Thermal, Mechanical, and Biodegradation Properties of Polylactide/Hemp Fibre Composites

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Abstract

Biodegradable composites based on polylactide (PLA) and industrial hemp fibres were prepared by melt processing in a co-rotating twin-screw extruder and characterised in terms of their thermomechanical and biodegradation behaviour. Composites containing 5, 10, 20, and 30 wt.% hemp were produced and investigated using thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), scanning electron microscopy (SEM), tensile testing, melt flow rate (MFR) determination, and soil burial biodegradation tests conducted over 60 days.

TGA results showed that the addition of hemp decreased the thermal stability of the composites, shifting the onset of degradation to lower temperatures. DSC analysis revealed that hemp fibres acted as nucleating agents, promoting heterogeneous nucleation and inducing melting–recrystallisation phenomena, resulting in the appearance of a double melting peak. SEM micrographs indicated good dispersion and acceptable interfacial adhesion at lower hemp loadings (≤ 10 wt.%), while higher loadings led to agglomeration, void formation, and phase separation. Tensile strength and elongation at break decreased progressively with increasing hemp content, while the tensile modulus showed a modest improvement up to 10 wt.% hemp. Notably, the melt flow rate increased significantly with hemp loading. This unusually high increase in melt flow rate at elevated hemp contents may suggest partial degradation of the PLA matrix during processing. Biodegradation tests demonstrated that higher hemp content accelerated mass loss in soil.

The results indicate that PLA/hemp biodegradable composites with a favourable balance of thermal, mechanical, and processing properties can be obtained at hemp loadings of up to 10 wt.%, making them promising sustainable materials.

Keywords

Polylactide, PLA, industrial hemp, biodegradable composites, thermomechanical properties, biodegradation

1 Introduction

Polymeric materials have become indispensable in modern society due to their versatile mechanical and thermal properties, low density, and ease of processing. They are widely used in various industries, including packaging, automotive, construction, and biomedicine. However, the extensive use of conventional petroleum-based plastics has raised serious environmental concerns, primarily due to their persistence in the environment and contribution to microplastic pollution.[1] This has accelerated global efforts towards the development of sustainable, biodegradable alternatives derived from renewable resources.

Polylactide (PLA), a biodegradable aliphatic polyester produced from renewable feedstocks such as corn starch, sugarcane, or other fermentable sugars, has emerged as one of the most promising biopolymers.[2,3] PLA offers good biocompatibility, high strength, and transparency, making it suitable for packaging, 3D printing, disposable items, and biomedical applications.[4–7] Despite these advantages, PLA has certain limitations, including brittleness at room temperature, relatively low heat distortion temperature, and slow biodegradation rate under ambient conditions.[8–10]

To overcome these drawbacks and enhance overall performance while maintaining biodegradability, PLA is frequently reinforced with natural fibres or fillers.[11,12] Industrial hemp (Cannabis sativa) fibres have attracted considerable attention as a sustainable reinforcement due to their high cellulose content, excellent specific strength and stiffness, low density, renewability, and low cost.[13–16]

Nevertheless, incorporating natural fibres, such as hemp, into PLA matrices presents challenges, including poor interfacial adhesion between hydrophilic fibres and the hydrophobic polymer, fibre agglomeration, and reduced thermal stability.[17,18] These issues can significantly affect the

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final properties of the composites and limit their industrial applicability.

This study focuses on the preparation and comprehensive characterisation of biodegradable PLA/hemp composites containing 5, 10, 20, and 30 wt.% ground industrial hemp. The composites were produced by twin-screw extrusion and the influence of hemp content on thermal stability, crystallisation behaviour, morphology, rheological and mechanical properties, as well as soil biodegradation, was systematically investigated. The aim was to determine the optimal hemp ratio that provides a favourable balance between processability, mechanical performance, and biodegradability for potential industrial applications. Although numerous studies have investigated PLA/natural fibre composites, most have focused on only selected properties. This study provides insight into the combined influence of high loadings of finely ground hemp particles processed by twin-screw extrusion on thermal degradation, melt flow behaviour, and biodegradation.

2 Experimental

2.1 Materials and preparation of PLA/hemp composites

The composites were prepared using polylactide (PLA) supplied by Luminy (LX175, MFR 6 g 10 min^{-1} (2.16 kg/210 °C), 96 % L-isomer), and hemp fibres obtained from a local grower in Croatia. The hemp stems were collected as agricultural waste after harvesting the seeds and flowers. The hemp fibres were obtained irregularly ground with a broad particle-size distribution and maximum particle size of approximately 3 mm. The composites were prepared by melt blending using a Rondol Top Bench 21 co-rotating twin screw extruder. The temperature profile in the extruder was set to 160/175/185/195/200/190 °C (from hopper to die), and the screw rotation speed was set to 30 rpm. The compositions of the studied composites are listed in Table 1.

