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Verification of the probability of elastomers degradation in natural environments

Lenka Markovičová[1,*], Viera Zatkalíková[1], Ján Sovík[1], Tatiana Kojnoková[1]

[1] University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia; viera.zatkalikova@fstroj.uniza.sk (VZ); jan.sovik@uniza.sk (JS); tatiana.kojnokova@fstroj.uniza.sk (TK)
*Correspondence: lenka.markovicova@fstroj.uniza.sk, Tel.: + 421-41513-2610

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Abstract
A wide range of elastomers allows to manufacture products that meet high demands of consumers. They are prepared from a mixture of several rubbers, rubber chemicals, additives and reinforcing materials (fibres), which allows you to obtain the desired properties of the products. The other components of rubber compounds are fillers, carbon blacks and plasticizers. Rubber chemicals supplement the mixture in small quantities of related products, which affect vulcanization and regulate their properties, so they have an irreplaceable role in the preparation of rubber products. The aim of experimental part is to assess the properties of the degradation environment on samples of rubber composites to change their properties. The result of the performed mechanical tests to evaluate and compare the obtained values of mechanical properties of rubber compounds and to predict the possibility of biological degradation of the tested material.

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1. Introduction

The challenge of trash disposal management is one of the many issues that humanity faces as. Waste polymers are a severe environmental hazard because polymeric materials do not decompose quickly. Tires for planes, lorries, cars and other vehicles consume a lot of rubber. However, when these tires are no longer serviceable and are abandoned after a long run, only a few grams of rubber are abraded out of the tire. Because of the crosslinked structure of rubbers and the inclusion of stabilizers and other chemicals, almost all of the rubber from worn-out tires is thrown, which takes a long time to degrade naturally (Adhikari et al., 2000).

Tire disposal has risen to the top of the priority list. Huge amounts of tire waste have generated major environmental pollution issues that have impacted everyday living around the world. Tires are one of the most common rubber products due to market need. Tires are typically manufactured using multiple layers of rubber and a variety of additional substances, including carbon black, to help form composite structure of appropriate thickness (Ippoliti et al., 2016; Abdulrahman et al., 2022). The vulcanisation process improves the tensile strength, elasticity, and other properties of rubber (Katzenberg et al., 2016; Sajithkumar et al., 2016). It depends on the proportions of the various compounds used in its manufacture as well as the details of the vulcanization process, such as the type of materials used, the time of the process used, and the temperature used.

The technique of disposing of tire waste is the biggest issue with recycled rubber. The procedures rely on the combustion or pyrolysis of tires, whether for the creation of petroleum in the form of liquid hydrocarbons or for the production of energy (Rajabi et al., 2010), both of which result in the loss of rubber that is not compensated. Waste tires are occasionally utilized without modification, however particle matter emits dirt, which needs to be checked (Gomes et al., 2010). Other approaches, such as mechanical (Lapkovskis et al., 2020), thermomechanical (Seghar et al., 2019), and mechano-chemical (Yehia et al., 2004), are primarily concerned with waste tires that have not been modified. Furthermore, because rubber emits compounds into the environment, the employment of these processes results in losses of rubber raw materials as well as environmental pollutants (Wik et al., 2009).

Both natural and synthetic polymers are degraded by microorganism such as bacteria and fungi, although little is known about the biodegradation of synthetic polymeric materials (Gu et al., 2000). The reason for this is most likely related to the relatively slow rate of degradation in natural environments and the recent creation and fabrication of this class of materials (Shah et al., 2013).

Processes that act as degradation can be used to recycle rubber. Degradation is a phenomenon when the individual properties of the degraded material decrease and at the same time deteriorate.

UV degradation (Zanchet, 2019), chemicals (Khamani, 2018), heat degradation (Lee, 2016), and the action of microorganisms such as Streptomyces coelicor, Thermonospora curvata or Gordonia westfalica (Rose, 2005) are all processes that cause the characteristics of rubber compounds to deteriorate.

2. Experimental

The experimental material was the textile parts of the truck tire carcass (Fig. 1).

