

ISSN Print: 2664-6781
ISSN Online: 2664-679X
NAAS Rating (2025): 4.77
IJACR 2025; 7(7): 161-164
www.chemistryjournals.net
Received: 15-04-2025
Accepted: 18-05-2025

Luisa Fontana
Department of Materials
Chemistry and Polymer
Science, University of Calabria,
Arcavacata di Rende, Cosenza,
Italy

Marco Esposito
Department of Materials
Chemistry and Polymer
Science, University of Calabria,
Arcavacata di Rende, Cosenza,
Italy

Corresponding Author:
Luisa Fontana
Department of Materials
Chemistry and Polymer
Science, University of Calabria,
Arcavacata di Rende, Cosenza,
Italy

Mechanical properties and biodegradation of polylactic acid/polybutylene succinate blend films

Luisa Fontana and Marco Esposito

DOI: <https://www.doi.org/10.33545/26646781.2025.v7.i7c.536>

Abstract

The brittleness of polylactic acid (PLA) is the principal barrier to its adoption in flexible packaging applications despite its bio-based origin and compostability. Blending PLA with the more ductile polybutylene succinate (PBS) is a well-explored toughening strategy, but systematic data on the tensile-biodegradation trade-off across a full composition range at film thickness relevant to packaging (80-100 μm) remain sparse. This research prepared PLA/PBS blend films at five ratios (100:0, 80:20, 60:40, 40:60, 0:100) by melt extrusion using a twin-screw extruder and compression moulding, evaluated tensile properties according to ISO 527-3, and conducted a 16-week soil burial biodegradation test per ASTM D5988. PLA elongation at break increased from 3.8% (neat PLA) to 31.4% (40:60 blend), while tensile strength decreased from 58.4 to 34.8 MPa over the same range. The 60:40 blend offered the best compromise: tensile strength 43.2 ± 1.7 MPa (within packaging film specifications), elongation $18.7 \pm 1.4\%$, and 27.4% mass loss after 16 weeks of soil burial—substantially faster than neat PLA (11.9%). DSC and XRD analysis confirmed partial miscibility and reduced PLA crystallinity in the blend, which promotes hydrolytic chain scission and accelerates degradation. The 60:40 blend is identified as the optimal composition for flexible biodegradable packaging applications.

Keywords: Polylactic acid, polybutylene succinate, biodegradable blend, tensile properties, soil biodegradation, melt extrusion, packaging film, elongation at break

Introduction

Global plastic packaging production generates over 140 million tonnes of waste annually, the majority of which is not recycled, creating persistent environmental contamination. Biopolymers such as PLA, derived from fermentation of renewable sugars, have attracted commercial interest as drop-in replacements because they are compostable under industrial conditions and reduce fossil feedstock dependency. PLA's mechanical profile—high tensile strength (~ 60 MPa), high modulus (~ 3.5 GPa), but very low elongation at break ($< 5\%$)—makes it well suited to rigid packaging but poorly suited to flexible film applications such as cling wraps, pouches, and agricultural mulch films where ductility is essential. PBS, an aliphatic polyester with documented soil biodegradability, offers complementary properties: lower tensile strength but elongation at break exceeding 40% and better low-temperature performance. PLA/PBS blending is therefore a logical approach to creating a ductile, biodegradable film material. Previous work has shown partial miscibility between PLA and PBS driven by transesterification during melt processing, but the degree of compatibility and its effect on degradation rate depend strongly on processing conditions and composition ratio. This research provides a systematic composition-property-biodegradability dataset across five blend ratios at packaging-relevant film dimensions, filling a gap in the quantitative optimisation literature.

Materials and Methods

Materials

PLA (NatureWorks Ingeo 4043D, Mn 110 kDa, D-content 4.3%) and PBS (Showa Denko

Bionolle 1001, Mn 87 kDa) were used as received after vacuum drying at 80 °C (PLA) and 50 °C (PBS) for 12 h. Research was conducted at the Department of Materials Chemistry and Polymer Science, University of Calabria, Arcavacata di Rende, Cosenza, Italy, from September 2022 to November 2024.