Table 1 – Sample composition
Tablica 1 – Sastav uzoraka

Sample Uzorak	*w*(PLA) / %	*w*(hemp) / %
PLA	100	0
PLA_H5	95	5
PLA_H10	90	10
PLA_H20	80	20
PLA_H30	70	30

Preliminary experiments showed that the hemp fibres required further grinding to a particle size below 100 μm to enable successful extrusion. Therefore, they were ground using an IKA-Werke M20 laboratory mill and subsequently sieved using a Retsch AS200 sieve-shaker to obtain the desired particle size. Prior to extrusion, both the PLA and the hemp fibres were dried at 60 °C for 24 h to remove residual moisture. No additional fibre modification was performed in order to determine the pure effect of different hemp loadings on the properties of the composites.

2.2 Thermal properties

Thermogravimetric analysis (TGA) of the composites was carried out using a TA Instruments Q500 thermogravimetric analyser over the temperature range of 25–600 °C at heating rate of 10 °C min^{-1}. Nitrogen was used as the carrier gas at a constant flow rate of 60 ml min^{-1} throughout the analysis. Differential scanning calorimetry (DSC) was performed using a Mettler-Toledo DSC 3 calorimeter to evaluate the thermal properties of the composites. Polymer samples weighting 5 mg were placed in aluminium pans and heated from 25 to 200 °C at a standard heating/cooling rate of 10 °C min^{-1} under the nitrogen stream with a constant flow rate of 100 ml min^{-1}. The glass transition temperature (T_g), cold crystallisation temperature (T_{cc}), melting point (T_m), and melting enthalpy (ΔH_m) were determined in the second heating cycle. Proprietary Mettler Toledo STARe software was used for DSC analysis. T_g was determined as midpoint, whereas T_m and T_{cc} were determined as peak values.

2.3 Tensile properties

The tensile properties of the PLA/hemp composites were evaluated using a Shimadzu AGS-X in accordance with ISO 527-3 standard for films and sheets. The gauge length was 40 mm, while the crosshead speed was set at 10 mm min^{-1}. Test samples were prepared by hydraulic pressing of the composites at 190 °C for 5 min at 10 MPa in rectangular (10 × 10 × 0.1) cm moulds followed by cutting the final samples to dimensions of (10 × 1 × 0.1) cm. The results represent the average of five samples.

2.4 Morphology

Scanning electron microscopy (SEM) was utilised to examine the morphology of the cross-section of the PLA/hemp composites using a Tescan Vega 3 at 10 kV. The samples were sputter coated with Au/Pd prior to measurement.

2.5 Melt flow rate

Melt flow rate (MFR) of neat PLA and PLA/hemp composites was determined in accordance with ASTM D1238 using a piston load of 2.16 kg at a barrel temperature of 210 °C on a Davenport MFI machine.

2.6 Biodegradation

For the biodegradation test, samples of the same dimensions as those used for tensile testing were first weighed. They were then buried to a depth of 5 cm in a container filled with commercial gardening soil for 60 days. The container was maintained at room temperature (23 ± 2 °C) and watered twice a week. The burial depth was selected to ensure continuous contact between the samples and the surrounding soil while maintaining stable moisture conditions throughout the experiment. After 60 days, the samples were removed, washed, dried, and weighed again to determine mass loss. The test duration of 60 days was selected to enable comparison of the relative biodegradation behaviour of the investigated formulations within a practical laboratory timescale. No attempt was made to characterise the microbial population present in the commercial gardening soil.

3 Results and discussion

3.1 Thermal properties

TGA results are shown in Fig. 1 as thermogravimetric (TG) and differential thermogravimetric (DTG) curves, and in Table 2 as temperature at 5 % mass loss (T_{95}), temperature at maximum degradation rate (maximum of DTG curves – T_{max}), and solid residue at 600 °C. Neat PLA degraded in a single step between 330 and 380 °C, leaving a residue of 1.6 %, which is consistent with literature reports.[19] Hemp degraded in three stages. The first stage, corresponding to a mass loss of 4.9 % below 150 °C, can be attributed to the release of intrinsic water. The second and third degradation stages overlapped, exhibiting a "shoulder" at around 250 °C and a maximum at 310 °C, corresponding to the simultaneous degradation of cellulose, hemicellulose, and lignin.[8,13] The thermal degradation of hemp constituents resulted in the formation of highly thermally stable products, as evidenced by the residue after pyrolysis of 51 %.

