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Influence of activated charcoal as filler on the properties of wood composites

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ABSTRACT

In the present work a small percentage of activated charcoal was added in the thermosetting urea–formaldehyde (UF) resin and the performance of adhesives and wood composite was observed. The effect of activated charcoal on the curing kinetics and the Crosslink density of UF resin was investigated, using differential scanning calorimetry. The activated charcoal has an accelerating effect on the curing of the UF resin. The Crosslink density of resin increases and the activation energy decreases. The influence of the activated charcoal addition was particularly noted in medium density fiberboard by the increase in the value of modulus of rupture and internal bond strength of the panel, a direct indication of the performance improvement with the addition of a small amount of activated charcoal. The formaldehyde emission significantly decreases with the addition of activated charcoal.

1. Introduction

The wood-based panels largely represented by particleboard, medium density fiberboards (MDF), plywood and oriented strand boards (OSB). These panels are the major constituent for the production of wood furniture and other interior house constructions (i.e. flooring, wall paneling etc.). The global wood-based panel market valued over US$ 80 billion in 2011 [1]. Wood-based panel are typically made with a heat-curing adhesive that holds the wood fibers or wood-particles components together.

UF resin is one of the largely used adhesive for interior-grade wood-based panels specially in particleboard (PB), a medium density fiberboard (MDF) manufacturing. It has some advantages like fast curing, less in price and good mechanical strength of the panels but has many drawbacks like lower water resistance, higher emission of formaldehyde. The weakness of UF resins to hydrolysis and the presence of free non-reacting formaldehyde in the panels together responsible for the problem of formaldehyde emission from the panels during manufacturing and service life.

The molar ratio of formaldehyde to urea (F/U) is the most essential factor for affecting the formaldehyde emission liberation from the panels. The formaldehyde emission can be lowered by using the combination of UF resin and formaldehyde free adhesives [2–4]. Several methods for manufacturing the low formaldehyde emission panels have been studied, such as reducing formaldehyde to urea molar ratios [5] and addition of formaldehyde scavengers to the resin [6]. However, the other physical and mechanical properties of wood-based panels are badly affected [7–10]. The chemical additives like formaldehyde scavengers are being used to reduce the formaldehyde emission from panels. The amine (primary or secondary) containing compounds such as urea, ammonia, melamine are the commonly used scavengers [11]. However, the addition of formaldehyde scavengers consumes the free formaldehyde in excessive available for the cure reaction, accordingly weakening the internal bonding [12].

The use of activated carbon as formaldehyde absorbent has been investigated by many researchers. Rayon-based activated carbon as formaldehyde absorbent [13] and activated charcoal is used as bio-scavenger for decreasing the formaldehyde emission from melamine formaldehyde resin [14]. The activated charcoal absorbs the free formaldehyde from MDF panel [15]. The lignocellulosic materials are often used as fillers for formaldehyde based resin like cellulose in phenol formaldehyde resin, and it increases the adhesion strength due to secondary forces, such as van der walls, H-bonding and electrostatic forces [16]. Tannin powder used as filler in UF resin and effects on the activation energies [17] and tannin from Pine wood as a filler for PF resin [18].

In the present work the effects of activated charcoal as filler on peak curing temperature, Crosslink density, and the activation energy of UF resin are discussed with the help of differential scanning calorimetry. The effect of activated charcoal on the formaldehyde emission, physical and mechanical properties of MDF was investigated.

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2. Materials and methods

2.1. Materials

Urea–formaldehyde resin was provided by Dynea Malaysia Sdn. Bhd. The resin has the solid content 64.4%, the F/U molar ratio was 1, pH was 8.27, and viscosity 170 CP. Mixed tropical hardwood fibers were provided by the Robin Resources Sdn. Bhd, Malaysia. The activated charcoal granules were procured from Hamburg (HmbG) Chemicals. The granules were ground into very fine powder using Retsch^{R}, ZM 200 grinder at 18,000 RPM after that the very fine activated charcoal was a sieve out using 400 US mesh size.

2.2. Mechanism of mixing of UF resin and AC

To obtain a uniform dispersion of activated charcoal powder in the resin, mechanical stirring with Heidolph model RZR 2041was done for 30 min at 2000 RPM. The 200 g of UF/AC resin to the desired volume concentrations of 0.20%, 0.52% and 1.04% was prepared.

$$\varphi = \frac{[w_P/\rho_P]}{[(w_P/\rho_P)+(w_R/\rho_R)]} \times 100 \quad (1)$$

where φ is the volume concentration of innovative resin in percent, w_P, w_R are the weight of powder and resin respectively in kg and ρ_P, ρ_R are the density of particle and resin respectively in kg/m^3. The modified resin was named based on percent added as AC1, AC2 and AC3. The resin in the absence of carbon powder is referred to as AC0.

