Could aerogels from lignin-containing forest materials be used for cushioning in packaging systems?

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Cushioning materials are commonly used in packaging systems for storage and transport to provide support and to minimize damage from impact forces generated during sudden contact. For instance, they play an essential role in reducing losses from the orchard to the consumer. A 2009 article by Chen *et al.* reported on three alkali-based softening treatments to reduce the content of lignin and hemicellulose of cylindrical luffa to present a cushioning mattress. Notably, better comprehensive strength and recovery ability were obtained when the porous sample contained a moderate amount of lignin and hemicellulose. As a promising porous material, aerogels have favorable properties such as high surface area, low density, light weight, and high porosity with a three dimensional (3D) network, which have attracted much attention. In the process to prepare such an "aerogel from natural forest" (AFNF) materials, researchers typically have removed most of the lignin and hemicellulose to obtain ultralight AFNF with a high crystallinity index. So, taking inspiration from the cylindrical luffa study, it is proposed here that AFNF be used as cushioning material for packaging, and that the optimum lignin content might be much higher than previously envisioned.

Keywords: Aerogel; Cushioning packaging; Porous material; Recovery from compression

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Cushioning Materials for Packaging

A primary function of cushioning materials used in packaging is to reduce the magnitude of forces acting upon the contained items during transportation. More than that, a good ability to recover from compression is important to provide continuous protection. Furthermore, no harmful solvents should be released to the packed commodities during storage. The extent of moisture adsorption and response to temperature must be suitable for each application. If cushioning packaging materials prepared as an aerogel from natural forest (AFNF) materials meet these standards, they could be a good alternative to meet future needs. A recent study showed that biodegradable foam cushions can have good shock adsorption capacity and can also be recycled after their use (Sohn *et al.* 2019).

Preparation of AFNF

AFNF also has unique characteristics compared to other aerogels, including ultralight weight, biodegradability, and flexibility. These attributes can be expected to accelerate their wide potential use in absorbents, catalyst supports, supercapacitors, and sensors, *etc*. Cellulose is the reinforcing constituent of high strength and modulus in the cell walls of plant materials. There are also hemicellulose and lignin embedded in the matrix. In the preparation of AFNF from rice husk (Tadjarodi *et al.* 2012), coconut shell (Wan *et al.* 2015), or corn straw (Li *et al.* 2018), a large fraction of the hemicelluloses and most of the lignin components were first removed from the cell wall. During the chemical

processing, the crystalline cellulose became the dominant component and further self-assembled. After regeneration and freeze drying, AFNF was obtained. The solvents, temperature, and ultrasonic treatment directly affect the size of porous, surface area and mechanical properties. The porosity and crystalline index are commonly characterized. Also, it is well known that the presence of lignin can enhance the hardness and increase the hydrophobic properties. The contents and distributions of lignin, hemicellulose, and amorphous cellulose could cause differences in compressive deformation (Fig. 1). Therefore, the structure of AFNF could be tuned so as to meet the cushioning requirements of different commodities.

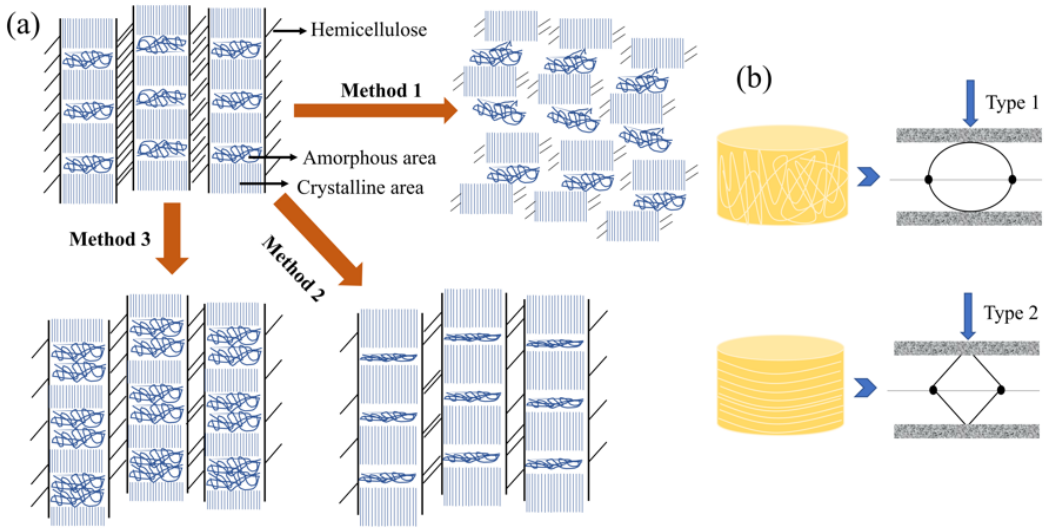

Fig. 1. Schematic of (a) different methods to remove hemicellulose and lignin from plant material, leading to structures having different nanostructure; (b) compressive deformation of samples with different structure (new drawing inspired by Chen *et al.* 2019)

Suggestion and Efforts

Dry aerogels containing moderately high levels of lignin can be obtained from plants including wood, agriculture crops, and the by-products of some crops using appropriate physical and chemical treatments. The processing technologies have been found to affect their chemical composition, porous structure, and the shape. Such attributes are essential for the strength and damping characteristics. Also, cushioning packaging materials from cylindrical luffa provide evidence that the *in situ* modification to prepare cushioning materials could also be suitable for wood forest materials because of their detailed multi-level structural organization, from fibers to a vascular system. Of course, the compressive strength or plateau stress and hydrophobic properties should be investigated relative to the requirements of different commodities. For instance, antibacterial or anti-mildew agents could also be imported into the porous material to avoid the poor fungus resistance. The high surface area of AFNF is expected to be advantageous for agents to be adhered. In summary, there appear to be bright prospects for use of aerogels from lignin-containing plant materials as the basis for preparing cushioning layers for packaging.

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References Cited

Chen, Y., Zhang, K., Zhang, T., Yuan, F., Su, N., Weng, B., Wu, S., and Guo, Y. (2019). "Effect of softening treatments on the properties of high-density cylindrical luffa as potential mattress cushioning material," *Cellulose*, 1-22. DOI: 10.1007/s10570-019-02766-6

Li, Y., Liu, X., Cai, W., Cao, Y., Sun, Y., and Tan, F. (2018). "Preparation of corn straw based spongy aerogel for spillage oil capture," *Korean Journal of Chemical Engineering* 35(5), 1119-1127. DOI: 10.1007/s11814-018-0010-3

Sohn, J. S., Kim, H. K., Kim, S. W., Ryu, Y., and Cha, S. W. (2019). "Biodegradable foam cushions as ecofriendly packaging materials," *Sustainability* 11(6), 1731. DOI: 10.3390/su11061731

Tadjarodi, A., Haghverdi, M., and Mohammadi, V. (2012). "Preparation and characterization of nano-porous silica aerogel from rice husk ash by drying at atmospheric pressure," *Materials Research Bulletin*, 47(9), 2584-2589. DOI: 10.1016/j.materresbull.2012.04.143

Wan, C., Lu, Y., Jiao, Y., Jin, C., Sun, Q., and Li, J. (2015). "Ultralight and hydrophobic nanofibrillated cellulose aerogels from coconut shell with ultra strong adsorption properties," *Journal of Applied Polymer Science*, 132(24), 42037. DOI: 10.1002/app.42037.