The thermal stability of the PLA/hemp composites followed an almost regular trend of change, with both the onset of degradation (T_{95}) and the temperature of the maximum degradation rate (T_{max}) decreasing with increasing hemp ratio, while the residual mass increased. T_{95} decreased from 332.3 °C for neat PLA to 264.6 °C for the PLA_H30 composite; T_{max} decreased from 355.5 to 309.2 °C, while the residual mass increased from 1.6 to 16.5 %.

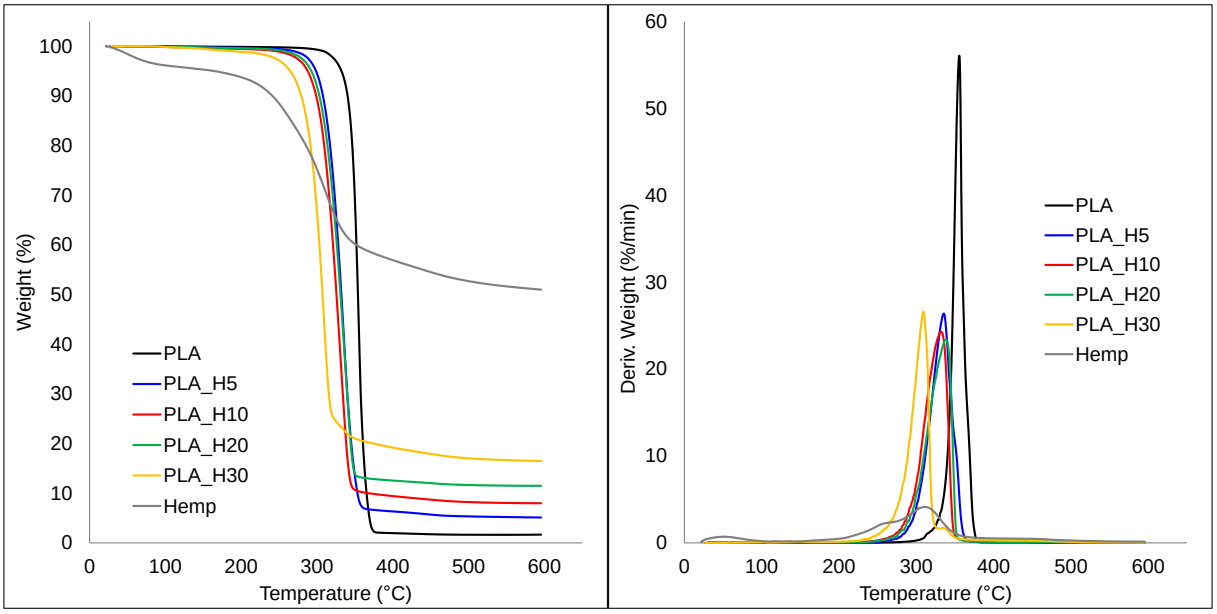


Fig. 1 – TGA scans of PLA/hemp composites; TG (left) and DTG curves (right)

Slika 1 – TGA termogrami kompozita PLA/konoplja; TG (lijevo) i DTG krivulje (desno)

Table 2 – Results of TG analysis
Tablica 2 – Rezultati TG analize

Sample Uzorak	Hemp	PLA	PLA_H5	PLA_H10	PLA_H20	PLA_H30
T_{95}/°C	164.3	332.3	298.7	287.8	292.5	264.6
T_{max}/°C	310.3	355.5	335.5	331.7	338.6	309.2
Residue/% Ostatak/%	51.0	1.6	5.1	8.0	11.5	16.5

The reduction in thermal stability of the composites is primarily associated with the lower degradation temperature of hemicellulose and lignin fractions present in hemp fibres. Their earlier thermal decomposition may have additionally catalysed degradation of the PLA matrix through the formation of volatile degradation products.[20]

The DSC results are shown in Fig. 2 as DSC scans from the second heating run, and in Table 3 as temperature of glass transition (T_g), enthalpy (ΔH_{cc}), and temperature (T_{cc}) of cold crystallisation, as well as melting enthalpy (ΔH_m) and melting temperature (T_m). The degree of crystallinity (X_c) was also calculated using Eq. (1), where ΔH_m° represents melting enthalpy of 100 % crystalline PLA (93.6 J g^{-1},[21]), and w represents weight fraction of the polymer in the composite.