2.3. Characterization techniques

(a) Differential scanning calorimetry (DSC)
DSC measurements were carried out in Differential scanning calorimetry (DSC) Q-1000 model supplied by TA Instruments, USA. The resins of 6 mg is placed on high pressure aluminum crucibles. The samples were heated from 30 °C to 200 °C in an inert atmosphere of nitrogen maintained at 50 ml/min flow rate, with an identical empty crucible used as a reference in the measurement process. The heating rates employed were 5, 10 and 15 °C/min. The peak curing temperature (T_p) estimated at different heating rate (i.e. 5, 10 and 15 °C/min). E_a is calculated from the slope of a plot of the natural logarithm of heating rate versus the reciprocal of the corresponding type [in degree Kelvin (K)] using Kissinger's equation [19] Eq. (2).

$$\ln(\beta/T_p^2) = -E_a/RT_p + \ln(AR/E_a) \quad (2)$$

where, β is the heating rate, T_p is the peak curing temperature, R is the gas constant and A is the pre-exponential factor. The value of E_a and A were determined from the graph plotted between $[-\ln(\beta/T_p^2)]$ and $[100/T_p]$.

(b) Fourier transforms infrared spectroscopy
The pre-cured resin and samples were mixed with KBr and made into pellets to determine the bond formation using Fourier transform infrared spectroscopy (FTIR). The FTIR transmittance spectra were obtained with Perkin-Elmer spectrum 100 in the spectral range of 400–4000 cm^{-1}, with a resolution of 2 cm^{-1} and 50 scans.

(c) Scanning electron microscopy
The morphology of the prepared samples were examined using Field Emission Scanning Electron Microscopy (FESEM) system (JEOL JSM 840A-Oxford ISIS 300 microscope). The samples were carbon coated in order to provide good conductivity of the electron beam. Operating conditions were accelerating voltage 2–5 kV, probe current 45 nA, and counting time 60 s.

2.4. Preparation of medium density fiberboard (MDF)

Table 1 The MDF panels were prepared by mixing the fibers within innovative resin in rotary blender equipped with resin spraying. The 10 wt% UF resin. The wood fibers were mixed with resin and formed in the form of mat using forming box. The fiber mat is pre-pressed in cold molding press for 2 min at 10 kg/cm^2 pressure after that it is hot-pressed to the desired thickness. Table 2 shows all the details of MDF manufacturing using innovative UF resin. The panels were then conditioned to relative humidity of 65 ± 5% and a temperature of 20 °C to attain uniform moisture content in the panels. The boards were trimmed for determining the modulus of rupture (MOR), internal bond strength (IB) and estimate the formaldehyde emission from panels. The mechanical properties of MDF panels were evaluated as per ASTM standard D-1037. The internal bonding (IB) and modulus of rupture (MOR) of MDF panels are estimated with the universal testing machine (AG-20kN, Shimadzu Precision universal tester, Shimadzu Corporation, Japan).

2.5. Formaldehyde emission testing

The formaldehyde emissions from MDF panels was evaluated using the EN-120 (1992) perforator method. Around 110 g sample were put in a round bottom flask, that contain the 600 ml of toluene. The 1000 ml of distilled water was poured into the perforator attachment. The samples were boiled with toluene and passed through the distilled water for 2 h. In this process,

Table 1
MDF manufacturing parameters with different loading of activated charcoal.

Parameters	Values
Board dimensions	280 mm × 280 mm × 9 mm
Target density	775 kg/m^3
Platen temperature	180 (°C)
Pressing time	270 (s)
UF resin wt% of dry wood fibers	10 wt%
Activated charcoal volume concentration % of UF resin	0.0, 0.20, 0.52 and 1.04%
Number of boards for each type of concentrations	5 boards

Table 2
Shows the differential scanning calorimetry results and cure kinetics results of UF resin with different concentrations of activated charcoal.

Sample	Heating rate (°C/min)	Peak curing temperature (°C)	$[-\ln(\beta/T_p^2)]$ vs.$[100/T_p]$	Activation energy (kJ/mol)
AC0	5	115	$y=-14.641x$	121.9
	10	122	+27.419	
	15	126	$R^2=0.999$	
AC1	5	98	$y=-8.0991x$	67.4
	10	108	+11.621	
	15	116	$R^2=0.993$	
AC2	5	90	$y=-6.2712x$	52.2
	10	102	+7.1197 $R^2=0.991$	
	15	112		
AC3	5	88	$y=-5.866x$	48.9
	10	102	+6.1386	
	15	111	$R^2=0.999$	