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MACROMOLECULAR COMPOUNDS AND POLYMERIC MATERIALS

Biodegradable Composites of Polyvinyl Alcohol and Drain Silt for Agriculture

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Abstract—Mechanical, sorption, and service properties of composite materials of polyvinyl alcohol and drain silt were studied with the aim of using these composites for fabrication of vessels for plant growth.

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The share of plastics used in agriculture is about 2% in Europe, 4% in the United States, and 20% in China. Plastics are used as films for greenhouses, tunnels, mulching, and ensilage, as vessels for plant sowing, thinning, and growth, and as containers. These items are made of traditional plastics (polyethylene, polypropylene, polystyrene) characterized by good physicomechanical properties and low cost [1]. However, these materials have also certain drawbacks. They are produced from nonrenewable natural resources and do not degrade in the environment. After the end of service, they should be reprocessed or incinerated. Most frequently they are disposed of in dumps where they lie for decades.

The best solution of the problem of polymeric waste is the use of biodegradable polymers. These are plastics based on natural biopolymers and chemically and microbiologically synthesized polymers [2–4]. One of possible lines in preparation of biodegradable materials is preparation of composite materials based on renewable natural polymers: starch, cellulose, proteins, containing diverse additives [5–8]. The best known are composites based on starch and polyvinyl alcohol [9, 10]. A biodegradable material in composites can be a binder or filler. Such plastics are suitable for fabrication of consumer's goods (disposable vessels, bags, boxes, seeding pots) which are fairly readily utilized after the end of the service life. The use of fillers, on the one hand, decreases the cost of polymers and, on the other hand, allows utilization of organic wastes from agriculture or other fields as additives. Replacement of traditional plastics with biodegradable plastics will also allow the use of composting as the most environmentally and economically efficient method for utilization of agricultural wastes [11].

A specific kind of additives that would be appropriate to use as a component of biodegradable composites for agriculture is drain silt. In large cities it is formed in an amount of about 1/3 of the total amount of production and consumption wastes. Therefore, it becomes topical to develop new utilization procedures. Utilization of drain silt is often associated with its use in agriculture as fertilizer or as additive in preparation of various composts [12]. Thus, polymeric composites containing drain silt would make it possible to expand both the assortment of biodegradable materials for agriculture and the set of procedures for utilization of wastes from water treatment facilities.

The goal of this study was to examine the physicomechanical and sorption properties of composites of polyvinyl alcohol and drain silt and to assess the possibility of using them for fabrication of vessels for plant growth.

EXPERIMENTAL

For formulating biodegradable composites we used polyvinyl alcohol IF-17 (Kuraray

Specialities Europe), glycerol (Barta a Cihlar, Czechia), and drain silt taken from municipal water treatment facilities. The dried and ground silt was sieved

Table 1. Content of PVA and silt in the mixture for preparing composites

Formulation no.	Content, %	
	PVA	Silt
1	10	0
2	8	2
3	6	4
4	4	6
5	2	8

through a sieve with a mesh size of 1 × 1 mm.

Samples for tests were prepared as follows. A mixture of water, polyvinyl alcohol (PVA), and silt (PVA to silt ratios are given in Table 1) was stirred at 80°C for 60 min, after which glycerol (4%) was added. From the resulting mixtures, we prepared films by pouring 10-ml portions of the mixtures into Petri dishes 10 cm in diameter and drying at 60°C. The thickness of the resulting films (μm) was as follows: formulation no. 1, 110; no. 2, 160; no. 3, 220; no. 4, 220; and no. 5, 260.

The mechanical properties of films were measured on a special device for uniaxial extension [13]. In the course of extension, we measured the sample elongation and the stretching force. Taking into account the cross sections of samples cut to obtain the required shape, we calculated the mechanical stresses in films and plotted the stress–strain dependences $\sigma = f(\varepsilon)$. Typical $\sigma = f(\varepsilon)$ dependences for dry and wet films of formulation nos. 3 and 4 are shown in Fig. 1. The Young modulus characterizing the resistance of films to extension was calculated from the slope of the $\sigma = f(\varepsilon)$ curves in the initial step of extension when the strain did not exceed 2%. From the same characteristics we evaluated the tensile strength of the films and their relative elongation at maximal load.

To determine the water absorption, samples were kept in a desiccator with 100% relative humidity at 20°C and weighed after a definite time.

The permeability to water vapor was determined gravimetrically using small glasses charged with a certain amount of water. The samples being tested were tightly fixed on the glass opening. Then the glasses with the films were kept in a desiccator with zero relative humidity at 20°C. After a definite time, the glasses with the films were weighed, and the permeability to water vapor ($g\ m^{-2}\ day^{-1}$) was calculated from the weight loss.

