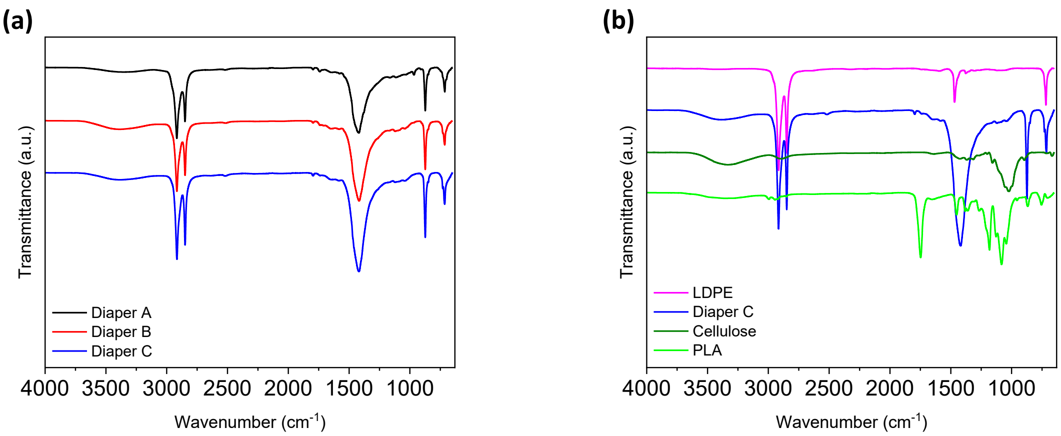

Figure 4.3. FTIR spectra of (a) diapers A, B and C backsheet samples and (b) diaper C, LDPE, PLA and cellulose.

In Figure 4.3b, PLA exhibited a strong and sharp peak at ~1740 cm^{-1}, attributed to C=O stretching in ester functional groups. This peak is not present in the spectra of all the diaper samples, conclusively demonstrating that PLA is not part of their composition. The lack of ester-based C=O signals in diapers and the strong presence of aliphatic features confirms they are PE-based. Lastly, the IR spectrum of cellulose is characterized by a broad O−H stretching band at 3 330 cm^{-1}, due to the presence of hydrophilic hydroxyl groups. C−H stretching is observed at 2 977−2 892 cm^{-1}, while the intense peak at 1 000-1100 cm^{-1} is associated with C–O–C stretching and C–H rocking vibrations of the pyranose ring (Sikhosana, 2023; Motloung, 2024). nterestingly, all the IR vibrations emanating from the cellulose structure are observed, albeit to varying degrees, in the IR spectrum of diaper C (Figure 4.3b).

SEM was used to evaluate the morphological composition of diaper C in comparison with LDPE and PLA. It was further used to evaluate changes that took place after biodegradation of these samples. This technique was important for understanding microstructural interactions, especially the hypothesis of the presence of a polysaccharide-based natural fibre, most likely cellulose, on the polymer surface, as suggested by FTIR and TGA results. Figure 4.4 presents SEM micrographs of all three samples before and after biodegradation.

