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Effects of different nanoclay loadings on the physical and mechanical properties of *Melia composita* particle board

Photo 1.
Material use for the experience:
Melia composita: a. Tree; b. Flower and fruit; c. Bark; d. Leaf and flower.
e. Nanoclay: Cloisite Na^+.
Photo (a, b, c, d) Rksrathore, Vijay, P. Grard. *Melia composita* Benth. [online] India Biodiversity Portal, Species Page: {name of species field}, Available at: http://indiabiodiversity.org/species/show/261673 [Accessed date Sep 11, 2017].
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RÉSUMÉ

EFFETS DE DIFFÉRENTES CHARGES DE NANOARGILE SUR LES PROPRIÉTÉS PHYSIQUES ET MÉCANIQUES DE PANNEAUX DE PARTICULES EN BOIS DE *MELIA COMPOSITA*

La présente étude a permis d'analyser les effets de l'ajout d'une charge de nanoparticules de Cloisite Na^+ (nanoargile) dans une résine d'urée-formaldéhyde utilisée dans la fabrication de panneaux de particules. La Cloisite Na^+ a été incorporée à 2 %, 4 % et 6 % de la masse sèche de résine. La densité, l'absorption d'eau (AE), le gonflement (G), les modules de rupture (MR) et d'élasticité (ME) et la résistance interne à l'arrachement (RI) ont été mesurés pour évaluer la performance des panneaux. Des améliorations significatives ont été constatées pour G, MR et ME avec de la Cloisite Na^+ incorporée dans la résine. Plus précisément, pour les échantillons au liant UF additionné de 6 % de nanoargile, les valeurs MR et ME augmentent respectivement de 34 % et de 65 % par rapport aux panneaux de référence.

Mots-clés : *Melia composita*, propriétés mécaniques, nanoargile, panneau de particules, propriétés physiques, urée-formaldéhyde.

ABSTRACT

EFFECTS OF DIFFERENT NANOCLAY LOADINGS ON THE PHYSICAL AND MECHANICAL PROPERTIES OF *MELIA COMPOSITA* PARTICLE BOARD

This study investigated the effects of adding a filler of nano-sized particles of Cloisite Na^+ (nanoclay) to urea-formaldehyde resin on the physical and mechanical properties of particle boards made with this resin. Cloisite Na^+ was introduced at rates of 2%, 4% and 6% of the dry mass of the resin. Density, water absorption (WA), thickness swelling (TS), modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond strength (IB) were measured to evaluate the performance of the boards. Significant improvements were observed for TS, MOR and MOE when Cloisite Na^+ was added to the resin. More specifically, in samples bonded with UF resin and 6% nanoclay, 34% and 65% increases were observed in MOR and MOE respectively compared to the control boards.

Keywords: *Melia composita*, mechanical properties, nanoclay, particle board, physical properties, urea-formaldehyde.

RESUMEN

EFECTOS DE DIFERENTES CARGAS DE NANOARCILLA EN LAS PROPIEDADES FÍSICAS Y MECÁNICAS DE TABLEROS DE PARTÍCULAS DE MADERA DE *MELIA COMPOSITA*

Este estudio permitió analizar los efectos de la adición de una carga de nanopartículas de Cloisite Na^+ (nanoarcilla) en una resina de urea formaldehído (UF) empleada en la fabricación de tableros de partículas. Se incorporó Cloisite Na^+ en proporciones del 2%, 4% y 6% de la masa seca de la resina. Se evaluó el desempeño de los tableros midiendo la densidad, la absorción de agua (AA), el hinchamiento (H), los módulos de ruptura (MOR) y elasticidad (MOE) y la resistencia en cohesión interna (RI). Con la incorporación de Cloisite Na^+ en la resina, se observaron mejoras significativas en H, MOR y MOE. Más concretamente, en las muestras encoladas con UF y nanoarcilla al 6%, se observaron aumentos en MOR y MOE del 34% y 65%, respectivamente, con respecto a los tableros de referencia.

Palabras clave: *Melia composita*, propiedades mecánicas, nanoarcilla, tablero de partículas, propiedades físicas, urea formaldehído.

