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EFFECT OF THE MOISTURE CONTENT OF BIODEGRADABLE PLASTIC OBTAINED BY THE PRESSING METHOD ON SOME OF ITS PHYSICAL PROPERTIES

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Abstract. A biodegradable artificial material obtained by combining potato starch with ethylene-acrylic acid copolymer was investigated. Water absorption curves were determined for samples of the plastic placed in air at 40°C temperature and 75% and 95% humidity. The process of water absorption by samples of the biodegradable material from the 75% relative humidity of the air was described with an exponential relation, and with a linear one from 95% air humidity up to a certain critical moisture content where further absorption became exponential. An increase in moisture content of the biodegradable material caused an increase in electric capacity and decreased stress to breaking point.

Keywords: biodegradable film, starch, absorption, strength, electric capacity

INTRODUCTION

The annual production of synthetic materials is about 100 million tons [1]. Noteworthy is the increasing participation of materials used in the production of packaging. In the coming years, Poland is envisaging an increase in package production at the level of about 10% annually [7]. Packaging, when their usually short-lived task is done, becomes useless detritus and mostly ends up in waste dumps [8]. The accumulation of waste and packaging over many years in the natural environment is a series ecological problem [9].

The basic principle underlying the management of environmentally harmful refuse is the prevention of its production [13]. Hence it is advisable to seek and implement alternative solutions, with the aim of replacing materials which are hard to decompose by new ones, which undergo total or partial degradation under natural conditions. The optimum solution would be the use of packaging of good functional properties (mechanical, barrier, waterproof etc.) and yet fully biodegradable. The use of such packaging is possible only if its production costs are low [4]. No-one has yet succeeded in producing packages meeting such requirements. A compromise solution is the use of materials composed of synthetic polymers and a natural biodegradable polymer. Here starch is the natural polymer most often used, due to its availability and low cost as well as easy modification and processing [10]. The functional properties of the materials obtained are satisfactory [6]. The materials are partly biodegradable because of their starch content [2,11]. A detrimental feature of materials containing starch is their ability to absorb relatively large amounts of water from the increased humidity in the atmosphere [12]. Water contained in the plastic seems to affect its physical properties.

The aim of the work was to determine the sensitivity to water of synthetic materials containing considerable amounts of starch by finding out the effect of some of its physical properties.

MATERIALS AND METHODS

The artificial material was made of potato starch, ethylene-acrylic acid copolymer (EAA), glycerine and polyethylene (LDPE Malen E) [5]. A starch composite (8 mass parts of starch, 2 parts of EAA and 2 parts of glycerine) was mixed with polyethylene in three ratios: 5:5, 7:3 and 9:1. A sheet was obtained by the extrusion method using a laboratory Brabender extruder at temperatures of between 110-125-140°C and pressing with a laboratory press at 130°C and 10 MPa pressure. From the 0.8 mm thick sheeting, forms were cut 40 mm in length and 20 mm wide, and then placed in a Feutron GmbH climatic chamber at a temperature of 40°C and a relative air humidity of 75% and 95%. Increases in material mass were determined as dependent on the length of time it was kept in the chamber. Based on the initial mass and moisture content of the material (determined thermogravimetrically) and the results obtained, water absorption curves were made.

After the material had reached an equilibrium moisture content it was kept in the chamber for 24 hours extra, and then tested for its strength and electric properties.

The tensile strength test was carried out using an Instron 5544 device.

The extensometer head with a measuring range up to 2kN moved at 5 mm min^{-1} speed. The test lasted until the sample broke down at breaking stress (σ_{max}) and breaking strain (ε_{max}).

In order to find out whether it is possible to determine the moisture content of a biodegradable material by electric methods, electric capacity measurements were done of the samples studied. The measurements were carried using an RLC Automatic Bridge (Fluck) with flat electrodes and an electromagnetic field of 1 kHz frequency [3]. The results were corrected for sample thickness (measured with a digital slide).

