PAPER PRESENTATION

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Research Article

Preparation and Investigation of a Fully Biobased Adhesive Composed of Gum Arabic and Soy Protein Isolate for Plywood

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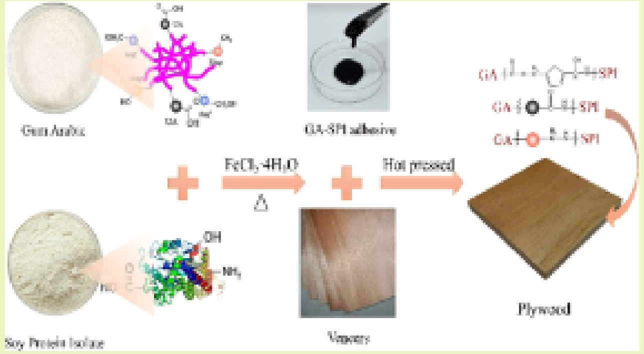
ABSTRACT: In this study, a novel, fully biobased adhesive (GA-SPI) was formulated by using gum arabic (GA) and soy protein isolate (SPI). The preparation conditions, curing behavior, synthesis, and curing mechanism of this adhesive were investigated. The results indicated that the optimized adhesive with a 1:1 (GA:SPI) mass proportion and 70% solid content was synthesized by adding 5% $FeCl_3 \cdot 4H_2O$ as catalyst at 90 °C for 2 h. When we tested the bonding ability of adhesive on plywood, the wet shear strength achieved 0.97 MPa, which exceeds the requirements of the China National Standard (≥0.7 MPa). The curing behavior of the GA-SPI adhesive was researched by measuring the insoluble mass proportion and conducting thermal analysis. The results showed that 55% insoluble mass proportion was obtained when the adhesive was heated at 170 °C for 10 min, and the endothermic reaction occurred at around 150 °C. To investigate the synthesis and curing mechanism of the GA-SPI adhesive, HPLC, ATR FT-IR, and Py-GC/MS analyses were utilized, and the results suggest that the hydrolysis of GA and Maillard reaction between GA, SPI, and hydroxymethylfurfural (HMF) occurred during the synthesis and curing process.



KEYWORDS: *gum arabic, soy isolate protein, eco-friendly adhesive, plywood*

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OUTLINE

- Introduction
- Terminologies
- Why this paper?
- Background work
- Results and Discussion
- Conclusions
- Future Directions

Figure 1. Photograph of the plywood bonded by gum arabic and soy isolate protein in the initial experiment.

INTRODUCTION

- Adhesives play a pivotal role in the fabrication of wood-based materials.
- The use of formaldehyde-based adhesives, notably urea-formaldehyde resin, accounts for ~ 98.4 % total consumption in China in 2021.
- Formaldehyde-based adhesives are known to pose serious health risks during utilization.
- To regulate these adhesives, plant based fully biobased adhesive can be a game changer in the field of adhesives.
- The use of Gum Arabic and Soy protein Isolate composite as adhesive for plywood manufacturing has been investigated.

INTRODUCTION

- Gum Arabic (GA) is a biopolymer exhibiting a remarkable property for easy water solubility, even at elevated concentrations forming a solution with low viscosity.
- The potential utility of saccharides and plant proteins as foundation materials for adhesive use is explored in plywood manufacturing.
- GA is a plant waste product comprising a complex amalgamation of polysaccharides (mainly composed of galactose, rhamnose and arabinose units), glycoproteins, and glycolipids.
- This investigation delved comprehensively into the optimal preparation conditions, curing behavior, synthesis, and curing mechanism governing the curing process of the resultant GA–SPI adhesive.

TERMINOLOGIES

- **Shear Strength**- The ability of material to resist the shear stress applied either vertically or horizontally without any breakdown.
- **Dry Shear Strength**- Resistance offered by material in dry state.
- **Wet Shear strength**- Resistance mainly towards water or moisture.
- **Mixing method**- The physical means of adding and forming a homogeneous mixture.
- **Synthesis method**- Chemical reaction happen between the constituent particles and individual component lose its identity.
- **Curing**- This is a method to crystallize out the component from liquid by the action of heat or light etc.
- **Wood failure**- It provides the adhere stability of wood fibers with adhesive. More the % of Wood failure suggests greater stability.