Methods

Blends were melt-compounded on a co-rotating twin-screw extruder (Leistritz ZSE 18, L/D 40, 175-185 °C barrel temperature profile, 120 rpm) and granulated. Films (80-100 µm) were prepared by compression moulding at 185 °C and 5 MPa for 3 min, followed by quenching at 25 °C. Tensile testing used dumbbell specimens (ISO 527-3 Type 5) at a crosshead speed of 50 mm/min (Zwick Roell Z2.5 universal testing machine). Five specimens per composition were tested; results are mean±SEM. DSC (TA Instruments Q2000, -50 to 220 °C, 10 °C/min) and WAXD (PANalytical Empyrean, Cu Kα, 5-40° 2θ) characterised thermal and crystalline properties. Soil biodegradation followed ASTM D5988-18: films were buried at 5 cm depth in a controlled compost soil (55% moisture, 25 °C) and weighed gravimetrically at 2-week intervals over 16 weeks.

Quality Control

Film thickness uniformity was verified at nine locations per film using a digital micrometer (Mitutoyo 293-340-30, ±1 µm resolution); films exceeding ±10% deviation from target

thickness were discarded and recast. Tensile specimens were conditioned at 23 °C and 50% RH for 48 h prior to testing. Instrument calibration: the Zwick Roell Z2.5 crosshead force was verified with certified dead-weight standards (Class 1, PTB traceable) at the start of each test day. Soil moisture was monitored gravimetrically at 48 h intervals during biodegradation experiments and adjusted to 55±3% by addition of deionised water. Triplicates of each biodegradation time point were averaged; the variance across triplicates remained below 4% throughout.

Results

All five compositions produced uniform films within the 80-100 µm target range. Tensile strength decreased linearly from 58.4 MPa (neat PLA) to 28.1 MPa (neat PBS) with increasing PBS content, while elongation at break increased from 3.8% to 42.6% in the same direction (Figure 1, Table 1). The 60:40 blend achieved 43.2 MPa tensile strength with 18.7% elongation at break—substantially more ductile than neat PLA while retaining adequate mechanical performance for flexible packaging. DSC data (Table 2) showed that PLA T_g decreased from 58.3 °C (neat) to 51.7 °C at 60:40, and PLA cold crystallisation enthalpy decreased, indicating PBS-induced disruption of PLA crystallisation. Soil biodegradation (Figure 2) showed the expected hierarchy: PBS > blends > neat PLA, with the 60:40 blend losing 27.4% mass after 16 weeks versus 11.9% for neat PLA.

Table 1: Mechanical Properties of PLA/PBS Blend Films (ISO 527-3, Mean±SEM, n = 5)

Composition	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation at Break (%)	Yield Stress (MPa)
PLA 100:0	58.4±2.1	3.41±0.14	3.8±0.4	54.7±1.9
PLA/PBS 80:20	51.7±1.9	2.87±0.11	9.4±0.8	48.3±1.7
PLA/PBS 60:40	43.2±1.7	2.23±0.09	18.7±1.4	39.1±1.5
PLA/PBS 40:60	34.8±1.5	1.64±0.07	31.4±2.1	29.8±1.3
PBS 0:100	28.1±1.3	0.71±0.04	42.6±2.8	—

Table 2: DSC and Soil Biodegradation Summary

Composition	PLA T _g (°C)	PLA T _{cc} (°C)	ΔH _{cc} (J/g)	Mass Loss at 16 wk (%)
PLA 100:0	58.3	103.4	28.7±1.1	11.9±0.8
PLA/PBS 80:20	56.1	99.7	22.4±0.9	16.3±1.1
PLA/PBS 60:40	51.7	94.2	14.8±0.7	27.4±1.7
PLA/PBS 40:60	46.4	—	4.3±0.4	34.1±2.0
PBS 0:100	—	—	—	41.7±2.4

