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OPTIMIZATION OF BIOCOMPOSITE MATERIALS FOR OUTER SHELL OF BUILDINGS

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ABSTRACT

The subject of the article is a bio-composite material which will serve as the outer shell for buildings. It deals with the testing and optimization of bio-composite laminate. Conventional constructions materials, such are steel and plastic are currently used for buldings envelopes. Bio-composites may be used as a suitable alternative material. They are made by nature fibers and matrix. Bio-composites will have great potential in the future in the construction industry as the outer envelope of buildings. The main intention of this article is to analyze the impact of UV radiation and humidity on bio-composites and creation a bio-composite panel for using in building envelope with inclusion of wider use of these types of materials in the future.

INTRODUCTION

Biocomposites represent the most advantageous material for structures in terms of ecology, sustainability, global warming and energy saving. They are also an ideal material in terms of economic demands. Biocomposites are made of natural materials and are an alternative to commonly used synthetic composites. These relatively new materials are currently used in many industries, including the construction industry. Biocomposites represent an element that is composed and manufactured exclusively from biologically renewable and naturally degradable sources. Biocomposite consists of matrix (resin, PLA – Polylactic acid, biodegradable thermoplastic polymer derived from natural renewable sources) and an inner reinforcing layer of natural fibers (obtained from plant stems - mostly Linen, Jute, Flax). The matrix provides the role of the protective casing, preserves the shape of the composite and protects the inner reinforcement. Petrochemical resins are replaced by natural resins or PLA and synthetic fibers (carbon, glass fiber) are replaced by natural fibers (Flax, Linen, Jute). [1]

DEGRADATION

The main cause of the degradation of natural fibers due to moisture is the presence of the hydroxyl group and other polar groups in the natural fibers. This group makes the fibers hydrophilic. Polymer composites are capable of absorbing moisture in humid environments or when immersed in water. This is most relevant for natural fiber composites [2]. It has been shown that the absorption of water by biocomposites is typically 0.7 to 2% after 24 hours, 1 to 5% per week and 18 to 22% after several months. This applies to fibers with a high content of hydrophilic components [3]. Higher humidity also causes microbial degradation - biodegradation. Outdoor biocomposites are exposed to direct sunlight, which breaks covalent bonds in organic polymers, causing yellowing, color fading, weight reduction, surface roughening. Impairment of mechanical properties and brittleness of the material, which is increased by outdoor use, are: UV resistance, moisture resistance,

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dimensional stability. The UV-induced weathering process causes a loss of tensile strength of the composite material. When biocomposite samples are exposed to external environment, it leds to fiber and matrix degradation [3]. The ultraviolet radiation absorbed by the polymer modifies the chemical structure and cleaves the molecular chain. Degradation processes of weathering create changes in chemical, physical and mechanical properties of materials [4]. Photodegradation creates a photo-oxidation process that creates cracks. Cracks on the surface cause light scattering (bleaching effect in appearance) and impair mechanical properties. During production process, hydroperoxide and carbonyl catalysts can be introduced into the composite. These absorb UV radiation at wavelengths above 290 nm and trigger photochemical reactions.

TESTING

The samples of the tested biocomposites have a core of woven flax fiber. The test samples are divided as follows: a 1-layer sample of woven flax fiber in natural shade and shade of bordeaux in PLA (polylactic acid) matrix, a 1-layer sample of woven flax fiber in natural shade and shade of bordeaux in PP (polypropylene) matrix and a 3-layer sample of woven flax fiber in natural shade and shade of bordeaux in PLA matrix. The edges of the samples were sealed and samples were placed in test frames. *Note: abbreviation L N.PLA.3V 04 means: laboratory tested, natural color, PLA matrix, 3layers, number of sample.* Testing of degradation is performed under laboratory conditions according to STN EN ISO 4892-3: Plastics. Methods of exposure to laboratory light sources. Part 3: Fluorescent UV lamps (ISO 4892-3: 2016). [5] Method A was chosen from Table 4 - Exposure Cycles (Table 1): Accelerated laboratory aging with UVA-340 type fluorescent lamps. From this part was selected cycle no. 2. This cycle corresponds to the standard testing of plastic products.

Table 1. ISO 4892-3: 2016, Table 4 - Exposure cycles.