The measurements were done in 9 repetitions for each experimental variation.

RESULTS AND DISCUSSION

The process of water absorption by samples of the biodegradable plastic from air with a relative humidity $\varphi = 75\%$ is described by the exponential relation:

$$M(t) = M_0 + (M_E - M_0) \cdot (1 - e^{-\frac{t}{T}}) \tag{1}$$

The dynamics of the process within the range from initial moisture content (M_0) of control samples to an equilibrium moisture content (M_E) is determined by the time constant (T). Instead, water absorption by samples of the biodegradable material from air with a relative humidity $\varphi = 95\%$, in the range from the initial moisture content (M_0) to critical moisture content (M_K) obtained after time (t_K), is described by a linear function, with allowance for the jump in moisture content (ΔM), as follows:

$$M(t) = (M_0 + \Delta M) + k \cdot t \tag{2}$$

Further increase in water absorption, occurring from moisture content M_K after time (t_K), is described by the exponential relation:

$$M(t) = M_K + (M_E - M_K) \cdot (1 - e^{-\frac{t - t_k}{T}}) \tag{3}$$

The absorption curves are shown in figures 1, 2 and 3 while figure 4 presents equilibrium moisture content (M_E) reached by the samples studied. The largest water absorption was found for plastic with a 90% starch composite content and $M_0 = 14.5\%$, which in air of 95% humidity reached $M_E = 41.3\%$ in 20 hours, and in air of 75% humidity reached $M_E = 22.6\%$ during a similar time. The plastic with the

70% starch composite content and $M_0 = 11\%$ in air of 95% humidity reached $M_E = 31\%$ in 30 hours, and in air with a 75% moisture content $M_E = 17.1\%$ was reached over a five times longer period. The lowest water absorbing power was found for plastic with a 50% content of starch composite and $M_0 = 7.4\%$, which in air with a 95% humidity reached $M_E = 16.7\%$ in 50 hours, and in air of 75% humidity it reached $M_E = 11.2\%$ in only 10 nights and days.

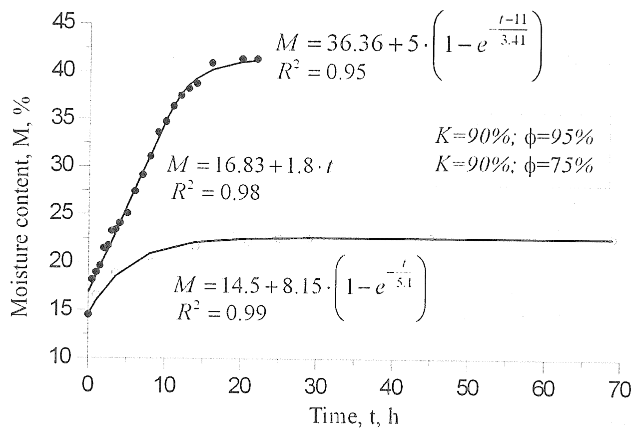

Fig. 1. Water absorption from air with a humidity of $\varphi = 95$ and $\varphi = 75\%$ for plastic with a 90% starch composite content (*K*)

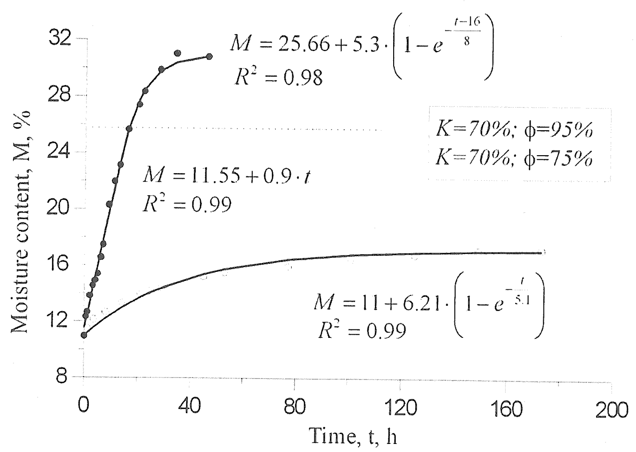

Fig. 2. Water absorption from air with a humidity of $\varphi = 95$ and $\varphi = 75\%$ for plastic with a 70% starch composite content (*K*)

