The physical – mechanical properties of low-density polyethylene films

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Abstract. Polyethylene (PE) is the most commonly used polymer. Most of the polymers are processed by the packaging sector. PE products are the most recycled plastic due to the short life of packaging materials. The experiment is based on real issues in the recycling of plastic waste in a world that is increasingly up to date. One way of recycling it is to produce returnable plastic bottles that can be used up to 50 times. The low-density polyethylene (LDPE) film is applied to the plastic bottles before filling with a specific medium. After the contents of the bottle have been consumed, the LDPE film is stripped. Subsequently, a new recyclable film is applied to the bottles used and the process is repeated. Changes in the properties of LDPE films applied to these returnable bottles have been evaluated by several tests (tensile test and water absorption test). The tests were performed on unused LDPE films and on used LDPE films, which were filled with the medium for 3 months. The fill media was chosen from commonly available goods.

1. Introduction

Polyethylene is considered a plastic material with long-term mechanical properties, easy treatability and weldability. These properties decided for using of low density polyethylene (LDPE) films for protection of plastic containers. Application of the LDPE films as wrapping on container transported often aggressive media makes possible their cyclic using.

Nowadays, the container is determined only for one usage and it is liquidate after usage. By application of the wrap foils the economical as well as environmental effect can be achieved because decreasing of plastic waste is very urgent in this era. The eventuality of multiple times using of plastic container the LDPE films must have optimal properties to be able protect containers against contamination [1].

Degradation of polymers according to effecting factors (temperature, mechanical loading, present microorganism, chemicals etc.) can be shown like thermo-degradation, biodegradation, oxidation, mechanical degradation etc. [2]. The processes of the forming have negligible effect but they can evoke structural changes with influence on long-term behaviour [3, 4]. The effect of elevated temperature during forming can be observed because the assumption of heat increased kinetic energy of macromolecules can overcome attachment forces among polymers and they can behave like liquids. The polymers structure is changed by various ways (breaking or crosslink of polymer chain [5-7]. The goal of our work is to compare the mentioned properties of the original LDPE films and after their application to container.
2. Experimental material

The investigated foils are made from low-density polyethylene of the thickness 50 ± 2 µm welded in longitudinal direction. Low density is caused by high number of the side chain CH₃. Crystallinity is about 40 – 50 %. Experiments are focused on investigation of mechanical properties of the LDPE foils after their exposure in the coca cola marked C (acid environment, pH = 2.23), disinfectant marked S (the main component is the sodium hypochlorite, pH = 13.37) and tenside cleaner marked SR (pH = 3.35). Foil samples were exposed for 3 months in all the three media. After the exposure, all the evaluated parameters were compared with the unaffected foil (O LDPE).

3. Experimental methods and results

The tensile strength characteristics of the PE are sensitive to structural changes. This is because the crystalline regions significantly affect the modulus. The other effect observed is that of strengthening due to the molecular orientation imparted during the film blowing. This is because of the molecular grade tensile properties are higher in the direction of the covalently bonded carbon – carbon chain than in the transverse direction, which is dominated by the much weaker van der Waals bonds [8-10]. The effect of various exposure environment and exposure time on the LDPE mechanical properties foils in the longitudinal and transverse directions were examined. The tensile strength at break was determined according to STN EN ISO 527 [11], with a jaw speed of 50 mm.min⁻¹. In each direction (longitudinal – L, transverse – T) 5 samples were tested, the results being the average of 5 measurements. The tensile strength after 3 months of exposure increased in all the environments compared to the tensile strength of the original sample (figure 1). On the contrary, the disinfectant caused the tensile strength increase approximately 2.5 times compared to the original foil. Figure 2 shows the change in tensile strength at break depending on the environment and exposure time.

The water absorption test for plastics is carried out in cold (method A) and in boiling water (method C). The method consists in determining the weight gain of test pieces immersed in cold and boiling water over a prescribed time. The test specimens should have the same shape and dimensions. At least 3 immersion test bodies shall be tested the prescribed time into the water container. After the time has elapsed, they are removed from the water, dried and weighed to the nearest 1 mg (ISO 640112) [12].

