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Biopolymeric Materials

Technological Aspects of Biopolymers Based on Yucca Gloriosa Fiber

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(Presented by Academy Member Ramaz Katsarava)

Based on renewable plant raw materials, the leaves of „Yucca gloriosa“, a woody plant of the lily family, a health-safe bioorganic composite material were obtained, where the binder is one of the world's industrial plastics, secondary isotactic polypropylene powder. By mixing the binder and crushed ”Yucca gloriosa” fiber, using the hot pressing method, the samples were modified with tetraethoxysilane liquid. For the resulting composite, its own weight, water absorption, compressive strength, and impact strength were determined. Modification of composites has improved their mechanical properties. The modification of materials reduced the rate of water absorption by 1.5-2 times, and the compressive strength improved by 10-15%. At 60 wt% filling, a high impact strength index of –12.5 kJ/m^2 was observed, which is 2-3 times higher than the strength of polypropylene of the same filling with Tungo oil production waste – Tungo box shell flour, thereby proving that Yucca gloriosa fiber is a reinforcing ingredient of the biocomposite. The microstructure and chemical composition of bioorganic composite materials were studied using an optical biological microscope and infrared spectroscopy (FTIR). *© 2024 Bull. Georg. Natl. Acad. Sci.*

biocomposite, Yucca gloriosa, polypropylene, cellulose, biomass, FTIR

Carbohydrates are important representatives of natural macromolecules and perform various functions: they are the structural basis of living organisms (cellulose, chitin), a source of energy (glycogen), and sensitive receptors of cell membranes (glycoproteins). These properties are due to the presence of hydroxyl groups (inter- and intramolecular hydrogen bonds) in the carbohydrate molecule. Carbohydrate products (S-, N-, Si-, Br- glycosides) are widely used in various fields of pharmaceutical technology, agriculture, and industry. This is due to their membrane permeability and biocompatibility with living cells [1-3].

The virtually inexhaustible resources, chemical structure, unique properties, and biodegradability of bipolymers are of constant interest to scientists and technologists [4-8]. Environmentally friendly and renewable biopolymers are used in almost all sectors of the national economy. In this regard, researchers have a growing interest in bioorganic composite materials [9-12]. The properties and benefits of various cellulosic materials make them promising alternatives for environmental applications [13].

In recent years, global pollution has prompted humanity to take action to preserve nature against various threats. These threats include air pollution, which contributes to global warming, water pollution, and the depletion of natural resources. Developing and utilizing eco-materials is essential to achieving sustainable development and reducing the impact of human activities on the environment. Researchers focus on composite materials reinforced with natural fibers, as these composites combine good mechanical properties with low density [14].

Around the world, bioorganic composite materials are produced based on various types of plant cellulose fibers and thermoplastic polymers. Biocomposites are characterized by low cost, lightness, environmental friendliness, and high performance properties. The homopolysaccharide cellulose enters the cells of higher plants and serves as a natural structural material, providing high mechanical strength and elasticity to plant tissues. Researchers are focusing on composite materials filled with natural cellulose fibers because these composites combine good mechanical properties with low density, which in the future will allow industrial polymer materials to be converted into materials with biodegradable properties [15].

The polymer matrix may be a primary or secondary polymer, such as polyethylene, polypropylene, polystyrene, polyvinyl chloride, polyvinyl alcohol, and others. Wood flour is mainly used in biopolymer composites, the grain size of which is standardized and made from non-resinous wood, such as spruce. In many countries, it is made from rice husk flakes and hazelnut shell flour. It should be noted that in Asian countries, other types of plant fibers are used to fill them. Table 1 presents the chemical composition of various plant cellulose fibers, showing that “Yucca gloriosa” contains as much cellulose as hemp, second only to cotton, which is classified as a seed plant fiber rather than a cultivated leaf fiber. Their chemical composition is different: sisal, kenaf, flax, hemp, etc., types whose technological and physical-mechanical properties are close to those of composites filled with wood flour [16].

