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Comparison of the properties of the original and applied LDPE foils in returned bottles

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Abstract
A constant increase in the production of plastic products is a major cause of general environmental pollution. The past decade recognized how significant recycling plastic waste and the development of biodegradable materials is. This paper takes a new look at reducing the amount of plastic waste in the environment. Plastic bottles are "dressed" in a special PE (polyethylene) foil before filling. After the content is consumed, the foil is removed of the bottle. Such foil can be used for transporting other products more than once. The work focuses on the investigation of the changes in properties of the light density polyethylene (LDPE) foils caused by forming during their application to the bottle. It was decided that the optimal method for this investigation was to compare the mechanical and rheological properties PE foils before and after their application to the bottle.

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1. Introduction

Plastic containers and bottles are very often used when transporting solid and liquid media. After being used, plastic containers have to be liquidated. Application of protective light density polyethylene (LDPE) foils on the container makes it possible for them to be reused. Due to the application of wrap foils, the economic, as well as, environmental effects can be achieved, as the decrease of plastic waste is urgent these days. Polyethylene is considered a suitable wrapping plastic material with convenient mechanical properties; easy treatability and weldability.

Therefore, mechanical and rheological properties are very important for use of (LDPE) foils for protection of plastic containers. During application to the container the LDPE foil is formed at higher temperature and the pressure of 6 bars. These conditions can develop some degradation. The possibility of multiple use of plastic container requires from LDPE foils to have the optimal protective properties also after their application to the containers.

The aim of the work is to characterize the changes after the application of foils to a container, as foils will be exposed, during their use, to various circumstances; therefore, they have to be in a proper condition.

Degradation of polymers according to affecting factors (temperature, mechanical loading, present microorganism, chemicals etc.) can be shown as thermal degradation, biodegradation, oxidation, mechanical degradation, etc. (Allen, 2010). The processes of the forming have negligible effects, but they can evoke structural changes exerting an influence on their long term behaviour (Allen, 1992; Ravve, 2000; Capone, 2007). The effect of increased temperature while forming can be observed, as the assumption of heat increased the kinetic energy of macromolecules can overcome the attachment forces among polymers; thus they can behave similarly to liquids. The polymers structure is changed in various ways, e.g., by breaking or crosslinking a polymer chain (Ducháček, 1999; Hassam et. al, 2004; Mcmurry, 2004). The goal of the following work is to compare the mentioned properties of the original LDPE foils before and after their application to a container.

2. Experimental

The investigated foils are made of light density polyethylene of the thickness 50 ± 2 μm welded in longitudinal direction. Low density is caused by a high number of the side chains CH_3.

The crystallinity is about 40 – 50%. The experiments focus on the investigation of the visco-elastic and mechanical properties of LDPE foils before and after their application to a container by means of the rheological test and tensile test. The REM was used for surface morphology characterization, because impermeability of the foils is very important,

The morphology of the LDPE foil before and after forming was observed by REM and is shown in Figure 1.

