

Investigation of the biodegradation of polyvinyl chloride using modified rice starch

*Hayot Istamov**, *Bakhodir Mukhiddinov*, *Furqat Toshtemirov*, and *Lola Tilavova*

Navoi State University of Mining and Technologies, Navoi, Uzbekistan

Abstract. A This article examines the effect of modified rice starch on the biodegradation of polyvinyl chloride (PVC), with an emphasis on changes in the physico-chemical and mechanical properties of the polymer. In light of the global growth in the production and consumption of PVC, which leads to an increase in the volume of its waste, the development of effective disposal methods is becoming a critical task. The study shows that the addition of rice starch to PVC significantly accelerates its biodegradation under the influence of soil microorganisms. The research methods included analysis of biodegradation in various types of soil, thermogravimetric, IR analysis, SEM analysis, as well as assessment of the physical and mechanical characteristics of samples before and after biodegradation. The results confirm the hypothesis that modification of PVC with rice starch not only contributes to faster biodegradation of the material, but also makes changes in its structure and properties, which opens up new prospects for the development of environmentally friendly polymer materials. These studies can be used to develop new approaches to the disposal and recycling of PVC, reducing its negative impact on the environment.

1 Introduction

From 2010 to 2022, global PVC consumption increased by about 30% and currently stands at 47.5 million tons. It is expected that by 2025 the global consumption of PVC will reach 53 million tons, and in 2030 it may reach 60 million tons [1-2]. PVC consists of long-chain polymers with chlorine atoms. This structure, combined with additives such as plasticizers and stabilizers, provides resistance to environmental degradation [3-4].

Due to the stability of the chemical structure of PVC and extremely slow decomposition in natural conditions, for several decades, the main issue is the disposal of the material after the end of its use. Single-use packaging materials, which emit toxic substances during their decomposition, polluting the soil and groundwater, pose a special environmental danger [5-8]. Currently, there are several ways to dispose of polymer waste, these are, first of all, incineration, burial, composting, and recycling. However, each of these methods has a number of significant disadvantages, including low efficiency, difficulty in the preparatory stages of processing, environmental hazards and technological difficulties of production, etc [9-12].

* Corresponding author: dilshod.axtamov.89@mail.ru

That is why it is relevant to develop formulations and technologies for producing PVC-based polymer composites with degradable characteristics that take effect after the end of the product's service life under the influence of external factors (soil microorganisms, light, oxygen, water, etc.) [13-14]. Increasingly new biodegradation methods are being actively used to solve environmental problems, with microorganisms playing a special role in this [15]. These microorganisms interact with polymer materials in various roles, depending on environmental conditions and their biological nature.

2 Materials and methods

Research The object of the study was PVC synthesized in an aqueous suspension medium by polymerization of vinyl chloride in the presence of a heterogeneous catalyst - mercury chloride impregnated with activated carbon obtained in Navoiazot JSC, the molecular weight of which was 450.000. Samples of the compositions were prepared in a single-screw PVC extruder with modified rice starch in a ratio of 5.0 wt.%, 10 wt.%, 15 wt.%, 20 wt.% at a temperature of 130 °C, with a screw turnover of 31ob/min. A film was obtained from the resulting PVC composition with starch by hot pressing and its biodegradation was studied.

The biodegradation of PVC compositions was carried out in three different types of soil mixed with cow manure and soil: soil (control), 50 wt.% of manure and 50 wt.% soil, 90 wt.% of manure and 10 wt.% soil according to GOST 9.049–91 standard. Samples of PVC and PVC compositions with modified rice starch, with a size $R = 5$ cm, were introduced into prepared soils under controlled conditions of temperature and humidity of the environment, at different time durations. Its biodegradation was studied over a period of 1 to 6 months. Post-exposure analysis: samples of PVC and its starch compositions were prepared for microstructural studies and studied before and after exposure to the environment for 1 to 6 months of its biodegradation.

The derivatographic analysis of the samples was performed on the device "Differential thermal analyzer DTG-60 Shimadzu" in the temperature range of 30-700 °C with a heating rate of 5 degrees/min. The IR analysis was performed on the Shimadzu IRTracer-100 device in the range from 400 cm^{-1} to 4000 cm^{-1} in accordance with GOST 57941-2017. The physical and mechanical characteristics were studied using the AGS-X bursting machine. Shimadzu, with a speed of 5 mm/min. To study the structural changes, SEM analysis was used in the JEOL JSM-IT200 device with accelerating voltages of 5 kV and 10 kV, with a beam current of 1.2 nA in accordance with GOST R ISO 27911- 2015.

Optical microscopy was performed for visual evaluation on an Olympus CX41 microscope, with 100x magnification. in accordance with GOST R 57800- 2017.

3 Results and discussion

The thermal characteristics of biodegradable polyvinyl chloride compositions with modified rice starch after biodegradation have been studied, the results are shown in Figure 1 and in Table 1 - Table 3.

The biodegradation of polyvinyl chloride compositions with starch is estimated by DTA curves, the results of which are presented in Figure 1 and Table 1.