The tests of the service properties of vessels under natural conditions were performed as follows. From

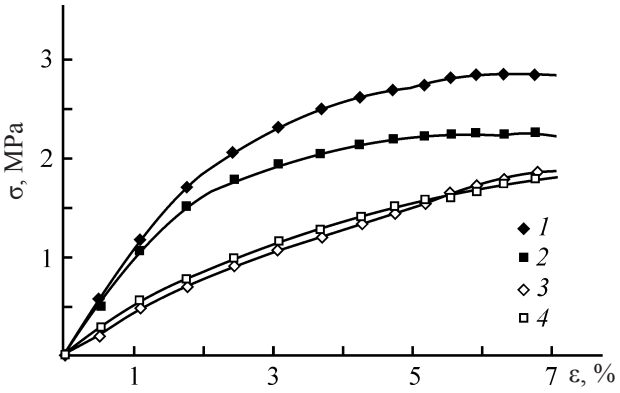

Fig. 1. Typical $\sigma = f(\varepsilon)$ dependences for films of formulation nos. (*1, 3*) 3 and (*2, 4*) 4. (σ) Mechanical stress and (ε) relative elongation. Films: (*1, 2*) dry and (*3, 4*) wet.

formulation no. 4, we prepared pots and grew there plants (surfinine) for 1 month. The soil temperature was measured daily, and the soil moisture content, on the fourth day after watering. Changes in the mechanical properties of the vessels after their use were evaluated visually.

The biodegradable materials from which vessels for plant growth are fabricated should be sufficiently strong to stand transportation. Their mechanical properties should not be impaired in the wet state (e.g., after plant watering).

The results of determining the mechanical properties of dry and wet (kept in a desiccator with 100% relative humidity at 20°C for 7 days) films of composites of PVA and silt are given in Table 2. The strength characteristics of commercial polypropylene (nos. 6, 7) and polystyrene (no. 8) samples cut from plant growth vessels are given for comparison.

It can be seen that the dry films are stronger than the wet films. With increasing silt content, the strength of the dry films decreases and that of the wet films increases (by 80% for formulation nos. 3 and 4).

Films of PVA–silt composites (except formulation no. 5) surpass the polypropylene and polystyrene films in the relative elongation at maximal load. For the dry films, this parameter decreases with increasing silt content. For the wet films, the relative elongation varies with the silt content insignificantly, except formulation no. 5 for which this parameter decreases by 25%.

The Young modulus characterizing the film elasticity passes through a maximum with increasing silt content. The highest Young modulus is exhibited by formulation

Table 2. Mechanical properties of films

Film no.	Tensile strength, MPa		Young modulus, GPa		Relative elongation, %	
	dry films	wet films	dry films	wet films	dry films	wet films
1	5.8	1.0	0.14	0.017	7.4	7.4
2	5.2	1.2	0.16	0.023	6.8	7.2
3	2.8	1.8	0.12	0.041	6.0	7.0
4	2.0	1.8	0.10	0.050	5.6	7.0
5	0.6	0.6	0.05	0.016	2.4	5.6
6	37.3		1.10		5.1	
7	45.3		1.25		5.5	
8	31.3		1.14		3.8	

no. 2 in the dry state and no. 4 in the wet state. The Young modulus of synthetic films (nos. 6–8) is considerably higher than that of PVA–silt films.

Data on water absorption of the films are plotted in Fig. 2. The films are saturated with water within 7–8 days. The sorption power of the samples depends on their composition. With a decrease in the PVA content, the sorption power of the films decreases until the PVA : silt ratio reaches a certain level. With a further decrease in the PVA content and an increase in the silt amount, the sorption power of the films increases.

The permeability of films to water vapor varies with the silt content insignificantly:

Formulation no.	1	2	3	4
Permeability to water vapor, g m^{-2} day^{-1}	107	117	119	90

The sorption power, water-retaining power, and permeability to water vapor of the vessels significantly affect the moisture content and temperature of soil in pots. The mean values of the temperature and moisture content of soil in the course of plant growth in peat, cellulose, and polypropylene vessels and in vessels made of the composite (formulation no. 4) are given in Table 3. It can be seen that the composites of polyvinyl alcohol and drain silt are suitable for fabrication of vessels for plant growth. In the course of tests, these materials, as well as polypropylene, preserved high temperature and moisture content of the soil, required for plant growth. The mechanical properties of the vessels after their use changed insignificantly.

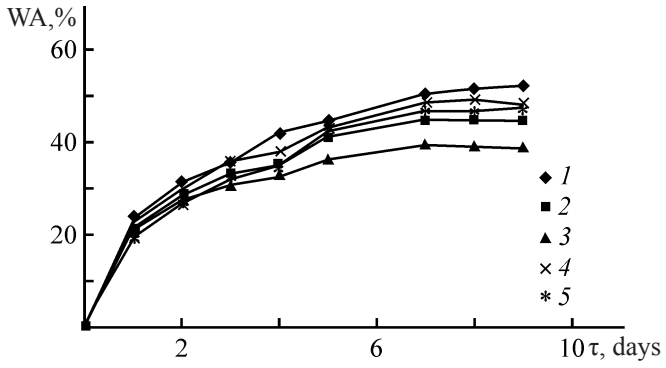

Fig. 2. Water absorption WA of films as a function of time τ. (*1–5*) Film formulation nos.

CONCLUSIONS

(1) Polymeric composites of polyvinyl alcohol and drain silt are suitable for fabricating vessels for plant growth.

(2) The presence of drain silt in composites favors improvement of physicomechanical properties of films in the wet state. The sorption properties and permeability to water vapor of these films ensure uniform moisture and temperature conditions in the soil.

Table 3. Temperature and moisture content of soil in vessels

Vessel material	Temperature, °C	Moisture content, %
PVA–silt	25.1	72.1
Peat	22.9	42.4
Polypropylene	25.6	93.1
Cellulose	22.6	30.7

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