Fig. 1. Experimental material

The foils are made of two layers of rubber. A textile polyester layer is inserted between the two layers of rubber, which ensures that the carcass of the tire has the basic properties. Butadiene-styrene rubber (SBR), Natural rubber (NR), Isobutylene-isoprene rubber (IIR), and Butadiene rubber (BR) are the several types of rubber that form a rubber compound in foils.

Samples were prepared from the experimental material and evaluated for chemical resistance. The sample were divided into three different degradation media and their marking consists of two symbols X and Y. X is degradation environment: DS – dry soil, WS – wet soil, WSB – wet soil with probiotic bacteria. Y is time of exposure to degradation environment: 0 – without exposure, 1 – one month exposure, 2 – two months exposure, 3 – three months exposure. For example, the designation of the DS-3 sample means that the sample was exposed in dry soil for three months.

Chemical resistance is determined using unloaded test specimens. The impact of the environment on variations in the weight of test specimens is kept track of. Weight loss can be a factor that indicates possible degradation of the rubber composite. Samples were weighed on an analytical scale before exposed and then placed in an exposure environment.
After exposure, samples were taken from the soil at set intervals, cleaned with water and weighted. The change in the mass of the sample (weight loss) is determined according to the formula:

$$weight\ loss\ (\%) = \frac{m_1 - m_2}{m_1} . 100 \quad (1)$$

In formula m_1 is the weight of the sample before exposure and m_2 is the weight of the sample after exposure in grams. Weight of samples is given in grams, weight loss is given in percent. After exposure, the pH of the exposure medium was measured.

3. Results and discussion

The change in the weight (weight loss) of the samples after exposure in three different natural environments was observed in the experiment. During the exposure, every fourth day was:

- a controlled ambient temperature of 4.6°C after the first month of exposure, 8.4 °C after the second month and 12.1°C after the third month,
- samples exposed in the WS were flooded with stream water and samples exposed in the WSB with water from the stream to which the septic tank cleaning probiotic bacteria were added.

Table 1 shows the changes in the weight of the samples in dry soil at different time intervals.

Table 1. Weight change in dry soil (DS)

time [month]	0	1	2	3
m_1/m_2 [g]	0.72347	0.70726	0.70644	0.70562
Weight loss [%]	-	2.24	2.35	2.46

Table 2 shows the changes in the weight of the samples in wet soil at different time intervals.

Table 2. Weight change in wet soil (WS)

time [month]	0	1	2	3
m_1/m_2 [g]	0.72561	0.71362	0.69590	0.68925
Weight loss [%]	-	1.65	4.09	5.01

Table 3 shows the changes in the weight of the samples in wet soil with bacteria at different time intervals.

Table 3. Weight change in wet soil with bacteria (WSB)

time [month]	0	1	2	3
m_1/m_2 [g]	0.77314	0.71502	0.70470	0.70259
Weight loss [%]	-	7.52	8.85	9.13

Based on the values obtained in Tabled 1 to 3, we can see that the weight of the samples varied in each exposure environment. Already after the first month of exposure, changes in sample weight were observed in all environments. The greatest weight loss of the sample after the first month of exposure was observed in wet soil with bacteria. The same trend of sample weight loss was observed after the second month of exposure. The greatest weight loss of the samples was in wet soil with bacteria after three months of exposure in wet soil with bacteria.

There are many studies that test the effect of different types of bacteria on rubber degradation. For example, in Nguyen et al (2020) the possibility of degradation of natural rubber by Bacteroidetes and Proteobacteria was tested. The researchers recorded a weight loss of 48.37% rubber samples after only 14 days of exposure. In Nawong et al. (2018) the authors found a weight loss of 18.38% after 30 days of exposure in a bacterial environment.

The last part of the experiment was a comparison of soil pH before and after exposure. The results are shown in Figure 2.