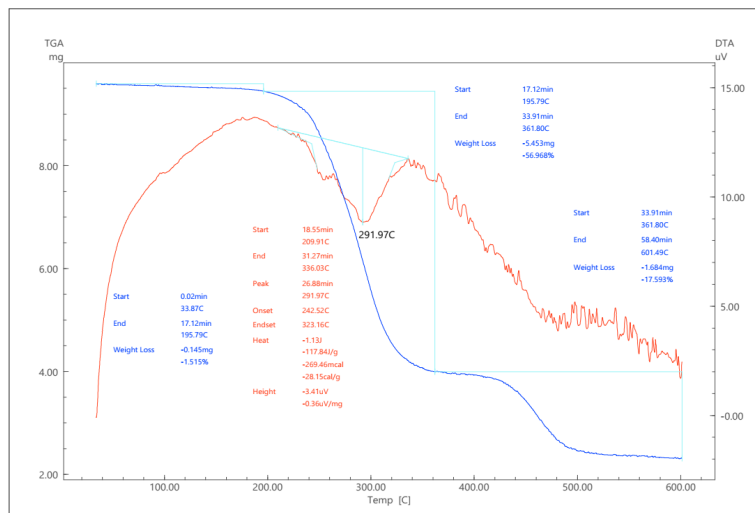


Fig. 1. Derivatogram of biodegradable polyvinyl chloride compositions with 30.0 wt.% dioctyl phthalate and 5.0 wt.% starch.

Analysis of the results of the study (Figure 1 and Table 1) shows that the weight loss of PVC compositions begins at a temperature of 50 °C and is 0.725 wt.%. The weight loss increases with increasing temperature. For example, at 200 °C; 300 °C; 400 °C; 500 °C and 600 °C, the mass loss is 6.251; 45.35; 53.85; 68.49 and 74.97 wt.%, respectively.

Table 1. The results of the analysis of the DTA curves of polyvinyl chloride compositions with different concentrations of modified rice starch.

№	Temperature, °C	Weight loss, %				
		PVC+30.0 mass, % DOP	PVC+30.0 mass.% DOP and 5.0 mass. % starch	PVC+30.0 mass.% DOP and 10.0 mass. % starch	PVC+30.0 mass.% DOP and 15.0 mass. % starch	PVC+30.0 mass.% DOP and 20.0 mass. % starch
1	50	0.652	0.725	0.841	0.922	0.978
2	100	1.885	2.985	3.285	3.985	4.185
3	150	3.251	4.112	4.984	5.124	6.695
4	200	5.981	6.251	7.651	8.751	9.215
5	250	22.55	23.41	24.22	25.65	26.87
6	300	32.35	45.35	46.35	47.25	50.35
7	350	44.89	46.85	47.21	48.32	49.55
8	400	52.85	53.85	54.52	55.85	56.87
9	450	64.52	65.32	66.78	68.25	69.87
10	500	67.49	68.49	69.49	70.54	72.32
11	550	69.12	70.12	71.45	73.87	74.12
12	600	73.33	74.97	76.42	77.12	78.88

An analysis of the results of the study of DTGA curves in Figure 1 shows that the curve consists mainly of two sigmoids, which occur in two stages in the process. The first stage occurs in the temperature range from 208 °C to 326 °C, with a mass loss of 45.09 %. The second stage occurs in the temperature range from 326 °C to 500 °C, with a mass loss of 71.49 %.

Intensive decomposition of polymers mainly occurs after 200 °C and reaches a maximum at 500-600 °C, while the mass loss is 78.88 wt.%.

Analysis of the results of the study of DTGA curves of polyvinyl chloride compositions with different starch concentrations (Figure 1, Figure 2, Table 1) it is shown that with an increase in starch concentration, the thermal stability of PVC compositions decreases. For example, at 300 °C, the starch concentration is 5.0; 10.0; 15.0 and 20.0 wt.% in PVC, the weight loss is 45.35; 46.35; 47.25 and 50.35 wt.%, respectively.

The decomposition rate of polyvinyl chloride compositions with different concentrations of modified starch was also calculated according to the DTGA curves, the results of which are shown in Table 2.

Analysis of the results of the study (Table 2) shows that with increasing starch concentration, the decomposition rate of the compositions increases. For example, at 200 °C, the decomposition rate at concentrations in the composition of PVC is 5.0; 10.0; 15.0 and 20.0 wt.% starch, the decomposition rate is 1.125; 1.235; 1.325; 1.452 and 1.652 mg/min, respectively.

Table 2. The change in the decomposition rate of polyvinyl chloride compositions from the starch concentration.

№	Temperature, °C	Decomposition rate, mg/min				
		PVC+30,0 mass. % DOP	PVC+30,0 mass.% DOP and 5,0 mass. % starch	PVC+30,0 mass.% DOP and 10,0 mass. % starch	PVC+30,0 mass.% DOP and 15,0 mass. % starch	PVC+30,0 mass.% DOP and 20,0 mass.% starch
1	50	0.610	0.720	0.880	0.887	0.912
2	100	1.630	1.741	1.744	1.812	1.978
3	150	1.985	1.998	2.085	2.120	2.256
4	200	1.125	1.235	1.325	1.452	1.652
5	250	4.298	4.320	4.452	4.652	4.874
6	300	4.620	4.780	4.895	4.925	5.122
7	350	2.984	3.084	3.112	3.210	3.320
8	400	4.652	4.874	4.987	5.052	5.252
9	450	3.985	4.185	4.201	4.385	4.442
10	500	2.201	2.402	2.625	2.874	2.997
11	550	1.582	1.687	1.784	1.874	1.987
12	600	1.489	1.562	1.632	1.787	1.987

But with increasing temperature, the decomposition rate of polyvinyl chloride compositions changes extremely (Table 2). For example, at a starch concentration of 5.0 wt.% and temperatures of 150 °C, 250 °C, 350 °C, 450 °C, 550 °C, the decomposition rate is

1.998; 4.320; 3.084; 4.185 and 1.687 mg/min, respectively. This is due to the decomposition of polyvinyl chloride itself in different stages of polymer oxidation.

