Properties of wood plastic composite panels made from waste sanding dusts and nanoclay
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What is This?
Properties of wood plastic composite panels made from waste sanding dusts and nanoclay

Mehrab Madhoushi¹, Arash Chavooshi¹, Alireza Ashori², Martin P Ansell³ and Alireza Shakeri⁴

Abstract
This article presents the application of waste sanding dusts in order to evaluate its suitability as reinforcement for thermoplastics as an alternative to wood fibers. The effects of sanding dust loading and nanoclay content on the physical and mechanical properties were also studied. Overall trend showed that with addition of sanding dusts, tensile and flexural properties of the composites were significantly decreased, due to the reduction of interface bond between the fiber and matrix. It was found that flexural, tensile and withdrawal strength of fasteners were moderately enhanced by the addition of 2 wt% nanoclay in the matrix. However, with increase in the nanoclay content (4 and 6 wt%), the flexural and tensile properties decreased significantly. The results also showed that the withdrawal strengths of screws are much higher than those of nails. At certain amount of sanding dust, with increasing nanoclay loading the withdrawal strengths of fasteners (screws and nails) were considerably decreased. The thickness swelling and water absorption of the composites dramatically decreased with the increase in nanoclay loading. Except thickness swelling, both variable parameters (sanding dust and nanoclay contents) showed significant influence on physico-mechanical properties.

Keywords
Nanoclay, waste sanding dusts, wood plastic composite, withdrawal strength of fasteners

Introduction
In recent years, wood plastic composites (WPCs) have attracted great attention in academic and industrial sectors due to considerable processing advantages and improvement in certain physical and mechanical properties.¹ The utilization of lignocellulosic materials in the production of WPCs is attractive particularly because of low cost and high volume applications.² Biodegradable lignocellulosic fillers possess several advantages compared to conventional inorganic fillers, such as lower density, lower abrasiveness, lower cost, higher specific strength and greater deformability.³,⁴ Lignocellulosic materials can be obtained either from wood, non-wood plant fibers or waste wood.⁵

The word “waste” projects a vision of a material with no value or useful purpose. However, technology is evolving that holds promise for using waste or recycled wood to make an array of high-performance composite products. When lignocellulosic fibers, resins and other materials are used as raw materials for products such as paper, they require extensive cleaning and refinement, but when recovered fibers, resins and other materials are used to manufacture composites, they do not require extensive preparation. This will, in turn, greatly reduce the potential cost of manufacturing.⁶ There is an increasing interest in using waste lignocellulosic-based materials due to the worldwide diminishing of wood resources.⁷,⁸ Iran has a large quantity of waste biomass such as sawdust and sanding

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dusts (SDs) generated in wood-based industries. The SD is cheap, highly available and harmful for human health. The possibility of using waste SDs in the development of WPCs is very attractive, especially with respect to the large quantity of SD produced daily. Hence, the development of new value-added products, to utilize the recovered SDs, is assuming greater importance. The addition of SD to thermoplastics renders the resulting composites viable from both the mechanical properties and the environmental points of view. In addition, utilization of SDs in manufacturing of WPCs can lead to low production costs.\(^7\)^\(^9\)

The type of lignocellulosic material,\(^10\) fiber content,\(^11\)^\(^12\) source of polymer\(^13\) and coupling agents\(^14\)^\(^15\) have a strong influence on the mechanical and physical properties of WPCs. Clay nanoparticles (nanoclay) improve the mechanical properties of composites including tensile modulus, flexural modulus of elasticity, hardness, dynamic modulus of elasticity and the degree of crystallinity.\(^16\) In addition, they improve the manufacturing process by raising the thermal decomposition temperature of the polymer matrix, enhancing the heat-releasing rate and delaying ignition time.\(^15\) Nanoclays (NCs) have a high-aspect ratio and form exfoliated and intercalated surfaces resulting in better shaping of the polymer composite,\(^17\) which affects the physical properties and microstructure of molded components. The impact of NC fillers on WPC properties depends on shape, size, aspect ratio, type, amount and quality of the dispersed particles and their adhesion to the matrix.\(^18\) Small amounts of NC particles can significantly improve the mechanical properties and thermal and dimensional stability in the composite. For instance, the tensile strength of WPCs increased dramatically by adding 1% to 3% by weight of NC, but properties gradually reduced by further increasing the amount of NC.\(^1\)^\(^19\) The Young’s modulus,\(^4\) weathering resistance\(^20\) and water uptake resistance\(^21\) of WPCs may also be improved by adding NC.

