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Nano-engineered plywood panels: Performance properties

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ABSTRACT

Nanotechnology has a huge potential to develop novel wood composites with enhanced properties. Engineering plywood panels having improved physical and mechanical characteristics by nanotechnology was the main goal of this work. Melamine urea formaldehyde resin used to produce plywood panels was reinforced with various nanomaterials at different loading levels. Density, moisture content after submersion, thickness swelling, water absorption, modulus of rupture, modulus of elasticity, bonding strength, and screw withdrawal strength of the plywood panels were carried out according to national or international standard methods. The results obtained in this study showed that nanomaterial reinforcement significantly affected the physical and mechanical characteristics of the plywood panels. The findings indicate that it is possible to produce novel wood composites having improved performance properties by using nanotechnology.

1. Introduction

Plywood panels are among wood composite materials that are made from wood veneers as renewable bioresources. Plywood panels are mostly used for structural applications. Plywood panel production capacity was 180,000 cubic meters in 2010 in Turkey. The estimated plywood production capacity for 2013 is 247,000 cubic meters in Turkey with 55 production lines. The increase in the plywood production capacity can be attributed to the growth in both Turkish construction industry and yacht-ship building industry [1–4].

Nanoparticles can be used as fillers or additives in polymers for various desired material property improvements. Therefore nanoparticles are receiving increased interest for research and development [5]. Nanomaterial-reinforced composite sandwich panels and laminate flooring were developed by Candan [1]. Formaldehyde emission properties of the nanomaterial-reinforced laminate flooring were studied by Candan and Akbulut [6]. The effect of different nanomaterials on the formaldehyde emission properties of particleboard and plywood panels were investigated by Candan and Akbulut [2]. It was stated that low formaldehyde-emitting composites can be manufactured by using proper nanomaterial type and loading level. Cai et al. [7] reinforced melamine urea formaldehyde adhesive with montmorillonite nanoclay. After that wood was modified with the nanomaterial-reinforced adhesive to obtain polymer nanocomposites. Cai et al. [8] reinforced melamine urea formaldehyde adhesive with aluminum silicate nanoclays and examined its curing and dynamic mechanical behavior. Kordkheili et al. [9] examined physical and mechanical properties of polymer type panels made from single wall carbon nanotubes and wood flour.

Zhang and Smith [10] reinforced phenol–formaldehyde (PF) resin with nanoclay and studied its effect on the permeability of oriented strand lumber. Lei et al. [11] examined the effect of nanoclay on the properties of the PF and phenol–urea–formaldehyde (PUR) adhesives. It was concluded that the addition of small percentages of nanoclay did not increase much the performance of PF and PUR resins used as adhesives for plywood and particleboard panels. Lei et al. [12] modified urea–formaldehyde (UF) resin with different loading levels of nanoclay and then produced particleboard and plywood panels. It was reported that water resistance of plywood panels improved with nanoclay reinforcement. It was also concluded that nanoclay reinforcement enhanced bonding strength of particleboard panels. Zhang et al. [13] reinforced UF resin with modified nanocellulose and manufactured plywood panels. It was stated that formaldehyde emission values of the plywood panels decreased with increasing nanocellulose content up to 1.5%. It was also indicated that bonding strength of the plywood panels increased as nanocellulose content increased up to 1.0%.

Veigel et al. [14] studied the properties of the particleboard and oriented strandboard panels bonded with cellulose nanofibers reinforced UF or MUF resin. It was reported that thickness swell values of the particleboard panels bonded with UF adhesive containing 1% nanocellulose were lower than the panels bonded with unreinforced UF adhesive. Further increase in nanocellulose

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loading level (3%) increased thickness swelling values of the particleboard panels. It was also concluded that the particleboard panels bonded with UF adhesive containing 1% nanocellulose had higher bonding strength and modulus of rupture values than the particleboard panels with neat UF adhesive. Similarly, when the nanocellulose content increased to 3%, both of the strength values decreased in UF bonded particleboard panels. The authors also stated that OSB panels had similar results with particleboard panels.

There is only limited study in the literature investigating physical and mechanical properties of plywood panels reinforced with various nanomaterials at different loading levels. The overall goal of this work was to develop nano-engineered plywood panels having enhanced performance properties by nanotechnology. The influence of the nanomaterial type or loading level on the physical and mechanical properties of the plywood panels was evaluated in this study.

2. Experimental

2.1. Materials

Wood veneer sheets, melamine urea formaldehyde (MUF), and additives were supplied by Cag Forest Products Inc., also located in Kastamonu, Turkey. The wood species used to manufacture plywood panels in this study were *Tetraberlinia bifoliolata and Populus* × *canadensis Moench*. The nanosilica (nanoSiO_2), nanoalumina nanoAl_2O_3, and nanozinc oxide (nanoZnO) particles used to modify MUF adhesive were provided by a chemical company. The average particle size values (APS) of the nanoparticles ranged from 15 nm to 50 nm and purity of the nanoparticles was 99.9%.

