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Effects of hardener type, urea usage and conditioning period on the quality properties of particleboard

İlkay Atar [a], Gökay Nemli [a], Nadir Ayrilmis [b,*], Mehmet Baharoğlu [c], Bünyamin Sarı [a], Selahattin Bardak [d]

[a] Karadeniz Technical University, Faculty of Forestry, Trabzon, Turkey
[b] Istanbul University, Faculty of Forestry, Istanbul, Turkey
[c] Recep Tayyip Erdoğan University, Vocational School of Technical Sciences, Rize, Turkey
[d] Artvin Çoruh University, Faculty of Forestry, Artvin, Turkey

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ABSTRACT

The effects of hardener type (ammonium chloride, ammonium sulphate and aluminium sulphate), urea usage (with urea and without urea), and conditioning period (one day and one month) of the particleboard on the physical (thickness swelling), mechanical (modulus of rupture, modulus of elasticity and internal bond strength), surface properties, and formaldehyde emission of particleboard and acidity of the wood particles were investigated. The hardener type was found to be effective all of the properties of particleboard. The pH of the wood particle with the urea was slightly higher than that of particles without urea.

The lowest pH value for the resinated wood particles was obtained from ammonium chloride, followed by ammonium sulphate and aluminium sulphate, respectively. The best quality properties were obtained from the particleboards manufactured with ammonium chloride, followed by particleboard made with the ammonium sulphate and aluminium sulphate, respectively. The urea usage significantly decreased the formaldehyde emission of the particleboards while it slightly decreased the mechanical properties and increased thickness swelling. Increasing conditioning period of the particleboards from one day to one month improved the quality properties.

1. Introduction

Urea–formaldehyde (UF) resin is the primary binder of interior-grade wood composite boards, such as particleboard, medium-density fiberboard, and plywood due to its short press time, low cost, excellent adhesion, intrinsic cohesion, high reactivity and water solubility, and lack of color in the finished product. One current challenge is to reduce or eliminate the relatively high formaldehyde emission levels of boards that arise due to the UF resin [1,2]. Formaldehyde is considered a priority pollutant by the United States Environmental Protection Agency [3]. Researches have been focused in reducing the emissions or exposure to formaldehyde by adding scavengers, using alternate fossil fuel based-resins without formaldehyde or by using binders based on renewable materials like those based on soy flour [4,5].

The rate and extent of formaldehyde emission from particleboard as well as physical and mechanical properties are influenced by a large number of parameters including mole ratio of formaldehyde/urea, resin level, catalyst level and composition, moisture content and distribution prior to pressing, board post-treatment, duration of storage before use, and scavengers [6–9]. Hoong et al. [2] reported that the formaldehyde emission (0.128–0.407 mg/l) of plywood increased as the amount of solid content increased from 15 to 40 wt% while the mechanical properties improved. In other study, Nemli et al. [10] reported that the average roughness value of particleboard decreased from 13.6 to 8.5 μm as the amount of resin in the core layer-face layer increased from 8–10% to 10–12%. They stated that this was due to increasing of bonding and contact between the wood particles. Guru et al. [4] stated that the hardness values of particleboard linearly increased with increasing urea/formaldehyde ratio up to 0.97 and further increment in the urea/formaldehyde ratio slightly decreased the hardness.

Some important factors on the formaldehyde emission of the particleboard as well as technological properties are hardener type, urea usage, and conditioning period of the particleboard. The effects of these factors on the formaldehyde emission, thickness swelling, mechanical properties, and surface quality of the particleboard have not been extensively investigated in the literature. The objective of this study was to investigate the effects of hardener type, urea usage and conditioning period on the quality properties

* Corresponding author. Address: Department of Wood Mechanics and Technology, Forestry Faculty, Istanbul University Bahcekoy, 34473 Istanbul, Turkey. Tel.: +90 (212) 226 1100x25083; fax: +90 (212) 226 1113.
E-mail address: nadiray@istanbul.edu.tr (N. Ayrilmis).

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of three layer particleboards. The process conditions of particleboard having low formaldehyde emission and high technological properties were determined from manufacturing process variables.

2. Materials and methods

2.1. Manufacture of particleboards

Pine (*Pinus brutia* Ten.) wood (90 wt%), beech (*Fagus orientalis* Lipsky) wood (5 wt%) and poplar (*Populus tremula* L.) wood (5 wt%) particles were used in the manufacture of particleboards. The particleboards were produced in a commercial particleboard plant (Starwood Forest Products Company) in Inegol, Turkey. First the wood particles were classified using a horizontal screen shaker. The particles remained between 3 and 1.5 mm sieves and between 1.5 and 0.5 mm sieves were utilized in the core and surface layers of the particleboards, respectively. The wood particles were dried at 220 °C temperature to reach target moisture content 1%. E_2 grade commercial UF resin having 65% solid content at 11% and 9% adhesive levels based on the oven-dry weight were used for the outer and core layers of particleboard, respectively.

