

CHAPTER

4

NANOCELLULOSE REINFORCED POLYPROPYLENE COMPOSITES

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4.1 SUITABILITY OF NANOCELLULOSE FOR REINFORCING POLYPROPYLENE COMPOSITES

Nanocellulose (NC) refers to cellulose materials that possess one or more dimensions at the nanoscale. It can be derived from a range of sources, including plants, animals, and microorganisms. Based on structural form and morphology, nanocellulose can be categorised into several types: nanocrystalline cellulose (NCC), nanofibrillated cellulose (NFC), bacterial cellulose (BC), electrospun cellulose nanofibres (ESC), and regenerated cellulose nanofibres (RC). Among them, nanocellulose whiskers (NCW) are rod-shaped particles typically measuring 5–10 nm in diameter and 100–400 nm in length, generally produced via acid hydrolysis of plant fibres. The use of sulphuric acid during hydrolysis introduces sulphate groups onto the surface of NCC. NFC, which includes both crystalline and amorphous regions, is produced through mechanical disintegration following chemical or enzymatic pretreatment, such as TEMPO-mediated oxidation.

Nanocellulose, particularly NCC and NFC, is a promising reinforcing filler due to its outstanding properties, including low density, high purity, large aspect ratio, extensive surface area, high tensile

strength, elevated elastic modulus, abundant hydroxyl groups, low toxicity, and good biocompatibility.

Polypropylene (PP) is a widely used polyolefin known for its excellent mechanical properties, ease of processing, and superior electrical insulation. It finds extensive application in household products, packaging, automotive components, electronics, and military systems. With its ever-expanding usage, the demand for high-performance PP continues to grow. One common strategy to enhance PP properties is the incorporation of fillers. Inorganic fillers can increase mechanical strength, wear resistance, and thermal stability. However, inorganic fillers tend to increase the density of PP composites, often two to three times higher than that of the base polymer, leading to higher transportation costs and labour intensity. Although materials like carbon nanotubes and graphene provide lower-density alternatives, their high cost limits commercial viability. Additionally, composites reinforced with inorganic fillers generally lack biodegradability.

Recent research has focused on the development of lightweight, high-performance, and environmentally friendly PP composites. This is particularly relevant for the automotive sector, where reducing vehicle weight is essential to improve fuel efficiency and lower greenhouse gas emissions. These goals can be achieved by modifying the base material, employing low-density fillers, and optimising processing techniques.

Cellulose-reinforced PP composites offer a compelling alternative due to their lightweight nature, excellent mechanical performance, sustainability, and recyclability. These materials can reduce the weight of automotive parts by up to 25% compared to traditional components. For instance, PP composites reinforced with 30% cellulose fibres have shown tensile strengths between 43 MPa to 58 MPa, flexural modulus of 5.5 GPa, and impact strength of 50 kJ/m² (Sayeed et al., 2023). Such composites have the potential to replace glass fibres in various structural applications. Furthermore, the integration of 30 wt% pre-fibrillated cotton fibres via in-situ fibrillation and compounding have increased the tensile modulus from 1.60 GPa (neat PP) to 4.59 GPa and improved impact strength from 2.46 kJ/m² to 2.84 kJ/m² (Liang et al., 2023).

Recent studies further confirm the mechanical and thermal performance enhancement of PP through NC reinforcement. For example, incorporating 5 wt% of spray-dried nanocrystalline cellulose (SD-NCC) via a two-step melt-blending technique achieved a tensile strength of 34.1 MPa, flexural strength of 57.3 MPa, and impact strength of 1.96 kJ/m². The thermal degradation onset temperature increased from 420.3°C (neat PP) to 426.1°C, suggesting improved thermal stability (Sabaruddin et al., 2025).

In another study, the addition of 2 wt% NFC and 0.1 wt% Fusabond increased tensile strength by 38% and Young's modulus by 87% (Yakkan et al., 2018). Similarly, reinforcement with 3.5 wt% of silylated NFC enhanced tensile strength by 12.6%, impact strength by 86.1%, and hardness by 7.4% (Kahawita et al., 2018). Maleic anhydride-grafted PP has also been utilised as a compatibiliser, further enhancing the tensile properties and thermal stability, as evidenced by an increase in the degradation onset temperature from 400°C to 420°C (Benchikh et al., 2024).

The NC has thus gained recognition as a lightweight, high-strength, and eco-friendly filler for PP composites. These composites present a cost-effective, high-performance solution for applications across the automotive, aerospace, and consumer goods sectors. Nonetheless, challenges remain in achieving uniform NC dispersion in PP due to inherent incompatibility, which researchers continue to address via surface modifications of NC. This chapter reviews recent progress in PP nanocomposites reinforced with NC and discusses ongoing challenges and future opportunities in this rapidly evolving field.

4.2 ROLE OF NANOCELLULOSE IN POLYPROPYLENE COMPOSITES

Numerous studies have reported significant enhancements in NC/PP composite properties compared to neat PP. These improvements include increased tensile strength, stiffness, and thermal performance, making the composites more competitive for industrial applications. NC