

## A Short Review on PLA Biodegradable Green Packaging Reinforced Nano Filler

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**Abstract:** Polylactic acid (PLA) is gaining popularity for green packaging due to its eco-friendly nature. However, drawbacks like brittleness and low heat resistance limit its wider use. This review explores how reinforcing PLA with nanoclay fillers can improve its properties, including mechanical strength, heat tolerance, and barrier functions, while maintaining biodegradability for sustainable packaging. While these enhancements offer advantages, challenges such as dispersion of the fillers, cost factors, and safety regulations will also be addressed. Future research will focus on developing efficient techniques for using nanofillers. Overall, this review emphasises the immense potential of PLA-nanofiller composites as a promising and practical alternative for eco-friendly packaging, aligning with global efforts to reduce plastic waste and environmental damage.

**Keywords:** *polylactic acid (PLA); nano fillers; green packaging; biodegradability*

### INTRODUCTION

The growing concern for environmental degradation and pollution has spurred a surge in interest for

sustainable packaging solutions. These alternatives to traditional plastic packaging offer significant potential to minimise environmental impact. As environmental awareness rises, consumers increasingly demand products with reduced environmental footprints. This emphasis on sustainability is driving industries to adopt practices that reduce waste and pollution. Furthermore, consumers actively seek out products with eco-friendly packaging, recognizing the link between environmental health and human well-being. Many companies are strategically incorporating sustainability initiatives to improve their brand image and meet stakeholder expectations. Phelan and co-workers have conducted a study on companies and how they address plastic pollution and what are the sustainable packaging methods they practise [1].

Polylactic acid (PLA), a biodegradable and bioactive thermoplastic derived from renewable resources like corn starch, cassava roots, or sugarcane, is emerging as a key material for sustainable green packaging. PLA is produced through

polycondensation of lactic acid or ring-opening polymerization of lactide. Marek Brzeziński & Basko have stated that this structure is known as a stereocomplex, which leads to enhanced thermal stability and mechanical strength with decreased degradation time or drug release [2]. A study was conducted by Kalita and fellow researchers to determine the biodegradation and characterisation of PLA infused with algae biomass which eventually shows higher degradability [3]. Additionally, microorganisms can break down PLA back into lactic acid, a naturally occurring and non-toxic compound, further enhancing its biodegradability.

Nano fillers are microscopic particles, typically between 1 and 100 nanometers in size. These tiny particles are incorporated into polymer matrices to improve various properties of the material. They can significantly alter the physical, chemical, mechanical, and structural (morphological) properties of materials. Nano fillers can be broadly classified into two categories: organic and inorganic. Studies have been conducted by Abdul Khalil and friends between organic and inorganic nano fillers and their improvements in the basic properties of composites [4].

### PLA IN GREEN PACKAGING

The range of physical, chemical and mechanical properties makes PLA a versatile biodegradable polymer that is most suitable for packaging. PLA has a transparent appearance which is similar to conventional plastics. The density of PLA is around 1.24g/cm<sup>3</sup> making it relatively lightweight compared to other polymers [5]. The melting point ranges from 150°C to 180°C [6].

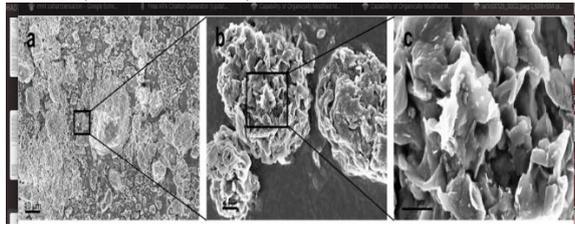
As for the chemical properties, PLA is known to have moderate chemical resistance. However, it may be degraded by strong acids or bases. In a 3D printing materials corrosion test the PLA has degraded when interacted with strong solvent [7].