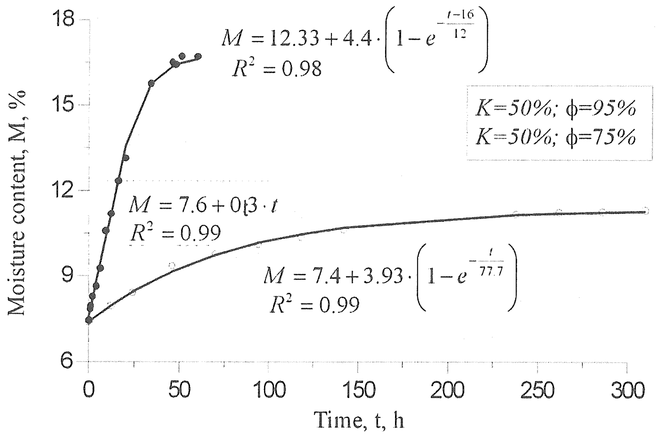

Fig. 3. Water absorption from air with a humidity of φ = 95 and φ = 75% for plastic with a 50% starch composite content (K)

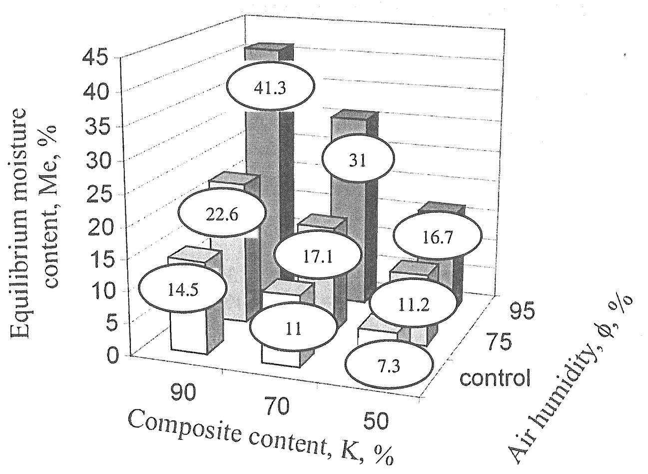

Fig. 4. Equilibrium moisture content (M_E) of plastic of various starch composite content (K)

Figure 5 shows strain-stress curves for samples of the biodegradable plastic of various equilibrium moisture content (M_E), which depended on the content of composite (K) and air humidity (φ). Wet samples broke down at considerably lower stress and larger strains compared with samples which had not been wet.

Mean values of stress (σ_{max}) and strain (ε_{max}) at breaking point are shown in figures 6 and 7. The values of (σ_{max}) decreased from 7.6 to 5.5 MPa in moisture content range from 7.4% to 16.7% for plastic with a 50% content of the composite, from 8.8 to 2.5 MPa in moisture content range from 11% to 31% for plastic with a 70% composite content, from 8.7 to 0.7 MPa in moisture content range from 14.5% to 41.3% for plastic with a 90% composite content. In the range of low moisture content, the larger content of starch composite is conducive to reaching larger values of (σ_{max}). Increased moisture content causes the values of (σ_{max}) to become lower for plastic of larger composite content compared with plastic of lower composite content. The plastic that was not subjected to wetting, of starch composite content 50%, 70% and 90%, broke at strains (ε_{max}) of magnitudes 32%, 12% and 5%, respectively. An increase in moisture content up to equilibrium values reached in air of 75% humidity resulted in largest values of (ε_{max}), equal to 62%, 33% and 0.26%, respectively. Further increase in moisture content up to equilibrium values reached in air of 95% humidity contributed to a decrease (ε_{max}) up to 53%, 24% and 10%. A lowered composite content was conducive to the greater elasticity of the plastics.