The amount of energy consumed ($\mu\text{V}^*\text{s}/\text{mg}$) for the decomposition of a PVC polymer composition with dioctyl phthalate and with various concentrations of modified starch was also studied using the differential thermal analysis curve (DTA), the results of which are shown in Table 3.

Table 3. The results of the analysis of the amount of energy consumed by the DTA curves of polyvinyl chloride compositions with different concentrations of modified starch.

№	Temperature, °C	The amount of energy consumed ($\mu\text{V}^*\text{s}/\text{mg}$)				
		PVC+30.0 mass. % DOP	PVC+30.0 mass.% DOP and 5.0 mass. % starch	PVC+30.0 mass.% DOP and 10.0 mass. % starch	PVC+30.0 mass.% DOP and 15.0 mass. % starch	PVC+30.0 mass.% DOP and 20.0 mass. % starch
1	50	1.05	1.10	1.13	1.17	1.21
2	100	1.65	1.77	1.81	1.95	1.99
3	150	2.12	2.21	2.23	2.36	2.45
4	200	3.44	3.85	3.88	3.97	4.02
5	250	3.98	4.18	4.23	4.45	4.66
6	300	4.15	4.59	4.65	4.77	4.87
7	350	3.45	3.81	3.87	3.92	3.99
8	400	3.33	3.85	3.92	4.03	4.12
9	450	4.65	4.99	5.09	5.17	5.32
10	500	4.78	5.01	5.13	5.32	5.45
11	550	1.98	2.14	2.22	2.36	2.44
12	600	1.78	1.98	2.02	2.22	2.35

Analysis of the results of the study (Table 3) shows that PVC compositions containing 30.0 wt.% dioctyl phthalate require more energy consumption ($\mu\text{V}^*\text{s}/\text{mg}$) for polymer decomposition than the original PVC. For example, for the composition of the initial PVC at temperatures of 200; 300; 400; 500 and 600 °C, the amount of energy consumed for the decomposition of polymer compositions is 7.02; 8.15; 7.75; 5.86 and 9.77 $\mu\text{V}^*\text{s}/\text{mg}$, respectively. And for PVC compositions containing 30.0 wt.% dioctyl phthalate, the amount of energy consumed for the decomposition of polymer compositions is at temperatures of 200; 300; 400; 500 and 600 °C 3.44; 4.15; 3.33; 4.78 and 1.78 $\mu\text{V}^*\text{s}/\text{mg}$ (Table 3), respectively. This means that plasticized samples will require less energy to decompose the polymer than the original PVC.

Analysis of the results of the study (Table 3) shows that with an increase in the starch content in the composition, the amount of energy consumed ($\mu\text{V}^*\text{s}/\text{mg}$) for the decomposition of polymers increases.