Method A: Artifical accelerated weathering with UVA-340 lamps				
Cycle No.	**Exposure period**	**Lamp type**	**Irradiation**	**Black-panel temperature**
1	8 h dry 4 h condensation	UVA-340 (type 1A)	0,76 $Wm^{-2} \times nm^{-1}$ at 340nm UV lamps off	60 °C ± 3 °C 50 °C ± 3 °C
2	**8 h dry 0,25 h water spray 3,75 h condensation**	**UVA-340 (type 1A)**	**0,76 $Wm^{-2} \times nm^{-1}$ at340nm UV lamps off UV lamps off**	**50 °C ± 3 °C Not controlled 50 °C ± 3 °C**
3	5 h dry 1 h water spray	UVA-340 (type 1A)	0,83 $Wm^{-2} \times nm^{-1}$ at 340nm UV lamps off	50 °C ± 3 °C Not controlled
4	5 h dry 1 h water spray	UVA-340 (type 1A)	0,83 $Wm^{-2} \times nm^{-1}$ at 340nm UV lamps off	70 °C ± 3 °C Not controlled

The total test time was set to 4000 hours. One sample of each species was taken after 500 hours. From the results of the testing of samples it is possible to state several facts, which are explained in the following subchapters.

INFLUENCE OF MATERIAL AND LAYERS ON COMPOSITE DEGRADATION

The monolayer samples whose matrix is formed by the PLA layer have degraded most rapidly. These samples began to degrade as early as 117 hours in laboratory conditions.

After 2000 hours, all single layer PLA samples were removed for overall degradation - total matrix damage was throughout the sample thickness.

Multilayer PLA samples and single layer PP matrix samples were more resistant due to the thicker coating and did not cause overall matrix degradation and moisture penetration into the fibers in the sample core. In figure 1., a change in the color of the sample is visible but no visible damage to the matrix. Total degradation of the sample occurred after 3000 hours.

Figure 1. Visible color changes of three-layer PLA samples - 170 h and 300 h and its total degradation after 3000 h on the right side.

When comparing the degraded samples with the reference samples, there is a difference in degradation due to material and composite thickness. Layer thickness has a significant effect on degradation, single layer PLA samples have degraded completely within 2000 h. However, when comparing the material base, single-layered PP samples degraded less (color change only) than three-layered PLA.

Bordeaux shade samples - the conclusion is similar to natural shade samples, but bordeaux shade samples have degraded significantly more.

The sample thicknesses were compared to the reference samples. Not all samples were measured, only selected samples at the end of testing (Table 2). The original samples were stored in a plastic waterproof and airtight container in a dark place to prevent their deterioration.

Table 2. Biocomposite sample thickness.

Biocomposite sample thickness				
Reference sample	Thickness (μm)	**Sample number**	Thickness (μm)	Percentage of thickness loss (%)
N.PP.1v	1097	**L N.PP.1v 07**	1088	0,82%
N.PLA.1v	575	**L N.PLA.1v 08**	546	5,04%
N.PLA.3v	1450	**L N.PLA.3v 07**	1242	14,34%
B.PP.1v	992	**L B.PP.1v 03**	981	1,11%
B.PLA.1v	543	**L B.PLA.1v 08**	506	6,81%
B.PLA.3v	1570	**L B.PLA.3v 06**	1020	35,03%

Based on the thickness comparison, it can be stated that the greatest difference in thickness was recorded in the case of the three-layer PLA shade of bordeaux. When comparing the percentage decrease in thickness, it can be stated that the color of the reinforcement has an effect on the degradation of the material - when

comparing the same composites with another color of the reinforcement, the thickness loss at the Bordeaux shade is higher.
By comparing the weights of the composites, it can be stated that the greatest percentage average weight loss was recorded for the 3-layer PLA shade of Bordeaux (Table 3).

Table 3. Biocomposite sample thickness.

Type of biocomposite	Average weight loss percentage (%)
N.PLA.3v	6,26%
B.PLA.3v	**12,62%**
N.PP.1v	3,24%
B.PP.1v	**3,87%**
N.PLA.1v	**9,65%**
B.PLA.1v	6,88%

When comparing the percentage weight loss, the same conclusion can be stated as for the thickness comparison and that the color of the reinforcement has an effect on the degradation of the material - when comparing the same composites with another color of the reinforcement, the thickness loss at Bordeaux shade is higher. However, this does not apply in this case to 1-ply PLA shades of Bordeaux. Higher value here is for 1-layer PLA samples of natural shade. This was caused by more imperfections on the matrix surface in the case of natural shade samples. The influence of the exposure time of the samples also has a considerable effect on the degradation of the material, which is also evident from the tables. Single-layer biocomposites encapsulated in PP (Polypropylene) reached the best results. However, these cannot be considered ecological, since biological plastic is not used in their matrix.