Table 1. Chemical composition of natural fiber

Fiber	Cellulose %	Hemicellulose %	Lignin %
Yucca gloriosa	72-80	10-12	8-10
Bamboo	26-43	20.5	21-31
Cotton	83-90	4	0.75
Flax	62-72	14-20	2.5
Hemp	81	14-22	4-13
Jute	59-72	12-20	17-21
Sisal	60-73	11-14	8-11

With natural organic and inorganic fillers, reinforced bio-composite materials have a great capacity to replace synthetic fibers” with “natural fibers”. Thanks to their low cost, lightness, ecological advantages, and high efficiency, they are produced based on various types of plant cellulose fibers.

Industrial polymer selected as a binder: secondary isotactic polypropylene is a universal plastic material and one of the lightest and cheapest polymers. It is impact-resistant, does not undergo deformation during bending, is chemically resistant, wear-resistant, and has good electrical insulation properties.

Phenolformaldehyde resins found in commercial wood burbushell tiles are classified as carcinogens because they contain formaldehyde [17,18]. World health experts have found that small concentrations of this substance in the human body cause headaches, shortness of breath, depression, and damage to the central nervous system. Today, the world has adopted standards to eliminate formaldehyde from the use of composite materials [19,20].

Our research team has proposed a new, cheap and accessible method for producing biocomposites based on renewable plant raw materials, in which phenolic resins are replaced with a non-toxic polymer material, secondary isotactic polypropylene, and high-strength “Yucca gloriosa“ fibers containing a large amount of fiber.

A very original method of obtaining fiber from the leaves of „Yucca gloriosa“ using sodium alkali is described in [21], where long, uncut fibers without lignin are obtained from its leaves, from which various products are made.

Experimental Materials

The powder of the secondary isotactic polypropylene was delivered from the city of Rustavi (Georgia), by the firm “Tomara“, the grain size of which was 15-300 µm. Tetraethoxysilane (TEOS) was purchased from Aldrich. Filler: “Yucca gloriosa” thrives in Georgia, in Tbilisi.

Methods of obtaining a biocomposite. Long pointed Yucca leaves were cut into small pieces and dried in the sun, then crushed to obtain fiber, then mixed (3-5 minutes) with 40, 60, or 80% polypropylene powder in a propeller mill. Test samples of composites were prepared by hot pressing method [22] in appropriate forms at a temperature of 170°C and a pressure of 100-120 MPa with a holding time of 10 minutes. The resulting samples were measured for bulk density, water absorption, compressive strength, and volumetric impact strength (toughness).

The water absorption of samples of any size was measured according to the ISO 62 2002 standard. The flexural strength was measured for specimens with a diameter of 10 mm and a height of 20 mm according to the ISO 604 2002 standard. Impact strength was measured using the “Izod method” according to the ISTM D256 standard on a “Dinstant“ instrument with 15x10 (1.5-4.5) mm size samples.

FTIR spectrometric research was carried out on a SHIMADZU “IRSPIRIT” device, wavelength 4000-600 cm^{-1}, mode UATR. The microstructure of the biocomposite was studied using an optical biological microscope (A16.2603-T2) and a digital camera (Euromex ME 2665).

Results and Discussion

In order to improve the physico-mechanical properties of the resulting composites, they were modified as an adhesion modifier with tetraethoxysilane which is a colorless, odorless liquid and it is used as a highly effective changing additive in the production of polymer composites.

Figure shows the difference between the unmodified and modified surfaces of “Yucca gloriosa” cellulose fiber. If microscope light clearly

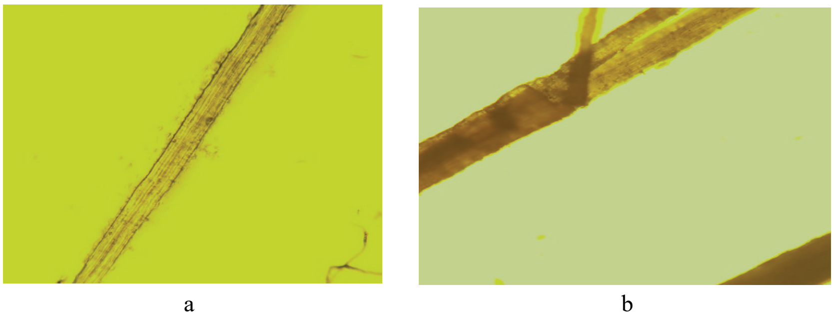
a b

Fig. Surface of unmodified (a) and modified (b) “Yucca gloriosa” cellulose fiber 5 wt% with tetraethoxysilane, of 100 times magnification.