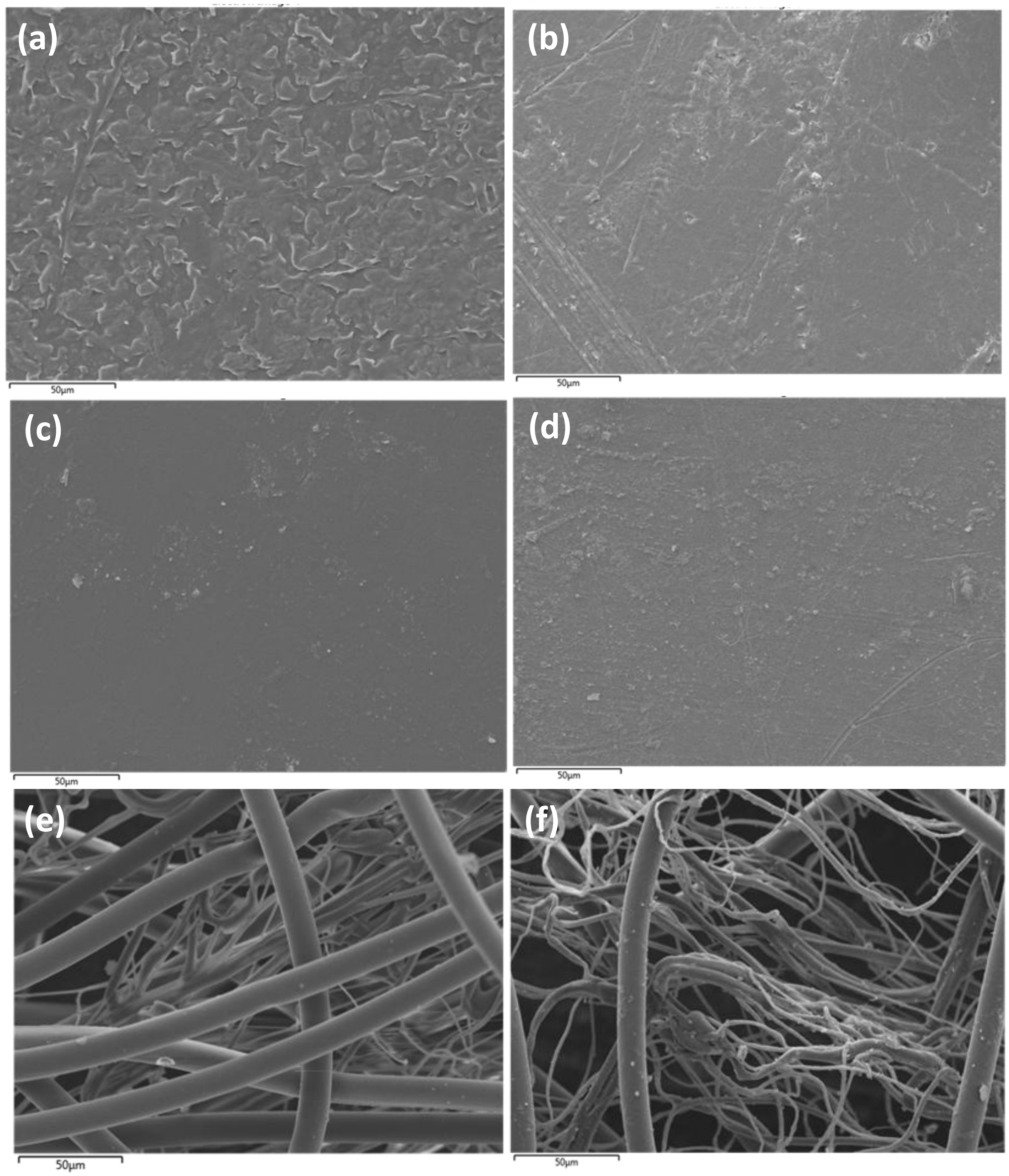

Figure 4.4. SEM micrographs of LDPE, PLA and diaper C samples before (a, c, e) and after biodegradation (b, d, f), respectively.

Diaper C reveals a heterogeneous fibrous morphology, consisting of inter-connected cylindrical fibers with varying thickness before biodegradation (Figure 4.4e). The thick fibers appear smooth and are typical of PE films, while the thin, loosely arranged fibers are consistent with cellulose fluff or superabsorbent polymer structures commonly found in diaper cores (Ajmeri and Ajmeri, 2010). Unlike the smooth and more compact surface observed in LDPE (Figure 4.4a), the surface of diaper C is more textured and irregular, suggesting that cellulose has adsorbed onto or fused with the polymer matrix, without forming a homogeneous blend. This supports the observations from FTIR, where O–H and C–O–C stretching peaks were visible in diaper C but were not present in LDPE. The observed morphology after biodegradation shows slight changes in the diaper C backsheet sample, while both PLA and LDPE largely remain intact. A change in the morphology of the fibres in diaper C is noticeable. SEM images post-biodegradation exhibited rough, corroded and thinner fibres (Figure 4.4f) in contrast to the initially intact and smooth fibres observed before biodegradation. This suggests that the cellulose infused in the diaper increased the hydrophilicity of the material, which is suitable for biodegradation, allowing for structural weakening and fragmentation (Zambrano et al., 2020). No visible morphological changes were observed in LDPE after the biodegradation test (Figure 4.4b), as the polymer remained intact with no significant erosion or cracks. This is due to its resistance to hydrolysis and biodegradation which is attributed to its hydrophobic carbon backbone and large molecular weight (Zambrano et al., 2020). This is also supported by biodegradation test results where the initial weight of the sample did not decline over time. For PLA, only minor morphological changes were observed after the biodegradation test compared to the starting sample (Figures 4.4c and 4.4d), despite the polymer being classified as biodegradable. This is further supported by a very small weight loss recorded during the biodegradation test, and it suggests that the hydrolytic degradation that occurred was insufficient. According to Mistry et al. (2023), PLA degrades effectively under industrial composting conditions characterized by sustained high temperatures which are challenging to maintain under non-industrial composting conditions. Although these outcomes are evidence of PLA biodegradability, they emphasize its dependence on industrial composting for efficient and rapid biodegradation. The observed morphology in SEM supports the idea that cellulose fibers possibly act as heterogeneous nucleating agents, changing the thermal crystallization behavior the polymer, giving rise to higher melting enthalpies. In addition, the rough surface of diaper C could increase hydrophilicity and thus biodegradation potential, aligning with the broader study aim of evaluating materials for eco-friendly backsheet alternatives.