WHY THIS PAPER?

- ✓ There is a pressing necessity to seek a natural, fully biobased adhesive as a substitute for formaldehyde-based and synthetic chemical adhesives.
- ✓ The synthetic approach, including optimized conditions, has been investigated in conjunction with the examination of the prepared adhesive using various instrumental techniques while assessing its resistance to water and moisture.

BACKGROUND

polymers

MDPI

Article

Synthesis and Characterization of Sucrose and Ammonium Dihydrogen Phosphate (SADP) Adhesive for Plywood

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Development and investigation of a two-component adhesive composed of soybean flour and sugar solution for plywood manufacturing

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ABSTRACT

In this study, soybean flour (SF) and various sugar solutions were utilized as raw materials to prepare eco-friendly plywood adhesives. First, the optimal preparation conditions were investigated by testing the bond performance. When SF was mixed with synthesized sucrose-ammonium dihydrogen phosphate (SADP) solution with 50% solid content in a 1: 4 mass proportion, the wet shear strength of the plywood achieved a maximum value of 0.83 MPa. This value exceeds the minimum limit of China National Standard GB/T 9846-2015. Second, the curing behavior of the SF/SADP adhesive was studied by measuring the insoluble mass proportion and thermal analysis. The results showed that the curing reaction of this adhesive occurred near 170 ℃. In addition, the curing mechanism was studied by ATR FT-IR and Py-GC/MS analysis. Based on the results, it was concluded that the cured adhesive formed a network structure via a polycondensation reaction between small-molecule compounds derived from the SADP solution and the products of the caramelization and soy flour. Dimethylene ether bridges were the main linkages of the final polymer. SEM microstructure analysis showed that the cured SF/SADP adhesive exhibited a more compact crosslinked structure than cured SADP.

ARTICLE HISTORY
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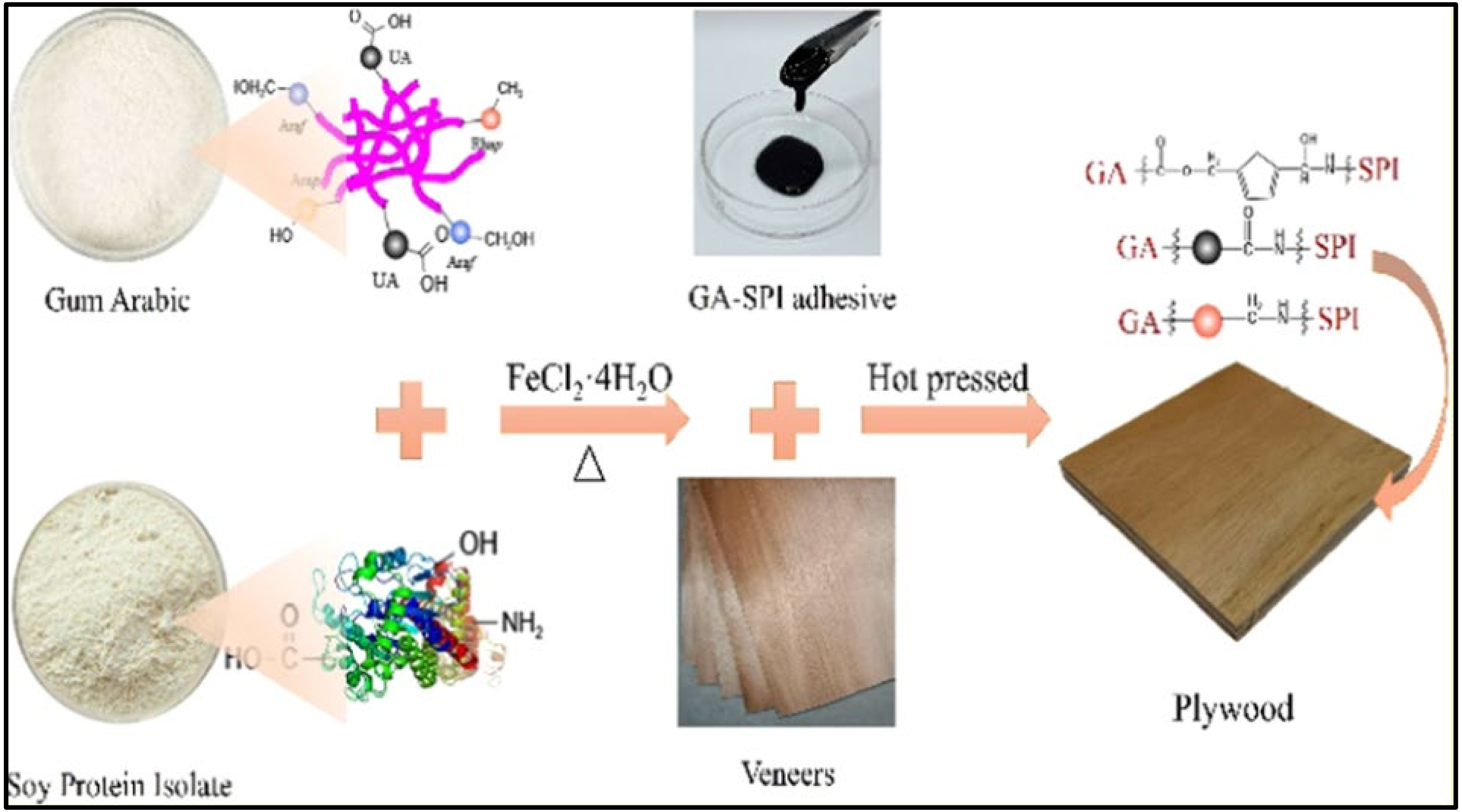
KEYWORDS
Soybean flour; eco-friendly adhesive; plywood; sucrose/ammonium dihydrogen phosphate

