Investigation of the Orientational Mechanical Properties of Biodegradable Extrusion Films Based on Polyolefins and Beet Pulp

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Keywords: Technological Process, Packaging Films, Cast Film Extrusion, Biodegradable Composite, Polyethylene, Polyethylene Glycol, Beet Pulp

Abstract. The article discusses the possibility of obtaining biodegradable films based on polyolefins and beet pulp by the extrusion method. Biodegradable composites of two mixes with 15% and 25% beet pulp content have been obtained. Compounding was carried out on a twin-screw extruder, and then samples of biodegradable films were obtained by cast film extrusion. The influence of the vegetable filler particles' orientation on the composites mechanical properties has been studied. It has been shown that composites mechanical properties significantly increase in the direction of polymer melt stretching.

Introduction

Filling polymers with vegetable fillers such as wood flour, straw, husk of cereal crops reduces the cost of polymer compositions and can significantly reduce the environmental burden after their use, which is especially important for disposable packaging materials [1-12]. Recently, there have appeared a lot of studies [4-25], which describe the compositions of biodegradable composites based on thermoplastic polymers and natural fillers such as starch, cellulose, rice husks, wood flour, and cereal straw.

The use of film polymer materials in agroindustrial complex is becoming more and more widespread [20-21]. This is due to their low price and excellent operational characteristics. However, after the end of their service life, these materials accumulate in landfills, where they slowly decompose and pollute the environment. Therefore, the development of compositions of biodegradable polymeric materials as well as the development of their production technological processes are currently the priority tasks [24]. The effect of biodegradability can be achieved by introducing vegetable fillers into synthetic thermoplastics [4-17]. In the Russian Federation, the main by-product of sugar beet production is beet pulp. Beet pulp - de-sugar beet shavings remaining after extraction of sugar from it by the diffusion method. The pulp is dried, granulated and pressed into briquettes. Fresh beet pulp contains (in% of dry matter weight): pectin – 24...32, cellulose – 22...30, glycans – 22...30, proteins – 1.5...3.0, ash – 3.0...8.2, lignin – 1.5...3.0, simple sugars – 0.2...0.3. In our opinion, the priority direction of beet pulp recycling can be its use as a filler for polymers.

Studies [11-15] show the use of polyolefins, wood and flax flour to obtain biodegradable compositions. Malaysian scientists [16-19] studied the biocomposites based on various binders with plant waste from sugar palm. These biocomposites have high mechanical properties and

thermal stability. However, as the authors note, these biocomposites are limited in widespread use in everyday life.

The purpose of this study was to refine the technological extrusion process for obtaining biodegradable films and study their mechanical properties.

Methods and materials

To produce biodegradable film, the following materials were used:

- low-pressure polyethylene of 273-83 grade, high-pressure polyethylene of 15303-003 grade, ethylene-vinyl acetate copolymer of 12206-007 grade, functionalized by the method of alkaline alcoholysis, were used as a polymer matrix;
- polyethylene glycol of 115 (4000) grade was used as a lubricant;
- crushed beet pulp with a particle size of less than 200 microns and a moisture content of less than 5% was used as a vegetable filler.

Table 1 shows the percentage ratios of polymer composites components used to develop the technological process for biodegradable films production.

Table 1. *Compositions of biodegradable polymer composites*

	Composition 1	Composition 2
HDPE 273-83	37	32
LDPE 15303-003	37	32
Sevilen 12206-007	10	10
Beet pulp	15	25
PEG 115	1	1

At the first stage, the components were mixed in a co-rotating twin-screw extruder to obtain homogeneous granules [2].

At the second stage, a laboratory line was assembled for the biodegradable films production by the cast film extrusion method (Fig. 1), including a drive and measurement unit HAAKE RheoDrive 7 OS, single-screw extruder Rheomex 19/25 PolyLab OS with barrel length $L/D = 25$, screw 3: 1 Standard Metering, forming extrusion sheet die with 150 mm width and adjustable thickness 0.2 ... 1.2 mm, three-roll sizing device with a pulling unit.

Fig. 1. *Laboratory line for the production of films by cast film extrusion method*

The extrusion temperature was 160° C in all areas. Screw rotation speed was 200 rpm. The torque of the screw shaft during the extrusion process did not exceed 50 Nm. The pulling device speed was 60% higher than the linear speed of rolls rotation of the sizing device, i.e. the longitudinal deformation of the film (stretching) was 1.6 in this case.

The mechanical properties of the composites were obtained in accordance with GOST (State Standard) 11262-2017 and GOST 9550-81. The methods used correspond to international test standards [4]. The tests were carried out on a UAI-7000 M tensile testing machine at a temperature of $23 \pm 2^\circ \text{C}$ and a clamping speed of 10 mm/min.

Results and Discussions

The obtained results of mechanical properties are presented in the Table 2.

Table 2. Physical and mechanical characteristics of biodegradable composite materials with 15% and 25% beet pulp filling.

Filler content, %	Elastic modulus, MPa	Relative extension, %	Nominal strength limit, MPa	Fracture strength, MPa
15	195 ± 8	141	$10,5 \pm 0,50$	25,3
25	170 ± 11	32	$10,4 \pm 0,50$	13,7

Table 2 shows that the mechanical characteristics of the developed composites are at a high level, which makes it possible to use them for the production of biodegradable packaging films.

Figure 2 shows the appearance of the extruded melt and the entry melt zone from the sheet die into the three-roll sizing device.

Figure 3 shows the films appearance with 15% and 25% filling.

Fig. 2. Appearance of the extruded melt and the entry melt zone from the sheet die into the three-roll sizing device.

Fig. 3. Appearance of the obtained films with the content of beet pulp 15% (a) and 25% (b)

The films obtained were tested for strength along and transverse the direction of stretching according to the above methods. The test results are presented in Table 3.

Table 3. Stress-strain indicators of films from compositions filled with beet pulp.

Composition and loading conditions of films		Elastic modulus, MPa	Tensile strength, MPa	Relative extension, %
15 % of pulp	Along stretching	244 ± 21	$28,3 \pm 3,8$	91 ± 19
	Transverse stretching	189 ± 5	$10,9 \pm 0,12$	38 ± 10
25 % of pulp	Along stretching	201 ± 15	$16,4 \pm 2$	92 ± 29
	Transverse stretching	155 ± 4	$10 \pm 0,4$	31 ± 4

According to the results obtained, it follows that during the films stretching a significant increase in strength and elastic modulus in the direction of stretching are achieved. For composites with 15%-filling, the increase in strength was more than 240%, and the increase in elastic modulus was about 30%. For composites with 25%-filling, the increase in strength was more than 160%, and the increase in elastic modulus was about 20%. In the transverse direction, the elastic and strength indicators correspond to the physical and mechanical characteristics of the composites obtained by the compression molding method. The obtained results of biodegradable composites mechanical properties correlate with the results of previous studies [3, 10, 14, 25].

Conclusion

Thus, under laboratory conditions, the possibility of producing films strengthened by uniaxial stretching from the developed biodegradable composites by the method of cast film extrusion has been shown. These characteristics determine the possibility of producing reliable products for packaging agricultural and food products by pneumatic vacuum molding.

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