Biodegradation studies were conducted in accordance with the Standard Test Method for Determining Weight Loss from Plastic Materials Exposed to Simulated Municipal Solid-Waste (MSW) Aerobic Compost Environment (ASTM D6003-96), using a stainless-steel container filled with organic compost. The compost was packed to a depth of 2 cm from the bottom, then diaper C, LDPE and PLA samples were placed on top of the compost with sufficient spacing in-between to ensure uniform degradation (Figure 4.5a). Subsequently, the three samples were covered with additional compost until the container was completely filled, with the depth of the samples from the top surface measured at 3 cm (Figure 5b). The container was stored at room temperature and the compost moisture was maintained by regularly sprinkling distilled water, as per the manufacturer's instructions.

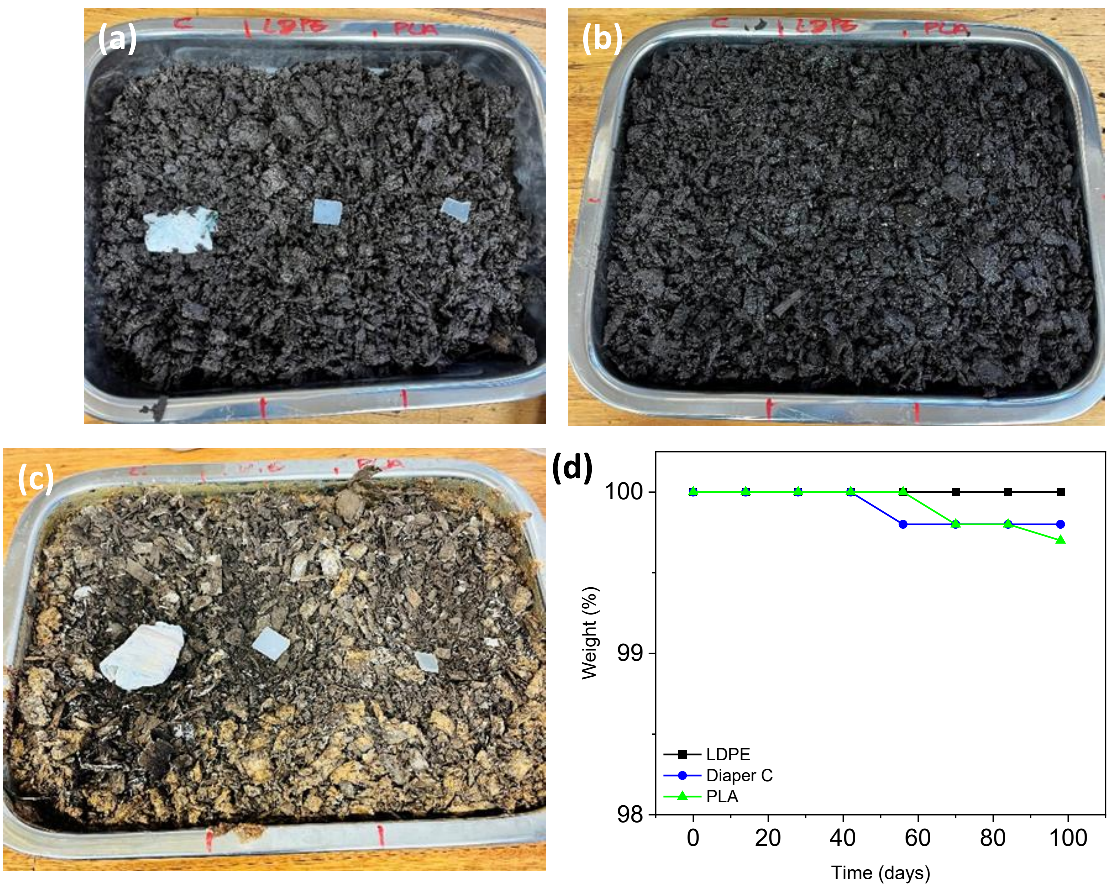

Figure 4.5. Test samples (a) before and (b) after being fully covered with organic compost. (c) Test samples after a 90-day soil burial test. (d) Biodegradation performance of diaper C, LDPE and PLA over time in an organic compost environment.

Figure 4.5d displays the biodegradation performance of the three samples over a 98-day period. Consistent with results from other techniques, diaper C is confirmed to be composed of LDPE with cellulose infusion. The observed weight loss in diaper C beginning on day 42, which occurs earlier than PLA, is attributed to the degradation of part of the cellulose component. This is consistent with the findings of Brunšek et al. (2023), who reported that cellulose typically degrades before PLA under soil burial conditions. However, the residual weight of diaper C remained unchanged beyond the partial degradation of cellulose, indicating that the remaining component is LDPE, a non-biodegradable polymer, and a small amount of cellulose. This reinforces the need for replacing LDPE in diaper backsheets with more environmentally responsible materials. PLA showed partial degradation beginning on day 56, with continued weight loss until the end of the test. Although the observed weight loss was minimal, and lower than the values reported by Yagi et al. (2009), Arrieta et al. (2014) and Boonmee et al. (2016), this discrepancy