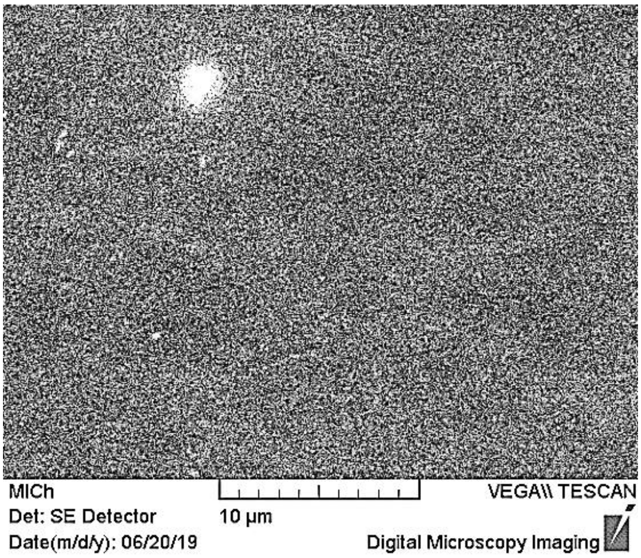

Fig. 1. Morphology of the original LDPE foils before application

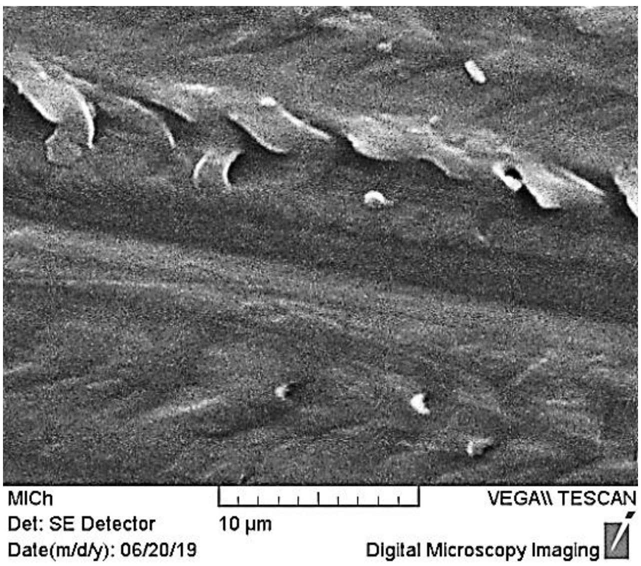

Fig. 2. Morphology of the LDPE foils after application

It can be seen that after the application of the foil to the container inhomogeneity of the surface is evident. The surface defects localization is affected by direction of forming (Fig. 2). The thickness of the foils increases but no perforation of them was observed. The intensity of changes can be restricted by the process of the foil application.

Tensile test

By the tensile test the changes of the mechanical properties (thickness and tensile strength at break) of the applied foils were investigated. The test was carried out in longitudinal and transverse directions on the foils as well as on of welded joints. The device was used ZWICK 2.5 with jaws distance 5cm and testing speed of 50 mm/min, according to the standard STN EN ISO 527. The average values of the measured parameters (σ_B – tensile strength at break [MPa], ε_B – elongation [%], E – Young's modulus [MPa]) are given in Table 1. The sample designation is O - original foil (before application in the container), A – applied foil (after application in the container).

Table 1. Results of tensile impact test

Sample	Thick-ness [μm]	σ_y [MPa]	σ_y [MPa]	ε_B [%]	E [MPa]
O-lon. dir.	51.40	1.79	12.96	276.02	260.40
O-trans. dir.	51.75	11.16	17.74	164.82	189.50
A-lon. dir.	60.60	10.35	8.63	246.46	133.80
A-long. Trans.	60.50	12.45	18.82	208.84	197.00
Welded joint	52.00	10.67	17.37	168.38	95.05

The profile of foils was changed by forming and it is supported by the thickness values in Table 1. The tensile strength in longitudinal direction dropped (direction of forming) and in transversal direction grew slightly. The elongation of the foils after forming decreased, to bigger extent in longitudinal direction. It signalises some changes in the structure of the foils. In the welded joints the tensile strength was almost identical on the original and the applied foils. The samples were in the both cases fractured apart from the welded joints.

Rheological measurement

The LDPE is a viscoelastic material and, therefore, it exhibits both viscous and elastic properties which mainly depend on the chemical composition and structure. The degradation process can affect the mentioned properties. By the Frequency Sweep test (FS) – Two-plates-Mode the rheological measurement could sensitively reflect them. The measured rheological characteristics made it possible to define the character of the structural changes of the LDPE. The measured parameters were: complex viscosity $\boldsymbol{\eta^*}$ (Pa.s), storage modulus $\boldsymbol{G'}$ (Pa) represented size of the deformed energy accumulated during slip loading, the loss modulus $\boldsymbol{G''}$ (Pa) representing volume of deformation energy consumed on slip movement of molecules and also it is the measure of the internal friction (Liptáková, 2011; Malkin, 2005; Mark, 2007). The measurements were carried out by the Physica Rheometer MCR 301 with a convective thermal device CTD 450. In Figure 3, the changes of the elastic and plastic modulus are shown. From the diagrams it can be observed that there is a shift of intersect of the G' and G" moduli of the formed foil (red) to the lower values of the angular frequency (a bit to the left in the diagram) which means a slight increase of the average molecular weight. The increase of the average molecular mass suggests that during application of foils to the container some macromolecules are crosslinked.

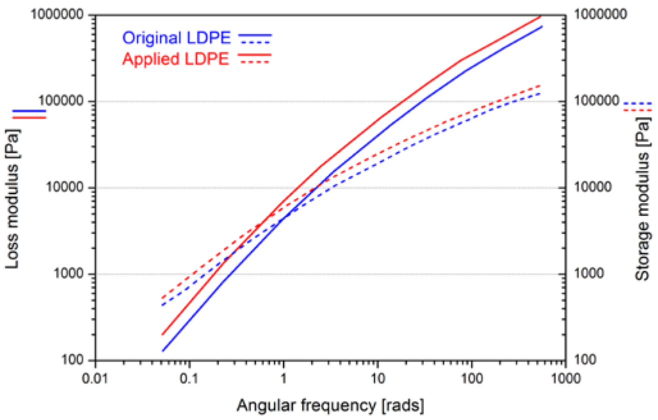

Fig. 3. Comparison of the measured elastic and plastic moduli of the original and applied LDPE foils

The shift of the moduli (G' and G") intersect to the slightly higher values in vertical direction means their broadening of the molar mass distribution in comparison with the original foil. As shown in Figure 4, the complex viscosity of the LDPE foil after forming to the container slightly increased by contrast to the original LDPE foil. The changes of structure identified by the rheological test affect their mechanical properties (Mezger, 2006; Vojsovičová et. al, 2011). However, by the rheological measurements it is not possible to investigate the directional changes of structure as it was identified by the tensile test.

