Improving water resistance of soybean meal-based adhesive by a polyepoxide and post heat treated process

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Introduction

With the increasing concerns over environmental, deployment of biodegradable and renewable biomass for the production of wood adhesives is not only inevitable but also responsive to suppressing the impact caused by formaldehyde-based adhesives.

Soybean meal is an attractive raw material for the bonding wood. It is abundant, renewable, low price, and environmentally friendly. The potential issues for the soybean meal adhesive are the bonding strength and the water resistance.

Objective

In this study, 5, 5 dimethyl hydantoin polyepoxide (DMHP) used as a cross-linker to enhance the water resistance of the soybean meal-based adhesive. Three-ply plywood specimens were fabricated with the resulting adhesives and their wet shear strength was tested. And, five-ply plywood specimens were fabricated with the resulting adhesives and after heat treated process their wet shear strength was tested.

Materials and Methods

Preparation of the DMHP

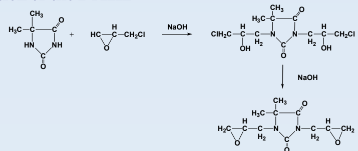
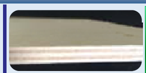


Table 1
Properties of the DMHP.

Name	Weight per epoxide	Epoxy value	Active group number	Viscosity/ mPa·s
DMHP	0.69-0.75	0.62	2	2300-3500

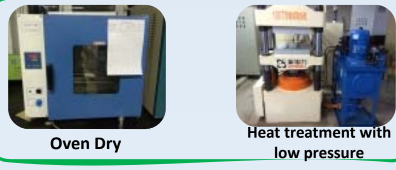
SM adhesive	SM/PAM adhesive	SM/PAM/SDS adhesive	SM/PAM/SDS/DMHP adhesive
Soybean meal flour (28 g) Deionized water (72 g)	Soybean meal flour (28 g) Polyacrylamide solution (72 g, 0.01%)	Soybean meal flour (28 g) Polyacrylamide solution (72 g, 0.01%) Sodium dodecyl Sulfate (1 g)	Soybean meal flour (28 g) Polyacrylamide solution (72 g, 0.01%) Sodium dodecyl Sulfate (1 g) DMHP-5%, 9%, 13%, 17%

Three-ply plywood specimens were fabricated with the resulting adhesives and their wet shear strength was tested. And adhesive properties were further characterized



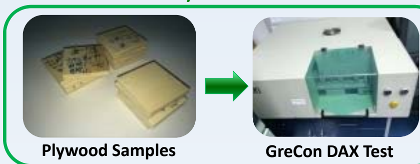
Five-ply plywood specimens were fabricated with the resulting adhesives and after heat treated process their wet shear strength was tested.

Heat treatment

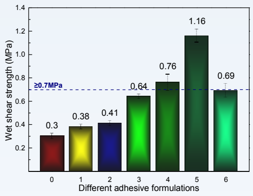


Water Resistance Measurement

Vertical Density Profile Measurement



Results and Discussion



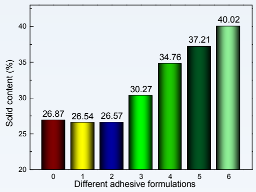
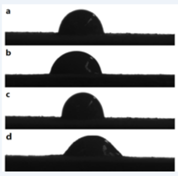


Fig. 1 and 2. The solid content and wet shear strength of different adhesive formulations: 0 (SM adhesive), 1 (SM/PAM adhesive), 2 (SM/PAM/SDS adhesive), 3 (SM/PAM/SDS/DMHP-5 wt% adhesive), 4 (SM/PAM/SDS/DMHP-9 wt% adhesive), 5 (SM/PAM/SDS/DMHP-13 wt% adhesive), 6 (SM/PAM/SDS/DMHP-17 wt% adhesive).

The wet shear strength of the plywood bonded with the adhesive upon 13 wt% DMHP additions increased by 182.9%, to 1.16 MPa.

With the DMHP addition up to 13 wt%, the solid content of the adhesive was 37.21%, which was increased by 38.5% compared to the SM adhesive.



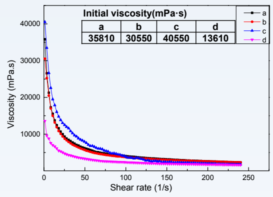
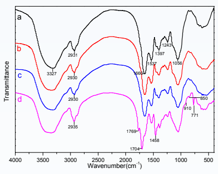


Fig. 3. The droplet picture of the (a) SM adhesive and its hybrid adhesive (b) SM/PAM, (c) SM/PAM/SDS and (d) SM/ PAM/SDS/DMHP adhesive on the wood substrate in 5 s after the deposition.
Fig. 4 The apparent viscosity of the different adhesives.

