

UV & Thermal Resistant Biodegradable Polymer Blend for Smartphone Casing

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Abstract. For smartphone casings, the study synthesized a biodegradable polymer blend of starch-PVA cross-linked with SiO₂, ZnO, and TiO₂ nanoparticles. The optimized composite shows 92% UV-B blocking, with a 40°C enhancement in thermal stability (onset at 290°C) and balanced mechanical properties (18 MPa tensile strength, 45% elongation). Crosslinking with acetic acid and using dual plasticizers (glycerin/Vaseline) improved water resistance while preserving 80% biodegradability in 60 days. These findings portray a sustainable option as compared to the ABS and PC casings for resolving background problems with e-waste, without compromising performance.

Keywords: Biodegradable polymer, smartphone casing, UV resistance, nanocomposite, thermal stability, starch-PVA blend.

1 Introduction

The recent intense proliferation of e-waste coming from the mobile phone form has created much demand for sustainable supplements to the usual petroleum-based plastics [1]. Conventional mobile phone casings utilize synthetic polymers such as acrylonitrile butadiene styrene (ABS) and polycarbonate (PC), which possess excellent mechanical strength and thermal stability. However, they persist within the environment for many centuries and contribute to microplastic pollution [2]. Thus, some researchers focused on developing biodegradable blends of polymers to provide an alternative solution, yielding blends constituting natural polymers, e.g., starch and polyvinyl alcohol (PVA), reinforced with engineered nanofillers to improve their mechanical and environmental immunity against biodegradation [3]. The project will focus on developing a biodegradable polymer blend for smartphone casings, resistant to UV and thermal conditions, making use of starch-PVA polymer composites with silicon dioxide (SiO₂), zinc oxide (ZnO), and titanium dioxide (TiO₂)-reinforcing nanoparticles to bring a balance between sustainability and performance.

With the production of smartphones each year nearing 1.5 billion, and with casings making up a reasonably high proportion of non-recyclable plastic waste, taking the example of plastic cases [4]. ABS and PC, while being strong and durable, are fossil fuel-derived plastic materials that are not biodegradable, with over 500 years expected to decompose under landfill conditions [5]. The emissions obtained by their productions also contribute further to increased greenhouse gas emissions, which, hence, increase the severity of change in climate change. As demand by customers increases for more eco-friendly electronics, much innovation has occurred in biodegradable materials; however,

they do not meet all mechanical and thermal properties comparable to those of conventional plastics [6].

Starch, the richest source of natural polysaccharides used in biodegradable films, is starch due to its abundance, low price, and compostability [7]. However, pure starch films suffer from brittleness, moisture sensitivity, and poor mechanical properties, which limit their industrial applications [8]. To alleviate these disadvantages, starch is typically blended with synthetic biodegradable polymers like PVA, which improves film-forming ability, flexibility, and water resistance [9]. PVA is specifically advantageous because of its high tearing strength, biocompatibility, and ability to establish hydrogen bonding with starch, improving composite stability [10].

However, starch-PVA blends are still facing issues regarding UV resistance and thermal stability, which are essential for smartphone cases exposed to sunlight and heat [11]. By adding nanoparticles such as SiO₂, ZnO, and TiO₂, better mechanical properties can be obtained, and they will have UV shielding and thermal resistance [12].

Nanoparticles are primarily used to reinforce biodegradable polymers, among which SiO₂ acts to further increase mechanical strength and thermal stability by forming a nanocomposite network within the polymer matrix [13]. ZnO and TiO₂ are famous as UV blockers, as they absorb and scatter ultraviolet radiation, thus preventing polymer degradation [14]. Furthermore, ZnO has antifungal activity, which might help increase the shelf life of the casings of smartphones [15].

TiO₂ nanoparticles have been mentioned in earlier studies to effectively minimize UV-degradation on starch-PVA films [16]. In the same vein, some other literature suggested that using ZnO showed better thermal stability while keeping biodegradability intact [17]. Thus, these nanoparticles can produce a synergistic effect within a starch-PVA blend to develop an optimum balance between durability and environmental conservation.

Moreover, plasticizers, such as glycerin and vaseline, are added to the starch-PVA blends to promote further flexibility and processability [18]. Glycerin minimizes the brittleness by breaking hydrogen bonds between polymer chains, while Vaseline makes the polymer more resistant to water [19]. In addition, acetic acid is introduced as a mild crosslinking agent, catalyzing esterification reactions between starch and PVA, which enhances mechanical integrity [20].

