RECENT RESEARCH ACTIVITIES

Transparent paper: A paradigm from nanofibers to nanostructured fibers

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In the digital era, ample information is being exchanged through electronic media and the demand for high-quality, smart, and portable digital devices is increasing sharply. Because of its very low coefficient of thermal expansion and transparency, glass has up to now been used extensively in the substrates of electronic devices such as displays and solar cells. However, in modern flat panel display (FPD) technology and solar cell production, continuous “roll-to-roll” (RTR) processing using flexible plastic substrates is expected to take over from conventional “batch” processing of glass substrates. Plastic is no doubt a good choice for flexible displays and solar cells. However, practical RTR processing has so far been prevented by the high coefficient of thermal expansion (CTE) of the plastics to be used. One possible way to reduce thermal expansion while only causing a low loss in transparency would be to use fillers with a diameter significantly smaller than the wavelength of visible light. Nanofibers are believed to have the potential to substantially improve the mechanical properties of polymers.

Cellulose nanofibers 4 to 20 nm in width, the major component of the plant cell wall and the most abundant bio resources on earth, have received great interest because of their outstanding mechanical properties due to their high molar mass and highly ordered extended chain polysaccharide nanofiber structures. This makes it a preferable candidate for RTR manufacturing processes because no discrepancy between the CTEs of the different materials used will arise. However, nanofibers production is high in energy consumption. Therefore, we developed a low thermally expanded transparent film by exploiting wood fibers that can be considered to be nanostructured fibers in which individual nanofibers do not significantly agglomerate. We thereby demonstrate that paper, used since ancient times, will be a next-gen optical material.

After removing lignin and hemicelluloses from wood pups, generation of hydrogen bonding among cellulose nanofibers in the wood pulp must be avoided. In this study, the wood pulps were acetylated with much care taken to maintain a never dried state. Furthermore, we attempted internal fibrillation using bead-mill of the pulp before acetylation. The moisture content of untreated pulp and acetylated pulp did not even change after fibrillation. As a result, the fibrillated acetylated pulp composites (thickness: 50 µm, fiber content: 17.1%) displayed 84.2% light transmission at a wavelength of 600 nm, as shown in and Figure 1. Despite the heterogeneous structure consisting of pulp of some one-tenth micrometer in width, the difference in the regular optical transmittance compared with that of the acetylated cellulose nanofiber composites was small.

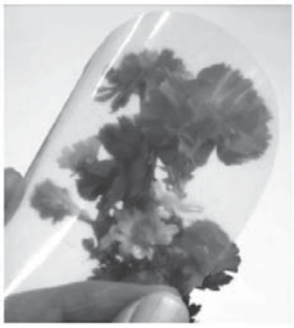
Figure 1. Wood pulp-based optically transparent nanocomposite.

The fibrillated acetylated pulp also enabled a reduction in the CTE of the composites. The addition of 24.5 wt% fibrillated acetylated pulp reduced the CTE of acrylic resin from 213 ppm/K to 13.1 ppm/K. This is 4 times more than the untreated pulp composites and 1.4 times more than the untreated fibrillated pulp composites. This is apparently due to the decrease in the number of fiber-fiber interactions caused by decreased intrafibrillar hydrogen bonding between pulps. However, interestingly, this value is comparable to the CTE of acetylated cellulose nanofiber-reinforced acrylic resin (12.1 ppm/K) with higher cellulose content such as 40%. This inspiring optically transparent and extremely low thermal expansion film could be fabricated through traditional paper manufacturing process, and thus is exceedingly closer to industrial application with prospects ready to be realized.

References

[1] Yano H, Sasaki S, Shams MI, Abe K, Date T, “Wood pulp based optically transparent film: A paradigm from nanofibers to nanostructured fibers”, *Advanced Optical Materials*, 2 (3), 231-234, 2014