The ultimate goal of the present research was to explore the potential of SDs as filler for producing WPCs. The specific objectives of this study were to (a) prepare WPCs with various loading level of SD material and NC and (b) characterize physical, mechanical, withdrawal strength of fastener and morphological properties of WPCs.

**Materials and methods**

**Materials**

Lignocellulosic material. The dust from surface sanding of medium density fiberboard (MDF) boards was used in this work. The SDs were obtained from a local MDF plant in the northern part of Iran. The particles were sifted with a vibrating screen. Particles that pass through 40-mesh and remained on the 60-mesh screen were used. Selected particles were oven-dried at 105°C to reduce the moisture content to less than 3%.

**Polymer matrix.** Injection molding grade polypropylene (PP), with trade name V30S, was supplied by Arak Petrochemical Co. (Iran). The PP was in the form of pellets with a melt flow index of 18 g/10 min at 190°C and a density of 0.92 g/cm\(^3\).

**Coupling agent.** Maleated anhydride grafted polypropylene (MAPP), in the form of pellets with a density of 0.91 g/cm\(^3\), a melt flow index of 64 g/10 min and maleic anhydride of 2 wt.%, was obtained from Kimia Javid Sepahan Co., Iran.

**Nanoparticles.** The NC, with trade name of Cloisite\(^8\)\(^15\)A, in powder form was used. Natural montmorillonite modified with a dimethyl, dehydrogenated tallow, 2-ethylhexyl quaternary ammonium (cationic exchange capacity = 125 meq/100 g clay, \(d_{001} = 31.5\) Å) was obtained from Southern Clay Products Co., USA.

**Preparation of composite panels**

Formulation of the mixes and abbreviations used for the respective mixes prepared are given in Table 1. Composites were produced in a two-stage process. In the first stage, SD, MAPP, PP pellets and NC powder were premixed mechanically at various formulations, and the mixtures were then fed into a laboratory counter-rotating twin-screw extruder (WPC-4815, Borna Pars Mehr Co., Iran). The temperature profile in the extruder was 170/175/185/190/185°C and the screw...
speed was set at 20 r/min. In the second stage, the extruded strand was passed through a water bath and pelletized. The resulting granules were then placed in hot press at 190°C for 7 min and finally cooled to room temperature under pressure. The pressure for heating was controlled at 3–3.5 MPa.

**Mechanical testing**

Specimens were tested following BS standard CEN/TS 15534-1:2007 for tensile, flexural and withdrawal strength of fasteners (screw and nail). The flexural properties were measured in three-point bend tests. All above-mentioned tests were conducted using a Universal Testing Machine (Instron 4486). The samples were cut to the dimension of $20 \times 2 \times 1$ cm$^3$ for the flexural and tensile tests and $5 \times 5 \times 1$ cm$^3$ for the withdrawal tests. Six replicates were tested for every property under each formulation.

**Physical testing**

Physical properties, namely water absorption and thickness swelling were tested in accordance with ASTM D 570. Before testing, the weight and thickness of each specimen were measured. Conditioned samples of each type of composite were soaked in distilled water at room temperature for 2 and 24 h. Samples were removed from the water, patted dry and then measured again. Each value obtained represented the average of six samples.