SYNTHESIS AND OPTIMIZATION



RESULTS AND DISCUSSION

Table 1. Detailed Information on GA-SPI Adhesives Prepared under Different Conditions

group	mass proportion (GA/SPI)	solid content of GA/SPI solution (wt %)	prepare method	viscosity (mPa·s)	pH
group 1	1/1	60	mixed at room temperature	5932	5.7
	2/1			10 212	5.7
	3/1			15 176	5.7
	4/1			21 250	5.6
	5/1			26 689	5.5
group 2	1/1	50	mixed at room temperature	2768	6.0
		60		5932	5.7
		70		13 181	5.0
group 3	1/1	70	mixed at room temperature	13 181	5.0
			synthesized at 90 °C for 1 h	13 262	5.5

Table 2. Detailed Information on GA-SPI Adhesives Prepared by Adding Catalyst

group	mass proportion (GA/SPI)	solid content of GA/SPI solution (wt %)	prepare method	catalyst	ratio of catalyst addition to GA-SPI solution (wt %)	viscosity (mPa·s)	pH
group A	1/1	70	synthesized at 90 °C for 1 h	oxalic acid ($H_2C_2O_4$)	10	7886	1.2
				phosphoric acid (H_3PO_4)		8067	2.1
				cupric sulfate ($CuSO_4$)		10 652	5.4
				ferrous chloride tetrahydrate ($FeCl_2 \cdot 4H_2O$)		7094	2.4
group B	1/1	70	synthesized at 90 °C for 1 h	ferrous chloride tetrahydrate ($FeCl_2 \cdot 4H_2O$)	0	13 262	5.5
					5	9185	3.4
					10	7094	2.4
					15	6342	1.1

RESULTS AND DISCUSSION

Table 3. Detailed Information on GA-SPI Adhesives Prepared under Different Synthesis Conditions

group	mass proportion (GA/SPI)	solid content of GA/SPI solution (wt %)	catalyst	ratio of catalyst addition to GA/SPI solution (wt %)	synthesis time (h)	synthesis temperature (°C)	viscosity (mPa·s)	pH
group a	1/1	70	$FeCl_2 \cdot 4H_2O$	5	1	90	9185	3.4
					2		11 965	3.6
					3		15 106	3.8
					4		22 250	4.2
group b	1/1	70	$FeCl_2 \cdot 4H_2O$	5	2	80	17 542	4.9
						90	11 965	3.6
						100	9337	3.0
						110	7205	2.9

