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Evaluation of properties of elastomer seal for fuel systems exposed to effects of rapeseed methyl ester

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Abstract

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Elastomer seals in fuel systems have to evince required mechanical properties also at exposure to fuels. The aim of the research was to determine an influence of various concentrations of rapeseed methyl ester (RME) on a change of mechanical properties of sealing O-rings made from polyacrylate elastomer (an indication ACM). A permanent deformation – compression set (CS), a tensile strength and an elongation after the exposure to the tested environment for the time 20 months were evaluated within the experiment. A fall of the tensile strength, the elongation and the permanent deformation – compression set CS was proved depending on the type of the fuel. The increased negative influence of various concentrations of RME (20% to 100%) on the tested properties of the sealing O-rings compared with the diesel oil complying with the standard EN 590:2004 was not proved. So a significant negative influence of degradation aspects on the tested properties of the O-rings of the ACM type (polyacrylate elastomer) was not proved.

Keywords: biofuels; O-ring; compression set; tensile strength; elongation

The European Union devotes a great attention to possibilities of using biofuels for a drive of mobile machines in present days. The biofuel is perceived as a liquid or gaseous substance made from biomass which is determined for transportation. Biofuels are renewable sources compared to traditional fossil fuels.

However, the use of biofuels in common combustion engines is not simple owing to different properties of these products. It is necessary to cope above all with lower calorific value, higher density and viscosity of these biofuels and to take into regard their impact on components, sealing elements of combustion engines above all (Imran et al. 2013; Pexa, Mařík 2013; Barrios et al. 2014; Müller et al. 2015).

Rapeseed methyl ester (RME) is one of the frequently used substitutes for diesel oil in the Czech Republic. RME is gained at pressing rapeseeds and by a subsequent chemical treatment of the pressed oil by means of a reesterfication. Despite the resultant product (RME) differs chemically from oil products, its fuel properties such as density, viscosity, calorific value and the course of combustion are very close to the diesel oil.

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Rapeseed methyl ester can be used in the engine also in 100% concentration. However, producers of the engines have to allow it.

Research studies are focused on a process of engine power and the combustion of rapeseed methyl ester (Hromádko et al. 2011; Soo-Young 2011; Imran et al. 2013, Pexa et al. 2013). So far, min. studies have dealt with material aspects of partial components of combustion engines which the fuel goes through. A great attention is devoted to the use of biofuels in engines at present, however, also the sealing elements which are the part of the fuel systems have to be observed at the implementation of the biofuels for securing an optimum function of the engine.

Elastomers are one of the main group of materials used for a manufacture of seals. Elastomers exhibit good flexibility and chemical resistance (Müller et al. 2015). The good flexibility of sealing elements can be eliminated by the influence of various fuels (Müller et al. 2015). The elastomer material is not entirely resistant to the fuels (Bafna 2013).

The O-ring is one of the basic and the most often used sealing elements (Bafna 2013; Richter 2014).

The aim of the research was to determine an influence of various concentrations of rapeseed methyl ester (RME) on a change of mechanical properties of sealing O-rings made from polyacrylate elastomer (an indication ACM). The permanent deformation – compression set CS, the tensile strength TS and the elongation E_b after the exposure to the tested environment for the time of 20 months were evaluated within the research.

MATERIAL AND METHODS

In the automotive industry, O-rings (13 × 1.9 mm) of the ACM type (polyacrylate elastomer) are mainly used. It is a durable elastomer (Müller et al. 2015). Sealing O-rings of the ACM type were used in the study as they are resistant to fuels, lubricants and various other ingredients.

Sealing O-rings were put into the diesel oil and RME (20, 40, 60, 80 and 100%) for the time of 20 months (Fig. 1). The seals provided by a manufacturer which were not exposed to the environment degradation (ethalon) were also tested. Within the research the changes in the permanent deformation CS, the tensile strength TS and the deformation E_b were evaluated.

The permanent deformation CS was measured with respect to a modified standard ISO 815:2000. The modification of the standard considered the use of standard real sealing rings as well as the time of the loading.