**Field emission scanning electron microscopy**

Studies on the morphology of the composites were carried out using field emission scanning electron microscopy (FE-SEM; Hitachi HHS-2R). The fracture surfaces of the specimens after tensile test were sputter-coated with gold before analysis, in order to eliminate electron charging.

**Statistical analysis**

Statistical analysis was conducted using SPSS programming (version 18) method in conjunction with analysis of variance (ANOVA) techniques. Duncan’s multiple range test (DMRT) was used to determine the statistical differences among the variables investigated at the 99% confidence level.

**Results and discussion**

**Mechanical properties**

Tables 2 and 3 show mechanical results in terms of flexural, tensile and fastener withdrawal properties.
Table 3. Analysis of variance on the effects of sanding dust (SD) and nanoclay (NC) contents and their interaction on some mechanical and physical properties.

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<th>Properties</th>
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</table>

A: Sanding dust; B: Nanoclay; df: degree of freedom; MS: mean of squares; SS: sum of squares; F: F value.

**Significant difference at the 99% level; ns = not significant.
of WPCs filled with (A2-A4, B2-B4 and C2-C4) and without NC particles (A1, B1 and C1). For easier comparison, changes (reduction or increment) for the properties are presented in Figure 1. The results showed that there were significant differences for all above-mentioned properties among the specimens. However, there was no significant difference for the interaction of variable parameters.

**Flexural properties**

Figure 1(a) elucidates results of the flexural strengths and moduli of WPCs with varying amounts of SD and NC. Maximum flexural modulus and strength were 2723 MPa and 27.7 MPa for composite type A2. The mechanical properties of WPCs depend on the properties of constituents and the interface interaction. However, when considering the flexural properties, homogeneity of the overall composite needs to be taken into account. Comparison of the results for composites with varying NC contents shows that the flexural moduli of the composites increase with increase in nanoparticles content. When an amount of 2 wt% NC was added, the flexural modulus showed the highest values, increasing by about 5% compared with samples without nanoparticles. This could be explained by the high stiffness of NC with high-aspect ratio. Another possible reason might be related to the formation of strong bonds between nanoparticles layers and PP matrix. Similar results have been reported by Deka and Maji, who studied the properties of polymer/wood flour/nanoclay composites. Their data showed

![Figure 1. Comparison of (a) flexural, (b) tensile and (c) fastener withdrawal properties of composites as function of the nanoclay (NC) and sanding dust (SD) loading.](image-url)
that the flexural modulus of a polymeric material is remarkably improved when nanocomposites are formed with NC particles. However, further addition of NC (4 and 6 wt%) could not improve the flexural moduli. It may be attributed to the aggregation of NC particles and a reduction in nanoclay lamination which would cause a reduction in strength. This is supported by the SEM micrographs.

Results also showed that different content of SD had significant effect on both flexural properties (Table 3 and Figure 1(a)). The highest values were observed in samples containing 40 wt% of SD and 2 wt% of NC (treatment A2). With increasing SD more than 40 wt%, the flexural moduli were decreased. A similar trend can also be seen in the values of flexural strengths. Various parameters influence the flexural properties of WPCs including the fiber-aspect ratio, fiber-matrix adhesion, stress transfer at the interface and mixing temperatures. It is also noteworthy that the flexural moduli of composites are significantly greater than the pure PP (1.5 GPa).

**Tensile properties**

In general, the trend results of tensile properties of the WPCs as function of lignocellulosic material and NC contents was similar to that of flexural properties discussed earlier. The tensile strength of the WPCs varies significantly with SD content (Figure 1(b)). The tensile modulus of elasticity ranges from 2025 to 4487 MPa, while the tensile strength varies from 13.9 to 29.5 MPa. In other words, modulus of elasticity of pure PP is enhanced at least 1.6 times. It was found that treatment A2 (with 40 wt% SD) showed superior strength and modulus compared to other treatments (with or without NC). Once SD loading increased, the tensile strengths and moduli tended to decrease considerably. This indicates weak interaction between the lignocellulosic material and polymer matrix. Nourbakhsh and Ashori\textsuperscript{19} reported that the dominant factor is the coupling agent, which can change the molecular morphology of the polymer chains near the wood-polymer interphase. It is expected that increasing MAPP content for the composites, which is made with higher content (40 and 60 wt%) of SD, could improve the tensile properties.