may be due to factors such as low microbial activity, reduced moisture retention in the compost, or the difference in the thicknesses and crystallinities of the used PLA films. Despite the slow degradation, these findings confirm that PLA is indeed biodegradable under soil burial conditions. Furthermore, it is anticipated that the use of thinner PLA films in commercial diaper manufacturing would result in a significantly faster degradation rates. As expected, LDPE did not show any mass loss under the composting conditions due to its non-biodegradable nature. The final (visual) inspection on day 98 (i.e. post-burial) showed little morphological changes in the LDPE and PLA samples, while the cellulose-rich layer in diaper C had mostly degraded (Figure 4.4c).

The inclusion of biodegradable polymers such as PLA in diaper backsheets holds a clear potential to enhance environmental sustainability. However, the complete adoption of PLA-based disposal diapers depends on a few factors: PLA has relatively low crystallinity and thus low thermal stability, which is disadvantageous during high-temperature processing (i.e. during manufacturing). In addition, the polymer is prone to brittle fracture, and thus cannot be employed in applications where high mechanical performance is a requirement (i.e. the diaper backsheet should be able to withstand impact forces and also bend without breaking). It has been shown in literature that through nucleation and reinforcement, the incorporation of bio-based nanofillers can significantly increase the crystallinity and thermal stability of PLA (Ngwenya et al., 2025). Furthermore, the brittle nature of the polymer can be overcome through blending with more ductile polymers, such as poly(ε-caprolactone), giving rise to materials with improved impact resistance (Fernández-Tena et al., 2023). Although results showed slower-than-expected biodegradation rates under the applied test conditions, the use of fillers such as cellulose have shown that the rate of biodegradation could be accelerated (Kalita et al., 2020).Therefore, of the various biodegradable polymers currently in the market, PLA remains the most cost-effective and promising candidate for replacing the PE family in single-use diaper products.