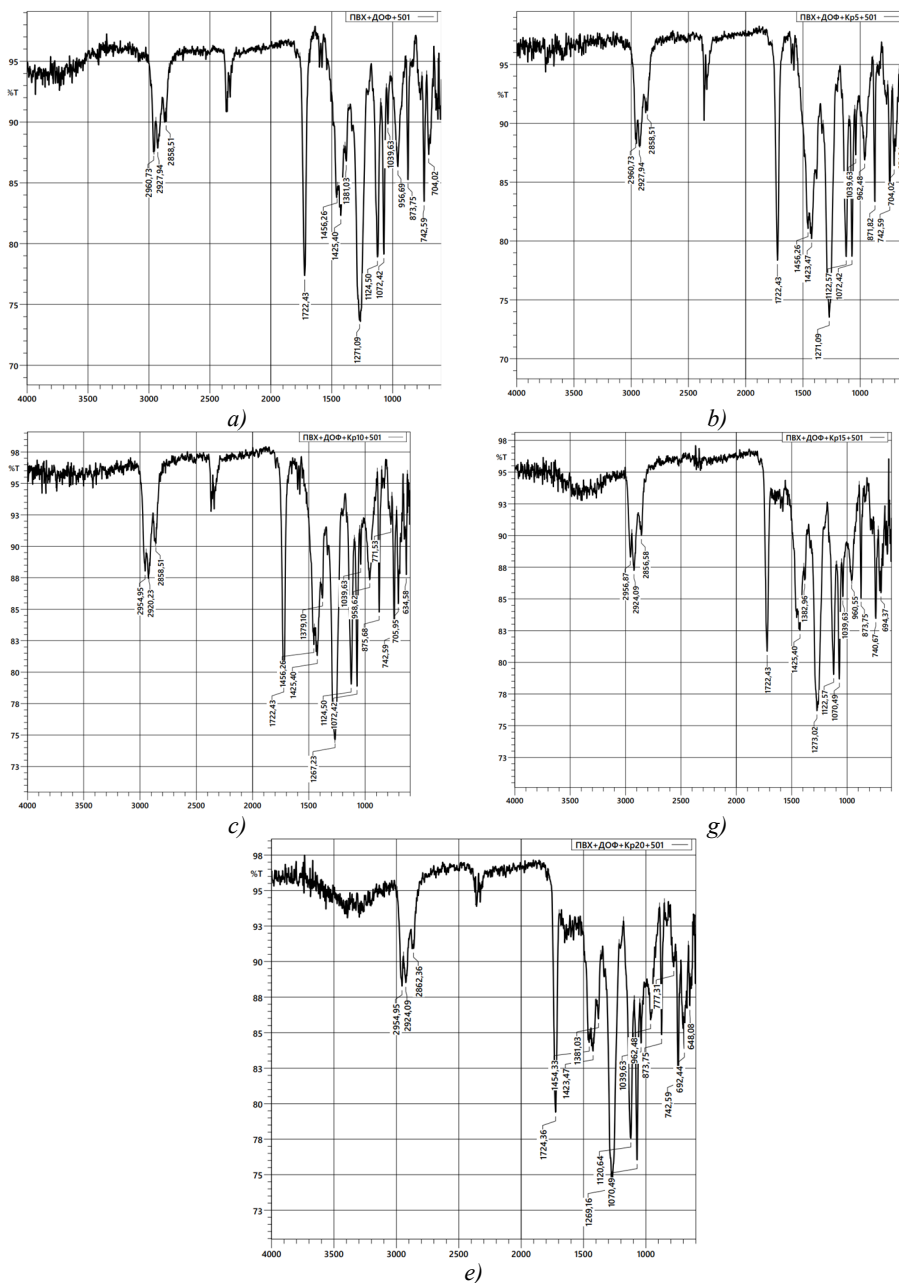


Fig. 2. IR spectra of compositions: a) plasticized PVC with DOF; b) plasticized with DOF PVC with 5.0 wt.% modified starch; c) plasticized with DOF PVC with 10.0 wt.% modified starch; g) plasticized with DOF PVC with 15.0 wt.% modified starch; e) plasticized with DOF PVC with 20.0 wt.% modified starch after being in the ground from 50 wt.% of manure and 50 wt.% soil.

Thus, based on the results of the study, it was established that the soil composition affects the biodegradation of polymer materials. It was determined that with an increase in the content of manure waste in the soil composition, the process of biodegradation of polyvinyl chloride increases.

The structure of biodegradable PVC compositions was also studied by IR spectroscopic method, the results of which are shown in Figure 2.

It is known that the biodegradation of polymer and polymer composite materials depends on many factors, such as temperature, soil composition and others.

For example, at 200 °C with starch concentrations of 5.0; 10.0; 15.0 and 20.0 wt.% of the PVC composition, the amount of energy consumed ($\mu\text{V}\cdot\text{s}/\text{mg}$) for the decomposition of polymers is 3.85; 3.88; 3.97 and 4.02 ($\mu\text{V}\cdot\text{s}/\text{mg}$), respectively. This is apparently due to increased intermolecular interactions between starch molecules and polyvinyl chloride macromolecules.

Analysis of the infrared spectrum of starch, absorption bands were observed in the following areas: 2926 cm^{-1} (CH_2), 1460 cm^{-1} ($-\text{CH}_2-$), 1340 cm^{-1} ($-\text{CH}$), $1020-960\text{ cm}^{-1}$ – cyclic compounds; 750 cm^{-1} ($-\text{CH}_2$)₄, 1660 cm^{-1} ($-\text{C}=\text{C}-$). In the area of 3420 cm^{-1} , low-intensity absorption bands belonging to the -OH group are observed.

Analysis of the IR spectra of plasticized PVC compositions with DOF, absorption bands were clearly observed in the regions of $3400-3600\text{ cm}^{-1}$, proving the formation of hydrogen bonds in groups in the form of $-\text{OH}\dots\text{H}$ and $-\text{OH}\dots\text{Cl}$. Absorption bands related to valence vibrations $-\text{CH}_2$ and $-\text{CH}_2$ and valence vibrations of the CH group - in the region of absorption bands $3030-2800\text{ cm}^{-1}$ were also observed. An intense absorption band was observed in the PVC spectrum, the maximum absorption band was 1637 cm^{-1} , in the region of $1618-1670\text{ cm}^{-1}$. It can be assumed that they relate to the double bonds of trans-vinylenes. Deformation vibrations confirming them are the formed absorption bands in the region of 950 cm^{-1} related to C-H bonds on irregularities.

Absorption bands related to the C-Cl bond were detected in the areas of 1500 cm^{-1} , 825 cm^{-1} and 668 cm^{-1} .

A comparative analysis of the IR spectra of PVC samples with starch in various soil conditions allowed us to assess the influence of the medium on the degree and rate of biodegradation of the material. With an increase in the proportion of manure from 50% to 90%, the following dynamics is observed:

1. The shift of the absorption band associated with alkyl groups C-H (approx. 2956 , 2927 and 2875 cm^{-1} in the initial composition) indicates changes in the alkyl chain, possibly due to oxidative processes or interaction with soil components.
2. The absorption bands at 1722.43 cm^{-1} corresponding to the C=O bond are preserved under all conditions, which may indicate the stability of this functional group in the process under study.
3. Changes in the intensity and position of the absorption band associated with aromatic bonds C=C (approx. 1643 , 1541 and 1458 cm^{-1}) may indicate the degradation of these structures in the soil environment.
4. Deformation absorption bands of C-H in alkyl groups (approx. 1421 , 1381 and 1274 cm^{-1}) and absorption bands of stretching of the C-O-C bond indicate the presence of ether structures that can also be modified during biodegradation.
5. The presence of the absorption band of deformation-related C-Cl bonds (approx. 873 and 738 cm^{-1}) in all samples confirms the presence of chlorinated compounds, however, their intensity and position change, which may indicate partial cleavage of chlorine and degradation of PVC during interaction with soil components and biomass.
6. A change in the absorption bands of C-O ether groups (approx. 1072 and 1037 cm^{-1}) in the spectra indicates a change in the content and structure of ether bonds during biodegradation.

