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The reduction of indoor air pollutant from wood-based composite by adding pozzolan for building materials

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ABSTRACT

The purpose of this study was to investigate the physico-mechanical properties and characteristics on reduction of formaldehyde and total volatile organic compound (TVOC) emission from medium density fiberboard (MDF) as furniture materials with added volcanic pozzolan. Pozzolan was added as a scavenger to urea formaldehyde (UF) resin for MDF manufacture. The moisture content, density, thickness swelling, water absorption and physical properties of MDFs were examined. Three-point bending strength and internal bond strength were determined using a universal testing machine. Formaldehyde and TVOC were determined by desiccator and 20 L small chamber methods as Korean standards method. With increasing pozzolan content the physical and mechanical properties of the MDFs were not significantly changed, but formaldehyde and TVOC emissions were decreased. Because pozzolan has a rough and irregular surface with porous form, it can be used as a scavenger for MDFs without any detrimental effect on the physical and mechanical properties.

1. Introduction

In the past, urea formaldehyde (UF) and phenol–formaldehyde resin binders have contributed greatly to the progress made by the wood industry. These adhesives are widely used as a major component in the production of building and furniture materials, such as medium density fiberboard (MDF), particleboard (PB), and plywood. However, decreasing the emission levels of formaldehyde fumes from wood-based panels manufactured using UF resins has now become one of the major concerns of the timber and wood adhesives industry, particularly in the case of adhesively bonded, wood products. Recently, attention has turned to other volatile organic compounds (VOCs) that may be emitted from wood products. These VOCs include chemicals naturally present in the wood, as well as those added during processing. In new energy-efficient buildings, air exchange rates are low, permitting concentrations of VOCs to accumulate to detectable and possibly harmful levels. The adverse health effects associated with these increased VOC concentrations include eye and respiratory irritation, irritability, inability to concentrate and sleepiness. Moreover, health and the environment constitute two key concerns of the 21st century [1–3]. Many Furniture materials emit VOCs which have the potential to affect health and comfort. The formaldehyde emission from wood-based materials is usually determined in a reaction chamber at a predefined temperature, humidity and ventilation rate. The concentration of formaldehyde in the air within the chamber is measured until a constant concentration is reached. This is a time consuming method and it also requires special equipment [4,5]. The Korean government has started controlling indoor air quality since 2004. The law from the Ministry of Environment regulates the use of pollutant emitted building materials and prohibits the use of materials that emit formaldehyde more than 1.25 mg/m^2 h (JIS A 1901, small chamber method). This is equivalent to E_2 grade (>5.0 mg/l) when changed to the desiccator method (JIS A 1460). Most suppliers and people are concerned about how to reduce pollutants from building materials and how to control indoor air quality [6]. Post-treatment methods to decrease and minimize formaldehyde release are based on compounds like ammonia, ammonium salts, or urea. Another effective way to reduce formaldehyde release is the addition of formaldehyde-binding substances ("scavengers") to the resin or to the wood particles [7,8]. A conventional formaldehyde scavenger added to UF resins is urea, which is often used in combination with ammonium chloride (about 20:1). Urea also acts as a buffer to control the pH and improve the stability of UF resins. Ammonium chloride acts as an acid catalyst of the curing reaction and as a scavenger. The urea/ammonium chloride system apparently has no effect on the resin curing and bonding properties of the PB product if it is added up to 10% of the UF resin dry weight. Other approved formaldehyde scavengers are organic amines. Especially in Sweden, dispersion systems based on formaldehyde-binding paraffins were developed [9]. These wax systems are often added to the wood particles before drying. The amounts necessary to obtain perforator values

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below 10 mg depend on plant conditions and on the perforator value of the untreated board. The scavenger does not negatively influence the board strength and pressing time [10,11].

Natural pozzolans are defined as either raw or calcined natural materials that have pozzolanic properties (e.g., volcanic ash or pumicite, opaline chert and shales, tuffs, and some diatomaceous earths). Historically, they are among the oldest materials used in combination with lime for construction purposes. For example, a volcanic eruption around 1500 BC on Santorin Island, Greece, left a large deposit of natural pozzolans there. In modern construction technology, natural pozzolans are still used in various applications [12]. Pozzolanic materials can be natural in origin or artificial and are available widely. They have been used throughout the world to make good quality concrete in recent years. Although they have been used successfully in many countries, research attention continues to focus on finding new and improved ways to form high strength concrete with new pozzolan additives. Due to the strength it imparts to concrete and its durability, the silica fume by-product from industrial waste materials is a well-known and very efficient pozzolan [11,13].

In this research, volcanic pozzolan was used to reduce VOCs emitted from MDF for furniture materials. Volcanic pozzolans are poorly crystallized materials rich in SiO_2 and Al_2O_3, with a porous form and a high content of absorbed water [14]. Therefore, the porous form of volcanic pozzolan is expected to absorb generated odor and VOCs of MDF. The purpose of this study on MDF bonded with UF resin was to investigate the effect of adding volcanic pozzolan as a scavenger on the physico-mechanical properties and on the characteristics on reduction of formaldehyde and total VOC (TVOC) emission.

2. Experimental

2.1. Materials

The wood fiber distributed from Dongwha Enterprise was made from Korean pine (*Pinus densiflora*) with a moisture content of 4%. UF resin was used to produce the MDF with a molar ratio of 1.25 (F/U). This resin was supplied by Tae Yang Chemical Co. Ltd. Before MDF manufacture, 3 parts (to resin) of 25% ammonium chloride as a hardener and 13 parts of 44% wax solution for water-proofing were added. Pozzolan was added as a scavenger at the level of 1%, 3%, 5% and 10% of UF resin.