$$\chi_c = \frac{\Delta H_m - \Delta H_{cc}}{\Delta H_m^\circ \times w} \cdot 100\% \qquad (1)$$

Neat PLA exhibited the highest glass transition temperature at 59.3 °C, while its corresponding composites showed a decrease in T_g with increasing hemp ratio, reaching 51.9 °C for PLA_H30. This behaviour can be attributed to several mechanisms. Since hemp fibres are highly hydrophilic due to the presence of hydroxyl groups, residual moisture in the fibres may vaporise during processing and act as a plasticiser for PLA, thereby decreasing T_g.[22] In addition, untreated hemp contains natural waxes, pectin, and lignin. At processing temperatures, some of these low-molecular-weight components may migrate into the PLA matrix and act as unintended plasticisers, increasing the free volume.[23] All samples exhibited a cold crystallisation peak in the range 110–120 °C. The PLA/hemp composites displayed higher cold crystallisation enthalpy (ΔH_{cc}) compared to neat PLA. This behaviour is attributed to the restriction of polymer chain organisation during cooling, followed by enhanced crystallisation upon reheating.[8]

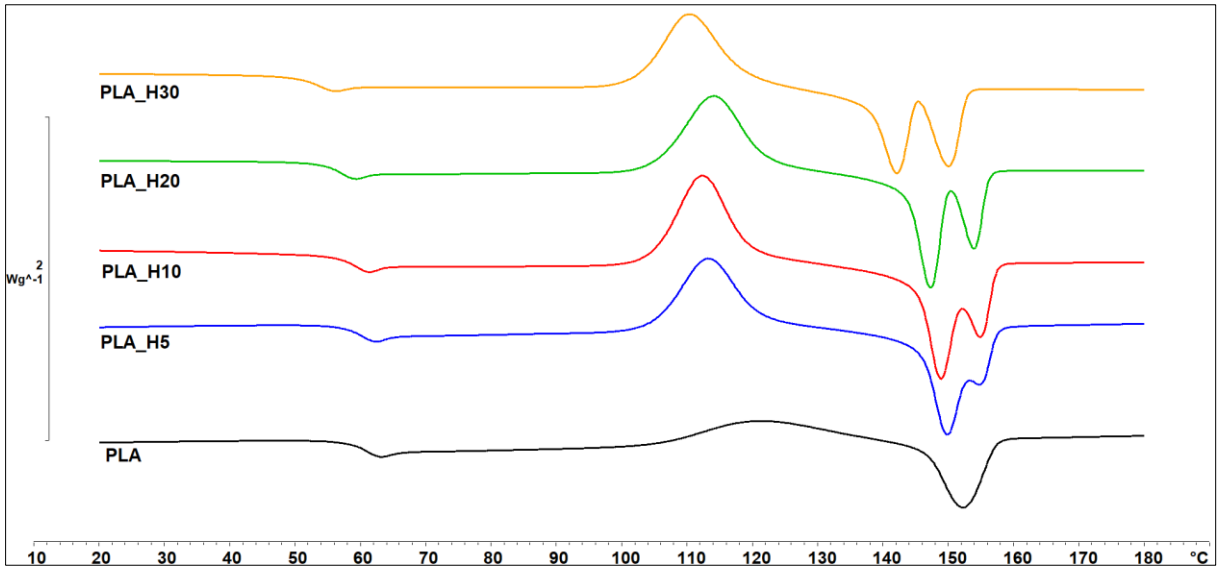


Fig. 2 – DSC scans of PLA/hemp composites
Slika 2 – DSC termogrami kompozita PLA/konoplja

Table 3 – Results of DSC analysis
Tablica 3 – Rezultati DSC analize

Sample Uzorak	PLA	PLA_H5	PLA_H10	PLA_H20	PLA_H30
T_g/°C	59.3	58.5	57.4	55.4	51.9
ΔH_{cc}/J g^{-1}	15.3	28.5	32.9	29.5	29.0
T_{cc}/°C	120.5	113.2	112.4	114.2	110.4
ΔH_m/J g^{-1}	18.3	32.5	35.5	32.8	30.5
T_m/°C	152.1	149.7	148.6	147.2	142.0
X_c/%	3.2	4.5	3.1	4.4	2.3