From the data obtained, it can be seen that the introduction of cow manure into the soil affects the rate and nature of biodegradation of PVC composites with starch. A higher organic

content (50% ratio) accelerates the processes of biodegradation, as evidenced by a change in the intensity and position of the characteristic absorption bands in the IR spectra.

Based on the comparative analysis of IR spectra for PVC composites with 15% starch content in various soil conditions with the addition of cow manure, the following conclusions can be drawn:

1. The state of alkyl groups: the observed changes in the absorption bands corresponding to the stretching of the C-H bonds of alkyl groups indicate oxidation processes and modification of alkyl chains during biodegradation.
2. Stability of carbonyl groups: the constancy of the absorption band at 1722.43 cm^{-1} under all conditions indicates the stability of carbonyl groups (C=O) under the studied conditions, which may be important for understanding the mechanisms of decomposition of PVC.
3. Degradation of aromatic structures: changes in absorption bands associated with aromatic C=C bonds may indicate degradation processes of these structures, which may be induced by bioactivity in the soil.
4. Effect on ether bonds: a change in the absorption bands associated with the C-O-C and C-O ether bonds confirms that these structures undergo changes during biodegradation, which may contribute to the rupture of the polymer chain.
5. The presence and change of chlorinated compounds: changes in the intensity and position of the absorption bands associated with the deformation of C-Cl bonds indicate possible chlorine cleavage reactions and changes in chlorine-containing PVC components.
6. The rate of biodegradation: an increase in the content of organic matter with a content of 50wt.% of manure and 50wt.% of the soil compared to 10wt.% of manure and 90wt.% of the soil contributes to a more intensive biodegradation process, which is reflected in a change in spectral characteristics.

It is known that the content of the modifier necessarily affects the physico-mechanical properties of polymer materials for the developed PVC compositions. Therefore, the study of the physico-mechanical properties of PVC compositions from the content of the modifier is an urgent task.

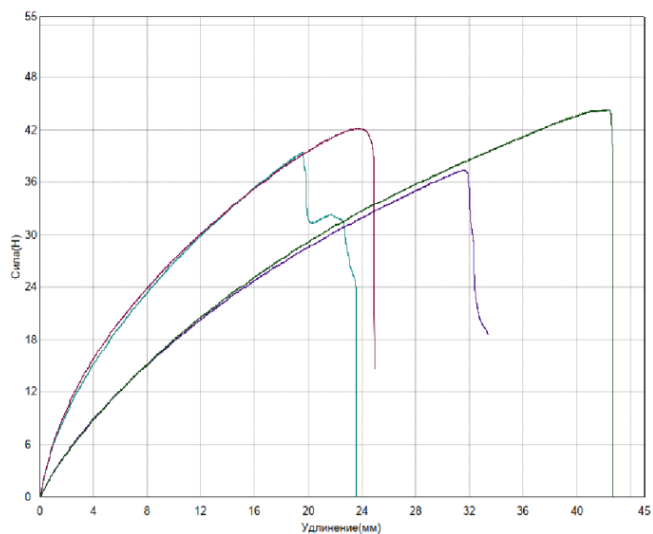


Fig. 3. Diagram of the dependence "deformation-elongation" of biodegradable compositions of PVC films: 1-PVC+5.0 wt.% modified starch.; 2-PVC+10.0 wt.% modified starch.

The physical and mechanical properties of PVC compositions before and after the biodegradation test were investigated. The results of the comparison of analyses of the mechanical parameters of biodegradable PVC film compositions from the starch content and from the nature of the soil environment, and at different exposure times are shown in Figure 3 – Figure 5. It was determined that with an increase in the concentration of modified starch and an increase in time, the tensile strength and elongation at break decrease.

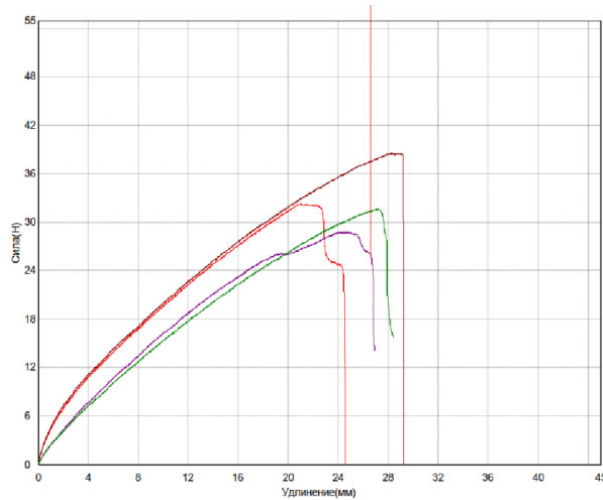


Fig. 4. Diagram of the dependence "deformation-elongation" of biodegradable compositions of PVC films: 1-PVC+15.0 wt.% modified starch.; 2-PVC+20.0 wt.% modified starch.