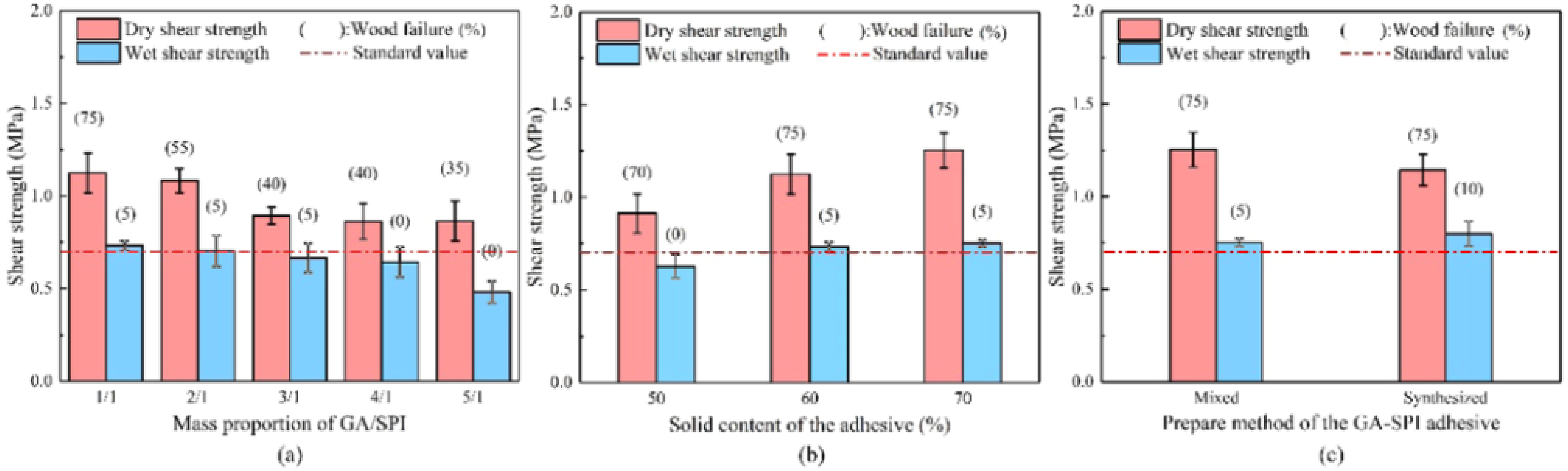


Figure 3. Effects of (a) mass proportion of GA/SPI, (b) solid content, and (c) preparation method on the bond performance of GA-SPI adhesive.

RESULTS AND DISCUSSION

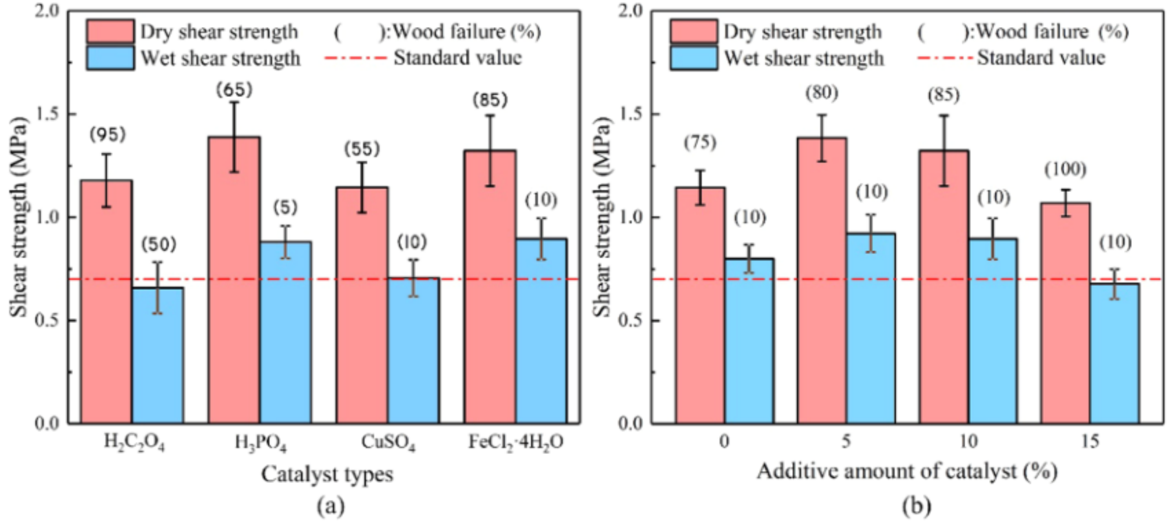


Figure 4. Effects of (a) catalyst types and (b) additive amount of catalyst on the bond performance of the GA-SPI adhesive.

