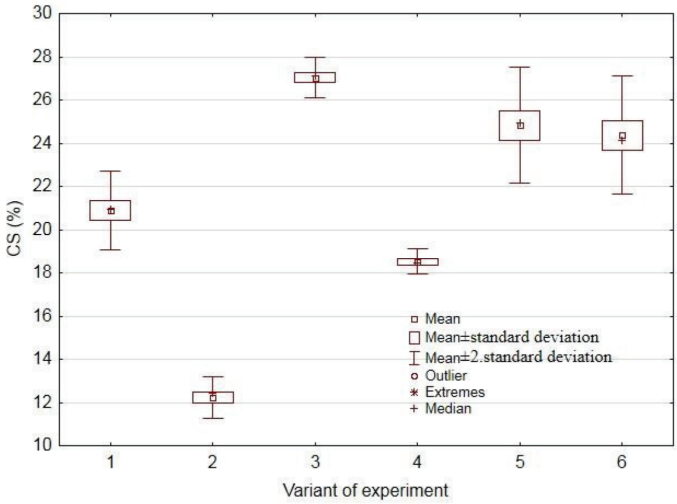

Figure 6. Results of compression set: 1 – Ethalon; 2 – Rapeseed Methyl Ester 20%; 3 – Sunfloweroil; 4 – Diesel fuel; 5 – Jatropha oil; 6 – Rapeseed oil.

The results of tests aimed at assessing the tensile strength are shown in Fig. 7. From the results it is evident that the variant no. 3 (sunflower oil) did increase the strength by about 15%. The decrease in strength was found in the variant no. 4 (diesel) by about 9%. From the viewpoint of the impact of various fuels on the tensile of the O-rings are as follows: H_0 hypothesis was not confirmed (p = 0.0033), i.e. the difference in the 0.05 level of significance of the experimentally tested variants can be identified.

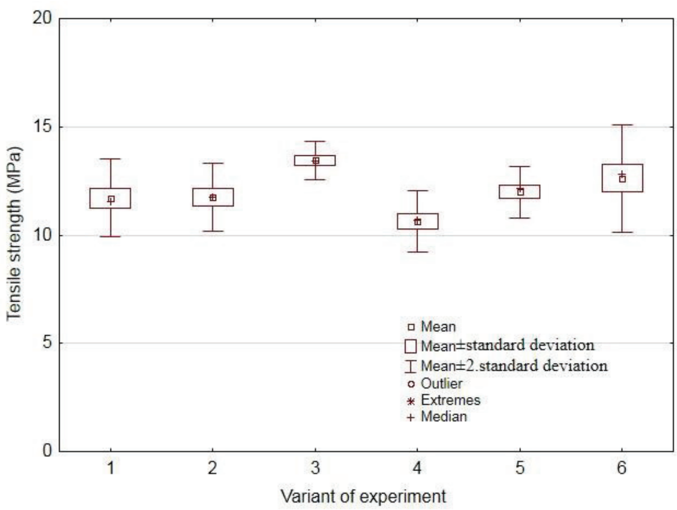

Figure 7. Results of tensile strength measurements: 1 – Ethalon; 2 – Rapeseed Methyl Ester 20%; 3 – Sunfloweroil; 4 – Diesel fuel; 5 – Jatropha oil; 6 – Rapeseed oil.

The results of tests aimed at assessing the deformation can be seen in Fig. 8. From the results it is evident that the variants 2–6 did decrease the deformation. The decrease was in the interval from 5.9 to 16.6%. From the viewpoint of the impact of various fuels on the tensile elongation of the O-rings the F-test results can be formulated as follows: H_0 hypothesis was not confirmed (p = 0.0076), i.e. the difference in the 0.05 level of significance among the tested variants can be found.

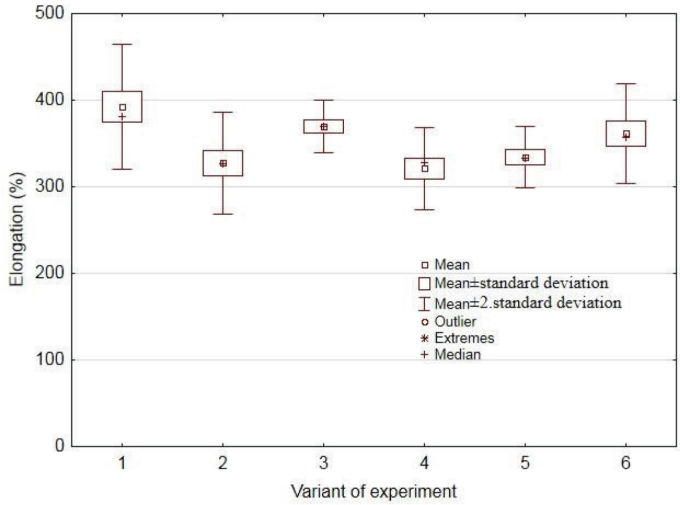

Figure 8. Results of elongation: 1 – Ethalon; 2 – Rapeseed Methyl Ester 20%; 3 – Sunfloweroil; 4 – Diesel fuel; 5 – Jatropha oil; 6 – Rapeseed oil.

Experiments results confirmed the influence of various tested fuels and biofuels (Richter 2014). Second significant parameter is the tested material of O-rings. Results of Bafna (2013) confirmed the significance of the factor. O-rings of the ACM (polyacrylate elastomer) type were used for the experiments.

CONCLUSIONS

From the results of experiments aimed at determining the changes in mechanical properties of the sealing O-rings of the ACM type influenced by various media (fuels) can lead to the following conclusions:

- Reduction in the density in the interval of about 6–9%. Test variants 2-6 cause the reduction in density of the tested O-rings.
- The increase in hardness was observed in two variants, namely no. 2 (RME – Rapeseed Methyl Ester 20%) and no. 5 (Jatropha oil). The increased hardness is negative. Other variants are characterized by hardness stagnation in comparison with the Comparative etalon (variant no. 1 – ethalon). Similar influence on hardness of the O-rings as by the standard diesel fuel were recognized by the variant 3 (sunflower oil), and variant 6 (rapeseed oil). The variants no. 2 and 5 do influence negatively the increase in hardness.
- The increase of the compression set occurred in three variants tested – no. 3 (Sunfloweroil), 5 (Jatropha oil) and 6 (Rapeseed oil). Increase in the compression

set is negative. The positive decrease in the compression set was detected in the variants 2 and 4. As a result of the comparison of the O-rings exposed to the standard diesel fuel and to other fuels became evident that variants – except no. 2 (RME – Rapeseed Methyl Ester 20%) – do negatively affect the Compression set.

- The tensile strength was increased only in the case of the variant no. 3 – Sunfloweroil (15%) and variant no. 6 – Rapeseed oil (7%). The variants no. 2–6 (2 – Rapeseed Methyl Ester 20%, 3 – Sunfloweroil, 4 – Diesel fuel, 5 – Jatropha oil, 6 – Rapeseed oil) demonstrated the decrease of deformation.

If the properties of the rubber elements change, a change of engine operating parameters (leak fuel system, in our case) occurs.

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