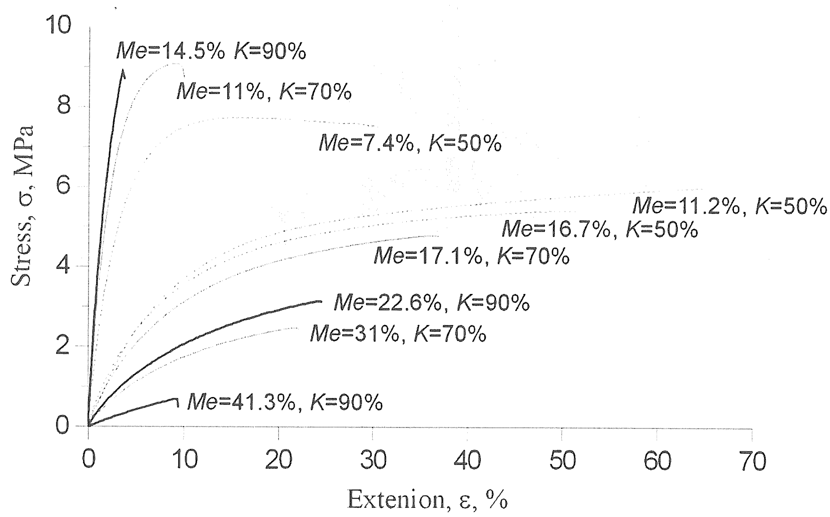

Fig. 5. Strain-stress curves for the biodegradable plastic of varied equilibrium moisture content (M_E)

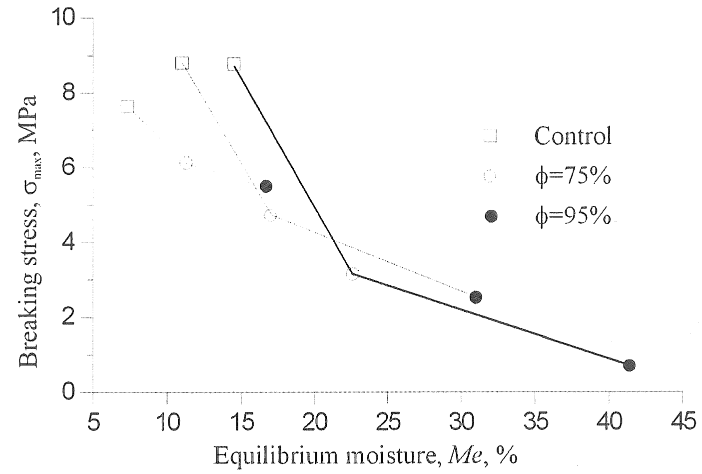

Fig. 6. Breaking stress (σ_{max}) for plastic of 50%, 70%, 90% composite content (*K*) and various equilibrium moisture content (M_E)

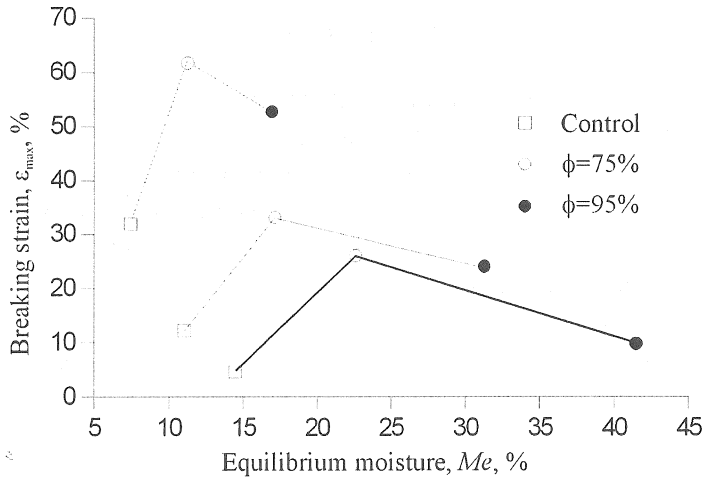

Fig. 7. Breaking strain (σ_{max}) for plastic of 50%, 70%, 90% composite content (*K*) and various equilibrium moisture content (M_E)

Figure 8 shows the mean values of electric capacity (*C*) for different variants of moisture content and composite content. The electric capacity increased with the rising moisture content and the starch composite content in the plastic.