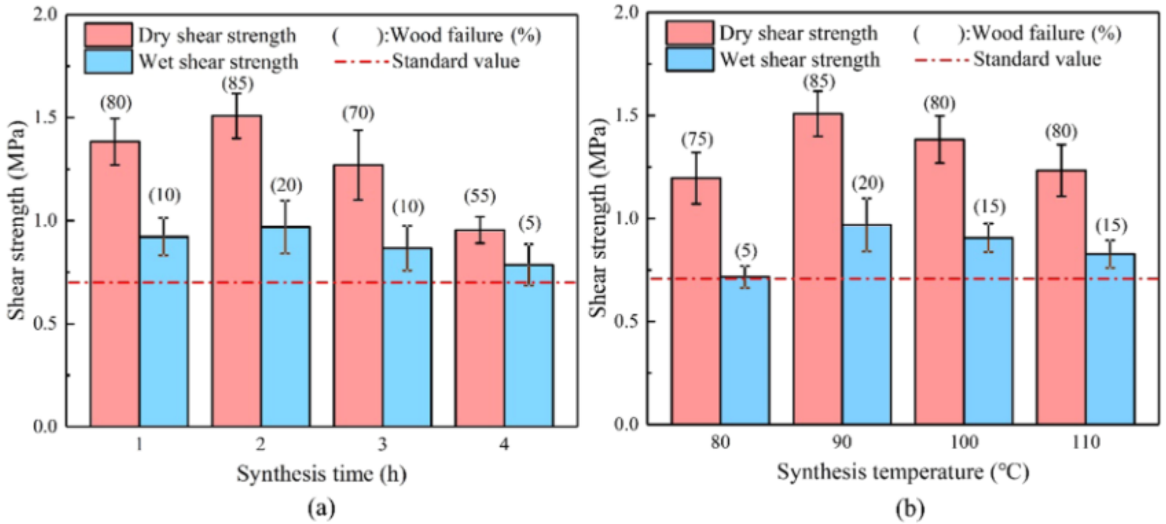


Figure 5. Effects of (a) synthesis time and (b) synthesis temperature on the bond performance of the GA-SPI adhesive.

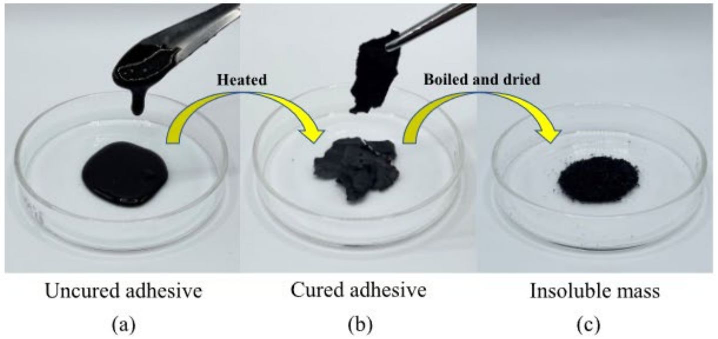


Figure 2. Schematic of the preparation process of insoluble substances from cured adhesive: (a) uncured adhesive, (b) cured adhesive, (c) insoluble mass.

