BRIEFING NOTE

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END-OF-LIFE OPTIONS OF BIOBASED PLASTIC MATERIALS AND ITS BIOCOMPOSITES

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KEY FINDINGS

End-of-life options of biobased biodegradable polymeric materials, in terms of mechanical recyclability and biodegradability (biological recycling) were investigated in different environmental conditions. The mechanical recyclability of bio-based polymers, such as polylactic acid (PLA), polybutylene succinate (PBS), polybutylene adipate terephthalate (PBAT), PBS/PBAT blend and PBAT/thermoplastic starch-based bio-composite were carried out by multiple melt extrusion techniques. The melt extrusion results showed that biopolymers (PBAT, PBS) and bio-composite (PBAT/TPS) were melt processable to 8 cycles, whereas PLA and a blend of PBS/PBAT were melt processable only up to 6 cycles. The results showed that PBAT and its PBAT/TPS bio-composite are the best performing bio-based materials in terms of multiple processing by melt-extrusion due to its melt strength as compared to other bio-based polymers (PLA, PBS) and blend (PBS/PBAT). Environmental abiotic degradation results suggest that accelerated thermal and hydrolytic conditions are significantly influencing the degradation of biobased polymers as compared to sunlight exposure. CO_2 biodegradation studies results suggested that industrial composting conditions are most suitable for enhanced biodegradation of biobased polymeric materials as compared to soil and marine water environments. The obtained results conclude that end-of-life options of these biobased biopolymers can be mechanically recycled by extruders or injection moulding as well as suitable for biological degradation for their long-term sustainability.

INTRODUCTION

Now a days, plastics have become vital materials used in everyday life applications. The plastic has grown exponentially due to its low cost, light weight, inertness, excellent properties, making them the ideal material for a wide number of applications from the automotive industry to various packaging products. However, there is increasing concern over the negative environmental impact generated by plastic waste and persistence of the products in the environment due to their inertness and resistance to degradation possessing a serious environmental hazard.

Annual plastic production was estimated over 390 million tons of plastics in 2020 and is expected to reach 1124 million tons by 2050. Currently, among the total amount of plastics, around 9% of plastics had been recycled, 12% was incinerated, and 79% was accumulated in landfills or the natural environment (UNIDO report 2019). In South Africa (SA), more than 90% of single-use plastic films (carrier bags, agricultural films and others) as well as short-term use consumer plastic items, are produced from petroleum-based chemical materials and are thus non-biodegradable. Single-use plastics are most used for packaging and service ware, such as cutlery, take away containers, bottles, wrappers, straws, bags and others. Plastic waste of single use and short-lived disposable products usually end up in landfills and oceans. Plastic pollution on marine life and ecosystems, causing harm to animals, marine plants and humans, and result in huge economic losses.

Substitution with alternative materials that meet functional requirements for specific applications that are easily recyclable or compostable after use can be one of the possible intervention strategies for reducing the leakage of plastic into the environment. Biodegradable polymers and renewable sourced and/or including polylactic acid (PLA), polybutylene succinate (PBS), polyhydroxy butyrate (PHB), produced are becoming increasingly attractive to replace non-biodegradable conventional polymers in a number of applications. These materials have comparable properties to those of conventional plastics, such as polyethylene (PE), polystyrene (PS) and polypropylene (PP) which has led to the growing interest in bio-plastics.

The increased use of biodegradable plastics may have serious implications for the plastic recycling and organic recycling, if not properly identified for biopolymer recycling of both process and post-consumer wate at an early stage. It is important to note that mechanical recycling of polymers allow persevering the material feedstock and the polymer composition as compared to energy recovery, chemical recycling and composting. However, the introduction of 'biodegradable' plastics to the market may create several issues that need to be addressed in terms of potential risk of contamination of recycling systems. Moreover, as the interest in biomaterials grows, the green marketing of product that are produced in an environmentally friendly manner, which after the end-of-product life do not contribute negatively to the environment such as landfill and compost conditions. Thus, it is becoming an important design criterion for sustainable biobased materials products that meets commercial and ecological acceptability and have recycling capabilities and/or triggered biodegradability.
Commercially available major biobased biodegradable polymers such as polylactic acid (PLA), polybutylene succinate (PBS) and polybutylene adipate terephthalate (PBAT) the strengths and weaknesses of end-of-life options have not been addressed in terms of mechanical recyclability by multiple melt extrusion processing and their potential biodegradability under different natural environmental conditions (i.e., soil, compost and marine water). Therefore, the project work was to investigate suitable processing conditions and viable methodology on the mechanical and biological recyclability of bio-based polymers (PLA, PBS and PBAT), their blend (PBS/PBAT) and bio-composite (PBAT/TPS) which can effectively address the post-consumer plastic waste issues.

METHODOLOGY

Mechanical recycling: Mechanical recyclability of bio-based polymers, such as polylactic acid (PLA), polybutylene succinate (PBS), polybutylene adipate terephthalate (PBAT), a blend of PBS/PBAT and PBAT/thermoplastic starch (TPS) based bio-composite were studied in comparison with conventional polyethylene (LDPE) plastic by multiple melt extrusion techniques and characterization analysis. The samples were multiple extruded using a twin-screw extruder. The thermal, mechanical, physical and chemical characterizations have been carried out after each cycle of processing to assess the extent of degradation.
Environmental abiotic and biodegradation studies: The effect abiotic degradation of biobased polymers, biopolymer blend and biocomposites were investigated under direct sunlight, static oven temperature at 60°C and hydrolytic conditions for three months. Before and after abiotic degradation, the test samples were characterized by structural and thermal properties. The ultimate biodegradation (mineralization) behaviours of these biobased biopolymers, blend and biocomposite based on amount of polymeric carbon mineralized to CO_2 was assayed under soil, composting and marine water conditions as per international standard test methods.