PLA can be the most suitable polymer to be used in green packaging due to several factors, particularly its biodegradability. Biodegradation of PLA has been determined under composting conditions by Luo and team, proving the biodegradability nature of PLA [8]. Apart from that, PLA is derived from renewable resources such as corn starch and sugarcane. However, conventional plastic is produced from depleting non-renewable resources such as petroleum, eventually causing harm to the environment. Besides, PLA is approved for food contact uses as it has been given green light by the Food and Drug Administration (FDA) [9].

### NANO FILLERS IN PLA

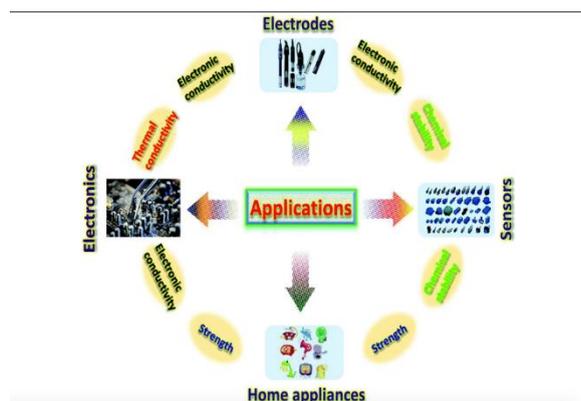
Nano fillers are reinforced with polymers such as PLA in order to come out with better performance in various applications. There are several types of nano fillers available that can be used to be incorporated into polymers like PLA such as nano cellulose, nano silica, graphene oxide, nano chitosan and nano silver [10]. All these types of nano fillers can be included within PLA as they tend to provide thermal and dielectric properties that can improve the nanocomposites produced as stated by Nilagiri Balasubramanian & Ramesh [11].

The very first common example of nanoclays is layered clay minerals that are used together with PLA to prepare nanocomposites. The most common type of clay mineral used with PLA is montmorillonite (MMT) which is used for packaging purposes [12]. Nanoclays are chosen to be used due to their availability and its ability to transform into nano sized particles. **Fig.1.** Shows the structure of the modified MMT studied when Nuruzzaman and his team were researching nanoclay as a carrier in a pesticide delivery system [13].



**Fig.1.** Morphological features of nanoclay [13].

Carbon nanotubes are cylindrical in shape and consist of a single layer of carbon atoms rolled up as sheets. This nano filler possesses limitations such as causing side effects to human health when used as a drug carrier which was studied by Zhang and his researchers [14]. **Fig.2.** Shows the applications of carbon nanotubes used in polymer composite materials as illustrated by Chen and his team [15].



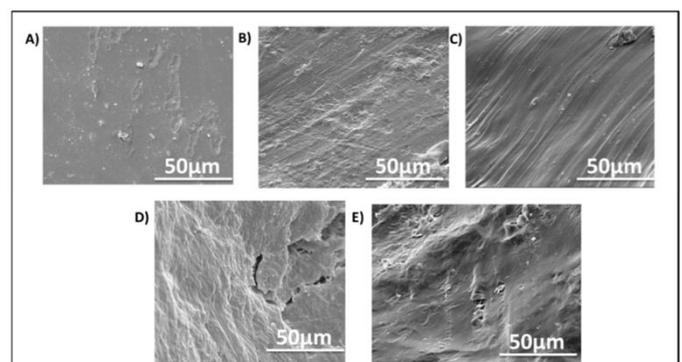
**Fig.2.** The broad range of carbon nanotube applications in polymer composite materials [15].

Metal oxides are also a type of common nanofiller that is reinforced with PLA. Zinc oxide (ZnO) and titanium dioxide (TiO<sub>2</sub>) are types of metal oxides that are incorporated with PLA to produce nanocomposites. Type of nanofillers used can be varied according to the final end product that is being produced. Cellulose nanofibers and layered double hydroxides are also types of nanofillers that are being studied by researchers.