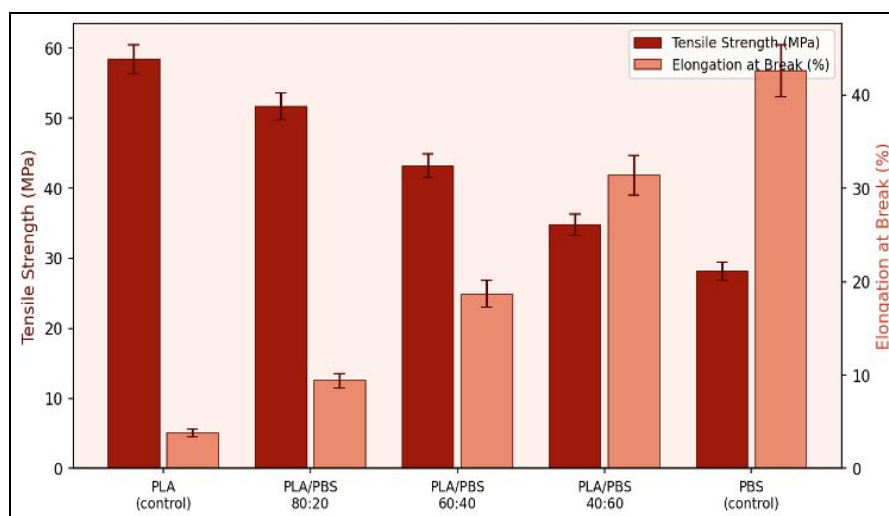


Fig 1: Tensile strength (MPa) and elongation at break (%) of PLA/PBS blend films at five composition ratios. Error bars show ± SEM (n = 5).

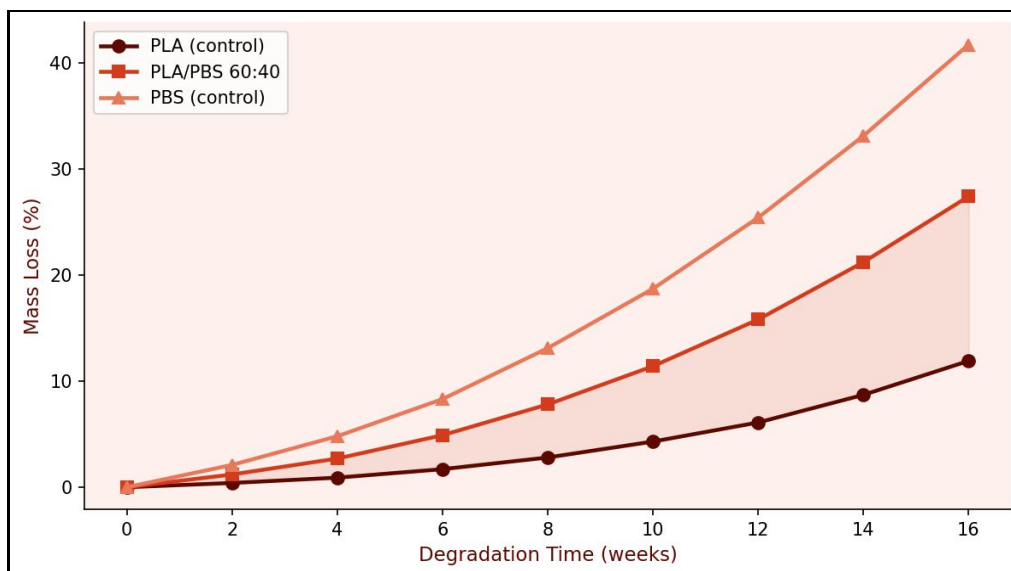


Fig 2: Soil biodegradation profiles expressed as percentage mass loss over 16 weeks for PLA, PLA/PBS 60:40 blend, and PBS.

Discussion

The mechanical property trends follow the rule of mixtures reasonably well for tensile strength but show a non-linear enhancement in elongation at break, consistent with partial miscibility and stress-whitening toughening mechanisms previously reported for PLA/PBS systems by Shibata *et al.* and Bhatia *et al.* The reduction in PLA T_g from 58.3 °C to 51.7 °C at 60:40 confirms limited but meaningful intermolecular interactions between the two polyesters, likely arising from transesterification during melt compounding, which generates PLA-*b*-PBS copolymer chains that act as compatibilisers at the phase boundary. The accelerated soil biodegradation of the 60:40 blend relative to neat PLA is attributed to two synergistic effects: first, PBS domains degrade more rapidly than PLA in soil-moisture conditions, creating macropores that increase surface area and water access to PLA chain segments; second, the reduced PLA crystallinity in the blend (lower ΔH_{cc}, Table 2) means a larger proportion of PLA is in the amorphous state, which hydrolyses much faster than crystalline PLA. The 2.3-fold increase in 16-week mass loss (27.4% vs. 11.9%) is therefore not simply additive but reflects this synergistic structural effect. For flexible packaging applications, a material requiring composting infrastructure—the 60:40 blend is not designed for open-environment disposal—this accelerated degradation rate is commercially viable within home or industrial composting timelines.