MAIN RESULTS

Figure 1 shows the tensile strength and percent elongation of multiple melt extruded bio-based polymers (i.e., PBAT, a bio-composite of PBAT/TPS, a blend of PBAT/PBS, PBS and PLA) in comparison to conventional LDPE plastic. The tensile strength and elongation properties of the biopolymer PBAT and its bio-composite made from PBAT/TPS, did not change significantly on the number of extrusion cycles (see Fig 1a & b). The mechanical properties showed PBAT and its bio-composite have a similar recyclability to conventional LDPE plastic. For the biopolymer blend made from PBAT/PBS, the tensile strength was reduced to 50% after the second extrusion cycle, but no significant reduction in the percent elongation was observed (Fig 1c). The observed reduction in tensile strength after the second extrusion cycle is likely due to the degradation of PBS in the biopolymer blend. The PBAT biopolymer has good thermal and mechanical properties, and it is a promising material for improving polymer blends such as PBS and PLA. In comparison to PBAT, PBS has a low melting temperature and poor thermal stability, which makes the blend not suitable for multiple recycling processes. The tensile strength results of multiple extruded PBS and PLA also showed similar behaviour to the PBAT/PBS blend (Fig 1c, d & e). After the second and fifth extrusion cycles of PBS, the tensile strength was reduced to 38% and 50% respectively. In the case of PLA, the tensile strength was significantly reduced to 55% after the second extrusion cycle (Fig 1e). The reduction of tensile strength indicated that PLA undergoes hydrolytic degradation catalysed by the physical and chemical composition of the lactic acid stereoisomers (Nomadola et al., 2021).

Mechanical properties results showed that PBAT and PBAT/TPS bio-composite were the best performing bio-based materials in terms of multiple processability by traditional mechanical recycling, due to their melt strength as well as compatibility and thermal degradation as compared to other bio-based polymers (PLA, PBS) and blend (PBAT/PBS) (Fig 1).

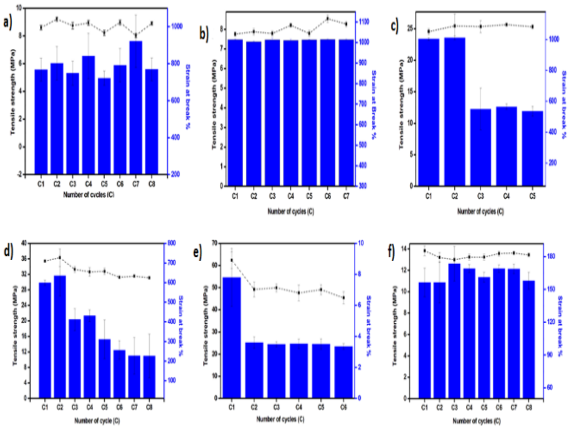

Figure 1. Tensile strength and strain at break for a) PBAT, b) PBAT/TPS biocomposite, c) PBAT/PBS blend, d) PBS, e) PLA and f) LDPE submitted for multiple melt extrusion processing cycles.

Abiotic degradation study results showed that biobased polymeric materials undergo significant degradation under accelerated thermal and hydrolytic conditions as compared to direct sunlight exposure. Biodegradation results show that bio-based plastic materials (PLA, PBS, PBAT and its blend) undergo higher rates of degradation under industrial composting conditions within 3-6 months than other soil and marine water conditions (Fig 2) . The research suggests that these bio-based polymeric materials can address the post-consumer plastic waste issues with added environmental benefits of traditional mechanical recycling or biodegradability/compostability, creating options for management at end-of-life, as well as economic, environmental and employment benefits.

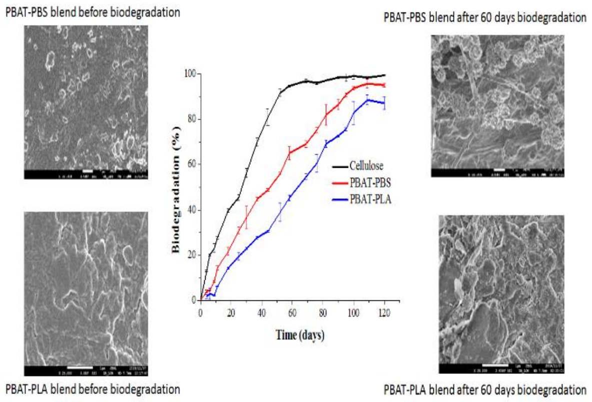

Figure 2. Biodegradation behaviour of biopolymer blends and cellulose (positive reference) under composting conditions

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Further information :

Report https://www.unido.org/sites/default/files/files/2019-06/UNIDO_Addressing_the_challenge_of_Marine_Plastic_Litter_Using_Circular_Economy.pdf

Research article https://doi.org/10.3390/polym14091894

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