INFLUENCE OF MATERIAL AND LAYERS ON COMPOSITE DEGRADATION

In the process of producing biocomposites, imperfections occur on the surface of the matrix; small to microscopic imperfections and cracks on the surface. These may be due to the material or used production process. After comparing the percentage of weight loss for 1-ply PLA natural shade samples, the samples were examined in more detail.
Samples and imperfections were then examined under an optical microscope and dimensions and depth were recorded.
Research has shown, among other things, that moisture has penetrated into the multilayer biocomposite specimens due to defects and imperfections on the matrix surface (Fig. 2). These drawbacks that arise in the manufacturing process reduce the thickness of the biocomposite coating and significantly reduce its life.

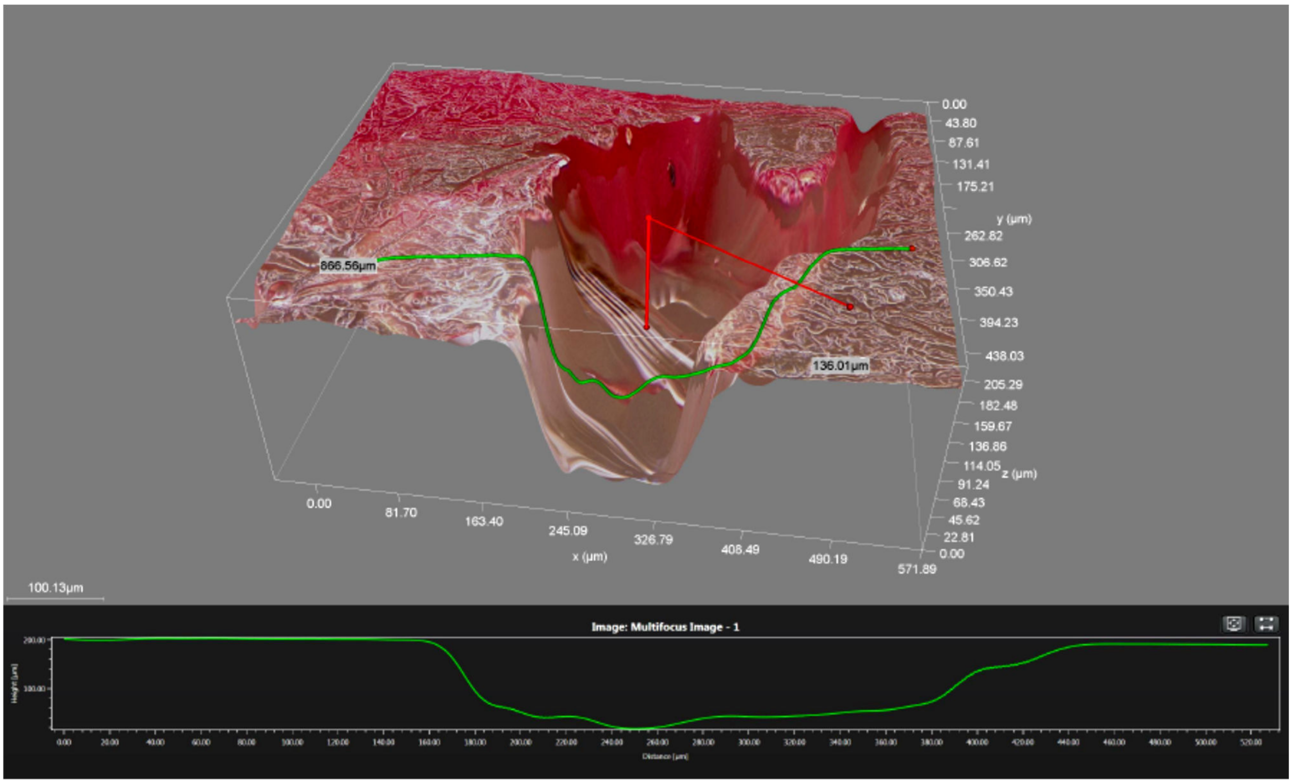

Figure 2. Imperfection on the surface of PLA samples - under a microscope in 3D space

Imperfections in other composites have shown that in some cases the imperfection is so deep that the fiber-protecting matrix is only a few micrometers thick. This causes rapid degradation and penetration of moisture into the interior of the hydrophilic reinforcement.

Based on the results of testing, it is recommended to change the production process or to add another covering layer of matrix material. This approach is especially needed in the manufacture of PLA biocomposites.

TREATMENT OF BIOCOMPOSITE LAMINATES

Under laboratory conditions, an attempt was made to treat the surface of biocomposites with a biological UV-resistant varnish, but this solution did not prevent the degradation of the composites, only postponed it by a few weeks.