2.2. Nano-engineered composite manufacturing

Melamine urea formaldehyde (MUF) adhesive was reinforced with nanoSiO_2, nanoAl_2O_3, and nanoZnO nanoparticles. The nanoparticles were added to the adhesives at a loading level of 1% or 3%. MUF, $(NH_4)_2SO_4$, NH_3, and flour were used as an adhesive, hardener, buffer, and filler, respectively, in the manufacture of the plywood panels. Plywood panels were made from nanomaterial-reinforced or unreinforced adhesives. The average thickness of the plywood panels was 8 mm. Press temperature, time, and pressure were 105 °C, 20 min, and 7 kg/cm^2, respectively. Three plywood panels were made from each test condition (nanomaterial type and nanomaterial loading level) plus a set of control panels were made, giving a total of 21 panels for evaluation.

2.3. Testing procedure

2.3.1. Physical properties

Nanomaterial-reinforced or unreinforced plywood panels were cut into test samples (50 mm by 50 mm by 8 mm) which were then conditioned in a climate controlled chamber with a relative humidity of 65% and a temperature of 20 °C until they reached an equilibrium moisture content, prior to the physical tests (TS EN 325) [15]. 15 samples were used for each of the physical tests. Density (TS EN 323) [16], thickness swelling (TS) (TS EN 317) [17], and water absorption (WA) (ASTM D1037) [18] of the composites were determined according to national or international standards. Firstly, all TS and WA samples were weighed and measured in thickness. Specimens were immersed vertically in water bath with a temperature of 20° ± 1 °C. TS and WA performance of the composites were determined after 2 h or 24 h water immersion period. Moisture content after submersion (MC) test was also conducted according to ASTM D1037 [18]. After the 24 h water soaking period, the TS&WA samples were dried in an oven at 103 °C until constant weights were reached and then weighed. The MC values of the specimens after 2 h or 24 h water soaking period were calculated based on the oven-dry weight of each specimen.

2.3.2. Mechanical properties

Flexural strength (TS EN 310) [19], flexural modulus (TS EN 310) [19], bonding strength (TS 3969 EN 314-1 [20], (TS EN 314-2) [21], and screw withdrawal resistance (TS EN 320) [22] tests were carried out to determine mechanical performance of the nanomaterial-reinforced or unreinforced plywood panels. The experimental composites were cut into test specimens. All specimens were conditioned in a climate controlled chamber with a relative humidity of 65% and a temperature of 20 °C until they reached an equilibrium moisture content, prior to the mechanical tests. 15 samples were used for flexural strength and flexural modulus tests while 20 samples were used for bonding strength and screw withdrawal resistance tests.

2.3.3. Scanning electron microscopy (SEM)

To evaluate morphological properties of the nanomaterial-reinforced composites, scanning electron microscopy (SEM) analysis were conducted. SEM micrographs were taken with a Field Emission-SEM (FEI Quanta FEG 450, The Netherlands) operated at 20 kV. All the specimens were coated with gold prior to the analysis.

2.4. Statistical analysis

To evaluate physical and mechanical properties of the plywood panels reinforced with nanomaterials, all comparisons were first tested using an analysis of variance (two-way ANOVA) at $p < 0.05$. Significant differences between the mean values of treated and untreated groups were determined using Duncan's multiple range test.

3. Results and discussion

3.1. Physical properties of the nano-engineered composites

The mean density values of the nano-engineered plywood panels ranged between 550 kg/m^3 and 640 kg/m^3. All of the plywood panels had similar density values, except the panels reinforced with 3% nanoAl_2O_3. The findings indicated that the nanomaterials did not affect the density values of the plywood panels. It also concluded that the manufacturing process of plywood panels was meticulously carried out.

Thickness swell (TS) results of the nanomaterial-reinforced plywood panels after both 2 h and 24 h water soaking time were

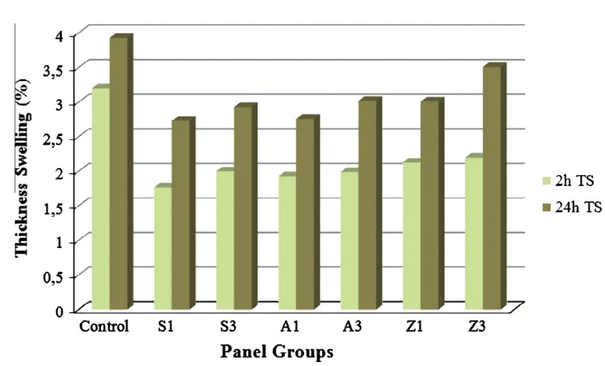

Fig. 1. Thickness swell results of the nano-engineered plywood panels. S1: 1% nano-SiO_2; S3: 3% nano-SiO_2; A1: 1% nano-Al_2O_3; A3: 3% nano-Al_2O_3; Z1: 1% nano-ZnO; Z3: 3% nano-ZnO.