The rough surface of the natural fibres provides a physical substrate that lowers the energy barrier required for PLA to form crystal nuclei, and thus hemp fibres act as nucleating agents, promoting crystallisation. When the amorphous composite is heated above its glass transition temperature, the mobile PLA chains rapidly flock to the hemp fibre surfaces and crystallize, producing a large exothermic cold crystallisation peak.[24] The shift of cold crystallisation peak to a lower temperature in the composites compared to neat PLA (from 120.5 to 110.4 °C) is another strong indicator of the fibre's nucleating efficiency. Overall crystallinity remained low (2–5 %) since the formation of many new crystals during the cold crystallisation phase caused an increase in ΔH_m and the numerator in Eq. (1) ($\Delta H_m - \Delta H_{cc}$) remained small. This confirms that the hemp fibres did not induce substantial crystallisation of the composite during manufacturing; rather, they dramatically accelerated the ability of PLA to crystallise when reheated.[25] Neat PLA exhibited a single melting point at 152.1 °C, indicating a relatively uniform crystalline structure. In contrast, all PLA/hemp composites displayed two distinct melting peaks, indicating that the addition of hemp fibres led to heterogeneous nucleation. This double melting behaviour may indicate melting–recrystallisation phenomena, commonly observed in PLA-based composites with heterogeneous crystalline morphology.[26] Crystallites formed near the fibre surface tend to be smaller and less perfect, melting at lower temperatures, while those formed in the bulk matrix are larger and more developed causing them to melt at higher temperatures.[27]

3.2 Tensile properties

The results of tensile tests are shown in Fig. 3 and Table 4, including tensile strength, elongation at break, and tensile modulus. Neat PLA exhibited a tensile strength of 42.9 ± 2.2 MPa and an elongation at break of 3.2 ± 1.0 %, typical for brittle semi-crystalline polylactide.[8,18] The incorporation of hemp fibres led to a progressive decline in both tensile strength and elongation at break, indicating that the incorporation of hemp fibres reduced tensile performance of the composites. At low hemp loadings (5 wt.%), the tensile strength remained relatively high, but a reduction was observed with an increase in hemp ratio, reaching only 3.9 ± 0.1 MPa for PLA_H30. Similarly, the elongation at break decreased sharply with increasing filler content, indicating increased brittleness of the material.[28]

Table 4 – Results of tensile tests
Tablica 4 – Rezultati mehaničkih svojstava

Sample Uzorak	PLA	PLA_H5	PLA_H10	PLA_H20	PLA_H30
Tensile strength/MPa Rastezna čvrstoća/MPa	42.9 ± 2.2	40.1 ± 5.6	25.8 ± 2.2	6.5 ± 1.1	3.9 ± 0.1
Elongation at break/% Prekidno istezanje/%	3.2 ± 1.0	1.5 ± 0.3	0.8 ± 0.1	0.2 ± 0.1	0.4 ± 0.1
Elastic modulus/MPa Modul rastezljivosti/MPa	2748 ± 394	3007 ± 479	3273 ± 233	1945 ± 1463	N/A

