Damage of the Cell Wall During Extrusion and Injection Molding of Wood Plastic Composites

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Abstract

To study material damage in wood cells during any transformation process, one must consider the molecular architecture of natural cellulosic fibers, which may eventually impact the overall mechanical behavior of wood fibers. In particular wood species, anatomical features and mechanical properties of the cell wall may determine the potential for stress transfer in hybrid materials. The wood cell damage was quantified in terms of the stiffness reduction of the S2 layer by measuring Young’s modulus with nanoindentations before and after processing. A modified rule of mixture based on a damage parameter affected by the latewood proportion and cell wall properties was proposed and validated.

Keywords: A. Wood, C. Damage mechanics, B. Mechanical properties, A. High density polyethylene.
Introduction

Wood cell architecture may suffer significant changes due to loading, heating conditions and physical-chemical environments during WPC (wood plastic composites) production. Extreme processing conditions may induce structural damage of wood flour particles, evidenced as bucking, cellular collapse and eventually fracture in cell walls, and consequently a poor reinforcement of the thermoplastic phase. Inside the primary wall of wood cells is the secondary wall, composed of a thin outer layer (S1), broad central layer (S2), and thin inner layer (S3). The S2 layer represents the major component of the cell wall, and its microfibrils are more longitudinally directed, explaining its relevance in terms of the mechanical properties of the cell wall and of wood [5-6-7]. This cell ultrastructure of the natural filler for WPCs may be altered in processing, resulting in plastic flow and eventually fracture at the microfibril or nanoscale level. In related literature, damage to composites is referred to as failure of the fiber-matrix interface, matrix cracking or crazing, fiber breaking and void growth [1]. Geimer, et al. studied damage in wood composites [2] and found no microscopic internal damage during the flaking process to produce flakeboards; but, the flakes did suffer internal damage during hot pressing resulting in lower mechanical properties, and evidenced in buckling, shearing and bending failure, most frequently in earlywood. More research needs to be done to quantify the actual damage in WPC, particularly in the filler material. In our research, we quantified wood cell damage in terms of the stiffness reduction of the S2 layer for the cell wall by measuring Young’s modulus with nanoindentations on the cell wall before and after processing.

Materials and Methods

In this study, we determined nanomechanical and localized properties (mainly of the S2 layer and middle lamella) before processing solid wood samples. We also established the potential decrease in mechanical properties for wood and proposed a modified rule for mixture.

Materials. Two wood species, Grand fir (GF) and Lodgepole pine (LP) were used to produce wood flour and composites with HDPE (high density polyethylene, Equistar LB 0100-00) as the matrix. Ponderosa pine and polypropylene (PP) were then used to validate the proposed model. The lubricant, Strucktol TPW113, was added to the formulation.

Nanoindentation on solid wood. A Triboscope Hysitron Nanomechanical test instrument was used to quantify the mechanical properties of the cell wall. Indentations were performed in earlywood and latemwood cells, and also in the middle lamella of solid wood samples. A Berkovich-type triangular pyramid indenter was used in a loading cycle with 300 μN nominal force. In an individual indentation experiment, the peak load (P_{max}), the depth at peak load (h) and the initial unloading stiffness (S), which is the slope of the unloading curve, were obtained. The geometry of the indenter and h, the contact area (A) was also calculated. Then, the reduced modulus (E_r) is determined according