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A novel particleboard using unsaturated polyester resin as a formaldehyde-free adhesive

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HIGHLIGHTS

- A novel particleboard via using UP resin as formaldehyde-free adhesive is performed.
- The new FF particleboard reaches national standards and M-1 grade (ANSI A208.1-1999).
- With and without PF treatment, properties of FF particleboards are changed greatly.
- PF treated wood particles to improve the interfacial adhesion of wood fibers and UP.
- The particleboard is low cost, efficient production and formaldehyde free.

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ABSTRACT

Wood-based artificial panels are still widely used even though they release harmful formaldehyde. In order to protect humans from exposure to formaldehyde, we successfully produced particleboards via surface treatment of wood fibers and using unsaturated polyester resin (UP) as formaldehyde-free adhesive. A phenolic formaldehyde (PF) aqueous solution was utilized to treat the wood particles to make them more compatible. The mechanical properties were investigated to see if the particleboards comply with national standards and M-1 grade (ANSI A208.1-1999). A water absorption test determined the dimensional stability of the FF particleboards. The PF-treated FF particleboards performed several times better than the untreated FF particleboard. Furthermore, the effect of the PF treatment on the interfacial adhesion of wood particles and UP was investigated using SEM, DMTA, and contact angle measurements. The results confirm that PF treatment improves the interfacial adhesion of UP and wood particles. Formaldehyde emission tests found no formaldehyde in the new particleboards. Our proposed low-cost fiber-treatment and efficient board production method may be suited for the commercial production of artificial panels.

1. Introduction

Formaldehyde, a well-known harmful substance, is still widely used for the production of urea formaldehyde resin, phenol-formaldehyde resin, and melamine resin [1]. Every year, millions of tons of resin are used to manufacture artificial boards, such as particleboards, middle density fiber (MDF) boards, and plywood. These are used to build furniture and wallboards, which release formaldehyde slowly but for a long time [1,2]. Studies to find less harmful alternatives focus on corn cob [3], waste wood [4], sawdusk [5], and others, but this alternatives have poor adhesive properties, water resistance and mildew resistance. In 2015, the government of China published the *Comprehensive List of Environmental Protection* (CLEP), which indicates that the production and use of formaldehyde resin add to the pollution of the environment. Therefore, the release of formaldehyde needs to be reduced by the development of better alternative artificial board manufacturing methods. Some artificial formaldehyde-free boards have already been explored, for example, MDI was used as particleboard binder [6]. However, many factory workers were diagnosed with pulmonary disease after exposure to MDI [7]. A safe alternative would be soybean glue, which is environmental friendly and formaldehyde-free, and it can be used as adhesive for artificial

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board production [8]. Liquefied wood is already utilized as a new particle-board adhesive system [9].

Unsaturated polyester resin (UP), polymerized from unsaturated acid, saturated acid, and polyol, are widely used in aviation, space flight, automobile, ships, and microelectronics [10]. Typically, styrene is used as solvent and cross-linking reagent to form the UP solution with a concentration of about 70 wt%. Organic peroxide is the curing reagent to initiate the required radical polymerization reaction of UP at high temperature. More than one centenary has passed since the invention of UP, and it is still widely used as sheathing material after compositing with grass fibers [11] and plant fibers, such as bagasse [12], ramie fibers [13,14], cotton [15], Palmyra fibers [16], and wood fibers [17], which enhances UP and leads to improved mechanical properties. S.N. Monteiro [18] used Curaua-fiber to enhance UP and showed that the tenacity of the composites increased with the increase of the fiber-volume fraction (VF). CNF are also utilized to strengthen UP. For a fiber VF of 45%, the mechanical properties of the composite UP are three times higher [19]. In order to blend natural fibers and UP homogeneously, fiber pretreatment is needed because of the different polarities. Generally, a silane coupling agent [20], maleﬁc anhydride [21], and some other reagents [16,22] are used to treat natural fibers to improve the interfacial bonding force in the UP matrix.

Interestingly, almost all studies on fibers and UP focuses on fibers enhancing the UP matrix [23–25]. However, UP can also be used as a formaldehyde-free adhesive to manufacture particleboard. In our opinion, one important problem is that the curing time for UP is too long to make the production efficient. Another problem is that the fiber-treating reagent must not be expensive. In this paper, we investigate the feasibility of particleboard production using the formaldehyde-free adhesive – UP and surface treatment of wood fibers. This technique may enable the commercial production of environmentally safe particleboards in the future.

