PLASTICIZING CELL WALLS AS A STRATEGY TO PRODUCE WOOD-PLASTIC COMPOSITES WITH HIGH WOOD CONTENT BY EXTRUSION PROCESSES

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A challenge in producing wood-plastic composites (WPCs) with a high wood content using extrusion processes is the poor processability, which gives rise to inadequate properties of the resulting WPC. Plasticizing the stiff wood cell walls can be a strategic response to this challenge. Two thoughts are addressed herein on improving the plasticity of wood particle cell walls: use of ionic liquids or use of low molecular weight organic thermal conductors. An ionic liquid can dissolve the cell wall surface and therefore reduce the stiffness of cell wall during an extrusion process. Organic thermal conductors can be incorporated into the cell wall (bulking) to improve the thermal conductivity, thereby sufficiently softening the lignin, a native plasticizer embedded in the cell walls. The potential issues that may arise as a result of these approaches are also presented and discussed.

Keywords: Wood; Plasticization; Wood plastic composites; Extrusion process; Ionic liquid; Lignin

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Challenges in Extruding WPCs with a High Wood Content

Extrusion processing is an approach to continuously produce wood-thermoplastic composites with various sectional shapes. Increasing the wood content has the potential to considerably reduce the cost and improve the environmental friendliness of WPC; however, this is accompanied with increased difficulties in the extrusion process, and one can expect reduced performance characteristics of the resulting WPCs. With the increased content of stiff wood particles, the friction within the partially molten composite material, as well as between the melt and the chamber inner wall in the extruder can significantly increase, which can result in a greater demand of driving power for the extrusion system and in a thermal degradation of wood particles due to partial overheating. Increasing the wood content will cause a reduced probability of wood particles being fully wrapped by the plastic. As a result, the resulting composites can suffer various issues related to mechanical strength, moisture sorption, dimensional stability, and susceptibility to fungal decay. One may ask, can improving the plasticity of wood cell wall during extrusion process be an efficient strategy to overcome these issues?

Techniques for Plasticizing Processes of WPC

1. Surface plasticization of cell walls using plasticizers

The traditional wood plasticizers such as water and ammonia are not applicable for the extrusion process of WPC due to their high vapor pressure. The workable plasticizers should have the characteristics of low molecular weight, strong hydrogen bonding ability, and high thermal stability. Recently, various imidazolium-based ionic liquids such as 1-allyl-3-methylimidazolium chloride have been reported to exhibit great ability in dissolving the wood/cellulose cell wall substance. Therefore, ionic liquids with appropriate melting temperatures can be technically used to improve the plasticity of wood particles in situ during extrusion processes of WPCs. Under high temperature and pressure, ionic liquids may dissolve or melt the surface of wood particles, thereby partially reducing the crystallinity (stiffness) of the cell walls. As a result, wood particles will yield under rotary shear stress and disperse more evenly within the plastic matrix. Of importance, the lost stiffness due to surface dissolution of cell walls can be partially recoverable once the extruded composite cools down. In addition, the wood particles collide with each other, and the dissolved surface substances may work as adhesives to bond the wood particles together under high temperature and pressure conditions in the extruder chamber, thereby forming a uniform association without an abrupt interface separating the phases; the plastic polymer chains can also penetrate into and entangle with the dissolved wood polymers on the surface. The improved interfacial adhesion can therefore compensate for the loss of stiffness of cell walls. Incorporation of ionic liquids can also impart anti-microbial and antistatic properties to the resulting composites, as well as improving the fire retardancy and resistance against fungal decay. However, high cost and leachability of ionic liquids are the main issues that impede their application in WPC processes. In addition, ionic liquids exhibit extremely high polarity and can absorb moisture from surrounding environment, which may cause dimensional instability of the resulting WPC. The presence of ionic liquids may also cause the formation of a weak interfacial layer between wood particles and plastic matrices.

2. Lignin of cell walls as natural plasticizer

Lignin accounts for more than 25% of the cell wall content of wood and exhibits a glass transition temperature of approximately 130 to 160 °C, which normally is below the temperatures (normally 170 to 210 °C) used for the WPC extrusion process. Therefore, lignin is native plasticizer embedded in the cell walls. If all of the lignin in the cell walls could be quickly softened, then the wood particles would exhibit plasticizing flow during the extrusion process. However, it is well known that wood is not a good heat conductor due to its porous nature, and the heat transfer rate will be relatively slow in cell wall interiors during extrusion compounding. Therefore, improving the thermal conductivity of cell walls may be a means of efficiently softening the lignin and consequently in plasticizing the stiff cell walls. Incorporation of organic monomers or low molecular weight oligomers with relatively high thermal conductivity into the cell walls can be an approach to raise the thermal conductivity of wood cell walls. The incorporated monomers/oligomers mainly become located in the micropores of the amorphous region and can move freely. As a result, the heat can be transferred inside of cell walls. The crystalline regions of cellulose are composed of highly ordered polymers and are not available to the incorporated movable chemicals; however, due to their high density, the crystalline regions should have a higher thermal conductivity than the amorphous regions. A main issue is that a high weight gain of chemicals may be required for wood cell walls to obtain sufficient improvement in the thermal conductivity of cell walls.