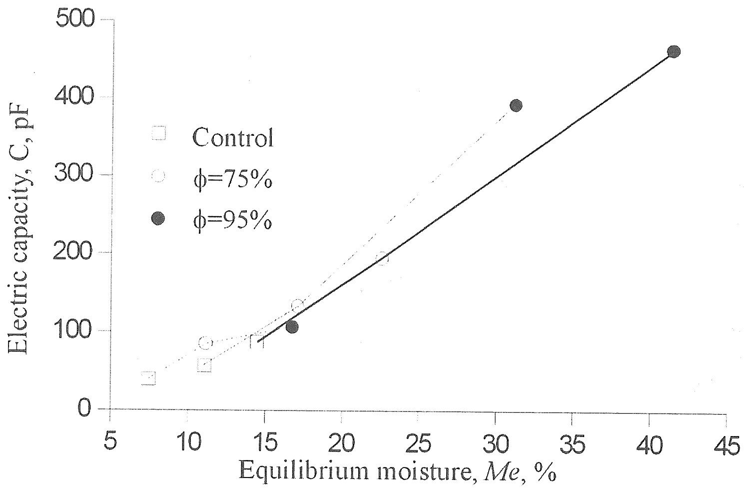

Fig. 8. Electric capacity (C) for plastic of 50%, 70%, 90% composite content (K) and various equilibrium moisture content (M_E)

CONCLUSIONS

Based on the investigation performed with the biodegradable plastic containing 50%, 70% and 90% of potato starch, the following conclusions can be drawn:

1. The process of water absorption by samples of the biodegradable material from the air with a relative humidity of 75% can be described with an exponential relation, and with a linear one from air with a humidity of 95% up to a certain critical moisture content where further absorption becomes exponential.
2. With increasing starch composite content and relative air humidity the equilibrium moisture content of the plastic increases and is reached in a shorter time.
3. The increased moisture content of the biodegradable plastic results in a lower stress at breaking point.
4. The largest value of strain at breaking point is reached by the plastic with equilibrium moisture content reached in air with a 75% humidity.
5. Increased moisture content of the biodegradable plastic causes increased electric capacity.

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WPŁYW WILGOTNOŚCI TWORZYWA BIODEGRADOWALNEGO SPORZĄDZONEGO METODĄ PRASOWANIA NA WYBRANE WŁAŚCIWOŚCI FIZYCZNE

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Streszczenie. Badaniom poddano tworzywo biodegradowalne powstałe z połączenia skrobi ziemniaczanej i kopolimeru etylenu z kwasem akrylowym. Wyznaczono krzywe absorpcji wody przez próbki tworzywa umieszczone w powietrzu o temperaturze 40°C i wilgotności względnej 75 i 95%. Proces chłonięcia wody przez próbki tworzywa biodegradowalnego z powietrza o wilgotności względnej $\varphi = 75\%$ opisano zależnością wykładniczą, a z powietrza o wilgotności względnej

$\varphi = 95\%$ zależnością liniową do pewnej wilgotności krytycznej, powyżej której dalsza absorpcja odbywała się zgodnie z zależnością wykładniczą. Wzrost wilgotności tworzywa biodegradowalnego powodował zwiększenie pojemności elektrycznej oraz zmniejszenie naprężenia w punkcie zerwania.

Słowa kluczowe: tworzywo biodegradowalne, skrobia, absorpcja, wytrzymałość, pojemność elektryczna