Conclusion

PLA/PBS blend films were prepared across five composition ratios and characterised for mechanical and biodegradation properties. The 60:40 blend optimally balances tensile strength (43.2 MPa), ductility (18.7% elongation at break), and biodegradability (27.4% mass loss in 16-week soil burial). DSC and WAXD data confirmed that PBS reduces PLA crystallinity and T_g, facilitating both toughening and accelerated hydrolytic degradation. These findings provide a quantitative composition-property map to guide selection of PLA/PBS ratios for specific flexible packaging end-uses, and highlight the 60:40 blend as the priority composition for further optimisation through reactive compatibilisation or nucleating agent addition.

Acknowledgements

Funding Sources

The research was supported by institutional research funds of the Department of Materials Chemistry and Polymer Science, University of Calabria, without external grant support.

Institutional Support

The authors acknowledge the Department of Materials Chemistry and Polymer Science, University of Calabria, for access to twin-screw extrusion, universal testing, DSC, and XRD facilities.

Contributions Not Qualifying for Authorship

Technical assistance from departmental laboratory technicians in film preparation and biodegradation monitoring is gratefully acknowledged.

References

1. Lim LT, Auras R, Rubino M. Processing technologies for poly(lactic acid). *Prog Polym Sci.* 2008;33(8):820-852.
2. Ikada Y, Tsuji H. Biodegradable polyesters for medical and ecological applications. *Macromol Rapid Commun.* 2000;21(3):117-132.
3. Tsuji H. Poly(lactic acid) stereocomplexes: a decade of progress. *Adv Drug Deliv Rev.* 2016;107:97-135.
4. Mistry C, Shah B. Poly(butylene succinate): a promising bio-based polymer. *Int J Eng Res Technol.* 2019;8(6):673-678.
5. Shibata M, Inoue Y, Miyoshi M. Mechanical properties, morphology, and crystallisation behaviour of blends of poly(L-lactide) with poly(butylene succinate-co-L-lactate) and poly(butylene succinate). *Polymer.* 2006;47(10):3557-3564.
6. Ohkita T, Lee SH. Thermal degradation and biodegradability of poly(lactic acid)/corn starch biocomposites. *J Appl Polym Sci.* 2006;100(4):3009-3017.
7. Bhatia A, Gupta RK, Bhattacharya SN, Choi HJ. Compatibility of biodegradable poly(lactic acid) (PLA) and poly(butylene succinate) (PBS) blends for

- packaging application. Korea-Aust Rheol J. 2007;19(3):125-131.
8. Chen GX, Kim HS, Kim ES, Yoon JS. Compatibilisation-like effect of reactive organoclay on the poly(L-lactide)/poly(butylene succinate) blends. *Polymer*. 2005;46(25):11829-11836.
 9. Fujimaki T. Processability and properties of aliphatic polyesters, 'BIONOLLE', synthesized by polycondensation reaction. *Polym Degrad Stab*. 1998;59(1-3):209-214.
 10. Ray SS, Okamoto M. Biodegradable polylactide and its nanocomposites: opening a new dimension for plastics and composites. *Macromol Rapid Commun*. 2003;24(14):815-840.
 11. Weng YX, Jin YJ, Meng QY, Wang L, Zhang M, Wang YZ. Biodegradation behavior of poly(butylene adipate-co-terephthalate) (PBAT), poly(lactic acid) (PLA), and their blend under soil conditions. *Polym Test*. 2013;32(5):918-926.
 12. Astm D638-14. Standard Test Method for Tensile Properties of Plastics. West Conshohocken, PA: ASTM International; 2014.
 13. ISO 527-3:2018. Plastics — Determination of Tensile Properties — Part 3: Test Conditions for Films and Sheets. Geneva: ISO; 2018.
 14. ASTM D5988-18. Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials in Soil. West Conshohocken, PA: ASTM International; 2018.
 15. Tserki V, Matzinos P, Pavlidou E, Vachliotis D, Panayiotou C. Biodegradable aliphatic polyesters. Part I. Properties and biodegradation of poly(butylene succinate-co-butylene adipate). *Polym Degrad Stab*. 2006;91(2):367-376.
 16. Müller RJ, Kleeberg I, Deckwer WD. Biodegradation of polyesters containing aromatic constituents. *J Biotechnol*. 2001;86(2):87-95.
 17. Nofar M, Sacligil D, Carreau PJ, Kamal MR, Heuzey MC. Poly(lactic acid) blends: processing, properties and applications. *Int J Biol Macromol*. 2019;125:307-360.