Utilization of waste cellulosic fibers and fines toward high-performance polypropylene composites: Effects of compatibilizer and compounding speed

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Abstract

This study investigated the feasibility of transforming waste cellulosic fiber and fines (WCFF) from the pulp and paper industry into value-added products in the form of high-performance polypropylene (PP) composites. PP and cellulose-based reinforcement composite systems suffer from incompatibility and uniform mixing challenges. Polypropylene is a non-polar hydrophobic polymer, while cellulose is a polar, hydrophilic material due to the abundance of hydroxyl groups. To enhance the compatibility and mixing of PP/WCFF composites, this research studied the effects of compatibilizer content and compounding screw speed on various thermomechanical and physical properties of the composites. PP was compounded with 20 wt.% WCFF at the presence of varying percentages of maleic-anhydride grafted PP (MA-g-PP: 0-5 wt.%). The compounding was conducted in a twin-screw extruder at three screw speeds of 300, 600, and 900 rpm. The composites' rheological, mechanical, thermal, density, and water absorption behaviors were thoroughly evaluated. The results showed that incorporating MA-g-PP into the PP composite at an optimal amount of 3 wt.% increased the tensile strength and tensile modulus, while reducing viscosity and water absorption. Crystallinity was also slightly increased with the addition of MA-g-PP, probably because of the increased crystal nucleation sites due to a better WCFF dispersion state. The screw speed also revealed significant effects on the mechanical behavior, viscosity, and crystallinity while no significant effect was observed on the thermal decomposition behavior, water absorption, and density. Overall, lower screw speed favored more enhanced mechanical properties. The optimal performance was achieved with 3 wt.% MA-g-PP and a screw speed of 300 rpm, which improved fiber dispersion and minimized fiber breakage and thermal degradation, resulting in a tensile strength of 41.29 MPa and modulus of 3,207.03 MPa—an improvement of 27.24% and 37.69%, respectively, compared to those of pure PP. This work suggests that optimized formulation and compounding processes can deliver significantly enhanced performance in PP with the incorporation of waste cellulosic materials toward developing more sustainable composites.

Keywords: Cellulose, Waste, Compatibility, Recycling, Composite, Processing, Sustainability.