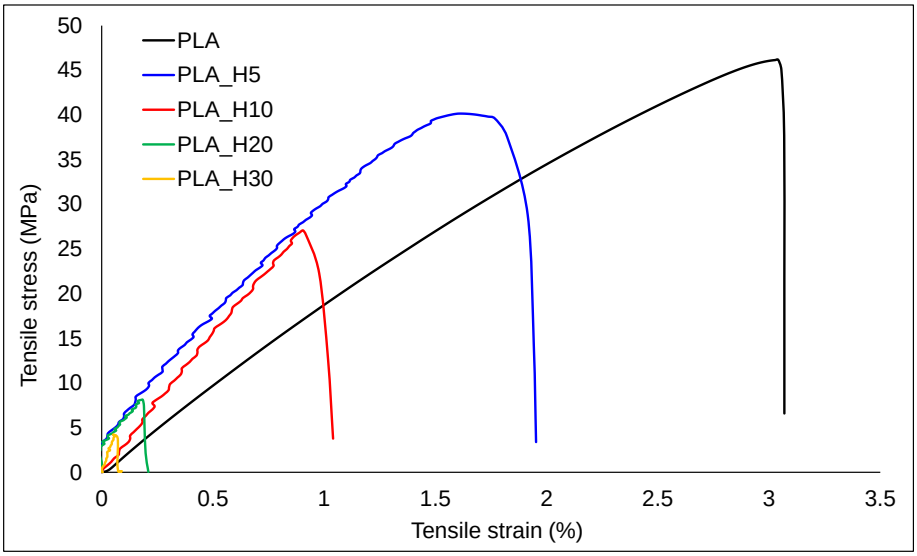


Fig. 3 – Stress-strain curves of PLA/hemp composites

Slika 3 – Krivulje naprezanje-istezanje kompozita PLA/konoplja

The tensile modulus showed a modest improvement at lower hemp loadings, reaching a maximum of 3273 ± 233 MPa at 10 wt. However, at higher loadings, the tensile modulus decreased and could not be reliably determined for PLA_H30 due to premature failure. Although hemp fibres possess inherently high stiffness, the expected reinforcing effect was limited due to insufficient stress transfer at the fibre–matrix interface, primarily caused by insufficient interfacial adhesion and particle agglomeration. At higher hemp loadings, agglomeration and void formation became dominant structural defects, outweighing any stiffening contribution of the fibres. Void formation and poor wetting of the fibres likely acted as stress concentration points, promoting premature crack initiation and brittle fracture.[8,28] Additionally, since hemp fibres release intrinsic moisture below 200 °C, as determined by the TGA results, and the samples used for mechanical testing were prepared by pressing at 190 °C, the evaporation of residual moisture may have induced the formation of small cavities, thereby further compromising the mechanical properties.

3.3 Morphology

SEM results are shown in Fig. 4 as micrographs of fractured surfaces of the PLA/hemp composites. The PLA_H5 and PLA_H10 composites displayed relatively smooth fracture surfaces with good dispersion of hemp particles and limited fibre pull-out, indicating acceptable interfacial adhesion between the hemp filler and the PLA matrix. Some small voids and irregularities are present, but the overall structure remains compact. In contrast, the PLA_H20 composite showed increased surface roughness, more pronounced voids and signs of fibre debonding. The PLA_H30 composite displayed the most heterogeneous morphology, characterised by large cracks, significant phase separation and poor embedding of hemp particles within the matrix. This indicates that higher hemp loadings led to agglomeration and weak interfacial bonding. These findings are consistent with previous studies on PLA/natural fibre composites, where poor compatibility between the hydrophilic fibres and hydrophobic PLA matrix results in weak interfacial adhesion and reduced overall composite performance.[8,28] The observed morphological defects are consistent with the deterioration of tensile properties at elevated hemp contents.

