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DYNAMICS OF WATER ABSORPTION AND TENSILE STRENGTH VARIATION OF BIODEGRADABLE PACKING FILMS WITH POTATO STARCH CONTENT

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Summary. An artificial material made of potato starch, ethylene-acrylic acid copolymer (EAA) and polyethylene was studied. Water absorption curve was determined at 20°C and 95% air relative humidity of the material placed in a FEUTRON GmbH climatic chamber. Tests of tensile strength of the plastic were done using a strength testing machine INSTRON 5566. Increased moisture content of the plastic induced decreased stress and increased strain at breaking point. Above the material critical moisture content the breaking strain was markedly reduced.

Keywords: biodegradable film, starch, water absorption, strength.

INTRODUCTION

The production of synthetic polymer packages is the source of continuous increase in the mass and volume of refuse shifted to the increasing number of waste dumps [1]. This world-wide problem and menace to the environment demands an effective solution. One way of refuse disposal is its recycling. However, this requires special technical devices for refuse segregation on the dump site, as the people are not prepared enough to do the initial segregation of the huge mass of waste they produce. The use of materials containing biodegradable components facilitates waste disposal. One of such components is hydrophilic starch, which causes the plastic to loose its initial properties when exposed to the effect of the environment and break up easier under the action of external forces [2]. Starch can be added unprocessed, as a filler, at about 10%. That can be increased to over 40% when processed (modified) starch is used [5].

The effect of starch content in a plastic material is due to the lack of compatibility between hydrophilic starch and the hydrophobic polymer [11]. The plastic material containing starch can, however, be successfully used as packaging material [6, 10]. An additional advantage is the complete renewability of starch as the basic raw material for production of this kind of packages [7]. One of the factors that limit the use of such biodegradable material is its water absorption.

The aim of the present studies was to determine the changes in tensile strength of the biodegradable plastic caused by the dynamics of water absorption from air of high relative humidity.

MATERIAL AND METHODS

The material investigated was obtained by combining potato starch, ethylene-acrylic acid copolymer (EAA) and polyethylene. A starch composite (8 parts of starch, 2 parts of EAA, 2 parts of glycerol) was mixed with low density polyethylene (LDPE Malen E) at 5:5 ratio [4], and a film was formed by the extrusion method in a laboratory Brabender extruder at 120-140-160°C [12]. Samples cut from the film of length $L = 40$ mm, width $s = 20$ mm, thickness $g = 1$ mm and initial moisture content of 7.4% were placed in a FEUTRON GmbH climatic chamber, where air relative humidity was 95% at 20°C. The water absorption curve of the biodegradable material was determined by measuring sample mass at set time intervals and the initial water content using the drying method. After 2.5 days and nights of keeping in the climatic chamber, some samples were taken to air-tight containers and their mechanical properties were determined for 4 consecutive days and nights. Tensile strength testing of the plastic was done with an INSTRON 5566 strength testing machine. A test ended with rupture of the sample (Fig. 1).

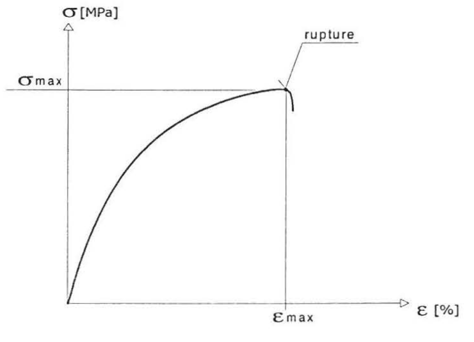

Fig. 1. Stress vs. strain curve of the biodegradable material.

RESULTS AND DISCUSSION

The process of water absorption by the biodegradable plastic placed in the climatic chamber was described with the exponential relation [9]:

$$W(\tau) = W_0 + \Delta W(1 - e^{\frac{-\tau}{T}}) \quad (1)$$

$$\Delta W = W_R - W_0 \quad (2)$$

The kinetics of that process, within the range from initial moisture content $W_0 = 7.84\%$ to equilibrium moisture content $W_R = 19.21\%$, is determined by the time constant $T = 54$ h (Fig. 2). After 170 hours the samples reached equilibrium moisture content. Keeping them further in the climatic chamber caused microbiological spoilage.

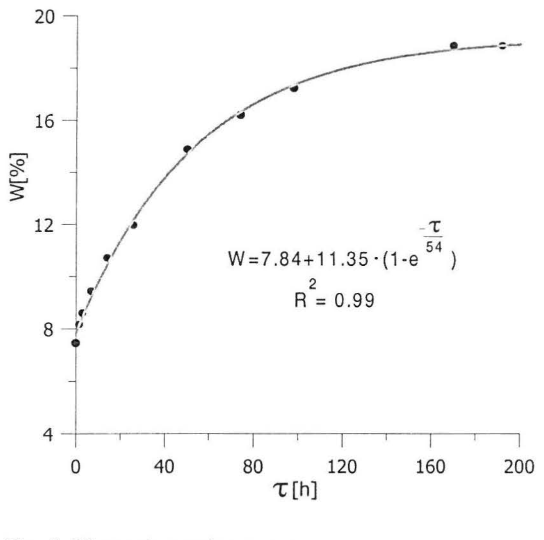

Fig. 2. Water absorption curve.

