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Effects of formulation variables on surface properties of wood plastic composites

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ABSTRACT

Degree of surface quality of wood plastic composites (WPCs) is a function of both raw material characteristics and the manufacturing variables. The WPC panels comprised of different panel densities (800, 950, 1000, and 1080 kg/m^3), wood flour contents (50, 60, 70, and 80 wt.%), wood flour sizes (<0.5, ⩾0.5 to <0.8, 0.8–1, and >1 mm), and hot-pressing temperatures (190 and 210 °C) were manufactured using a dry blend/flat-pressing method under laboratory conditions. The surface smoothness of the WPC panels improved with increasing WPC density, plastic content, and hot-pressing temperature while it deteriorated with increasing wood flour size. The reduction in the particle size of the WF resulted in a more compact structure on the WPC surface. In general, the wettability of the samples increased by increasing surface roughness.

1. Introduction

As a new kind of composites, wood–plastic composites (WPCs) are widely used in construction business, automotive industry, packing trade, carrying trade, and other fields (WPC) market. Although commercially less important, the predominant technologies to produce WPCs are extrusion to obtain endless profiles and injection molding leading to 3-dimensional forms. Another possibility is to produce WPCs on a flat-press [1–4]. The advantage of this technology is that only a relatively low pressure level is required, compared to extrusion and injection molding. When WPC panels are used as substrate for liquid coatings or thin laminate sheets for the production of indoor and outdoor furniture their surface characteristics in terms of roughness and wettability play an important role in determining quality of final product. In general, the degree of surface quality of WPC panels is a function of formulation variables such as raw material characteristics and hot-pressing parameters.

Standard contact measuring devices employing a stylus tracer, such as used in the metal and plastic industry was successfully employed to evaluate roughness characteristics of wood-based panels and WPCs [5,6]. One of the main advantages of the stylus method is to have an actual profile of the surface and standard numerical roughness parameters which can be calculated from the profile. Any kind of irregularities and magnitude of show-trough on the overlaid substrate can be objectively quantified. Therefore, it is important to quantify surface roughness of the panel to have a better overlaying of the substrate. In a previous study, it was reported that increasing surface roughness of WPCs improved delamination strength between WPC surface and wood veneer sheet [7]. A similar result was also found for liquid coatings in other study [8].

Wettability is defined as a condition of a surface that determines how fast a liquid will wet and spread on the surface or whether it will be repelled and not spread on the surface. Wettability is crucial for good adhesion in bonding between WPC and coating. Liquid surface coatings or adhesives have to wet, flow, and penetrate the cellular structure of wood in order to establish intimate contact between molecules of composite surface and coating. Contact angle (CA) method has been commonly used to determine wettability of WPCs [7,9]. If the CA is greater than 90°, the liquid tends to bead up. Liquids having CAs less than 90° tend to wet surfaces. A CA of 0° indicates a liquid will completely cover a surface, while a CA of 180° indicates the liquid beads up on a surface.

There are several ways to improve physical and mechanical properties of the WPC panels, namely using right size of raw material, optimum mixture and preparation of the elements in the WPC panel. Effect of formulation variables on physical and mechanical properties of WPC panels has been extensively investigated in previous studies [1–4,10,11]. Benthien et al. [1] have recently investigated effects of formulation variables on the physical and mechanical properties of the flat pressed WPCs. However, currently there is little information about surface properties of flat-pressed WPC panels [4,7,8]. The wettability and surface roughness are the most important factors affecting coating performance of

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the WPCs. The surface properties of the WPC panels made using dry blend method have not extensively investigated as a function of the composite formulation. The aim of the research reported here was to investigate effects of the formulation variables on the surface roughness and wettability of the WPC substrate for liquid coatings or thin laminate sheets.

2. Experimental procedure

2.1. Materials

Commercial softwood flour (WF) (Jeluxyl Weho 500 V) was supplied from a manufacturer (Jelu-Werk) of the WF located in Rosenberg, Germany. The WF was dried in a laboratory oven at 102 °C for 24 h to moisture content of 0–1% based on the oven-dry WF weight. Polypropylene (PP) powder PPH 9069 homopolymer with a melt flow rate of 25 g/10 min produced by Total Petrochemicals France, was used as the plastic material.