After consulting the presentation of the research results to the manufacturer, the company's production director and other representatives took into account the risks associated with the current state of the production process and the errors of imperfections introduced in the production of the samples. After consultation, samples were sent to Germany and their surface was modified. The surface was smoothed and the imperfections removed. The recommendations consisted in adding an additional layer of PLA to the surface of the composite. By heating and laminating, the composite surface was gradually smoothed. The individual phases of the process are shown in Fig. 3.

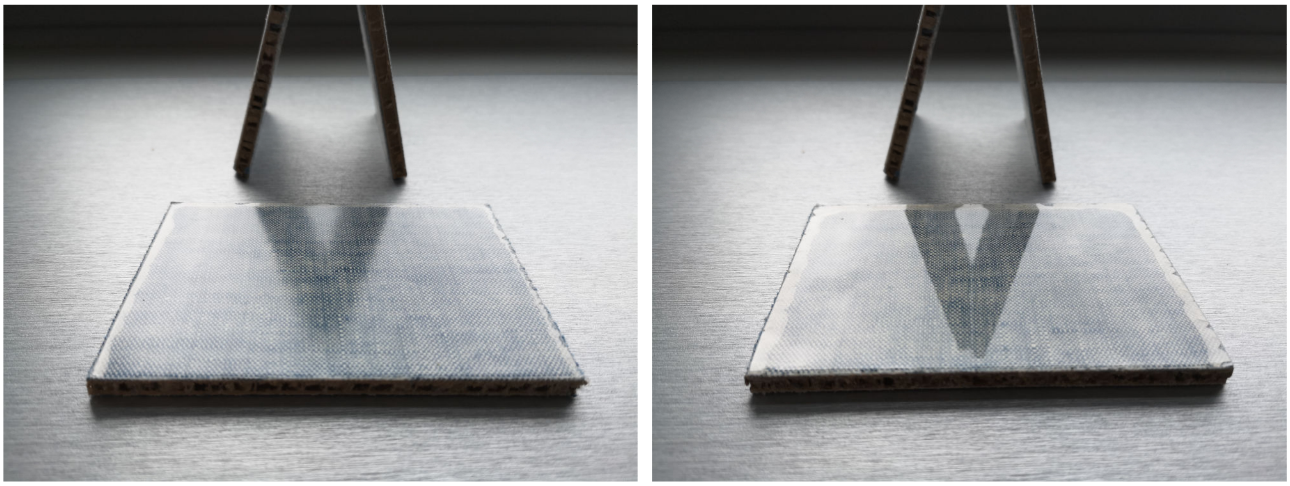

Figure 3. Smoothing the surface and removing imperfections

CONCLUSIONS

This research was mainly focused to the study of the degradation process of biocomposites under laboratory conditions and their surface protection. The assumption of using this type of material in construction is based on the possibility of replacing conventional materials. This will partially reduce the environmental burden in the construction industry.

Based on the results of the research, it is recommended to increase the thickness of the top layer of the matrix or to use several layers of PLA to prevent imperfections in the matrix and its subsequent degradation and thus the degradation of the entire laminate.

The color of the reinforcement layer and the thickness of the composite itself also have a significant effect on the degradation process. Therefore, it is recommended to choose color, thickness / number of layers depending on this fact.

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REFERENCES

[1] Bosák, L.: Starnutie bio-kompozitov v reálnych podmienkach a v laboratóriu. In Advances in Architectural, Civil and Environmental Engineering: 27th Annual PhD Student Conference on Applied Mathematics, Applied Mechanics, Geodesy and Cartography, Landscaping, Building Technology, Theory and Structures of Buildings, Theory and Structures of Civil Engineering Works, Theory and Environmental Technology of Buildings, Water Resources Engineering. 25. October 2017, Bratislava, Slovakia. Vol. 1. Bratislava: Spektrum STU, (2017), CD-ROM, p. 380-387. ISBN 978-80-227-4751-6.

[2] Shubhra, Q.T.H., Alam, A.K.M.M., Beg, M.D.H.: Mechanical and degradation characteristics of natural silk fiber reinforced gelatin composites. Mater Lett, 2011.

[3] Dittenber, D.B., GangaRao, H.V.S.: Critical review of recent publications on use of natural composites in infrastructure. Composites Part A Applied Science and Manufacturing, 2012.

[4] Beg, M.D.H., Pickering, K.L.: Accelerated weathering of unbleached and bleached kraft wood fibre reinforced polypropylene composites. Polymer Degradation and Stability, 2008

[5] STN EN ISO 4892-3: Plastics. Methods of exposure to laboratory light sources. Part 3: Fluorescent UV lamps (ISO 4892-3: 2016).