shows the surface structure of an unmodified fiber, then after modification, this structure is not visible since the light is reflected by tetraethoxysilane, which forms an apex on the surface of the fiber.

In the FTIR spectrum of sample 4 (cm^{-1}, γ, m.n.), a characteristic absorption bond of the OH group can be observed in the region of 3000-3500 cm^{-1}. The absorption band in the region of 2851-2920 cm^{-1} is characteristic by the valence bond of the –CH$_2$– group; for the valence vibrations of the C=O bond, a small absorption band is observed in the region of 1739 cm^{-1} (for non-substituted polysaccharides, this peak appears in many cases); 1000-1149 cm^{-1} region is characteristic of the (C-O-C) bond; 1419, 1598 cm^{-1} (C-H deformation); 1241-1316 cm^{-1} mixture of aliphatic and aromatic nitriles.

In the FTIR spectrum of the sample 5 (cm^{-1}, γ, m.n.), a characteristic absorption band of the OH group can be observed in the region of 3000-3500 cm^{-1}. The absorption band in the region of 2839, 2874 cm^{-1} is characteristic of the valence bond of the –CH$_2$– group (standing at the C$_6$ carbon atom). The absorption bond at 2948 cm^{-1} is characteristic of the vinyl group (-CH=CH$_2$). 1373 cm^{-1} (a mixture of aromatic amine); 1454 cm^{-1} (-CH$_2$-propylene); 1620 cm^{-1} (C=C); Due to the substitution of the aromatic group, an overlap has occurred, so the absorption band of the (C=O) group is not visible. Nitrile impurities are observed in the regions of 2339 and 2362 cm^{-1}. In the region of 1155 cm^{-1} a characteristic absorption bond of the (Si – O) bond is observed.

In Table 2, the resulting samples of the developed biocomposites are characterized by lightness (from 991 to 1178 kg/m^3), high compressive strength (41.2-76.6 MPa) and relatively high impact strength (7-12.5 kJ/m^2). It should be noted that the impact strength of composites filled with tung waste flour from the production of tung oil [23] does not exceed 5.5 kJ/m^2, which confirms that in our case, "Yucca gloriosa" fibers are a reinforcing element. With high filling, the water absorption of materials is 2-5%. Modification of these materials with 5 wt% tetraethoxysilane liquid reduced water absorption by 1.5-2 times, and the compressive strength improved by 10-15%. Because of the introduction of 5 wt% powder from the extraction of Chiatura mining and processing waste (sludge), the physico-mechanical properties of the composite were preserved, the density increased slightly at high

Table 2. Physico-mechanical characteristics and water absorbtion of PP+YGF* composites

№	Composite	Relative density, kg/m^3	Compression strength, Mpa	Impact viscosity, kJ/m^2	Water absorption, %
1	PP + YGF*[1] 40 wt%	991	66.0	8.8	0.1
2	PP + YGF 60 wt%	1090	53.5	9.5	2.0
3	PP + YGF 80 wt%	1175	41.2	7.7	6.5
4	PP + YGF 40 wt% modified with TEOS 5 wt%	1010	76.6	12.0	0.1
5	PP + YGF 60 wt% modified with TEOS 5 wt%	1054	56.3	12.5	1.2
6	PP + YGF 80 wt% modified with TEOS 5 wt%	1170	45.4	8.9	5.1
7	PP + YGF 35 wt% modified with powder* 5 wt%	998	62.5	8.2	0.1
8	PP + YGF 55 wt% modified with powder*[2] 5 wt%	1060	52.2	8.8	1.5
9	PP + YGF 75 wt% modified with powder 5 wt%	1178	42.1	7.5	5.0

Notes: *YGF - Yucca Gloriosa Fiber;
**Powder obtained as a result of leaching of the residue (sludge) of the Chiaturi mining and processing industry.

filling, and water absorption slightly decreased. But a technological effect appeared: reducing the mixing time to 1 minute. This is explained by the presence in the specified powder of more than 50 wt% crystalline silicon dioxide, which accelerates the grinding of strong cellulose fibers obtained from yucca leaves when mixed.