2.2. Flat-pressed WPC panel manufacture

Flat-pressed WPC panels were manufactured using standardized procedures simulated industrial production at the laboratory. After mixing the WF and PP powder, the mixture was placed in a rotary drum blender. Following the blending treatment, the mixture was weighed and then formed into a mat on an aluminum caul plate, using a 380 mm × 380 mm forming frame. Wax paper was used to avoid direct contact of the PP powder with the metal platens of the hot-press. The polymer based foam frame was used for the WPC formulations having densities between 800 and 1000 kg/m^3 while the aluminum frame was used for the WPC formulation having a density of 1080 kg/m^3 because the polymer based foam frame did not work (Fig. 1). The WPC mats were then subjected to the hot-pressing, using a computer controlled hot-press. At the end of the hot-pressing cycle, each panel was moved from the hot-press into a veneer press at room temperature for cooling, except for the WPC panels having 1080 kg/m$^{3.}$ The WPC panels having 1080 kg/m^3 were cooled in the hot-press (inline) without pressure after a pressing period of 1100 s. 10 mm thick panels were then trimmed to a final size of 300 × 300 mm. The WPC panels were kept in a climate room set at 20 °C and 65% relative humidity (RH) before they were cut into test samples. A total of 42 experimental panels, 3 for each type of WPC panel, were manufactured. The formulation variables for the WPC panels are presented in Table 1.

2.3. Determination of the surface roughness

Currently there are no standard methods to evaluate surface roughness of wood-based panels and WPCs. However, the stylus method is a well accepted one in metal and plastic industries due to its accuracy and ability to provide well defined numerical values for the measured surface. Therefore, the surface properties of the WPC samples were determined by employing a fine stylus profilometer Mitutoyo SJ-301 surface roughness tester. The samples with dimensions of 50 mm × 50 mm × 10 mm were conditioned in a climate chamber at 20 °C and 65% RH. Fifteen samples were taken from each type of formulation for the CA measurements. A total of sixty measurements, four measurements (two measurements parallel and two measurements perpendicular to each other) from each of the fifteen samples were performed for each type of formulation.

Three roughness parameters characterized by ISO 4287 standard [12], respectively, average roughness (R_a), mean peak-to-valley height (R_z), and maximum peak-to-valley height (R_y) were considered to evaluate the surface characteristics of the panels. The surface roughness parameters were calculated from the digital information. The vertical displacement of the stylus was converted into an electrical signal by a linear displacement detector before the signals were amplified and converted into digital information. R_a is the arithmetic mean of the absolute values of the profile deviations from the mean line and is by far the most commonly used parameter in surface finish measurement. Roughness values were measured with a sensitivity of 0.5 μm. Measuring speed, pin diameter, and pin top angle of the tool were 10 mm/min, 4 μm and 90°, respectively. The length of tracing line (L_t) and cut-off (λ_c) were 12.5 mm and 2.5 mm, respectively. Measuring force of the scanning arm on the samples was 4 mN (0.4 gf). The measurements were done at room temperature and pin was calibrated before the tests.

2.4. Determination of the wettability

The wetting behavior of the WPC samples conditioned at 20 °C and 65% RH was characterized by the CA method (goniometer technique). The CAs were obtained using with a KSV Cam-101 Scientific Instrument (Helsinki, Finland). The sessile drop method was used in the experiments. The CAs were determined simply by aligning a tangent with the sessile drop profile at the point of contact with the solid surface. The drop image was stored by a video camera and an image analysis system calculated the CA from the shape of the distilled water drop at room temperature. The image of the water drop was captured by a video camera and the CA was measured by digital image analysis software. After the 5 μL droplet of the distilled water was placed on the sample surface, the CAs from the images were measured at 1 s time intervals up to 90 s total. Fifteen samples with a size of 50 mm × 50 mm × 10 mm were taken from each type of formulation for the CA measurements. A total of sixty measurements, four measurements from each of the fifteen samples were performed for each type of formulation.

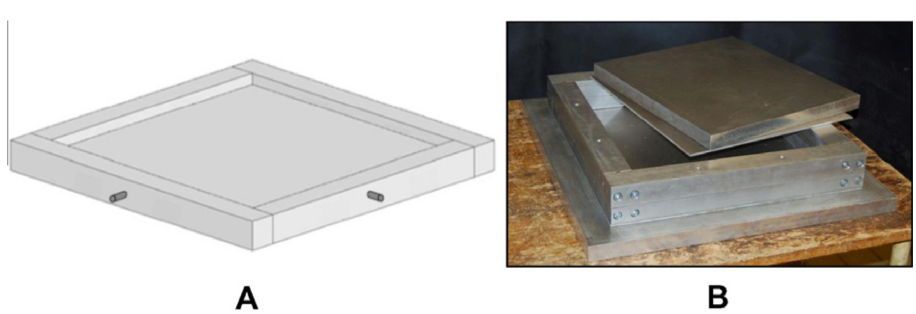

Fig. 1. Types of the forming frames used in the manufacture of the experimental WPC panels. (A: schematic drawing of the polymer based foam frame used for the WPC panels having densities of 800, 950, and 1000 kg/m^3, B: aluminum frame used for the WPC panel having a density of 1080 kg/m^3).