Flame-retardant, Mildew-Resistant Soy Adhesive for Foamed Wood and Other Wood Products

- Mid-term Report –

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1. Research overview and objectives

Engineered wood such as particle board, fiberboard, oriented strand board (OSB) and plywood are made by binding pieces of wood (wood flour, fibers, etc.) using adhesive under pressure and heat. Traditional formaldehyde-based adhesives have many advantages, including strong prepressing adhesion, high hot-pressing bonding strength, and good water resistance despite their environmental and human health hazards. Replacing these adhesives with green ones with similar performance is still challenging. This project aims to develop a fully bio-based, ambient temperature-curable soy protein adhesive with outstanding pre-pressing bonding strength, flame retardancy, and mildew resistance. The adhesive is formed through Schiff base reaction and coordination bonds using soy protein isolate (SPI), NaIO4 oxidized carboxymethyl cellulose (CMC) and tannic acid (TA), phytic acid (PA), and $CaCO_3$. The reaction and bonds synergistically impart the adhesive with high cohesive strength and strong wet adhesion. The intrinsic antimicrobial properties of TA and the inorganic crystals of $CaCO_3$ provide the adhesive with desirable mildew resistance. A high content of phosphorus from PA and nitrogen from SPI gives the adhesive good flame retardancy.

2. Completed work

(1) Preparation of SPI solution

20g SPI powder was mixed with 8 M urea solution to form a SPI/urea/water mixture with a 12 wt% SPI concentration. The mixture was magnetically stirred at 70 °C for 24 h to ensure complete dissolution.

(2) Preparation of adhesive

First, CMC (2g), PA (0.78g), TA (0.27g), and $CaCO_3$ (0.6g) were mixed with 16.8g SPI/urea/water mixture and stirred well to obtain the adhesive precursor. Then, $NaIO_4$ (0.8g) was added and the pH of the new mixture was adjusted to 9 using NaOH (2N) to obtain a gelled/cured adhesive system with appropriate viscosity.

(3) Characterizations

The gelation/curing of the adhesive was initially evaluated by observation of the adhesive's viscosity change before and after curing. The adhesive's potential to prepare particle boards was demonstrated by binding soy hull particles to form a preliminary particle board.

3. ***Progress of work and results to date***

To verify if the adhesive is ambient temperature-curable to provide excellent pre-pressing bonding strength, we initially compared the viscosity change of the adhesive before and after curing by direct visual inspection. As illustrated in Figure 1, when $NaIO_4$ was added to the adhesive precursor and pH was adjusted to 9, the mixture readily turned pink and viscous, indicating successful gelation of the adhesive. This is due to the oxidation of CMC and TA to form aldehyde groups. Schiff base reaction then occurred between amine groups of SPI and aldehyde groups of CMC and TA.

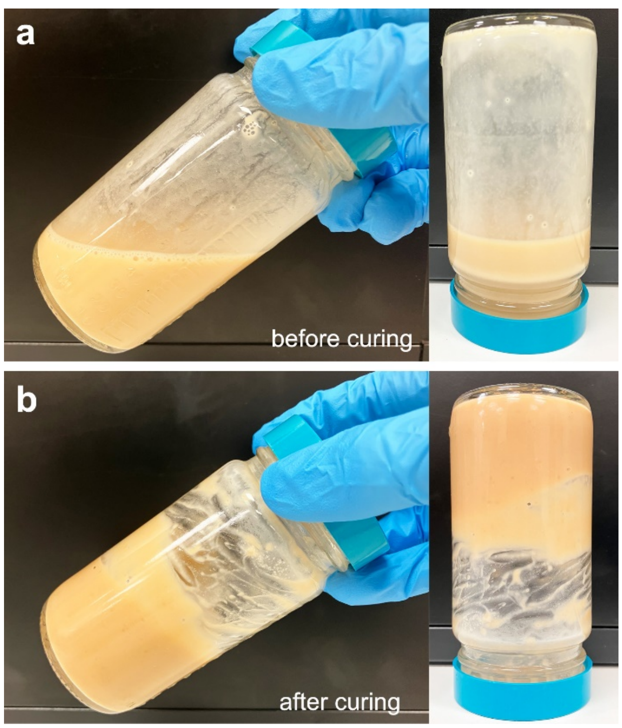

Figure 1. Photographs showing the ambient temperature-curable behavior of the adhesive before (a) and after (b) the addition of $NaIO_4$.

To verify the adhesive's potential to prepare particle boards, we blended it with soy hull particles, loaded the mixture into a cylindrical container, and placed it in an oven at 100 °C for 24 h (without any compression). As illustrated in Figure 2, the soy hull particles were successfully bonded into a solid piece resembling a particle board.

Figure 2. Photographs showing soy hull particles being processed into a cylindrical solid product after mixing with the adhesive and oven baking.

4. *Work to be completed*

Our hypothesis that *the mussel protein adhesion and the organic-inorganic hybrid adhesive system of oysters can be implemented on soy protein-based adhesives at the same time to improve their pre-pressing and wet adhesion strength* has been verified, and the potential of the adhesive for the production of particle boards has been demonstrated. We will carry out formulation studies to determine the optimal contents of all ingredients to achieve the best adhesion performance in the second half of the project. Adhesive viscosity and properties of the adhesive, including bonding strength (pre-pressing, after hot pressing, after soaking in water for 24h), mildew resistance, and fire retardancy, will be quantitatively characterized. Moreover, the adhesive's potential to be used to fabricate foamed siding and particle boards will be further investigated.

5. *Other relevant information*

We don't expect major hurdles in this research.

6. *Summary*

Preliminary results confirmed the feasibility of the proposed research idea, showing that the fully biobased soy protein resin can be cured under ambient temperature and has the potential to be used for the fabrication of particle boards.