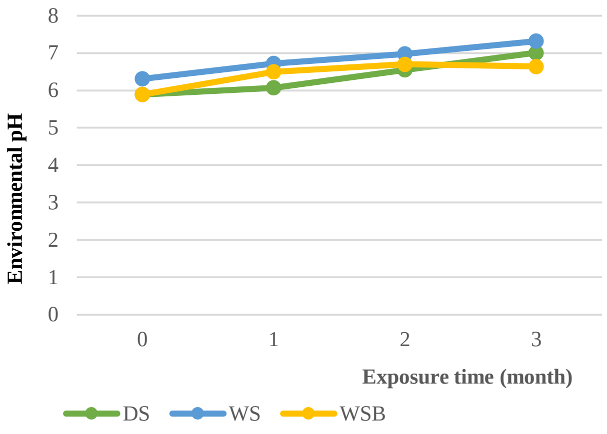

Fig. 2. pH change of experimental soil medium

We can see that the pH of the soil has changed at all exposure times and environments. Prior to exposure, the soil was slightly acidic (pH = 5.89 – 6.45). After 3 months of exposure, the pH in both dry and wet soil changed to alkaline (pH = 7.01 – 7.32).

4. Summary and conclusion

The aim of the experiment was to verify the possibility of biodegradation of rubber in natural conditions. One way to control rubber degradation was to monitor the weight loss of experimental samples in different environments and over different times. Commonly available soil was used as the exposure medium.

Dry soil, wet soil and wet soil with bacteria were used. The duration of exposure was set at 1, 2 and 3 months. The weight loss results of the samples after exposure were compared with the weight of the samples before exposure. Based on the results, we can conclude that in all environments and at all exposure times, a change in the weight of the samples, namely weight loss, was registered. The most significant weight loss was observed in rubber samples exposed to wet soil with bacteria after 3 months exposure (9.13 %) (Fig. 3).

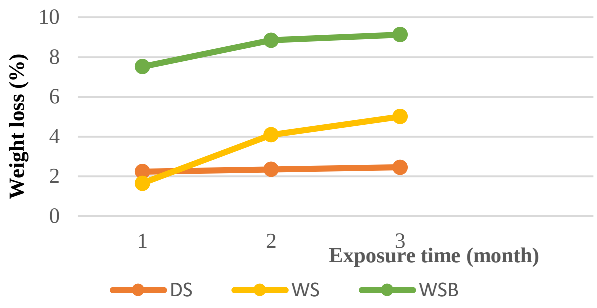

Fig. 3. Weight loss of rubber samples

The change in weight (loss) also corresponded to a change in the pH of the exposure medium. The pH values showed that even after a short exposure time, the substances from the exposed samples leached into the soil and there was a gradual change in the pH value from acidic through neutral to weakly basic pH (7.32). The components of the rubber additives were probably partially released from the samples into the soil.

The experiments conclude that the environment (soil, water, change of temperature, bacteria) in which bacteria are found degrades rubber the most. This option seems to be an appropriate solution to the ever-growing problem of polymer pollution in the ecosystem. The resulting amounts of waste produced by the excessive consumption of rubber products are so great that the pollution of our planet is alarming.

For this reason, the use of bacteria causing the decomposition of individual types of rubbers is a positive factor for the environment. However, this problem is associated with a large number of disadvantages, such as the slow rate of the biodegradation process of rubber, but also the growth rate of the initiators (bacteria) of this process is very slow. At present, biodegradation is a major subject of interest research and development.

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验证弹性体在自然环境中降解的可能性

關鍵詞
橡胶
降解
机械性能
环境
浪费

摘要
种类繁多的弹性体可以制造出满足消费者高要求的产品。它们由多种橡胶、橡胶化学品、添加剂和增强材料（纤维）的混合物制成，可让您获得所需的产品性能。橡胶化合物的其他成分是填料、炭黑和增塑剂。橡胶助剂在相关产品中少量补充混合物，影响硫化并调节其性能，因此在橡胶制品的制备中具有不可替代的作用。实验部分的目的是评估降解环境对橡胶复合材料样品的性能，以改变其性能。进行力学测试的结果，以评估和比较获得的橡胶化合物的力学性能值，并预测被测材料生物降解的可能性。