Introduction

Uses of additives have high significance for wood composite industry. These materials are often used to alter the performance of adhesives for improving the end product. Adhesion promoters, fillers and tackifiers are common type of additives used in resins. Along with these traditional additives, nano-additives are also gaining attention in the field of wood composites. These nano-sized particles with large surface area have been observed to alter the properties of adhesives as well as composites. Nanofiller can significantly improve or adjust different properties of the materials into which they are incorporated, such as optical, electrical, mechanical, thermal properties or fire-retardants properties, sometimes in synergy with conventional fillers (Marquis *et al*., 2011). At present, much attention is being paid to investigate nanocomposite materials comprising layered silica clay. Nano-plate fillers can be natural or synthetic clays, as well as phosphates of transition metals. Clay-based nanocomposites generate an overall improvement in physical performances. The most widely used ones are the phyllosilicates (smectites). They have a shell-shaped crystalline structure with nano-metric thickness. Clays are classified according to their crystalline structures and also to the quantity and position of the ions within the elementary mesh (Marquis *et al*., 2011). The most important characteristics pertinent to application of clay minerals in polymer nanocomposites are the richest intercalation chemistry, high strength and stiffness and high aspect ratio of individual platelets, abundance in nature, low cost and high gas barrier quality (Salari *et al*., 2012). It is found that slight percentage of nanoclay could improve the curing performance of the UF resin and physical and mechanical properties of wood and bamboo-based composites (Lei *et al*., 2008; Andrabi and Ismita, 2013). Nanoclay fillers have modifying effect on UF resin by decreasing resin viscosity, improving bonding and controlling its penetration into the wood tissues (Doosthoseini and Zarea-Hosseinabadi, 2010). Ashori and Nourbakhsh (2009) observed considerable improvement in mechanical and physical properties of boards when loaded from 2 to 6 weight % to the boards furnishes. Addition of Cloisite 30B resulted in significant improvement in mechanical properties of wood polymer composites (Samariha *et al*., 2015). However there is report of compactness of strips having more effect on oriented strand lumber when prepared with different concentration of UF resin along with nano-silane (Taghiyari *et al*., 2016a). One of the ways to decrease the formaldehyde emission of the UF boned panels is to use nano-fillers such as nanoclay and nano-SiO_2 because these materials have strong absorbability as well as high barrier property (Roumeli *et al*., 2012). Taghiyari *et al*. (2013a) observed that wollastonite nano-fibers contribute to bond formation between wood chips when applied; consequently they can improve physical and mechanical properties of particle board. Wollastonite has a high thermal conductivity coefficient that could accelerate the transfer of heat from hot-press plates and facilitate resin curing in the center of the mat (Taghiyari *et al*., 2013b, 2014). Against the background, the present study investigates the effect of three concentrations of Cloisite Na^+ (nanoclay) on physical and mechanical properties of particle board made from *Melia composita* using Urea Formaldehyde resin.

Materials and methods

Melia composita tree was felled from the campus of Forest Research Institute, Dehradun. Small sections of it were manually converted into chips by sickle. Particles were prepared by passing these chips through Condux mill. Preferred dimensions of particles in cutter type are usually 0.2 to 0.4 mm in thickness, 10 to 60 mm in length and 3 to 30 mm in width. The moisture content of the material leaving the drier was ranged from 6 to 12 percent. The particles were then air dried to about 6% moisture content. The particles were sieved through 60 and 40 microns mesh screen of horizontally vibrating screen machine for removing oversized particles and to get particles of uniform size. Urea formaldehyde (UF) resin in dry powder form was procured form ARCL Organics Pvt. Ltd. The Cloisite Na^+ used in this study was procured from Connell Bros. Company (India) Pvt. Ltd. Mumbai. The specifications of the Cloisite Na^+ are listed in table I.

UF resin was diluted to 40% solid content by mixing the resin powder with water. Nanoclay was added to urea formaldehyde resin in amounts 2%, 4% and 6% dry mass of resin. It was mixed with the resin using a mechanical blender at a speed of 4,500 rpm for 10 minutes. Ammonium chloride (NH_4Cl) was then added as a hardener in the resin at a level of 2% based on the weight of resin and mixed well for 5 minutes.

Table I.
Specifications of Cloisite Na^+.

Composition	Moisture %	Dry particle size µm (d50)	Packed bulk density g/l	Density g/cm³	Interplanar spacing d001 through XRD	Colour
Cloisite Na+	4-9	‹25	568	2.86	1.17 nm	Off white

Table II.
Physical and mechanical properties of particle boards at different concentrations of nanoclay.

