Composites: Part B 44 (2013) 48–51

Contents lists available at SciVerse ScienceDirect

Composites: Part B

journal homepage: www.elsevier.com/locate/compositesb

Evaluation of mechanical and physical properties of industrial particleboard bonded with a corn flour–urea formaldehyde adhesive

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ARTICLE INFO

Article history:
Received 22 December 2011
Received in revised form 3 May 2012
Accepted 8 July 2012
Available online 16 August 2012

Keywords:
A. Wood
A. Resins
B. Mechanical properties
B. Physical properties
B. Rheological properties

ABSTRACT

The aim of this study was to determine the effect of corn flour content of urea formaldehyde (UF) resin on the panel properties of particleboard. Corn flour was added to UF resin to decrease the free formaldehyde content of particleboard panels. Some physical (thickness swelling and rheological characterization), mechanical (modulus of elasticity, modulus of rupture, internal bond strength and withdrawal of screws) properties and formaldehyde emission of particleboards were evaluated. The results showed that the introduction of small proportions of corn flour (7%, by weight) in UF resins contributes to the improvement of mechanical and physical properties of the boards and reduced their formaldehyde emissions. Hazardous petrochemical UF could be partially substituted in industrial applications by addition of corn flour. To our knowledge, this is the first study on this kind of wood adhesives.

1. Introduction

Particleboard panels are made with wood particles and a wood adhesive. It is widely used in the manufacture of furniture, floor underlayment, cabinets, stair treads, home constructions, tabletops, vanities, speakers, sliding doors, displays, pool tables, electronic game consoles, kitchen worktops, and work surfaces in offices, educational establishments, laboratories and other industrial products [1]. The majority of particleboard panels are manufactured with UF. UF resins, the most well-known amino resins, have many advantages such as low cost, ease of use under a wide variety of curing conditions, the fastest reaction time in hot press, water solubility, low cure temperatures, resistance to microorganisms and to abrasion, excellent thermal properties, and their colorless qualities, especially the cured resin compared to other resins [2]. However, the greatest disadvantages of UF adhesive resins are their formaldehyde emission and its bond deterioration caused by water and moisture [1,3].

In recent years, many studies have been carried out with the goal of replacing UF with macromolecules that were obtained from natural source such as lignin [4,5], protein [6–9], starch [10–12] and bark tannins [13–16]. Very few studies were done on corn flour to explore its potential as a new adhesive application. Corn flour is abundant, renewable, inexpensive and readily available. The performance of corn flour-UF adhesives is dependent on the dispersion and unfolding of the starch in UF. The unfolded starch molecules have increased contact areas and interactions with the wood particles.

This study discusses the potential of corn flour for application in corn flour-based adhesive industry production for particleboard panels. Some physical; thickness swelling and rheological characterization and mechanical; modulus of rupture, modulus of elasticity, internal bond and withdrawal of screws properties were determined for the produced particleboards.

2. Experimental methods

2.1. Materials

The wood particles used in the production of industrial particleboard panels were obtained from Ets Labadie (Roquefort), France. They were screened and dried at 100 °C to achieve 2–3% moisture content. Corn flour was provided from Maïsadour Cooperative Group, France. Table 1 shows the corn flour chemical composition. Commercial resol-type liquid UF resin (which is a particleboard binder resin), was supplied by EGGER (Rion des Landes), France.

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http://dx.doi.org/10.1016/j.compositesb.2012.07.041

Table 1
Corn flour chemical composition.

Protein (%)	9.05
Fat (%)	4.22
Cellulose (%)	2.48
Ash (%)	1.07
Starch (%)	72.65

2.2. Preparation of resols and adhesives

UF resin has a density of 1280–1290 kg/m^3 at 20 ± 2 °C, pH value of about 8.5–9 at 20 ± 2 °C, a viscosity of 350–600 mPa s at 20 ± 2 °C and jell time of 40–50 s at 100 °C. The free formaldehyde ratio of UF is maximum 0.15% and the solution has a resin of 90 g + ammonium nitrate of 6 g and emulsion of 4 g.

The adhesives were prepared manually in advance by copolymerization at room temperature of 7% of corn flour (by weight) with the previously prepared resols [17].

2.3. Industrial particleboard preparation and testing

Industrial particleboard panels of dimension 8.2 m × 1.85 m × 19 mm were manufactured in EGGER-ROL (France) Group. 9% (w/w based on dry particles) of adhesive resin solid was loaded, at a total pressing time of 2.6 min and pressing temperature of 220 °C. Particles were dried to approximately 3% moisture content prior to application of resin. The target density was 680 kg/m^3. The fabricated particleboards were pre-conditioned at 25 °C and 65% relative humidity in a climate room for a week before testing. All tests were carried out to the appropriate European standards. The tests performed on the specimens were internal bond strength perpendicular to the plane of the board (IB) [18], static bending [modulus of rupture (MOR) and modulus of elasticity (MOE)] [19], thickness swelling (TS) (after 24 h) [20] and withdrawal of screws (WSs) [21]. The formaldehyde emission was determined using the desiccator's method, according to the ISO/CD 12460-4 standard [22]. Each measurement presented herein is the average for ten samples cut from two different boards.