Measurements were performed on an electromechanical testing machine MPTest 5.050 manufactured by the Czech company LaborTech. The equipment complies with the EN 7500-1:2004 requirements for Class 0.1. The crosshead position is detected with an accuracy of 0.001 mm. The experiment was performed as follows:

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

The height h_0 of the O-ring was determined by a crosshead position before the steep increase of the deformation force. The speed of the deformation force was 1 N/mm. The reason for this was a 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 the exposure of O-rings to biofuels. The height h_2 was determined by the crosshead position when the loading force has fallen to zero. Then it is possible to calculate the value CS:

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

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

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

The tensile properties of the 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 (Eq. 2). The max. tensile strength F_m was detected from the recorded tensile tests performed on the test machine MPTest 5050. The load speed of the crosshead was 100 mm/min. The wire hooks with a diameter of 2.9 mm were used for clamping of the O-rings.

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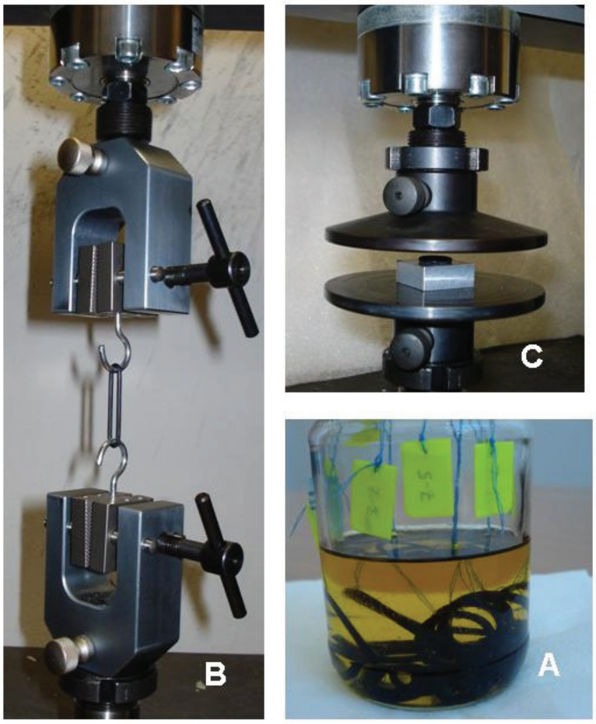

Fig. 1. Measurement of O-rings of 13 × 1.9 mm
A – positioning of O-rings in the tested medium; B – measurement of tensile properties TS; C – measurement of compression set CS

$$TS = \frac{F_m}{\left(\frac{2 \times h_0^2}{4}\right)} \quad (2)$$

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

The Elongation E_b was calculated by the Eq. (3):

$$E_b = \frac{\left(C_b - C_j\right)}{C_j} \times 100\% \quad (3)$$

where: E_b – elongation (%); C_b – final inner circumference of O-ring (mm); C_j – initial inner circumference of 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:

$$C_b = \pi \times 2.9 + 2 \times 2.9 + 2 \times L_b \quad (4)$$

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

A measurement of the tensile properties of the O-rings is shown in Fig. 1.

Statistical hypotheses of the measured data sets were also tested by the programme Statistica. Validity of the null hypothesis (H_0) shows that there is no statistically significant difference ($p > 0.05$) among the test data sets. Conversely the hypothesis H_1 negates the null hypothesis, which means that there is a statistically significant difference or a dependence between variables ($p < 0.05$) between the test data sets.

RESULTS AND DISCUSSION

The results of the tests aimed at assessing the compression set are shown in Fig. 2a. It is evident from the results that different fuels (concentrations) change the compression set of O-rings.

It is obvious from the experiment results that the diesel oil and various concentrations of RME fuel decrease the permanent deformation of the O-rings. It is a positive influence owing to the function of the O-rings sealing. It is stated in literature dealing with the rubber sealing elements that higher values of permanent deformation are considerably negative (Tuckner 2001). The experiment results confirmed the conclusions of the test with O-rings exposed to the diesel oil and 20% RME for 20 months (Müller et al. 2015).