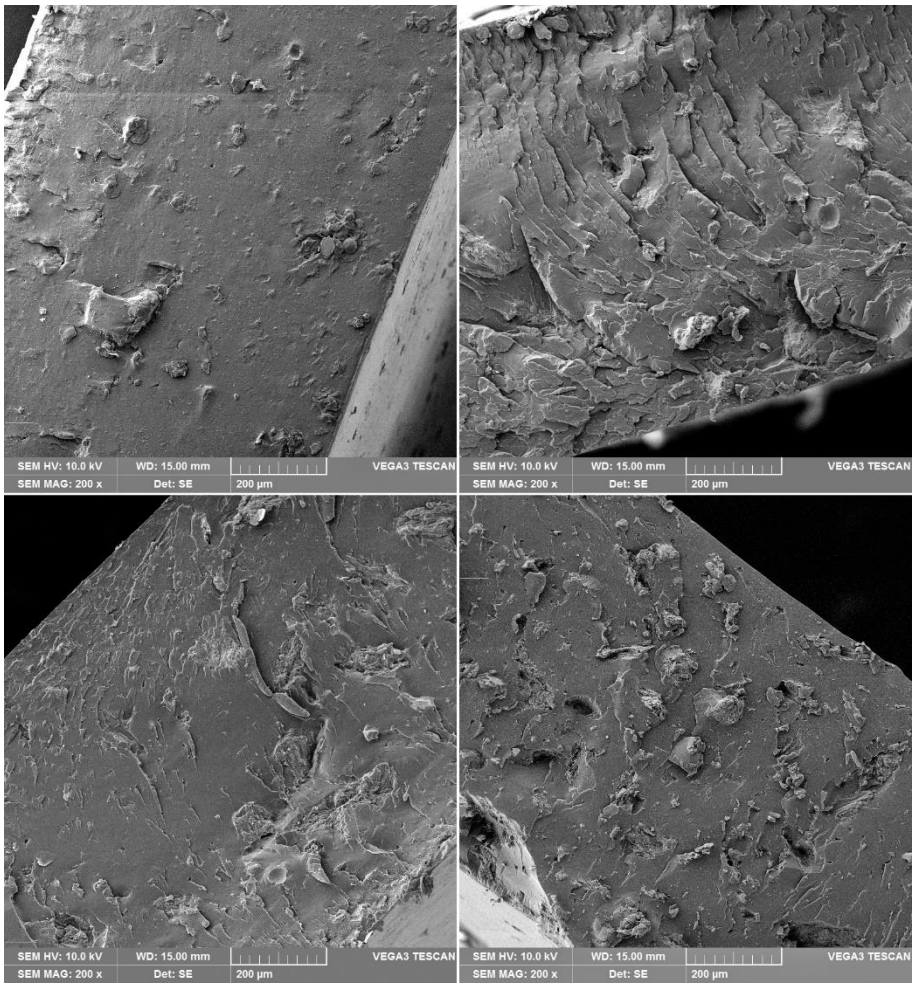


Fig. 4 – SEM micrographs of PLA/hemp composites taken at 200× magnification; PLA_H5 (upper left), PLA_H10 (upper right), PLA_H20 (bottom left), PLA_H30 (bottom right)

Slika 4 – SEM mikrografi kompozita PLA/konoplja snimljeni pri povećanju 200×; PLA_H5 (gore lijevo), PLA_H10 (gore desno), PLA_H20 (dolje lijevo), PLA_H30 (dolje desno)

3.4 Melt flow rate

Melt flow rates of PLA/hemp composites are shown in Table 5. Neat PLA exhibited an MFR value of 13.3 ± 0.5 g 10 min^{-1}, and the addition of 5 wt.% hemp did not significantly change the MFR. However, a clear increasing trend was observed with higher hemp loadings, reaching a very high value of 89.0 ± 4.4 g 10 min^{-1} at 30 wt.% hemp addition. This substantial rise in MFR with increasing hemp content indicates a significant reduction in melt viscosity. *Z. Rbihi et al.*[29] reported a reduction in viscoelastic properties at higher filler loading (30 wt.%), attributed to agglomeration and reduced dispersion efficiency. Nevertheless, this trend of decreased melt viscosity contrasts with several literature reports where the incorporation of fibres increased melt viscosity due to filler-matrix interactions.[8,30]

Lower thermal stability of hemp may cause partial degradation of the fibres during high-temperature processing, releasing low-molecular-weight compounds that further decrease the viscosity of the melt. In addition, *Mazzanti et al.*[31] reported that even small amounts of hemp fibres can accelerate hydrolytic degradation of PLA in the molten state due to residual water retained within the fibres, leading to a pronounced reduction in viscosity and molecular weight.

Table 5 – Melt flow rates of PLA/hemp composites

Tablica 5 – Rezultati masenog protoka taljevina kompozita PLA/konoplja

Sample Uzorak	PLA	PLA_H5	PLA_H10	PLA_H20	PLA_H30
MFR/g 10 min^{-1}	13.3 ± 0.5	13.3 ± 0.9	22.5 ± 1.4	32.6 ± 2.2	89.0 ± 4.4

Table 6 – PLA/hemp composites before and after biodegradation
Tablica 6 – Kompoziti PLA/konoplja prije i poslije biorazgradnje

Sample Uzorak	PLA	PLA_H5	PLA_H10	PLA_H20	PLA_H30
0 days 0 dana					
60 days 60 dana					

While the improved flowability can be advantageous, the extremely high MFR at 30 wt.% hemp suggests potential difficulties in maintaining dimensional stability, and may contribute to the poor mechanical performance observed at higher filler loadings.

3.5 Biodegradation

Biodegradation was evaluated using a soil-burial test as a simple comparative method rather than a standardised test of ultimate aerobic biodegradability.[32] The biodegradation results are presented in Table 6 as images of the samples before and after 60 days in soil, and in Table 7 as mass loss due to biodegradation and percentage of degradation. Visible discolouration occurred in all composite samples. Neat PLA exhibited a relatively low mass loss and a degradation of 1.7 % after 60 days, which is typical for PLA under ambient soil conditions because of its slow hydrolytic degradation rate at room temperature.[18,28]

The incorporation of industrial hemp resulted in a gradual increase in biodegradation with increasing filler content, reaching 4.8 % degradation at a 30 wt.% hemp ratio.

The enhancement in biodegradation can be attributed to the highly hydrophilic nature of hemp fibres, which increased water absorption and facilitated microbial attack. The presence of hemp creates a more favourable environment for microorganisms by improving moisture retention and providing readily degradable cellulosic components.[28] Moreover, natural cellulose-based fillers accelerate the biodegradation of PLA composites by promoting hydrolytic and enzymatic degradation processes.[33] Nevertheless, the relatively low overall mass loss most likely reflects initial hydrolytic degradation and preferential degradation of the hemp component.