RESULTS AND DISCUSSION

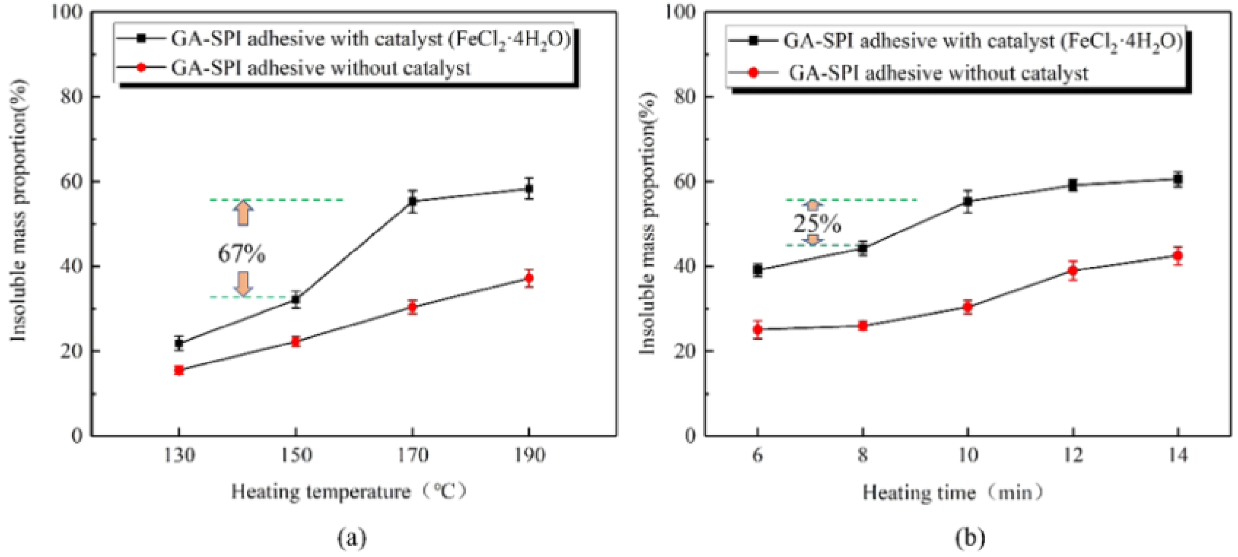


Figure 6. Insoluble mass proportion of GA-SPI adhesives with/without catalyst at various (a) heating temperatures and (b) heating times.

Table 4. HPLC Analysis Results of the Synthesized GA-SPI Adhesive with/without Catalyst

adhesives	galactose (g/L)	arabinose (g/L)	HMF (g/L)
GA-SPI adhesive without catalyst	144.9	64.3	4.5
GA-SPI adhesive with catalyst ($FeCl_2 \cdot 4H_2O$)	123.0	78.7	38.0

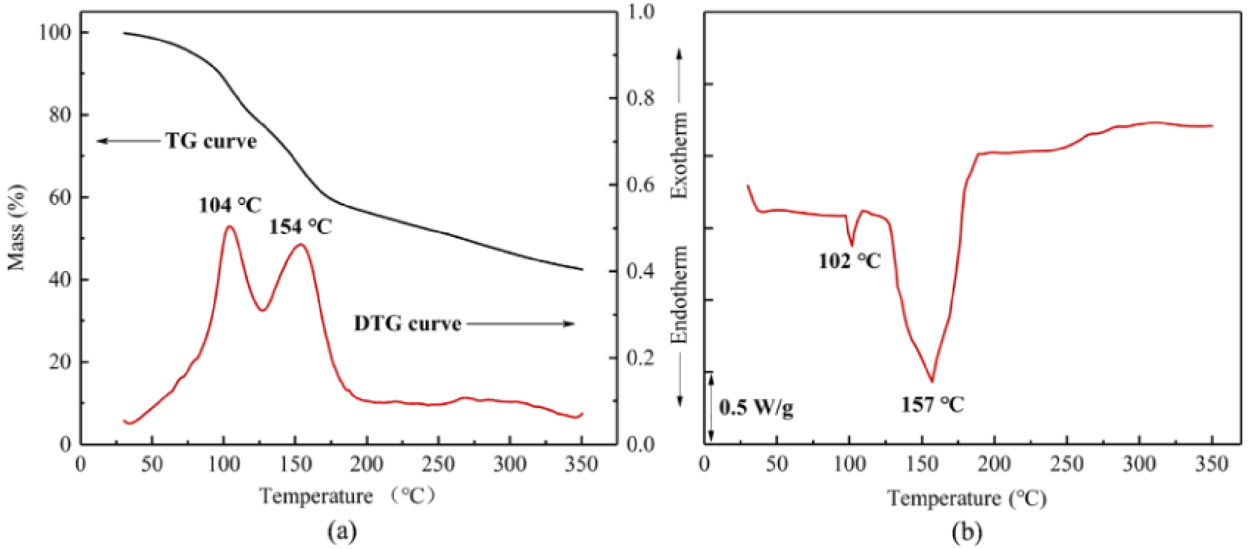


Figure 7. (a) TG and DTG, and (b) DSC curves of the GA-SPI adhesive.