When comparing the ductility of O-rings towards the etalon (21.02 ± 0.76%) the permanent deformation was always decreased. The fall of the permanent deformation ranged in the interval 12.46 to 53.28%. The fall was of 13.46% at the diesel oil. A more significant fall of the permanent deformation CS occurred at RME. At the concentration of RME in the interval 20 to 80%, the fall of the permanent deformation was ca. 33 to 40%. The most significant fall of the permanent deformation of CS occurred at 100% concentration of RME, i.e. CS 9.82 ± 1.09%.

In terms of the statistical testing it is possible to say that the etalon and the fuels are non-homogeneous groups, i.e. there is a difference among the tested fuels and the etalon. $P = 0.0000$ at the O-rings of the dimension 13 × 1.9 mm. The hypothesis H_0 was not certified, i.e. there is a difference among single tested variants of the experiment in the significance level 0.05.

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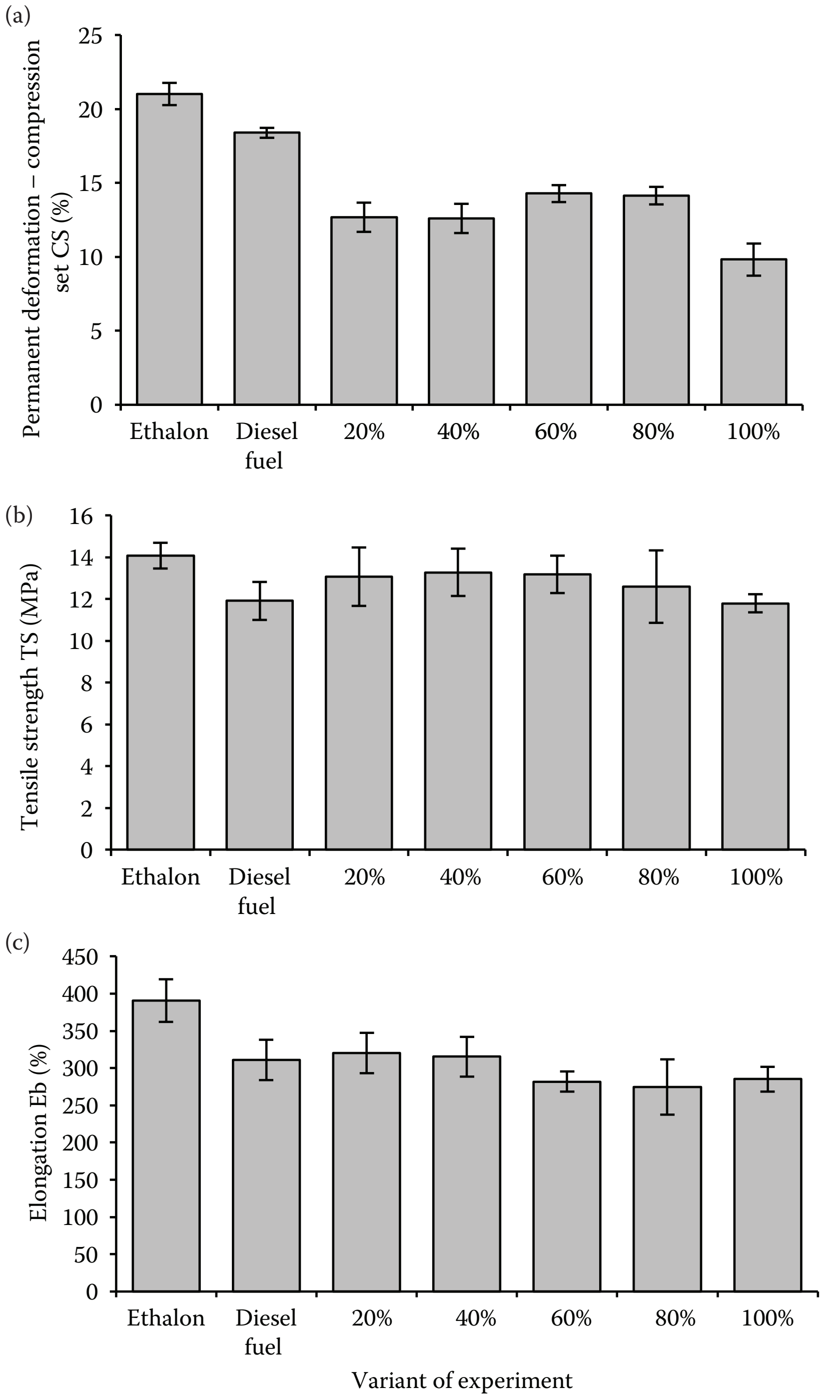