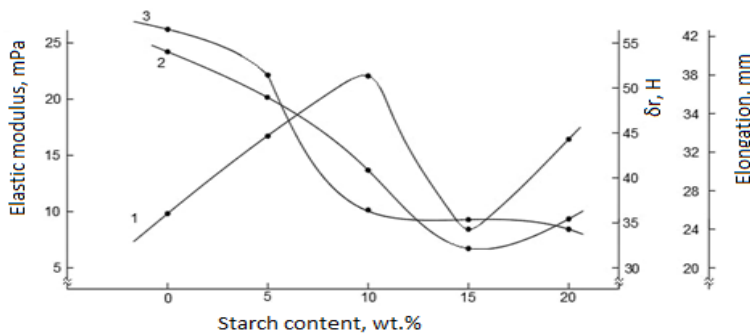


Fig. 5. Changes in the mechanical parameters of biodegradable PVC film compositions from the starch content after 6 months of exposure in the soil (soil composition: 50.0 wt.% sand and 50.0 wt.% manure): 1- tensile modulus of elasticity, 2-tensile strength, 3- elongation at break.

Thus, by selecting the composition of the soil and the holding time, the rate and degree of biodegradation of polyvinyl chloride can be adjusted.

The study of the surface of PVC film with modified rice starch is an urgent task. The surface of the PVC composition was examined with a scanning electron microscope, the results of which are shown in Figure 6, 7.

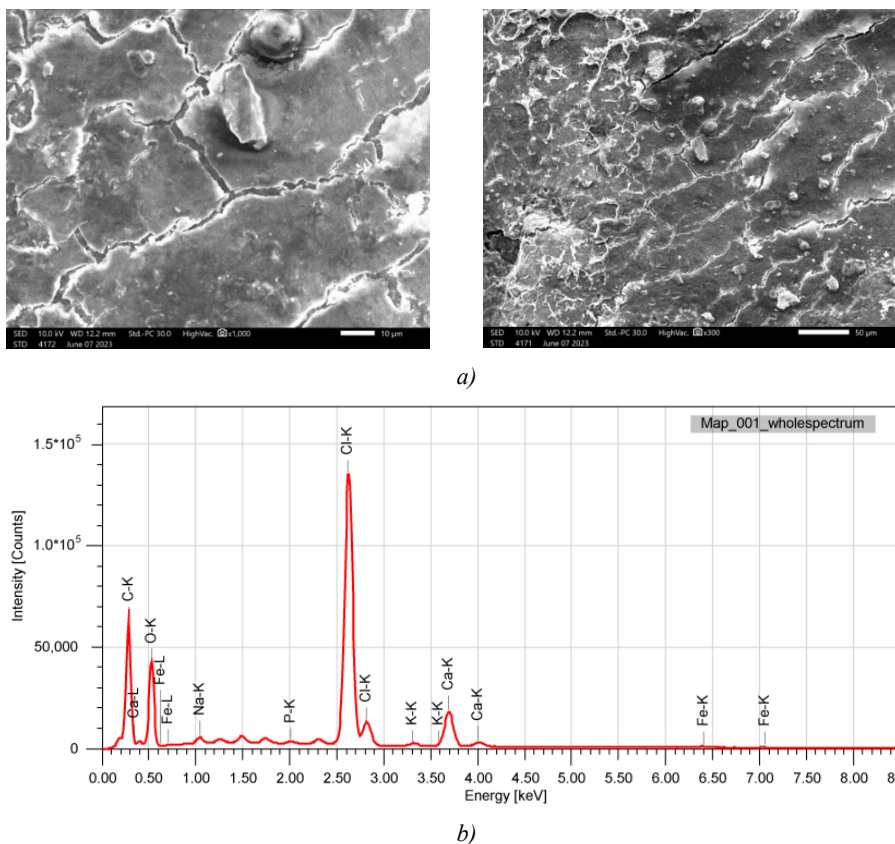


Fig. 6. Surface image (a) and semi-quantitative elemental composition of the surface (b) of plasticized PVC with a DOF of 30 wt.% with the addition of 10 wt.% modified rice starch before biodegradation.

The PVC composition mainly consists of carbon (C) 54.49%, oxygen (O) 25.18%, chlorine (Cl) 22.04% by weight and other elements in small amounts such as sodium (Na), phosphorus (P), potassium (K), calcium (Ca) and iron (Fe).

The surfaces of modified plasticized PVC with UP to 30 wt.% were also studied with the addition of 10 wt.% of modified rice starch after biodegradation, the results of which are shown in Figure 7.

An elemental analysis of the results of the study (Figure 7) shows that plasticized PVC with a DOF of 30 wt.% with the addition of 10 wt.% of modified rice starch after biodegradation mainly consists of carbon (C) 58.45%, oxygen (O) 16.63%, chlorine (Cl) 16.23% by weight, as well as magnesium (Mg) and calcium (Ca) in smaller amounts.

Comparing the results of the analysis before and after the biodegradation of PVC compositions, it was determined that the carbon (C) content increases, the chlorine (Cl) content decreases, and the oxygen content remains almost unchanged. Other elements such as magnesium (Mg) and calcium (Ca) are present only in the second composite after biodegradation.