Figure 3 presents some of the strain-stress curves of the biodegradable plastic samples at various moisture contents. Samples of moisture content $W = 7.4\%$ broke at a small strain $\varepsilon_{max} = 6\%$ on reaching a large stress $\sigma_{max} = 8.2$ MPa. Rupture of samples of over twice as large moisture content $W = 16.2\%$ occured at smaller stress $\sigma_{max} = 4.4$ MPa, but at a substantially increased strain $\varepsilon_{max} = 30\%$. This relationship was described by an exponential function within the whole moisture content range (Fig. 4).

Increased moisture content of the samples resulted, however, in increased rupture strain ε_{max}. That relation was described by an exponential function in the range from initial moisture content to a certain critical value of about 16%. Wetting the samples more than the critical value resulted in a marked decrease of strain at breaking point (Fig. 5) – a behaviour not shown by a biodegradable material with 30% content of wheat starch obtained by pressing [8]. In view of the fact that the critical value (16%), close to equilibrium moisture content (19.2%), was reached after 74 hours, the cause of the phenomenon may have been the development of micro-organisms.

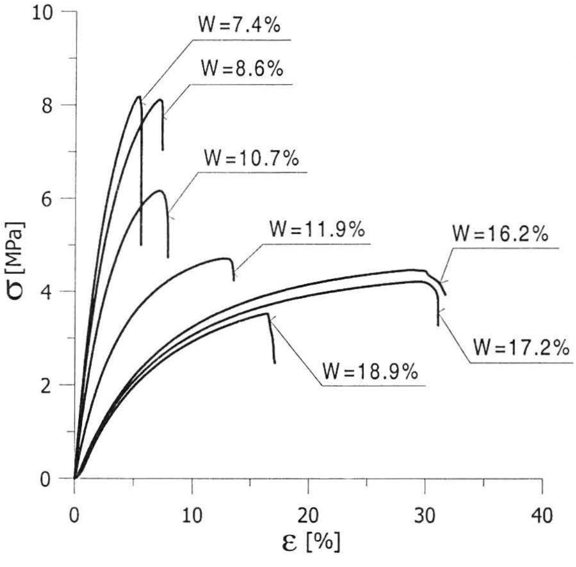

Fig. 3. Some of the strain-stress curves for the biodegradable plastic.

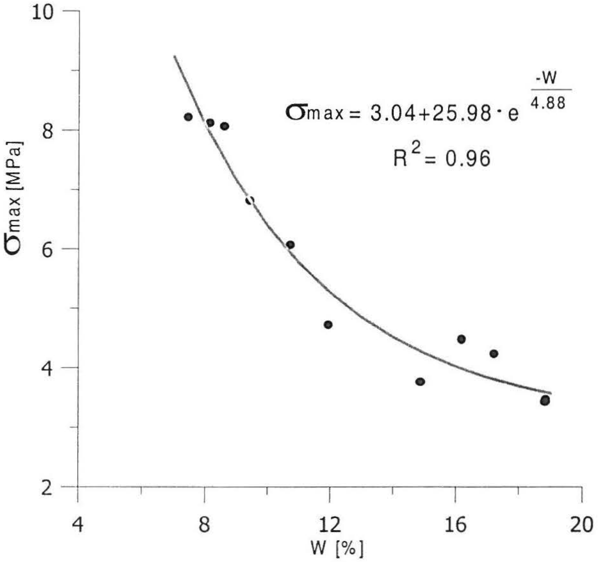

Fig. 4. Relation between breaking stress σ_{max} and moisture content of the biodegradable material.

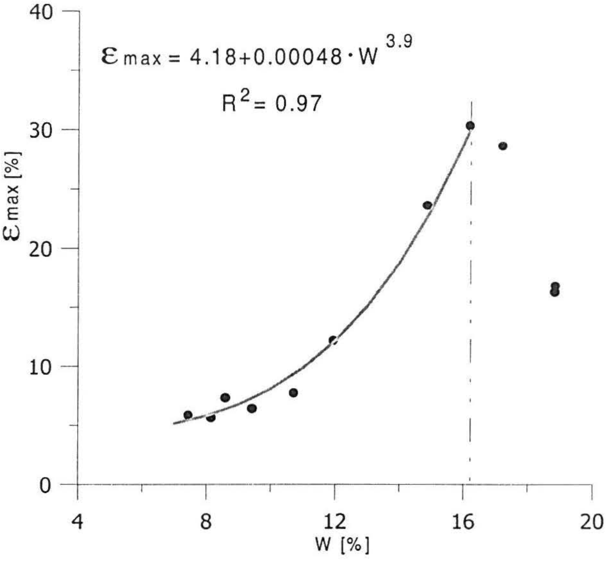

Fig. 5. Relation between the breaking strain ε_{max} and moisture content of the biodegradable plastic.