Fig. 2. Results of permanent deformation – compression set CS (a), tensile strength measurement (b) and elongation (c)

In terms of the impact of various fuels (the diesel oil, different concentrations of RME) on the permanent deformation – for compression set CS of the O-rings the *F*-test results are as follows: the hypothesis H_0 was not confirmed ($P = 0.0000$), i.e. the difference can be identified among the tested variants in 0.05 level of the significance.

The results of tests aimed at assessing the tensile strength and the elongation are shown in Fig. 2b and 2c. It is obvious from the experiment results that the diesel oil and various concentrations of RME fuel decreased the tensile strength and the elongation. The decrease is a negative aspect owing to the sealing function of O-rings.

The fall of the tensile strength always occurred at all tested fuels when comparing the tensile strength of the O-rings to the etalon (14.08 ± 0.62%). The fall of the tensile strength ranged in the interval 5.62 to 16.19%. The fall of 15.34% occurred at the diesel oil.

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The fall of the elongation always occurred at all tested fuels when comparing the elongation of the O-rings to the etalon (390.80 ± 28.36%). The fall of the elongation ranged in the interval 18.07 to 29.63%. The fall was of 20.37% at the diesel oil.

In terms of the statistical testing of the tensile strength it is possible to say that the etalon and the fuels are statistically homogeneous groups, i.e. there is no difference among the tested fuels and the etalon. $P = 0.0796$ at the O-rings of the dimension 13 × 1.9 mm. The hypothesis H_0 was certified, i.e. there is no difference among single tested variants of the experiment in the significance level 0.05.

In terms of the statistical testing of the elongation, the fuels and the etalon are statistically non-homogeneous groups, i.e. there is a difference among tested fuels and the etalon. $P = 0.0002$ at the O-rings of the dimension 13 × 1.9 mm. The hypothesis H_0 was not certified, i.e. there is a difference among single tested variants of the experiment in the significance level 0.05.

The experiment results confirmed the conclusions of the test with the O-rings exposed to the diesel oil and 20% RME for the time of 20 months (Müller et al. 2015).

From the measurement results, it was possible to determine the equations describing the influence of the concentrations 20 to 100% of RME on the elastomer sealing for fuel systems. The Eq. (5) describes the influence of the RME concentration on the permanent deformation – compression set CS. The Eq. (6) describes the influence of the RME concentration on the tensile strength TS. The Eq. (7) describes the influence of the RME concentration on the elongation E_b.

$$CS = -0.0209RME(\%) + 13.958 \quad (5)$$

$$TS = -0.0162RME(\%) + 13.76 \quad (6)$$

$$E_b = -0.553RME(\%) + 328.74 \quad (7)$$

where: CS – permanent deformation – compression set (%); TS – Tensile strength (MPa); E_b – elongation (%); RME(%) – concentrations of rapeseed methyl ester (%)

CONCLUSION

The following conclusions can be deduced from the results of the experiment aimed at determining the changes in mechanical properties of the sealing O-rings of the ACM type influenced by various fuels:

– The fall of the tensile strength TS in the interval ca. 6 to 16% was proved depending on the type of the fuel. No statistical influence was proved among the etalon and the tested fuels in terms of the statistical testing.
– The fall of the elongation E_b in the interval ca. 18 to 27% was proved depending on the type of the fuel. No statistical influence was proved among the etalon and the tested fuels in terms of the statistical testing.
– The fall of the permanent deformation – compression set CS in the interval ca. 13 to 53% was proved depending on the type of the fuel. A statistical influence was proved among the etalon and the tested fuels in terms of the statistical testing.
– The increased negative influence of various concentrations of RME (20 to 100%) on the tested properties of the sealing O-rings compared with the diesel oil complying with the standard EN 590 was not proved. So no significant negative influence of degradation aspects on the tested properties of the O-rings of the ACM type (polyacrylate elastomer) was proved.

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