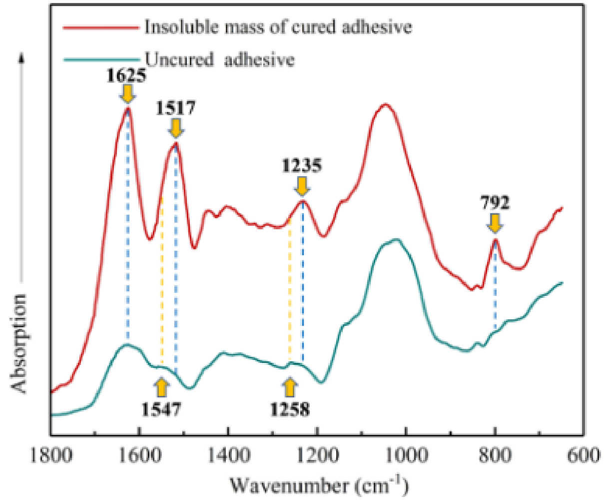


Figure 8. ATR FT-IR spectra of insoluble matter derived from the cured GA-SPI adhesive and uncured adhesive.

PLAUSIBLE REACTION

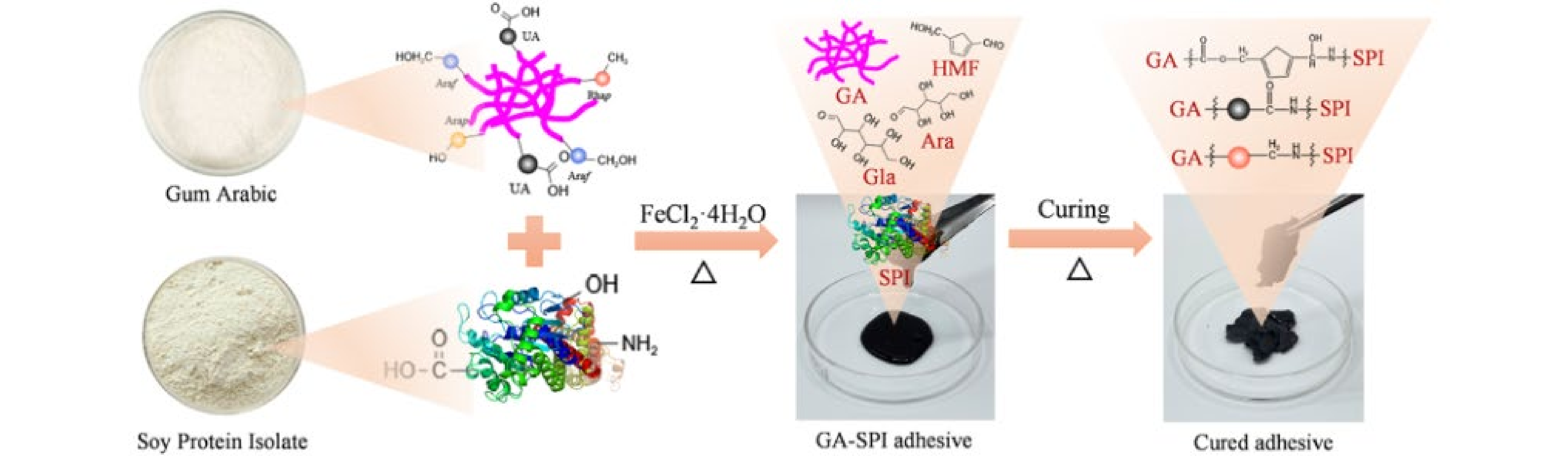


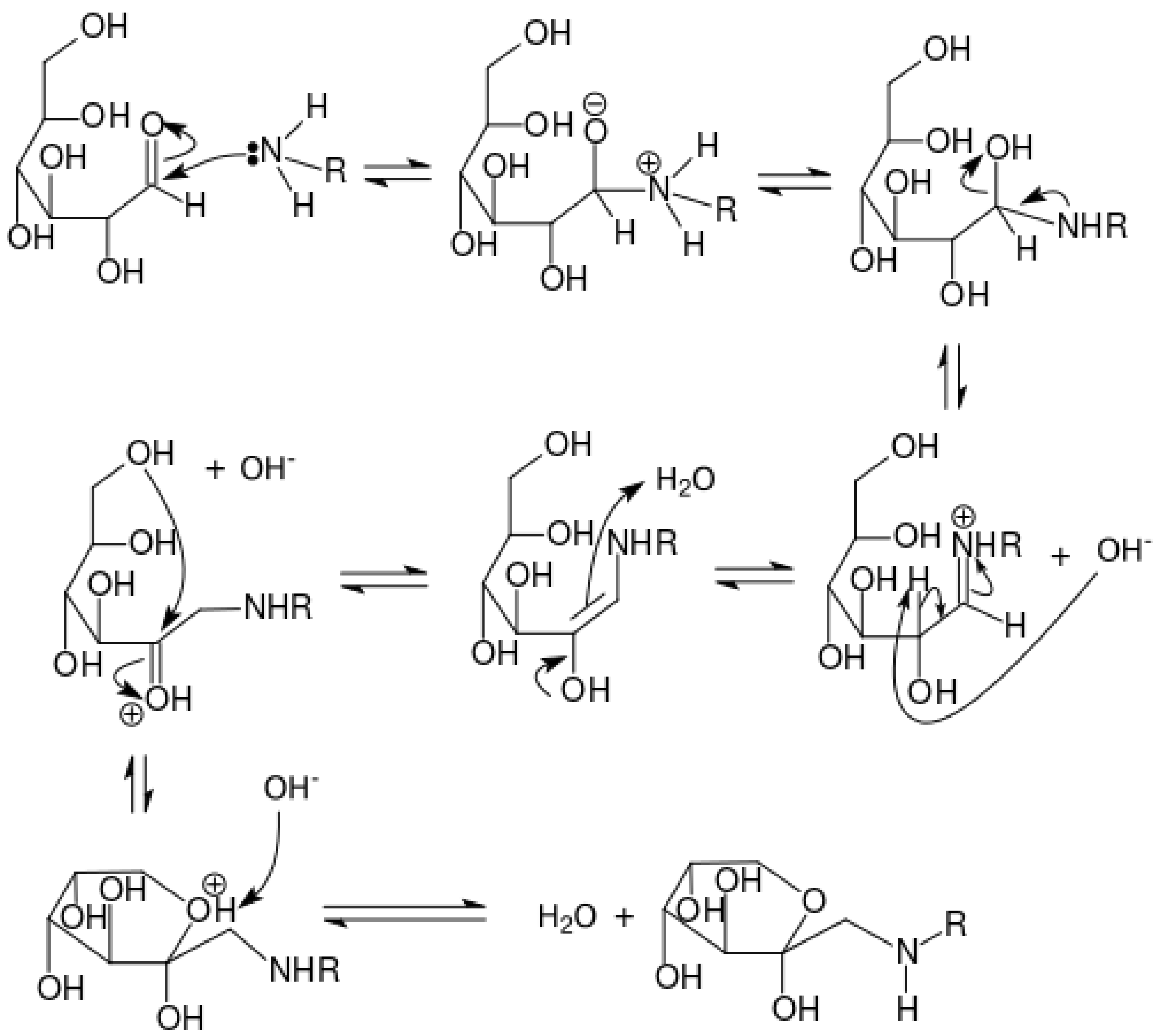
Figure 9. Possible reaction pathway during the synthesis and curing process of the GA-SPI adhesive. Ara*f*: α-L-Arabinofuranose; Ara*p*: α-L-Arabinopyranose; UA: β-D-Uronic acid; Rha*p*: α-L-Rhamnopyranose; Gla: Galactose; Ara: Arabinose.

CONCLUSIONS

- ✓ An adhesive composed of gum arabic and soyprotein isolate (GA-SPI) was prepared and curing mechanism has been established.
- ✓ The results clarified the optimized preparation conditions of 1:1 (GA:SPI) mass proportion and 70 % solid content, and the synthesis by adding 5 % $FeCl_2 \cdot 4H_2O$ as a catalyst at 90 °C for 2 h.
- ✓ The resulting wet shear strength of the board bonded by optimized GA-SPI adhesive at 170 °C for 10 min was 0.97 MPa, satisfying the standard (≥ 0.7 MPa).
- ✓ The results show that GA hydrolyzed to arabinose and galactose during the synthesis process, with some of the galactose converting to HMF catalyzed by Fe^{2+}.

-THANK YOU

MAILLARD REACTION



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