The composites filled with 2 wt% NC (treatments A2, B2 and C2) showed the highest values for tensile strength and modulus amongst the composites evaluated, whereas composites with 6 wt.% NC (A4, B4 and C4) exhibited the lowest properties. This result is consistent with the general observation that the introduction of nano-sized particles into a polymer matrix increases its tensile properties.\textsuperscript{4} Nourbakhsh and Ashori\textsuperscript{19} reported that the modulus of composites at higher NC loading might not be increased because of the nanoparticle agglomerates. One of the most important parameters in fabricating composites is nanoparticles dispersion in the matrix.

**Withdrawal strength**

The screw and nail withdrawal strengths of the composites are shown in Figure 1(c). The fastener strengths of the WPCs vary significantly with SD and NC loading levels (Tables 2 and 3). Composites made with 40 wt% SD (A2) exhibited the highest screw and nail withdrawal resistances; whereas composites filled with 60 wt% SD (C4) showed the lowest properties. A similar result was observed for samples without NC (A1, B1 and C1) by Madhoushi et al.\textsuperscript{12} At certain amount of SD material, the different withdrawal strengths among the manufactured panels can be attributed to the role of NC. As it can be seen from Figure 1(c), 2 wt% NC (A2, B2 and C2) loading could improve the fastener strengths. However, further addition of NC did not show any improvement in these properties, which is consistent with previous reported results.\textsuperscript{4} The decrease in withdrawal strength at higher SD and NC contents may be due to the poor interfacial adhesion between the lignocellulosic material and the polymer matrix resulting in weak interfacial regions.

Wechsler and Hiziroglu\textsuperscript{4} believe that the heterogeneity and the high surface area-to-volume ratio of NC particles enable them to reinforce organic materials effectively. They enhance the interface between two phases acting as reinforcement. However, at higher amount of clay nanoparticles form interlocked aggregates which surround the SD and prevent the formation of favorable bonding between the fiber and the matrix.

**Physical properties**

One of the most important properties to be evaluated for WPCs is water absorption, since it can affect the mechanical properties and also dimensional stability. According to the statistical analysis, all variable factors exerted a significant influence on water absorption for 2 h and 24 h immersion as a single factor (Tables 2 and 3). However, the interaction between the two variable parameters was not significant for water absorption and thickness swelling.

**Water absorption**

Figure 2(a) shows the percentages of the water uptake for the WPCs, which vary depending upon the lignocellulosic material and NC contents. The water absorption values vary from 0.3% to 3.5% and from 1.4% to 10% for 2 and 24 h immersion, respectively. It is worth
mentioning that pure PP does not absorb moisture due to its hydrophobic nature, indicating that moisture is absorbed by the lignocellulosic material in the WPCs. With the increase in the SD content, there are more water residence (free –OH) sites, thus more water is absorbed. Additionally, large number of porous tubular structures present in fiber accelerates the penetration of water by the so-called capillary action. Similar results have been published by Nourbakhsh and Ashori, who studied the influence of moisture content on fiber/matrix adhesion for PP/bagasse nanocomposites. In all cases, the water uptake was found to increase with the increase in the time of immersion.

At certain amount of fibrous material, the different water absorptions among the manufactured panels can be attributed to the role of NC. Figure 2(a) clearly shows that the water uptake decreased moderately with increasing NC loading in the composites – a trend that is true for all treatments. It can be observed that the composites made with 6 wt% NC (A4, B4 and C4) exhibited the lowest water absorption as compared to those made without NC (A1, B1 and C1). This is possible because the organically modified clay increases the tortuous path for water transport and, as a result, water diffusivity decreases. Decrease in the available space for water absorption due to the occupation of void spaces in the fiber by the NC can be another mechanism for the lower water uptake of nanocomposites.