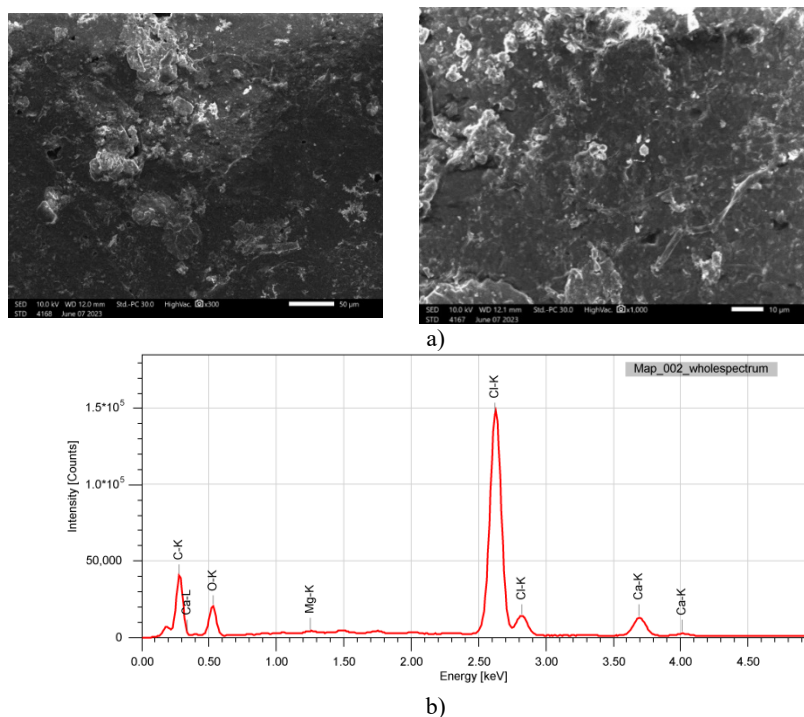


Fig.7. Surface image (a) and semi-quantitative elemental composition of the surface (b) of plasticized PVC with a DOF of 30 wt.% with the addition of 10 wt.% modified rice starch after biodegradation.

These data indicate possible chemical changes occurring in the composition after biodegradation. The increase in the amount of carbon is explained by an increase in the number of microorganisms on the surface, and a decrease in chlorine and the appearance of magnesium and calcium indicate the process of vital activity of microorganisms after biodegradation.

We also examined the surface of the films and assessed the degree of biodegradation before and after 6 months of exposure in soil with a different composition of the composition of plasticized PVC with a DOF of 30 wt.% with different starch content. The results of the investigation and assessment of the biopreimage of the surface of films of samples of PVC compositions on an electron microscope are shown in Table 4-5.

Table 4. Table of visual assessment of the degree of biodegradation before and after 6 months of exposure in the ground.

Composition of the composition	Soil	Soil 50 mass.% + 50 mass.% manure	Soil 10 mass.% + 90 mass.% manure
PVC+DOP			

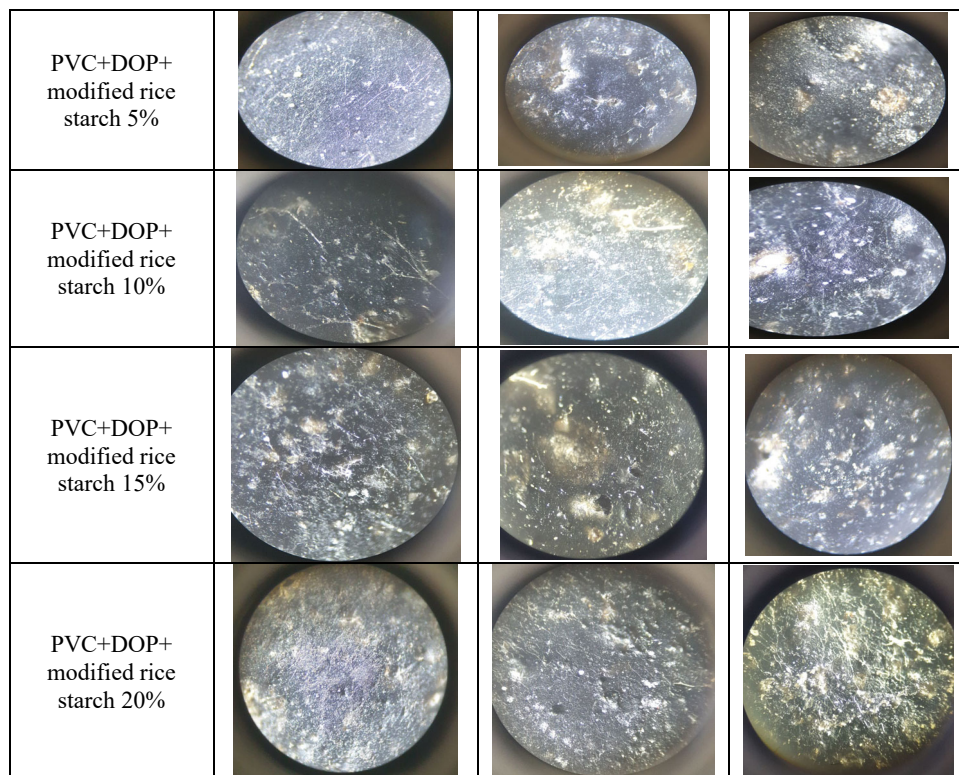


Table 5. Assessment of bio-damage of PVC-based composite materials.