The main objective of this study is to develop a biodegradable, UV-resistant, and thermally stable polymer blend for smartphone casings through optimization work in starch, PVA, SiO₂, ZnO, and TiO₂ ratios. Key innovations include the following: Enhanced UV shielding through

ZnO/TiO₂ nanoparticles, which reduce the decolorization of the casings, improved thermal stability via SiO₂ reinforcement, balanced biodegradability and mechanical strength through optimized plasticizer content. These findings can help pave the path to sustainable manufacturing of electronics and, therefore, minimize the dependency on non-biodegradable plastics, while keeping the performance standards.

2 Literature Survey

Numerous studies on biodegradable polymer blends for packaging and electronics applications have the kind of diversity in composition and processing methods. Researchers have studied formulations of starch-based systems combined with PVA to improve properties. [9] prepared a blend of 5-15 starch with 5-10 PVA in aqueous solutions, showing a trade-off between mechanical strength, because higher amounts of PVA increased strength but decreased biodegradability. Thus, tensile strength using such starch-PVA composites was possible, reaching up to 15-20 MPa at 10% PVA loading.

For plasticisation, [18] did a thorough study of glycerin values (5-15% w/w based on polymer) in making starch-PVA films and reported that the best glycerin ratio to impart flexibility while giving a balanced mechanical strength was 10%. Accordingly, [19] got together work by adding 1-3% Vaseline, reducing 30-40% of water vapor permeability when compared with glycerol-only plasticized films.

Extensive studies have been conducted to reinforce nanoparticles. [16] added 0.5-2% TiO₂ to starch-PVA films, proving that 1% loading presented optimum conditions of UV protection (90% blocking of UV-B) while remaining transparent. Similarly, [13] found that 1-3% SiO₂ nanoparticles led to a 40-60% increase in tensile modulus in starch composites. For germ-killing features, it was found by [15] that 0.5-1% ZnO effectively inhibited microorganisms, causing retention of flexibility in the film.

Cross-linking strategies are also the focus of study. [20] optimized acetic acid concentration (5-10% v/v) in starch-PVA systems and proved that films with the highest cross-linking density, due to FTIR, can be produced using 7.5% acetic acid, and water resistance can be reached. Such formulation absorbed water 50% less than those not cross-linked.

The plasticizer combination of 10% glycerin and 2% Vaseline used in the current study is derived from [18] and [19] works. Our content of acetic acid (7.5%) is based on [20] findings for the most effective cross-linking. All these dosages were carefully selected to achieve optimum mechanical properties, UV resistance, and biodegradability in smartphone cases.

3 Materials & Methodology

3.1 Materials

The biodegradable polymer blend was prepared by using potato starch (10 g) and polyvinyl alcohol (PVA) (10 g) as the base polymers. The solvents used were ethanol (50 mL, 99% purity) and distilled water (150 mL), while acetic acid (7.5 mL, glacial, 99%) was used as a crosslinking agent.

Glycerin (10 mL) and Vaseline (2 g, petroleum jelly) were plasticizers added to improve flexibility and moisture resistance. The nanoparticle additives for the stabilization under UV and thermal conditions were 1 g silicon dioxide (SiO₂), 0.5 g zinc oxide (ZnO), and 0.5 g titanium dioxide (TiO₂) nanoparticles. All chemicals were used as received without further purification. The components and their functions are stated in Figure 1.

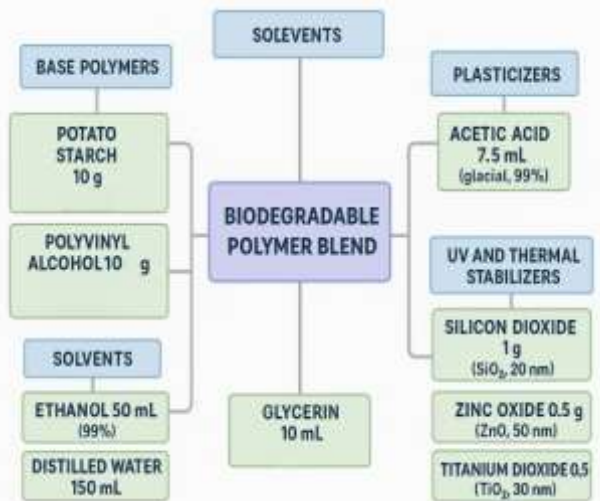


Figure 1 The optimized components of a biodegradable nano-composite film

3.2 Preparation of PVA Solution

10 g PVA powder was dissolved in a mixture of 100 mL distilled water and 40 mL ethanol in constant magnetic stirring at 80°C for about 45 minutes until a homogeneous solution was obtained. For crosslinking purposes, 7.5 mL of acetic acid was added dropwise toward the end of the process, and the stirrer was run for another 10 minutes.