Nanoclay %	Density (g/cm³)	WA (%) 2hrs	WA (%) 24hrs	TS (%) GA	TS (%) SA	MOR (N/mm²)	MOE (N/mm²)	IB (N/mm²)
CONTROL	0.80	25.77	42.62	23.49a*	6.64a	12.85c	1,201.74b	1.664
2%	0.79	18.53	38.08	8.73b	3.24a	15.24b	1,400.74b	1.964
4%	0.82	27.57	45.99	10.20b	3.06b	15.31b	1,833.18a	1.676
6%	0.80	23.95	40.57	7.31b	3.12b	17.22a	1,987.51a	1.771

* Different alphabets indicate different significance levels.
TS (GA): Thickness swelling during general absorption; TS (SA): Thickness swelling during surface absorption;
WA: Water absorption; MOR: Modulus of rupture; MOE: Modulus of elasticity; IB: Tensile strength perpendicular to the grain.

In preparation of particle boards dried particles were blended with UF resin in a rotating drum type mixer fitted with a pneumatic spray gun. Resin weighing 10% of the dry weight of the *M. composita* wood particles was used for spraying. Boards for each nanoclay loading and controls as reference boards were prepared. All boards were compressed at 21.0 kg/cm² at 150 ºC for 15 minutes. Particle boards were prepared in 21 x 21 inches dimensions by use of laboratory press and were conditioned for 2-3 days at room temperature before converting to samples. Six samples from control boards and nine samples for each test from nanoclay loaded boards were cut and tested according to Indian Standard 2380 (BIS, 1977).

Results and discussion

The physical and mechanical properties of particle boards are given in table II. One way ANOVA (analysis of variance) was performed to discern significant difference at 95% level of confidence. Duncan's subsets were formed to understand the individual comparisons wherever necessary.

Density of the Boards

Average density values of the boards without and with nanoclay loadings varied from 0.799 g/cm³ to 0.8273 g/cm³. Statistical analysis of the density data revealed that the densities of boards with 2%, 4% and 6% nano loading and reference boards do not differ significantly (table III). This point to the fact that the composite manufacturing procedure has been performed precisely (Candan *et al.*, 2015) and also that addition of nanoclay has not altered the density of the boards. This observation may be useful if addition of nanoparticles can contribute to improvement in other important properties without compromising on the density.

Water absorption (WA) and thickness swelling (TS)

Water absorption (WA) after 2 hours and 24 hours did not show any significant variations even compared with the controls (tables II and III). The values ranged from 38% to 46% for 24 hours, which is within the permitted values as per Indian standards 3087 (BIS, 1985). Hosseyni *et al.* (2014) also observed that adding different loading levels of Na^+ MMT into UF and MDI resin gave no significant effect in absorption properties.

Thickness swelling (TS) during general absorption (GA) decreased considerably after addition of nanoclay into the resin. The mean values were statistically different for reference board and boards with nanoclay loadings (table III). Thickness swelling (GA) in boards with 2% loading showed 62% decrease compared to reference board. Two subsets were formed for general absorption by Duncan's grouping test with the control values occupying a separate group and lower values of nanoclay loaded boards occupying the other. Thickness swelling during surface absorption (SA) also depicted a similar trend as in general absorption. The decrease in thickness swelling was approximately 53% compared to reference board. The presence of nanoclay can obstruct the capillaries in wood which can contribute to control the thickness swelling of boards prepared with nanoclay added resins (Khanjanzadeh *et al.*, 2012).

It is pertinent to note that particular nanoclay can give different results with different resins as far as TS and WA are concerned. For instance WA and thickness swelling of wood composite was significantly reduced by adding nanomer 1.44 p to the resin; however nanomer PGV did not show effects on the stability of water absorption and TS of the same wood composite (Mamatha *et al.*, 2013). Thus we see that addition of Cloisite has improved the swelling properties in spite of the fact that the water absorption properties of particle board did not improve due to nanoclay loading.

Modulus of rupture (MOR)

Bending strength is one of the most important mechanical properties of wood composite panels since it influences their structural performance for applications. MOR values of control and nanoclay loaded boards are within the values prescribed in IS 3087 (BIS, 1985). MOR showed significant improvement with nanoclay loadings in the present study (tables II and III) Maximum value for MOR (17.22 N/mm²) was obtained for particle boards with 6% nanoclay loading and showed improvement of 34% compared to reference board,

Table III.
ANOVAs for physical and mechanical properties.