Table 7 – Results of biodegradation
Tablica 7 – Rezultati biorazgradnje

Sample Uzorak	PLA	PLA_H5	PLA_H10	PLA_H20	PLA_H30
Initial mass / g Početna masa / g	1.5492	1.4324	1.3353	1.4771	0.8036
Mass after 60 days Masa nakon 60 dana	1.5235	1.4095	1.2986	1.4208	0.7647
Mass loss Gubitak mase	0.0257	0.0229	0.0367	0.0563	0.0389
% of degradation % razgradnje	1.7	1.6	2.7	3.8	4.8

4 Conclusion

Biodegradable PLA/hemp composites were successfully prepared by twin-screw extrusion and comprehensively characterised. The addition of ground industrial hemp significantly influenced the thermal, morphological, mechanical, rheological, and biodegradation properties of the material. Although hemp fibres reduced thermal stability and acted as effective nucleating agents, they also led to a substantial increase in melt flow rate, most likely due to thermal degradation during processing. Mechanical properties deteriorated with increasing hemp content, particularly above 10 wt.% due to poor interfacial adhesion and fibre agglomeration observed by SEM. On the other hand, the biodegradation rate in soil was enhanced by the presence of hydrophilic hemp fibres. Overall, the optimal balance between processability, thermal stability, mechanical performance, and biodegradability was achieved at hemp loadings of up to 10 wt.%. This study demonstrates that moderate hemp loadings can provide a favourable compromise between sustainability and material performance, while excessive filler content leads to structural heterogeneity and degradation phenomena that limit practical applicability of the composites.

List of abbreviations and symbols
Popis kratica i simbola

PLA – polylactide
wt.% – weight percent
TGA – thermogravimetric analysis
DTG – differential thermogravimetry
DSC – differential scanning calorimetry
SEM – scanning electron microscopy
MFR – melt flow rate
T_{95} – temperature at 5 % mass loss
T_{max} – temperature at maximum degradation rate
T_g – glass transition temperature
T_{cc} – cold crystallisation temperature
T_m – melting temperature
ΔH_{cc} – enthalpy of cold crystallisation
ΔH_m – melting enthalpy
X_c – degree of crystallinity

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SAŽETAK

Toplinska i mehanička svojstva te biorazgradivost kompozita polilaktid/vlakna konoplje

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Biorazgradivi kompoziti na bazi polilaktida (PLA) i industrijske konoplje pripremljeni su taljenjem u dvopužnom ekstruderu i okarakterizirani s obzirom na termomehanička svojstva i biorazgradivost. Pripravljeni su kompoziti s 5, 10, 20 i 30 mas.% konoplje te ispitani primjenom termogravimetrijske analize (TGA), diferencijalne pretražne kalorimetrije (DSC), pretražne elektronske mikroskopije (SEM), rasteznim ispitivanjem, određivanjem masenog protoka taljevine (MFR) te je ispitana biorazgradnja ukopavanjem u tlo tijekom 60 dana.

Rezultati TGA pokazali su da dodatak konoplje smanjuje toplinsku stabilnost kompozita pomičući početak razgradnje prema nižim temperaturama. DSC analiza ukazala je da vlakna konoplje djeluju kao nukleacijski centri, potičući heterogenu nukleaciju i inducirajući pojavu taljenja i rekristalizacije, što je rezultiralo pojavom dvostrukog endoterma taljenja. SEM mikrografi pokazali su dobru disperziju i prihvatljivu adheziju pri niskim udjelima konoplje (≤ 10 mas.%), dok viši udjeli dovode do aglomeracije, pojave šupljina i separacije faza. Rastezna čvrstoća i prekidno istezanje postupno su se smanjivali s porastom udjela konoplje, dok je modul rastezljivosti pokazao neznatno poboljšanje do 10 mas.% dodane konoplje. Maseni protok taljevine znatno se povećao s dodanim udjelom konoplje. Taj neuobičajeno visok porast masenog protoka taljevine pri višim udjelima konoplje može ukazivati na djelomičnu razgradnju PLA matrice tijekom prerade. Ispitivanja biorazgradnje pokazala su da veći udio konoplje ubrzava gubitak mase kompozita u tlu.

Rezultati ukazuju na to da se biorazgradivi kompoziti PLA/konoplja s uravnoteženim toplinskim, mehaničkim i procesnim svojstvima mogu dobiti pri udjelima konoplje do 10 mas.%, čineći ih obećavajućim održivim materijalom.

Ključne riječi

Polilaktid, PLA, industrijska konoplja, biorazgradivi kompoziti, termomehanička svojstva, biorazgradnja

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