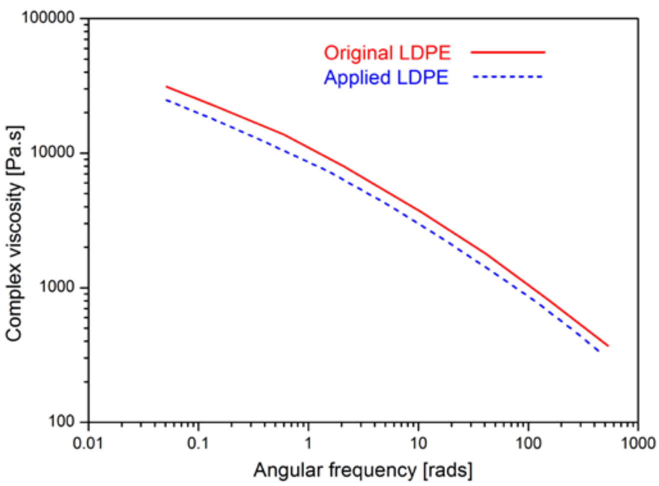

Fig. 4. Comparison of complex viscosity of the original and applied foils

Test of absorption

The experimental measurements of the foil absorbent ability in liquid media before and after application to the container were carried out in cold and boiling water according to ISO 62. The method consists in determining the weight gain of the test specimens. Method A consists of determining the water absorption of plastics in cold water at a temperature of 23°C ± 2°C for 24 hrs. ± 1 hr. Method C consists of determining the water absorption in boiling water at 100°C for 30 min ± 1 min. After 30 minutes, the samples were cooled in distilled water at room temperature of 23°C ± 2°C for 15 min ± 1 min. To calculate the absorbency, we need to know the weight of the test specimen before immersion in water (m_1), the weight of the test specimen after removal from the water (m_2) and the test specimen surface (A).

Table 2. Absorption of the original (O) and applied (A) foil

Sample	Sample area [cm^2]	X_1 [mg]	X_2 [$mg.cm^{-2}$]	X_3 [%]
	Cold water (Method A)			
O LDPE foil	2.83	0.07	0.024	0.531
A LDPE foil	4.40	0.11	0.026	0.524
	Boiling water (Method C)			
O LDPE foil	2.82	0.26	0.056	0.705
A LDPE foil	4.23	0.10	0.024	0.476

The results, which are shown in Table, indicated that the absorbability of the original foil is higher. It is in accordance with rheological measurement.

3. Summary and conclusion

The input experimental testing showed the degradation character of the LDPE foils after their application to the container and the results can be summarized:

- Morphology is markedly affected by application of the LDPE foils to the container and has directional character. This influences also the thickness of the foils.
- The visco-elastic properties of the LDPE foils are slightly changed by the foil application to a container. The increasing of average molar mass was measured what signalizes crosslinking of some macromolecules of the polyethylene. It caused the growth of the complex viscosity after forming. This changes affected absorbance ability of the tested foils.
- The changes instilled by application modified the tensile strength of the foils but different in longitudinal and transversal direction.
- The weld join tensile strength of the foils was not affected by forming LDPE foils to the container.

The effect of the forming on the LDPE foils can be restricted by optimization of the application conditions.

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退回瓶中原始LDPE箔和应用LDPE箔的性能比较

關鍵詞
聚乙烯箔
流变学
机械性能

摘要
塑料产品产量的持续增长是普遍环境污染的主要原因。在过去的十年中，人们认识到了可回收塑料废物和可生物降解材料的巨大发展。本文对减少环境中的塑料废物量进行了新的研究。灌装前，将塑料瓶用特殊的PE（聚乙烯）箔“包扎”。内容物消耗完后，将铝箔从瓶子上取下。这种箔可用于多次运输其他产品。这项工作的重点是研究在将轻质聚乙烯（LDPE）薄膜粘贴到瓶子上时形成的薄膜特性的变化。决定进行此研究的最佳方法是比较将PE薄膜粘贴到瓶子上前后的机械和流变性能。