Adding DMHP improved wettability and decreased viscosity to 13,610 mPa·s, which was beneficial to industrial use for a plywood adhesive..



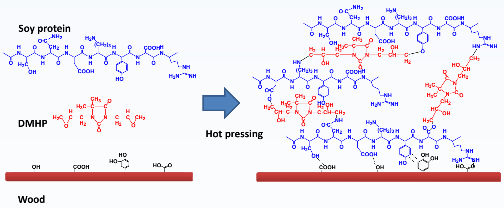


Fig. 5. The FTIR spectra of the different adhesives.

Fig. 6. The curing process of the SM/PAM/SDS/DMHP adhesive.

The DMHP could react with active groups on protein molecule to form a cross-linking network, which improved the water resistance of the resulting adhesive.

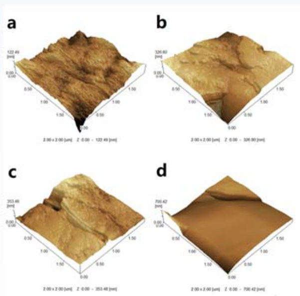


Fig. 8. AFM 3-dimensional image of the different cured adhesives.

	a	b	c	d
Ra (nm)	13.864	11.211	25.180	8.686

Adding DMHP could apparently reduce the surface roughness of the cured adhesive by 65.5% compared with that of SM/PAM/SDS adhesive. And the image showed no folds and a much smoother surface.

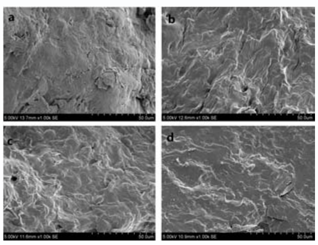


Fig. 9. The fracture surface micrograph of the different cured adhesives.

After the DMHP was introduced, fewer holes and cracks were observed, and the fracture surface of the cured adhesive became smoother and more compact.

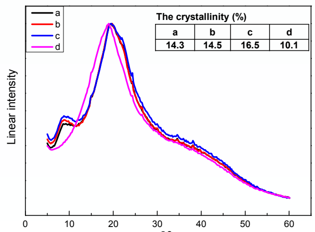


Fig. 7. The X-ray diffraction patterns of the different adhesives.

The characteristic peak at 20 values near 8.8was disappeared in the X-ray diffraction patterns after using the DMHP, which indicated that chemical reaction occurred between the DMHP and SM adhesive increased cross-linking density, thus decreasing the crystallinity.

Results and Discussion

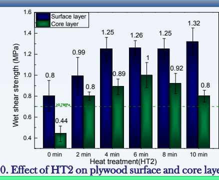


Fig. 10. Effect of HT2 on plywood surface and core layer wet shear strength.

With 4 min of low pressure heat treatment after 60 s/mm hot pressing, the wet shear strength of the surface layer and core layers of the resultant plywood increased by 56.3% to 1.25 MPa and 102.3% to 0.89 MPa, respectively. This is practical for the soybean meal-based adhesive application.

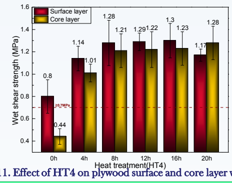


Fig. 11. Effect of HT4 on plywood surface and core layer wet shear strength.

With 8 h of no pressure heat treatment (120oC) following 60 s/mm hot pressing, the wet shear strength of the surface and core layers of the resultant plywood increased by 60.0% to1.28 MPa and 175.0% to 1.21 MPa, respectively.

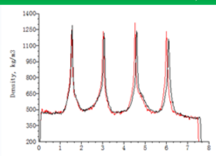


Fig. 12. Vertical density profile of plywood samples. (red line: vertical density profile of plywood with 120°C heat treatment for 8 h, black line: control.)

The results of vertical density profile show that the density of the adhesive layer increased and that the interior forces in plywood may be released and balanced during the heat treatment process, thereby improving wet shear strength.

Conclusions

Using 13 wt % the DMHP effectively improve the water resistance of the resulting adhesive by 182.9% to 1.16 MPa. All properties of the resulted adhesive met the requirement of plywood adhesive for industrial use.

With 4 min of low pressure heat treatment and with 8 h of no pressure heat treatment (120° C) following 60 s/mm hot pressing, the wet shear strength of the surface and core layers of the resultant plywood increased significantly.