Volcanic pozzolan was obtained from AutoWin Co. The chemical composition of pozzolan, as determined using an X-ray fluorescence spectrometer (Shimadzu XRF-1700, Japan), is shown in Table 1 which presents the high concentration of SiO_2 and Al_2O_3 elements in pozzolan [15,16]. The particle size of pozzolan is over 70 μm. These results were confirmed by the functional groups of pozzolan. Scanning electron microscopy (SEM) was used to measure the porous surfaces of the pozzolan using a SIRIOM SEM instrument (FEI Co., USA). The acceleration potential used during this investigation was 20 kV. The total scanning time during elemental map generation was 20 min. Prior to the measurement, the specimens were coated with gold (purity, 99.99%) to eliminate electron charging [11].

2.2. Methods

2.2.1. Manufacturing of MDF

The MDFs were fabricated using UF resin with pozzolan added to obtain a specific gravity of 0.8 and dimensions of 270 mm × 270 mm × 8 mm (length × width × thickness). The wood particles were placed in a rotary drum mixer and rotated as they were sprayed with the UF resin used as the composite binder. The quantity of adhesive was calculated to be 14% of the raw material based on the oven-dried weight. The mixture of particles and adhesives was cold pressed at 0.2 MPa for 2 min, to ensure the stability of the mat and to obtain the proper density gradient of the composites prior to hot pressing. The mixture was then hot pressed to form composite boards at a peak pressure of 3 MPa and temperatures of 160 °C. The press time was 5 min, with the pressure being released in two steps of 1 min each. The manufactured boards were pre-conditioned at 25 °C and 65% RH for two weeks before testing.

2.2.2. Physical and mechanical test

Moisture content, density, thickness swelling and water absorption were examined using the ASTM D 1037-99 method. Density was controlled by quality control testing, wherein each value represents the average of five samples. Three-point bending strength and internal bond strength were determined using a universal testing machine (Zwick Co.) using the ASTM D 1037-99 method. Each value represents the average of five samples. The results were compared with the ANSI A208.1-1999 standard.

2.2.3. Desiccator method for formaldehyde emission test

The Japanese standard method with a desiccator (JIS A 1460) was used to determine the formaldehyde emissions from manufactured MDFs with volcanic pozzolan. The emitted quantity of formaldehyde is obtained from the concentration of formaldehyde absorbed over a 24 h period in distilled or deionized water when the test samples of a specified surface area are placed in the desiccator filled with the specified amount of distilled water. The emitted formaldehyde was absorbed in a water-filled petri dish and was analyzed with the chromotropic acid method. The principle for determining the formaldehyde concentration absorbed in the distilled water is based on the Hantzsch reaction in which the formaldehyde reacts with ammonium ions and acetylacetone to yield diacetyldihydrolutidine [17].

2.2.4. 20 L Small chamber method

Before setting up the chamber and seal boxes, they were washed with water and baked out in an oven at 260 °C to eliminate any pollutants from the chamber itself. The 20 L small chamber was supplied with purified and humidified air at a given ventilation rate. The temperature and relative humidity (RH) inside the chamber were kept constant. The test conditions are shown in Table 2. Test pieces, the gypsum–rice husk board as rice husk adding contents, all sealed with seal boxes, were set in the chamber, and the air inside the chamber was sampled after 12 hours. Sampling conditions are shown in Table 3. Throughout the measurements, the air temperature and relative humidity inside the test chamber were kept constant at 25 ± 1 °C and 50 ± 5%, respectively, and ventilated at 0.5time/hour. Aldehydes were analyzed by HPLC, and TDS/GC–MS was used for VOCs, as shown in Tables 4 and 5. In this paper, TVOC was defined as the conversion of all areas of the peaks between C_6 and C_{16} to concentrations using the toluene response factor. The sample gas was collected by Tenax-TA and 2,4-DNPH cartridge 7 days after the sample specimens were installed into the 20 L small chamber, according to the regulations of the Ministry of Environment, Korea [18].

3. Results and discussion

3.1. Physical and mechanical properties

The moisture content of the different pozzolan was in the range of 7.5–7.9%, as shown in Fig. 1. Because a low pozzolan content of 1–10% of UF resin was added in order to avoid any detrimental effects on the normal properties of UF resin, the moisture content and density were not affected. No significant difference was found in the moisture content and density of the MDFs made with pozzolan at the investigated concentrations. The physical properties (thickness swelling and water absorption) of the investigated MDFs are shown in Fig. 2. The thickness swelling of MDFs was decreased with increasing pozzolan content. The thickness swelling was decreased by 4% with 1% added pozzolan. However, water absorption was not significant affected by pozzolan content. On the whole, the MDF physical properties were not markedly changed from those of control MDF (0% of pozzolan) with pozzolan content ranging from 1% to 10%. However, water absorption of MDFs was higher than PBs when pozzolan was added because of fibers in MDF [11].

Table 1
Chemical composition of pozzolan by weight percent [15].

Element	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	MgO	CaO	Na_2O	K_2O	MnO	P_2O_5	LOI[a]
Pozzolan	59.5	17.7	0.9	7.6	1.3	0.2	0.08	4.7	0.1	0.08	5.0

[a] Loss on ignition.