![Figure 1. Dependence of the breaking strength of the LDPE film on exposure environment and exposure time in longitudinal direction.](image-url)
The amount of water absorbed by the test specimen in mg is calculated using method A \((X_1)\) and C \((X_2)\) according to formula 1:

\[
X_{1,2} = m_2 - m_1 \quad (mg)
\]  

(1)

Amount of water absorbed by the test piece per unit of surface in mg.cm\(^{-2}\) is calculated using method A \((X_5)\) and method C \((X_6)\) using formula 2:

\[
X_{5,6} = \frac{m_2 - m_1}{A} \quad (mg.cm^{-2})
\]  

(2)

The amount of water absorbed by the test specimen in % is calculated using method A \((X_9)\) and method C \((X_{10})\), using formula 3:

\[
X_{9,10} = \frac{m_2 - m_1}{m_1} \cdot 100 \quad (%)
\]  

(3)

Mean values of water absorption for individual methods of water absorption determination are given in table 1. In cold water at 23 °C, the LDPE film absorbed some of the fluid based on the results, increasing its original weight. In cold water for 24 hours, there was in all cases a slight increase in the weight of the LDPE film by the selected media after 3 months. This represents in % the water absorption of the LDPE film in cold water from 0.2 to 1 %.

In boiling water at 100 °C, the weight of the LDPE film decreased to 0.6 % in the case of Savo compared to the original LDPE.

**Figure 2.** Dependence of the breaking strength of LDPE film from exposure environment and exposure time in transverse direction.

![Graph showing dependence of breaking strength](image)
Table 1. Absorbency of origin O LDPE film and LDPE film affected by media.

| Sample          | Sample area (cm²) | Sample weight (mg) | X₁,2 (mg) | X₅,6 (mg.cm⁻²) | X₉,₁₀ (%) |
|-----------------|-------------------|--------------------|-----------|----------------|-----------|
|                 | Before absorption | After absorption   | m₁        |                | m₂        |
| O LD-PE film    | 2.83              | 12.60              | 12.67     | 0.067          | 0.024     | 0.531     |
| Savo            | 1.43              | 7.62               | 7.66      | 0.040          | 0.030     | 0.570     |
| Saponate        | 1.52              | 8.22               | 8.29      | 0.077          | 0.048     | 0.945     |
| Coca-Cola       | 1.87              | 8.72               | 8.74      | 0.023          | 0.012     | 0.271     |
| Boiling water   | 2.82              | 12.40              | 12.48     | 0.260          | 0.056     | 0.705     |
| Savo            | 1.34              | 7.14               | 7.11      | -0.027         | -0.019    | -0.570    |
| Saponate        | 1.78              | 7.81               | 7.88      | 0.070          | 0.042     | 0.947     |
| Coca-Cola       | 1.64              | 8.29               | 8.36      | 0.067          | 0.042     | 0.813     |

The absorbency values of LDPE film in cold and boiling water expressed in mg are shown in figure 3. Higher water absorption in boiling water compared to cold water had O LDPE film and LDPE film affected by Coca-Cola. LDPE was influenced by Savo and Saponate to have a higher water absorption in cold water than boiling water. O LDPE film in boiling water has the highest absorbency.

**Figure 3.** Absorbency of O LDPE film and LDPE film influenced by medium in mg.

4. Conclusions

Based on experiments performed on LDPE films after exposure in 3 different environments for 3 months, we can conclude:

- Evaluation of the tensile strength test results are more complicated because they are influenced by the loading direction (longitudinal, transversal), as well as by regularity of the surface attack of media.

- The tensile strength of the LDPE foils increased in all the media already after 3 month exposure in both tested directions. It can be caused by physical effect of the liquid media which penetrate to intermolecular area.
The absorption of samples exposed to all three environments resulted in increased sample weight. Only in the case of Savo there was a weight loss, which could be due to the chlorine content of Savo, which during exposure was poorly bound to the polyethylene chains and was released by the elevated temperature in the absorbency test.

Based on the results, the water absorption of the LD-PE film in the water absorption test is up to 1% in cold water and up to 0.6% in boiling water.

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