№	Material	Rating, point			
		7 days	30 days	90 days	190 days
1	100% PVC	0	0	0	0
2	90% PVC + 10% modified rice starch	0	1	1	2
3	85% PVC + 15% modified rice starch	1	2	2	3
4	80% PVC + 20% modified rice starch	1	2	3	3

The compositions we obtained were buried in a mixture of soil + manure for a period of 1 month, 3 months, 6 months. Using a microscope, we found that microorganisms multiply over time on parts of the surface of the polymer film of our compositions. In Table 4. below, we have shown as examples our compositions compared with each other over 6 months.

Where, 3 points is the average growth of colonies of microorganisms (from 30% to 60% of the sample area); 2 points - a slight increase (from 10% to 30% of the sample area); 1 point - traces of microorganisms (less than 10% of the sample area is affected); 0 points - absence of microorganisms on the surface of the sample.

It should be particularly noted that the biodegradation index of pure PVC does not change throughout the entire research period. The bio-damage of the composition after 180 days is in the range of 30-60%. Thus, by adjusting the content of modified starch, cow manure and soil, the rate of biodegradation of PVC can be adjusted.

4 Conclusion

The thermal stability of polyvinyl chloride compositions with modified rice starch before and after biodegradation by the derivatographic method has been studied. The loss of mass, the rate of decomposition and the amount of energy consumed for the decomposition of PVC and its compositions are determined. It has been established that the thermal stability of PVC compositions depends on the composition of the soil and on the starch content.

It was determined that the introduction of cow manure into the soil enhances the biodegradation of PVC composites with starch, leading to a change in the chemical structure of the material. This leads to the conclusion that organically modified soil can be used to accelerate the process of biodegradation of polymer materials, which opens up new prospects for environmental management of PVC waste.

IR spectral analysis showed that data from the composition of soil with 50% manure indicates significant dechlorination. While at a ratio of 90% of manure, the changes were insignificant.

The mechanical properties of biodegradable PVC-based compositions with starch addition have been studied and it has been shown that the integration of a biopolymer into a polymer matrix is an effective way to improve the biodegradation of materials while simultaneously controlling their mechanical characteristics. The introduction of starch leads to changes in the tensile strength, toughness and elasticity of the composite, which opens up opportunities for optimizing their use in various fields where biodegradable materials with specific mechanical properties are required. Thus, the data obtained make a significant contribution to the development of a new generation of environmentally friendly polymer materials for sustainable development and minimizing the environmental impact of plastic waste.

Tensile tests showed that samples in an environment with 50% manure showed a significant decrease in tensile strength. There is a clear tendency to decrease the tensile strength to 40%.

The SEM analysis showed that there was a distinct colonization of microorganisms, and in samples in an environment with 50% manure, the growth of microorganisms was significantly higher.

The environmental problem of PVC can find an ally in organic-enriched soils. Despite the deepening of our understanding, the study of the action of microorganisms and environmental enrichment, for example, due to cow manure, opens up prospects for the development of sustainable PVC recycling strategies.

The data obtained confirm the important role of organic matter (cow manure) in the degradation of PVC, which may contribute to the development of populations of microbes capable of degradation of PVC.

References

1. A.A. Shah, F. Hasan, A. Hameed, S. Ahmed, *Biotechnology Advances* **26(3)**, 246-265 (2008)
2. P. Ramesh et al., *Journal of Polymers and the Environment* **27(10)**, 2121-2132 (2019)
3. D.T. Akhtamov, Kh.M. Vapoev, Kh.S. Beknazarov, *Universum: Technical Sciences* **2**, 24-29 (2021)
4. A.T. Jalilov, B.F. Mukhiddinov, A.G. Makhsumov, *Reports of the Academy of Sciences of the Republic of Uzbekistan* **5**, 40-45 (2022)
5. J.I. Arutchelvi et al., *Journal of Polymers and the Environment* **16(4)**, 286-289 (2008)

6. D.T. Akhtamov, A.T. Jalilov, A.G. Makhsumov, L.I. Tilavova, *Chemistry and Chemical Technology of Uzbekistan* **3**, 38-45 (2022)
7. B.F. Mukhiddinov, A.G. Makhsumov, S.Sh. Sharipov, *Universum: Chemistry and biology* **3**, 24-29 (2022)
8. D.T. Akhtamov, B.F. Mukhiddinov, Kh.M. Vapoev, S.Sh. Sharipov, *Universum: Chemistry and biology* **1**, 52-62 (2023)
9. B.F. Mukhiddinov, S.S. Negmatov, L.I. Tilavova, *Universum: Technical sciences* **11-4 (92)**, 24-28 (2021)
10. V.A. Burmistrov, S.A. Kuvshinova, O.I. Koifman, *Russ. Chem. Rev.* **85(2)**, 156-171 (2016)
11. E.R. Galimov, *Naberezhnye Chelny: Kazan (Volga Region) Federal University* (2012)
12. J. Hopewell et al., *Philosophical Transactions of the Royal Society B: Biological Sciences* **364(1526)**, 2115-2126 (2009)
13. E. Chiellini, A. Corti, S. D'Antone, *Progress in Polymer Science* **32(8-9)**, 877-890 (2007)
14. B. Gewert et al., *Environmental Science & Technology* **49(19)**, 11557-11564 (2015)
15. V.M. Pathak, Navneet, *Bioresources and Bioprocessing* **4(1)**, 15 (2017)