Conclusion

The introduction of 60 wt% of “Yucca glorious” fibers into the polypropylene composition doubled the impact strength, compared to a polypropylene composite filled with the same amount of flour from tung wood box waste. The new bio-composite materials are derived from free formaldehyde, using renewable plant fibers from great yucca and secondary isotactic polypropylene. They have enhanced physico-mechanical properties, are highly environmentally friendly, and have an easy production process that meets modern international standards for similar materials.

The addition of great yucca fibers to secondary isotactic polypropylene reinforced the composition and doubled its impact strength. The bio-composites produced through appropriate methods and technologies will be used to make comparatively low-cost building materials and various components for the automotive industry.

ბიოპოლიმერული მასალები

იუკა დიდებულის ბოჭკოზე დაფუძნებული ბიოპოლიმერების ტექნოლოგიური ასპექტები

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(წარმოდგენილია აკადემიის წევრის რ. ქაცარავას მიერ)

მრავალტონაჟიანი თერმოპლასტიკური პოლიმერების გადამუშავების სფეროში მეტად აქტუალურ საკითხს წარმოადგენს პოლიმერული ბიოკომპოზიტების შემუშავება განახლებადი მცენარეული ნედლეულის ბაზაზე. ერთდროულად მოხდება ორი ეკოლოგიური – განახლე-

ბადი მცენარეული ნედლეულის ნარჩენებისა და მეორეული პოლიპროპილენის უტილიზაციის საკითხების გადაწყვეტა. სამუშაოს მიზანს წარმოადგენს „იუკა დიდებულის“ ფოთლების ბაზაზე ჯანმრთელობისთვის უსაფრთხო ბიოორგანული კომპოზიციური მასალის დამზადება, სადაც შემკვრელი არის მსოფლიოში ერთ-ერთი სამრეწველო პლასტმასის, მეორეული იზოტაქტიკური პოლიპროპილენის ფხვნილი. შემკვრელისა და დაქუცმაცებული „იუკა დიდებულის” ბოჭკოს შერევით, ცხელი დაწნეხვის მეთოდით ნიმუშები მოდიფიცირებულ იქნა ტეტრაეთოქსისილანის სითხით. მიღებული ბიოკომპოზიტისათვის განისაზღვრა კუთრი წონა, წყალშთანთქმა, სიმტკიცე კუმშვისას და დარტყმითი სიბლანტე. მასალების მოდიფიკაციამ გააუმჯობესა კომპოზიტების მექანიკური თვისებები, შეამცირა წყალშთანთქმის სიჩქარე 1,5-2-ჯერ, ხოლო სიმტკიცე კუმშვისას გაუმჯობესდა 10-15%-ით. 60 მას.% შევსებისას დაფიქსირდა დარტყმითი სიმტკიცის მაღალი მაჩვენებელი 12,5 კჯ/მ^2, რაც 2,3-ჯერ მეტია ასეთივე შევსების პოლიპროპილენის სიმტკიცეზე ტუნგოს ზეთის წარმოების ნარჩენების – ტუნგოს კოლოფის ნაჭუჭის ფქვილით, რითაც მტკიცდება, რომ „იუკა დიდებულის“ ბოჭკო წარმოადგენს მაარმირებელ ინგრედიენტს ბიოკომპოზიტში. ბიოორგანული კომპოზიციური მასალების მიკროსტრუქტურა და ქიმიური შემადგენლობა შესწავლილ იქნა ოპტიკური ბიოლოგიური მიკროსკოპისა და ინფრაწითელი სპექტროსკოპიის (FTIR) გამოყენებით.

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