## ENHANCED PROPERTIES OF PLA WITH NANO FILLERS

The incorporation of nano fillers into PLA can influence and improve various properties of the nanocomposites produced. First, the mechanical properties of the PLA will improve heavily due to the addition of nano fillers. Kiendl and Gao have said that PLA can be too brittle to stand on its own which limits its widespread application [16]. The tensile strength of PLA will increase due to the dispersion of nano fillers within the PLA matrix. Apart from tensile strength, the flexural strength of PLA will also increase when nano fillers are added to the PLA. When nano fillers are added to the PLA, the nanocomposites produced will withstand high stress without having any breakage. These statements are evident in an experiment conducted by Markos Petousis and his team with the results showing that mechanical strength which is inclusive of tensile, flexural and impact resistance of PLA nanocomposites were enhanced due to the addition of nano fillers which was Al<sub>2</sub>O<sub>3</sub> [17].

Other than that, the thermal stability of the nanocomposites can be improved compared to the unmodified PLA. Neat PLA possesses 3 crystallization behaviour which heavily affects the thermal stability of the PLA [18]. The structure of PLA as a packaging will be maintained at higher temperatures, making it suitable for robust applications. **Fig.3.** shows the distribution of nano fillers with increasing percentages within the PLA matrix where it is observable that the matrix is becoming rougher from image A to E compared to the neat PLA in image A [19].



**Fig.3.** SEM images of PLA/MMT with increasing percentage from A to E [19].

PLA on its own has very poor barrier property. Barrier property is defined as the resistance of the material to substances such as gaseous, moisture and also ultraviolet rays. Nanofillers help to create a pathway for gas molecules which eventually decreases their rate of diffusion within the PLA matrix making PLA suitable for food packaging. Certain nanofillers do provide UV blocking-properties which is purposeful in protecting contents inside the PLA packaging.

### CHALLENGES AND LIMITATIONS

Reinforcement of nano fillers in PLA to produce green packaging can pose several challenges. Agglomeration can occur within the PLA matrix where the nano fillers clump together which was evident in research by Yan and his team. This is due to the high surface area-to-volume ratio of the nano fillers that can lead to strong Van der Waals forces. Due to these interactions, nano fillers will not be dispersed uniformly within the PLA matrix, eventually reducing the performance of nanocomposites produced mechanically [20].

There are some key factors to consider when scaling up the production of PLA as sustainable packaging. Raw materials to make the packaging should be taken into account which was evident in the study conducted by Wellenreuther and his researchers [21]. Since PLA is derived from renewable sources, the raw materials are heavily dependent on the agricultural market. There might be fluctuations in the agricultural market which can directly affect the cost PLA upscaling. Next, is the scalability which can heavily influence the cost to produce green nanocomposites. Switching from lab-scale to industrial-scale will be financially challenging due to high production costs [22].

Incorporation of nano fillers in PLA can be a difficult part which can be

hazardous to the health and environment. There are cases where certain nano fillers such as CNT are found to cause respiratory problems which lead to inflammation and fibrosis [14]. Nano fillers that persist for a long time period can have significant impacts on the ecosystem harming the soil and water quality.

### FUTURE PROSPECTS

PLA and nano filler technology is being explored to bring out the best of them to produce high quality functional materials. Smart and responsive composites are one of the trends that are being researched whereby the incorporation of nano fillers into PLA will make the nanocomposites respond to external stimuli such as temperature, pH or water [23].

Industrial applications are increasingly utilising PLA for food packaging due to its potential for enhanced properties without compromising biodegradability. This improved versatility, coupled with eco-friendly practices, can significantly contribute to a greener environment by promoting PLA as a sustainable alternative to conventional plastics, particularly in packaging [24].

### CONCLUSION

PLA biodegradable green packaging reinforced with nano fillers has all the potential to be a substitute for conventional plastics highlighting its bio-friendly nature. There might be certain limitations such as brittleness when it comes to using PLA on its own without modifying which can be solved by the addition of nano fillers. The bigger aspect of the challenge can be presented in terms of industrial and market scale addressing issues such as cost implications and also health risks involving nanocomposites production. However, all these limitations need proper further research not only scientifically but also from a marketing perspective to promote PLA reinforced nano fillers as sustainable green nanocomposites.

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