2.4. Rheological characterization

The rheological properties of the adhesives were determined via measurements obtained during rheological tests. The adhesives were tested with a rotary rheometer (ARES) with parallel plate's geometry. The main advantage of parallel plate technology over other measuring geometries is that the gap can be varied within limits to accommodate the adhesives. The plate diameter used was 25 mm and the gap between the plates was 1.5 mm. The experiments were carried out in an environment with controlled temperature. Silicone oil was used to prevent water evaporation. To be in the linear regime the strain value was set as 1%.

2.5. Density and porosity

The apparent density of the particleboard was determined by measuring the mass and volume, while material density of the board was measured with a Helium Pycnometer Accupyc 1330 (Micromeritics, USA). Porosity was given by Rahman equation [23,24]:

$$e = 1 - \frac{\rho_{ap}}{\rho_m}$$

where e, ρ_{ap} and ρ_m are porosity, apparent density (kg/m^3) and material density (kg/m^3) respectively.

2.6. Solid phase ^{13}C NMR analysis

The solid state ^{13}C NMR spectra of the corn flour, UF and corn flour:UF (7:93 by weight) resin systems used, were acquired at ambient temperature by using a Bruker 400 MHz spectrometer. Powdered samples were packed in a 4 mm zirconia rotors, sealed with Kel-FTM caps and spun at 7 kHz and at a contact time of 500 ms. Chemical shifts were determined relative to tetramethyl silane (TMS) used as control. Chemical shifts were expressed in parts per million (ppm). The assignments of the different peak shifts observed were both obtained from the relevant literature and calculated.

3. Results and discussion

First of all, the physical properties of corn flour:UF (7:93) were characterized. Various characterizations like stability, classification and reactivity of adhesives were studied. Secondly, the mechanical and physical properties of industrial particleboard prepared with corn flour:UF (7:93) adhesives were studied.

3.1. The physical properties of control UF and corn flour/UF (7:93) adhesives

In dynamic measurements, the elasticity can be described by the storage shear modulus G' and the viscous property can be described by the loss shear modulus G''. Experimental determination of the linear domain is an essential step in studying the rheological behavior of a product. This step allows fixing the area where both viscous (G'') and elastic (G') modules are completely independent of the applied deformation. This determination is performed by applying a strain sweep (0.01–100%) at 25 °C and 1 rad/s. Fig. 1 shows that for a deformation between 0.01% and 1%, the elastic and viscous modulus values of control UF and optimal corn flour:UF (7:93) adhesives are practically constant and does not depend on the deformation value. All rheological analysis to be presented in this work will be done by requiring the sample deformation of 1%.

The storage time of the wood adhesives is an important consideration on their commercial applications. Fig. 2 shows the time dependence of G' and G'' for control UF and corn flour/UF (7:93) adhesives at 25 °C, 1 rad/s and 1%. It can be seen that dynamic moduli (G' and G'') of both adhesives remain constant and parallel with time. This result shows excellent structural stability of control UF and corn flour/UF (7:93) adhesives. The dynamic moduli (G' and G'') values of corn flour:UF (7/93) adhesive are superior compared

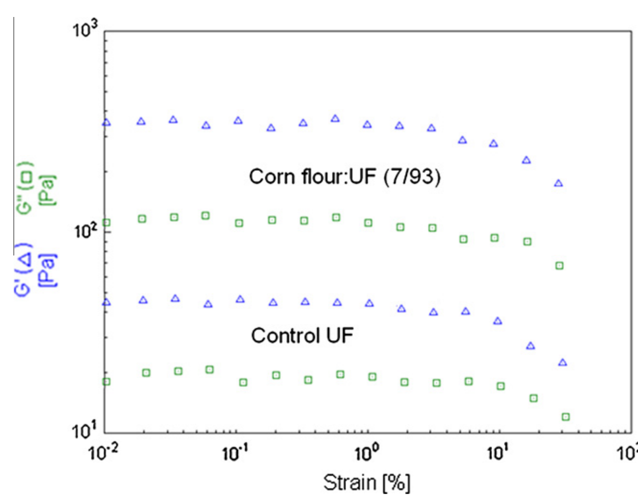

Fig. 1. Strain sweep of storage modulus (G') and loss modulus (G'') of control UF and corn flour-UF (7/93, weight ratios) resins at 25 °C and 1 rad/s.