4.4 Conclusions

This work presented a systematic analysis of three commercial diaper backsheets and also evaluated the suitability of PLA as a biodegradable alternative to petroleum-based PE. DSC showed that diaper C differs from diapers A and B in its crystallization and melting behavior, recording the highest melting enthalpy of the three diapers, possibly due to nucleation effects by the infused cellulose. The presence of cellulose was confirmed by FTIR, which identified O–H and C–O–C functional groups characteristic of cellulose, and by SEM, where fibrous structures, typical of cellulose fibres, were observed. TGA further demonstrated that diaper C, despite containing cellulose, retains the thermal degradation behavior of typical PE materials, with major decomposition occurring above 450 °C. The adsorbed cellulose slightly lowers the onset of degradation and increases residual mass but does not substantially enhance biodegradability, possibly due to insufficient amounts within the material. FTIR and TGA comparisons with PLA confirmed that the thermal behavior of PLA and complete degradation at lower temperatures (~360 °C) reinforce its role as a promising biodegradable reference polymer. Biodegradation testing over a 98-day period revealed that diaper C exhibited earlier signs of weight loss (from day 42), attributed to the partial degradation of the cellulose fraction, consistent with literature reporting that cellulose degrades before PLA under soil burial conditions. However, the remaining LDPE-based component of diaper C showed no further weight change, confirming its non-biodegradable nature. In contrast, PLA began degrading from day 56 and continued to lose mass over time, albeit at a slower rate relative to prior studies. Factors such as limited microbial activity, moisture content, crystallinity and film thickness may explain the slower biodegradation rate. Nonetheless, the test confirms that PLA is biodegradable under composting conditions and is likely to degrade faster in commercial applications using thinner films. Collectively, the findings show that while cellulose-infused PE back sheet materials such as diaper C represent a step toward sustainability, they fall short of fully addressing the environmental burden posed by traditional diapers. The limited biodegradation of diaper C underscores the need for a complete material substitution rather than partial modification. Replacing PE with PLA-based composites offers a more viable route toward achieving significant environmental benefits in single-use hygiene products without compromising structural integrity.

Acknowledgements

This work is based on the research supported in part by the Department of Science and Innovation (DSI) and the National Research Foundation (NRF) of South Africa through the Thuthuka Programme (Grant No.: TTK2204264865) and DSI-NRF Innovation Postdoctoral Fellowship (Grant No.: PSTD2205057154). Additional financial support was provided by the Postgraduate Student Fund of the Central University of Technology, Free State.

Conflict of interest

The authors declare no conflict of interest.

Ethical approval

Not applicable.

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Chapter 5

Conclusions

This dissertation investigated the environmental implications of current disposable diaper materials and evaluated biodegradable alternatives. The focus was on PLA as a sustainable substitute for PE in diaper backsheet layers. Through a two-pronged approach – first, a review of the global landscape of biodegradable polymers in diaper applications (Article 1), and second, an in-depth experimental characterisation and biodegradation assessment of commercial diaper backsheets (Article 2) – the study offered both theoretical and practical insights into material sustainability in single-use hygiene products.

The findings showed the urgent need to replace conventional. non-biodegradable polymers such as LDPE with alternatives that align with the goals of sustainable development. Article 1 highlighted that while LDPE offers mechanical advantages, its long environmental persistence and non-compostable nature make it increasingly untenable in light of growing waste burdens. PLA emerged as a leading candidate among biodegradable polymers due to its favourable environmental profile, cost-effectiveness, and commercial availability. Although inherently more brittle, its performance limitations can be overcome through blending or plasticisation, making it a realistic option for industrial-scale implementation.

Article 2 built upon this foundation by experimentally characterising the thermal, Structural, and morphological properties of three commercial diaper backsheets. Diaper C, which included cellulose components, exhibited unique thermal and surface characteristics not found in the LDPE-only samples (Diapers A and B). However, despite these modifications, Diaper C retained the core degradation profile of LDPE, revealing that the mere inclusion of biodegradable fillers, such as cellulose, does not translate into significant improvements in environmental performance. Biodegradation testing confirmed this: while the cellulose fraction of Diaper C degraded early, the LDPE matrix remained intact. In contrast, PLA demonstrated observable, albeit slower, mass loss under composting conditions, validating its classification as a biodegradable polymer and reaffirming its potential in backsheet applications.

Together, these findings showed that a partial substitution strategy, such as blending LDPE with cellulose, offered limited environmental gains. A full material transition to PLA or other biodegradable polymers, supported by advances in formulation and processing, is essential for meaningful environmental impact. Importantly, material substitution alone is not sufficient. Broader systemic changes, including regulatory frameworks, market incentives, and public education, are necessary to support a shift toward sustainable diaper manufacturing, particularly in regions with inadequate waste management infrastructure.

In conclusion, this dissertation advances the scientific understanding of biodegradable polymer performance in diaper applications and contributes valuable evidence in favour of PLA as a feasible and impactful alternative to PE. By combining literature-based analysis with experimental validation, the study provides a strong foundation for future research, product innovation, and policy development aimed at reducing the ecological footprint of disposable hygiene products.