Three different hardeners (ammonium chloride, ammonium sulphate, and aluminium sulphate) were added to the UF resin. 0.85 wt% the hardener (10 wt% water solution) for the surface layers and 2.5 wt% the hardener (25 wt% water solution) for the core layer based on the solid content of the UF resin were added in the resin. The chips were placed in a blender and sprayed with urea formaldehyde. 1 wt% paraffin (32% water solution) based on the solid content of the UF resin was used as a water repellent chemical in the manufacture of particleboards. As a formaldehyde scavenger, 1 wt% of urea (10 wt% water solution) based on the solid weight of the UF resin was added to resin in the manufacture of the some particleboard types given in Table 1. The layer composition of particleboards was designed to consist of 34% chips at the face layer and 66% at the core layer, and the target density of the particleboards was 0.63 g/cm^3. The mats were then subjected to hot pressing. The boards were pressed under 2.5 N/mm^2 pressure, at 225 °C, for 100 s. At the end of the press cycle, the board was removed from the press for cooling. The particleboards having dimensions of 2800 mm × 2100 mm × 18 mm were produced for each type of formulation. A total of 24 particleboards, 2 for each type of formulation, were produced (Table 1). Prior to the tests, the samples were conditioned in a climatized room at 20 °C and 65% relative humidity.

Table 1
The experimental design.

Particleboard types	Manufacturing process variables		
	Hardener type	Urea usage	Conditioning period of the produced panels after hot pressing
1	Ammonium chloride	Without urea	One day
2	Ammonium chloride	With urea	One day
3	Ammonium sulphate	Without urea	One day
4	Ammonium sulphate	With urea	One day
5	Aluminium sulphate	Without urea	One day
6	Aluminium sulphate	With urea	One day
7	Ammonium chloride	Without urea	One month
8	Ammonium chloride	With urea	One month
9	Ammonium sulphate	Without urea	One month
10	Ammonium sulphate	With urea	One month
11	Aluminium sulphate	Without urea	One month
12	Aluminium sulphate	With urea	One month

2.2. Determination of the acidity (pH) of the wood particles

The acidity (pH) of the particles was measured in an extract solution made by 5 g particle flour added to 150 ml water and boiled for 30 min. The pH-meter was used to measure acidity of the wood particles. Six samples for each type of wood particle were used to determine pH value.

2.3. Determination of thickness swelling and density of particleboard

Densities of the samples were evaluated according to the test method specified in EN 323 [11]. 20 replicate samples, 50 mm × 50 mm × 18 mm, from each type of particleboard were used for the density measurement. Thickness swelling (TS) tests were carried out according to EN 317 standard [12]. 20 replicate samples, 50 mm × 50 mm × 18 mm, from each type of particleboard were used for the TS measurement. Duration of the conditioning process was determined by regular weighing of the samples until no changes in the weights were detected. At the end of 24 h of submersion of the samples were taken out from the water and all surface water was removed a clean dry cloth. The samples were measured to the nearest 0.001 mm immediately. The sample thickness was determined by taking a measurement at a specific location, the diagonal crosspoint, on the sample.

2.4. Determination of mechanical properties of particleboard

The modulus of rupture (MOR) and elasticity (MOE) of the samples were performed according to EN 310 standard [13]. A total of twenty samples with dimensions of 410 mm × 50 mm × 18 mm were tested for each type of particleboard. The internal bond strength (IB) tests were conducted on the samples cut from the particleboards according to EN 319 standard [14]. 20 Replicate samples with dimensions of 50 mm × 50 mm × 18 mm from each type of particleboard were used to determine the internal bond strength.

2.5. Determination of formaldehyde emission of particleboard

Three samples (20 mm × 20 mm × 18 mm) were randomly taken from each type of particleboard for formaldehyde emission (FE) determination using the perforator method based on EN 120-1 standard [15]. The perforator test involves reflux in boiling toluene with approximately 110 g of small cube samples. The reflux speed of the system was adjusted to 30 ml/min, and extraction was conducted for 2 h. The extracted formaldehyde was collected in water, which was then added with 50 ml of iodine solution and 20 ml of sodium hydroxide in a dark room for 15 min. A 10 ml mixture of sulfuric acid and sodium thiosulphate solution was applied to the mixture until its color changes from light brown to light yellow.

2.6. Determination of surface roughness and wettability of particleboard

The samples used for wettability and surface roughness tests were sanded with a Sequence of 100 and 150 grit sand papers. The surface properties of the samples with dimensions of 50 mm × 50 mm × 18 mm were determined by employing a fine stylus profilometer (Mitutoyo SJ-301). Ten samples were used from each type of the particleboard for the surface roughness measurements. Three roughness parameters characterized by ISO 4287 [16] standard, 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 properties of the particleboards. The surface roughness parameters were calculated from the digital