2. Experimental section

2.1. Materials

Unsaturated polyester resin (UP, 330) and methyl-ethyl ketone peroxide (MEKP, concentration of 40%) were provided by Yongyue Science & Technology Co., Ltd. Wood particles (Poplar, Moisture Content: 12%), phenolic formaldehyde (PF, liquid form with 50% solids, 0.62% of free formaldehyde content) and wax was provided by Furen Wood (Fuzhou) Co., Ltd. The UP resin (UP 330) was from Yongyue Technology Co. Ltd. Recycled polyethylene terephthalate (PET) is used to produce UP330, which is cheap and environmentally friendly. Its molecular structure is shown in Fig. 1. Its viscosity is about 300 mPa·s. All materials provided above were of industrial grade and used without further purification or drying.

2.2. Preparation of the particleboards

1 kg wood particles with a moisture content of 12 wt% were added into a closed blender. 17.6 g PF was sprayed into the blender using a high-pressure spray-gun. Then, 88 g UP and 2.6 g MEKP were mixed homogeneously and sprayed into the blender. Subsequently, 8 g wax was cut in small pieces and added. The treated wood particles were assembled using a casting mold (mold area of 350 mm × 350 mm) to form a plate billet and then hot-pressed through a thermos-compressor (temperature: 200 °C, pressure: 5 MPa) for 4 min. The board size was about 30 cm × 30 cm × 1 cm, and 5 boards were prepared for characterization. The new particleboard was labeled as FF particleboard. The scheme diagram of the production procedure is shown in Fig. 1.

2.3. Formaldehyde emission test

The formaldehyde emission from the particleboard samples was measured using the desiccator method prescribed in the JAS (Japanese Agricultural Standard, Fig. 11) [26]. The 24 h desiccator method used a common glass desiccator with a volume of 10 L. Ten specimens cut into 150 × 50 mm samples from 3 particleboard pieces were subjected to the formaldehyde emission test using the desiccator method. The emission test lasted 24 h in the covered desiccator at 20 °C. The measurements were performed only once, after 1 day of the sample preparation.

2.4. Characterization

Panels were cut from the boards for the modulus of elasticity (MOE) test and the modulus of rupture (MOR) test, according to ASTM D 1037-96a [27]. The panels were prepared for internal bond (IB) and thickness swelling of water absorption (TS) according to ASTM D 1037-96a. The mechanical properties tests were conducted with a CMT6104 microcomputer-controlled electronic universal-testing-machine at a speed of 10 mm·min^{-1} (MTS Systems, Shenzhen, China) at room temperature and RH 50%. FF particleboards were exposed in moist air (RH 50%, room temperature) for over 1 month, and the MOR, MOE, IB and TS were measured in accordance with ASTM D 1037-96a.

Samples were taken from the fracture surface of the IB test and then observed using field emission scanning electron microscopy (FESEM) with 1 kV acceleration voltage.

Dynamic mechanical thermal analysis (DMTA) was performed in compress mode. The sample size was ca. 50 mm × 10 mm × 5 mm. Measurements were taken at a frequency of 1 Hz and amplitude of 20 μm between room temperature and 200 °C at a rate of 5 °C/min.

Contact angle tests were conducted on a DSA-100 (Germany, Kruss) between 0° and 180°. The FF particleboard, treated wood particles, PF, UP were tested.

3. Results and discussion

UP is still predominantly used as fiber reinforced material. Here we focus on the adhesive property of UP to manufacture artificial

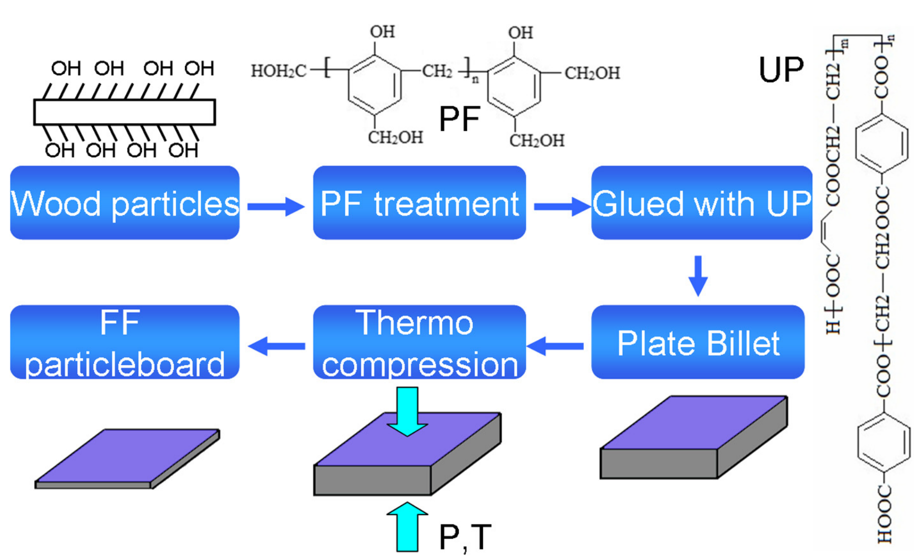

Fig. 1. Production procedure of manufacturing FF particleboard.