**Thickness swelling**

Thickness swelling is an important property that represents the stability performance of the composites. The effect of lignocellulosic material and NC on the thickness swelling of composites is presented in Figure 2(b). The thickness swelling of the composites increases with the water absorption and thus has a trend similar to that of the water absorption. As mentioned earlier, the poor absorption resistance of the cellulosic materials is mainly due to the presence of polar groups, which attract water molecules through hydrogen bonding. This phenomenon leads to a moisture build-up in the fiber cell wall (fiber swelling) and also in the fiber–polymer interface. This is responsible for the changes in the dimension of WPCs, particularly in the thickness and the linear expansion due to reversible and irreversible swelling of the composites.

The thickness swelling of the WPCs varied with SD content. Besides, thickness swelling decreased slightly with the incorporation of NC. However, SD and NC loading levels did have any significant effect on thickness swelling (Table 3). The thickness swelling values for 2 h immersion vary from 0.4% to 0.7%, and these...
values are increased for 24 h, varying from 1.0% to 1.7%. Composites filled with 60 wt% of SD and without NC (C1) exhibited maximum thickness swelling. In addition, the presence of NC leads to decreasing thickness swelling. The presence of NC in the composite hinders the permeation of water through the composite. Many studies have supported the above observation.15,22,25

Morphology characteristics

SEM is an effective media for the morphological investigations of the composites. Through SEM study, the distribution and compatibility between the fiber and the matrix could be observed. The significant improvements in tensile properties of the composites with incorporation of SD and NC were further supported by SEM micrographs. Representative micrographs of the tensile fracture surfaces in the four different formulations are reported in Figure 3. At 40 wt% SD content (Figure 3(a) and (b)), filler particles become the main component and few traces are seen where the filler particles have been pulled-out. This is a clear indication that SD has an effective interaction with PP matrix. The more uniform distribution evident in the sample containing 2 wt% NC (A2) suggests that the nanoparticles and PP was thoroughly mixed. Furthermore, the uniform distribution of NC in the matrix improved some mechanical properties.

In the case of the composites filled with 60 wt% SD (Figure 3(c) and (d)) many deep holes and cavities remained after the fillers were pulled out of the matrix. The presence of these holes means that the interfacial bonding between the filler and the matrix polymer is weak and therefore the SD could not provide an efficient stress transfer from the matrix. In the case of the composite with 6 wt% NC content (C4), some agglomerated NC particles were observed (Figure 3(d)). It means the lack of intimate bonding between NC and matrix led to numerous irregularities, which make the transfer of stress from the matrix to the SD poor and the mechanical properties of the NC were not fully utilized.

Conclusions

This study proves that SD and NC have remarkable effects on the physico-mechanical properties of the WPCs. Statistical analysis showed significant differences in the physical and mechanical properties of composites at the 99% confidence level. The composites with higher (50 and 60 wt%) SD contents exhibited lower mechanical properties. The decrement of mechanical properties at 4 and 6 wt% of NC was related to the agglomeration of NC particles. It was also confirmed with SEM micrographs. The water absorption and thickness swelling increased with the SD content; however, adding NC reduces (improves) these properties moderately. Since composite voids and the lumens of the fibers were filled with NC, this prevented the penetration of water by the capillary action into the deeper parts of composite. Therefore, the water absorption in composites filled with NC was significantly reduced. The SEM micrographs revealed some pulled-out traces on the fracture surfaces of the test samples made using 6 wt% NC, but a fewer pulled-out traces
and many broken fillers on the fracture surfaces of the test samples filled with 2 wt% NC, due to the stronger interfacial bonding. Finally, it concludes that utilization of certain amount of SD material in manufacturing of WPCs can lead to low production costs and eliminates the problem of accumulating and discarding wood industries waste.

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Conflict of interest

None declared.

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