Property	Source of variation	df	F	P value	Error*
Density	Nanoclay loading level	3	0.859	0.468	29
WA (2 hrs)	Nanoclay loading level	3	1.560	0.234	18
WA (24hrs)	Nanoclay loading level	3	1.968	0.155	18
TS (GA)	Nanoclay loading level	3	6.079	0.002	29
TS (SA)	Nanoclay loading level	3	3.554	0.026	29
MOR	Nanoclay loading level	3	8.872	‹0.001	29
MOE	Nanoclay loading level	3	6.958	0.001	29
IB	nanoclay loading level	3	1.397	0.264	29

* Error means “the variability within the groups” or “unexplained random error”.
TS (GA): Thickness swelling during general absorption;
TS (SA): Thickness swelling during surface absorption; WA: Water absorption;
MOR: Modulus of rupture; MOE: Modulus of elasticity;
IB: Tensile strength perpendicular to the grain.

whereas 2% and 4% loading showed similar but higher MOR compared to the controls. Taghiyari *et al.* (2016b) reported improvement in MOR of medium density fiber board due to addition of nano-wollastonite (NW), another mineral material. The improvement was attributed to the strong adsorption of NW on cellulose surface. Salari *et al.* (2012) also observed that that MOR significantly improved by incorporation of organo-modified montmorillonite (MMT) up to 5%. Hosseyni *et al.* (2014) also reported 33% to 39% improvement in MOR of particle boards made with nanoclay mixed UF and MDI resins. The presence of nanoclay as fillers in wood composites facilitates the stresses to distribute throughout the material helping in improvement in the strength properties (Lei *et al.*, 2008; Hosseyni *et al.*, 2014).

Modulus of elasticity (MOE)

MOE of boards varied from 1201.74 N/mm^2 to 1987.51 N/mm^2, with reference board giving the minimum and boards with 6% nanoclay loading giving the maximum MOE (table II). The mean values of MOE does not fall within prescribed limits of IS 3087 (BIS, 1985). But table II reveals a systematic improvement in the MOE values. This is from about 16.6% for 2% loading to up to 65% for 6% loading. ANOVA of the individual values showed that the MOE values are indeed significantly different. It is important to note that by adding nanoclay does not have any deteriorating effect on MOE. Hosseyni *et al.* (2014) and Candan *et al.* (2015) wherein observed that no significant differences in MOE values of composites reinforced with different nanoclay at different loading levels.

Tensile strength perpendicular to the grain (IB)

Internal bond strength gives information on the resistance of the face layer to the separation from the core. IB values of reference and nanoclay loaded boards are within the values prescribed in IS 3087 (BIS, 1985). Maximum value for IB (1.988 N/mm^2) was obtained for particle board with 2% nanoclay loading which accounted for an improvement of 18.03% compared to reference board (table II). Internal bonding strength seems to decrease at 6% nanoclay loading but it is not lower than reference board. Statistically no significant difference was observed in the IB values of reference boards and nanoclay loaded boards. Lei *et al.* (2008) observed that highest improvement in IB occurred with the 2% Na^+ MMT loading after which the improvement was rather small up to 8% Na^+ MMT, they suggested percolation theory to the networking capability of the clay nano-platelets to provide an explanation for improved behavior of the UF resin. Hosseyni *et al.* (2014) reported that adding Na^+ MMT accelerates the adhesion and strengthens transverse cohesion strength of UF. Since IB is one of the quality parameters for particle boards, it is safe to say addition of Cloisite Na^+ is not detrimental to the boards.

Conclusions

Melia composita particle boards prepared using urea formaldehyde (40% solid content) mixed with different loading levels of Cloisite Na^+ (2%, 4% and 6%) showed that in most of the parameters boards meet the minimum requirement as per the IS: 3087: 1985. Thickness swelling and modulus of rupture showed significant improvement with addition of nanoclay. The boards with 6% nanoclay content showed the maximum values for modulus of rupture (MOR). Modulus of elasticity (MOE) and Tensile strength perpendicular to the grain (IB) showed no effect due to nanoclay loading. Based on the findings of the study, it can be concluded that nanoclay loading has a positive and significant effect on thickness swelling (TS) and MOR values of boards without compromising with water absorption, elasticity and internal bond strength of the board.

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