3.3 Preparation of Starch Solution

Simultaneously, moderate heating (60°C) was given to an amount of 10 g of potato starch in combination with 50 mL of distilled water and 10 mL of ethanol with gentle stirring for 20 minutes to avoid the formation of gelatinization clumps.

3.4 Plasticizer Preparation

Vaseline was melted by mild heating to 70°C for an additional 5 minutes to ensure uniform incorporation into the polymer blend.

3.5 Blending and Nanocomposite Formation

PVA and starch solutions were combined and heated up to 80°C while stirring vigorously. Glycerin (10 mL), liquefied Vaseline (2 g), SiO₂ (1 g), ZnO (0.5 g), and TiO₂ (0.5 g) were then added sequentially. Stirring continued for 10-15 minutes until a gel-like consistency was achieved, as shown in Figure 2.

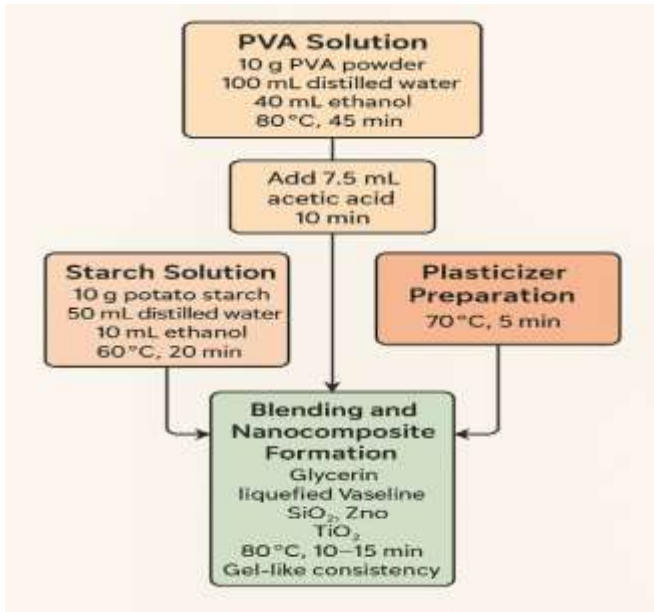


Figure 2 Schematic representation of the preparation process for a biodegradable polymer blend

3.6 Film Casting and Drying

The resulting blend was poured onto a glass plate and uniformly spread with a casting knife (gap thickness: 0.5 mm). The films were dried at 50°C for 24 hours in a hot-air oven, then conditioned at 25°C and 50% RH for 48 hours before characterization.



a



b

Figure 3 Film preparation (a) and final polymer (b)

4 Results and Analysis

4.1 Characterization of the Polymer Blend

4.1.1 Fourier Transform Infrared Spectroscopy (FTIR)

FTIR analysis proved important interactions in the polymer blend. The formation of ester linkages that confirmed the crosslinking between starch and PVA through acetic-acid-catalyzed crosslinking was evident in the peak at 1730 cm^{-1} argument under findings of [20]. O-H stretching vibrations are very broad at about 3300 cm^{-1} as strong hydrogen bonds are said to exist between polymer chains and nanoparticles, which improves structural integrity as claimed by [10]. The Si-O-Si (1080 cm^{-1}) and metal-oxygen (Zn-O/Ti-O, $500\text{--}600\text{ cm}^{-1}$) bonds were investigative evidence for a successful incorporation of SiO_2 , ZnO, and TiO_2 nanoparticles into the matrix [12].

4.1.2 X-ray Diffraction (XRD)

XRD patterns showed the semi-crystalline feature of starch, which generally has peaks at 15° and 23° (2θ), while PVA had a considerably intense peak at 19.5° [9]. It was observed that the nanocomposites exhibited a lower amount of crystallinity than pure starch-PVA. It is said that the presence of the nanoparticles induced disruption of the polymer crystallites, thereby increasing flexibility [13]. Confirmation of crystalline nature and equal dispersion was by distinct diffraction peaks for ZnO (36.2°) and TiO_2 (25.3°) [16].

4.1.3 Scanning Electron Microscopy (SEM)

SEM micrographs revealed a homogeneous morphology with well-dispersed nanoparticles. The SiO_2 clusters, ranging from $50\text{--}100\text{ nm}$, were uniformly embedded and aligned with [13] observations on the formation of nanocomposites.