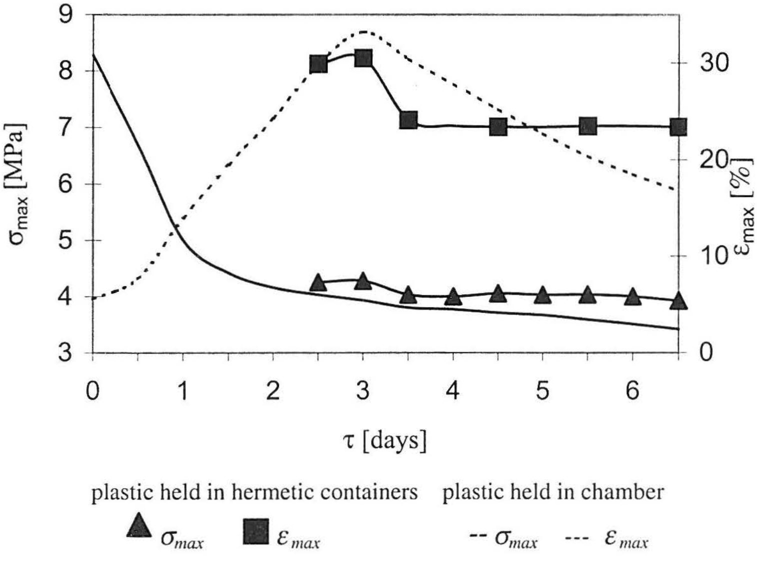

Fig. 6. Tensile strength properties of the plastic held in a climatic chamber and that moistened for 2.5 days and then held 4 days in hermetic containers.

Additional information was obtained from tensile strength tests performed with material samples of 15% moisture content, i.e. a bit lower than the critical moisture content, removed from the chamber after 60 hours. These samples were then held for 4 days outside the climatic chamber under conditions that excluded losses of water (hermetic containers). It turned out that after first 24 hours the breaking stress and strain decreased to values which remained constant during further keeping under hermetic conditions (Fig. 6). So it seems that also factors other than micro-organisms may decide about the existence of „critical moisture content". Those may be physical factors that cause weakening of the plastic structure. Thus, it can be stated that the plastic studied is a combination of materials that brings to the forth the specific properties of water.

CONCLUSIONS

Based on the investigations performed on the biodegradable material that contains potato starch as component, the following conclusions can be drawn:

1. The dynamics of water absorption by the biodegradable plastic can be described with the exponential function

$$W(\tau) = W_0 + (W_R - W_0)\cdot(1 - e^{\frac{-\tau}{T}}),$$

whose variation with time (τ) depends on the initial moisture content W_0, equilibrium moisture content W_R and time constant T.

2. Increasing moisture contents of the biodegradable plastic within the range from initial to equilibrium moisture contents causes the breaking stress to decrease according to an exponential function.
3. Increased moisture content of the biodegradable plastic up to the critical value of 16% induces increased breaking strain according to an exponential function. Increased moisture content of the plastic above a critical value results in a significant reduction in the breaking strain.

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DYNAMIKA ABSORBCJI WODY I ZMIANY WŁAŚCIWOŚCI WYTRZYMAŁOŚCIOWYCH BIODEGRADOWALNEGO TWORZYWA OPAKOWANIOWEGO WYTWORZONEGO Z UDZIAŁEM SKROBI ZIEMNIACZANEJ

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Streszczenie. Badaniom poddano tworzywo powstałe z połączenia skrobi ziemniaczanej i kopolimeru etylenu z kwasem akrylowym (EAA) i polietylenu. Wyznaczono krzywą absorpcji wody przez próbki tworzywa umieszczone w komorze klimatycznej firmy FEUTRON GmbH w temperaturze 20°C i wilgotności względnej powietrza 95%. Testy wytrzymałości tworzywa na rozciąganie przeprowadzono przy użyciu maszyny wytrzymałościowej INSTRON 5566. Wzrost wilgotności tworzywa powodował zmniejszenie wartości naprężenia i zwiększenie wartości odkształcenia próbek w punkcie zerwania. Przekroczenie krytycznej wartości wilgotności tworzywa powodowało znaczną redukcję odkształcenia zrywającego.

Słowa kluczowe: tworzywo biodegradowalne, skrobia, absorpcja wody, wytrzymałość.