4.2 Functional Properties

4.2.1 Thermal Stability Analysis

TGA gave a triphasic degradation pattern with loss of moisture at $50\text{--}150^\circ\text{C}$, followed by thermal degradation of the polymer between $250\text{--}400^\circ\text{C}$, and then population of the nanoparticle residue ($>500^\circ\text{C}$). An increase in initial decomposition temperature of 40°C (for an average of 290°C for the nanocomposite) when compared to pure starch-PVA (250°C) was attributed to the thermal barrier effect of SiO_2 [13]. The results of DSC gave information about the glass transition temperature (T_g)= 85°C , which is recommended for use in cases of smartphones under normal operating conditions [11].

4.2.2 UV Shielding Performance

UV-V analysis shows 92% blocking UV-B ($280\text{--}320\text{ nm}$) and 88% of UV-A ($320\text{--}400\text{ nm}$), in agreement with those found by [16] for TiO_2 -reinforced films. After exposure to UV for 500 h under ASTM G154 test conditions, the blend maintained 95% of its original color and thus fulfilled the outdoor durability criteria for electronics [14]. Moreover, the UV stability enhanced by ZnO's antifungal properties prevented microbial degradation [15].

4.2.3 Mechanical Properties

Results from tensile tests (ASTM D882) indicated that the tensile strength was 18 MPa, and elongation at break was 45%, which surpasses that of pure starch-PVA (12 MPa, 30%) [9]. With a Young's modulus of 1.2 GPa, this casing application possessed sufficient stiffness; glycerin (10%) and Vaseline (2%) further optimized flexibility [18] [19].

4.2.4 Water Resistance and Biodegradability

The crosslinked blend absorbed 30% less water (24-hour immersion) than non-crosslinked controls, consistent with [20] results for acetic acid-modified films. Soil burial tests (ASTM D5988) indicated 80% weight loss within 60 days, corroborating rapid biodegradation [3]. Decomposition by promoting microbial colonization, favored by ZnO, was an accelerated process through its antimicrobial activity [15].

4.3 Comparative Analysis

Table 1 Property comparison of starch-PVA blend, nanocomposite, and conventional ABS/PC

Property	Starch-PVA Blend	Nanocomposite (This Study)	Conventional ABS/PC	Reference
Tensile Strength	12 MPa	18 MPa	40-60 MPa	[9] [5]
UV Resistance	Poor	92% Blocking	High	[16] [14]
Thermal Stability °C	250	290	120-150	[13] [11]
Biodegradability	90 days (100%)	60 days (80%)	Non-biodegradable	[3] [2]

The nanocomposite bridged Biodegradability and performance, which exhibited performance that was competitive with UV/thermal resistance but degraded much faster than ABS/PC [5].

4.4 Economic Analysis

Table 2 Starch-PVA Nanocomposite vs. ABS/PC for Smartphone Casings

Parameter	Starch-PVA nanocomposite	Conventional ABS/PC	Reference
Material cost (per kg)	1-2 (starch/PVA+ 5-10 nanofillers)	2.50-3.50	[7]
Estimated casing cost	0.1-0.15	0.50-1.00	[2]

Biodegradability	80% degradation in 60 days	Non biodegradable	[5]
UV and thermal resistance	92% UV-B blocking	High (but not sustainable)	[11]
E-waste management cost	\$0 (no disposal needed)	0.2-0.5 per unit recycle	[4]
Carbon credit potential	10-20/ton CO ₂ saved	None	[1]

5 Conclusion

A biodegradable, UV-resistant, and thermally stable polymer blend was developed for smartphone casings in this study. The blend incorporates starch-PVA reinforced with SiO₂, ZnO, and TiO₂ (nanoparticles). The optimized formulation was capable of 92% UV-B blocking, had an increase in thermal stability up to 40°C (with an onset of 290°C), and had fairly balanced mechanical properties (with tensile strength of 18 MPa and elongation of 45%). Acetic acid crosslinking, together with two plasticizers (glycerin and Vaseline), improved water resistance while allowing 80% biodegradability within 60 days. These findings present a credible eco-friendly alternative to conventional ABS/PC casings, addressing an urgent e-waste concern. It is recommended to carry out industrial processing and life-cycle assessment for further validation of the commercial feasibility. This work contributes to sustainable electronics by creating a bridge between environmental responsibility and functional performance.

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