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(RESEARCH ARTICLE)

Fire efficacy improvement of particle boards by nanoclay

Ismita N. *, Mandape Aniket Shasikant, Kumar Shailendra, Shukla Shikhar and Kishan Kumar V.S.

Forest Products Division, Forest Research Institute, P.O. New Forest, Dehradun-248006. Uttarakhand, India.

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Abstract

The objective of this study was to evaluate the effect of addition of nanoclay to urea formaldehyde resin on the fire retardant properties of particle boards of Chinaberry (*Melia azedarach).* Three different clay loadings such as 1%, 2% and 3% were used for the preparation of the particle boards. The boards were prepared at specific pressure of 17.5 kg/cm² and temperature 110̊C. Test samples were cut from the produced boards and tested for flammability, flame penetration and rate of burning. The addition of 1% nanoclay provided significant improvement in all three aspects. The addition of 1% nanoclay delayed the ignition of the particle boards up to 13 minutes in comparison to control particle boards. In flame penetration and rate of burning, this loading level provided retardation by 1 minute and 1.3 times respectively compared to controls.

Keywords: Fire retardance; *Melia azedarach* wood; Nanoclay; Particle Board; Urea Formaldehyde

1. Introduction

Wood composites are most used wooden materials in household systems. Kitchen cabinets, doors etc are made up of composites, mainly particle boards. Good resistance to fire properties is essential for any type of composites. It is especially important for wood composites and wood polymer composites (WPC) used in construction, furniture and residential propose. Even for other applications fire resistance properties should be essentially known. In wood and wood composites, work has been done for decades to reduce the fire prone tendency of it. Though halogenated fire retardants are being used to reduce fire prone tendency of various products, their toxicity has raised a few questions [1]. These fire retardants are thus not environment friendly. They release smoke and carcinogenic gases. In trending era nano –fillers have also found their application against fire prone tendency of wood composites. However, Östman and Tsantaridis [2] raised a concern about the retention of fire-retardant treated wood retaining its hygroscopicity due to aging and weathering. Nano-fillers have large surface area and high reactivity. This property has been utilised to enhance the physical, mechanical and fire properties of the composites. A variety of nano particles are used as fillers to fabricate fire retardant nano-composites with improved mechanical and functional properties. The common nano particles used for fire retardants include nano-clay, single-walled carbon nano tubes, multi-walled carbon nano tubes, carbon nano-fibers and polyhedral oligomeric-silsesquioxanes (POSS) [3]. They also reported that compared to conventional fire retardants, these nano-particles are environmentally friendly, highly efficient, and capable of imparting polymers other properties. Nanoclays are low cost, easily available and have yielded improvement in the strength properties of plastic materials compared to general fire retardants which usually reduce strength properties [4,5,6]. The present study investigates the effect of different concentrations of nanoclay on the fire retardant properties of particle boards made from *Melia azedarach*.

* Corresponding author
E-mail address: ismita06@gmail.com

2. Materials and Methods

Nanoclay powder of size 80-150 nm (assay min 99%) was procured from SRL Connell Bros. Company (India) Private Limited. Nanoclay was dispersed in distilled water and sonicated for 30 minutes in bath sonicator.

Urea formaldehyde (UF) was procured in powder form from ARCL Organics Ltd. with the brand name of STRONGBOND-P-101G (IS: 848-2006 for MR Grade). This is a UF resin powder specially developed for plywood, particle board, flush door manufacturing and decorative overlaying. It is suitable for the manufacture of panels through both pre-pressing and direct hot-pressing production system conforming to various specifications.

Melia azaderach chips of 4 mm to 6 mm size were broken into finer particles through condux mill. The particles were air dried to about 6% MC and sieved through mesh number 60 and 40 screens to get particles sizes ranging from 0.240 mm to 0.420 mm. Dry powder of Urea formaldehyde (UF) resin was diluted to 40% solid content by mixing it with distilled water. Nanoclay at loading rates of 0% (N0), 1% (N1), 2% (N2) and 3% (N3) of dry mass of the resin was added to prepare four solutions of resins. Before adding nanoclay concentrations into resins, it was diluted with distilled water and bath sonicated for 15 minutes. The sonicated mixture was blended for 10 minutes under mechanical stirrer at a speed of 4500 rpm. This blended nanoclay solution was poured into diluted UF resin. This mixture was then again blended with mechanical mixer for 10 minutes. This was followed by adding hardener ammonium chloride (NH_4Cl) (2%w/v) of resin and mixing it well for 5 minutes under mechanical stirrer.

The prepared resin weighing 10% (v/v) of the dry weight of the wood particles was uniformly sprayed on the particles in a rotary blender at a pressure of 0.07 kg/cm^2. The caul plates were heated up followed by application of paraffin wax on them. A wooden frame of size 24”x24” was kept on the caul plate. The resin-blended particles were uniformly laid to form a single layered mat in the wooden frame. The mats were then pressed in the hot press at specific pressure of 17.5 kg/cm^2 and temperature 110̊C for 15 minutes. Particle boards thus prepared were left for 2-3 days at room temperature before preparing samples. Three boards of each nanoclay loading level were made so that nine to ten samples for the three fire resistance tests at each nano-loading level could be prepared (Table 1). Thus, in total 12 boards were prepared to get 112 test samples. Samples of particle boards were prepared for determination of fire resistance according to standard specifications for plywood in the absence of separate standards for particle boards in India [7, 8]. There are three tests to evaluate the fire efficacy as per above mentioned standard [7]. In flammability test, time taken for ignition of the sample is recorded. Flame penetration test determines the time taken for the flame to penetrate the thickness of the sample. In rate of burning test, time taken for 30% to 70% loss in mass is recorded for the purpose of estimation.

Table 1 Number of specimen and size of different test samples

Sr. No.	Properties	Specimen No.	Size of each test specimen (cmxcm)
1	Flammability test	9	12.5 x 12.5
2	Flame penetration test	9	12.5 x 12.5
3	Rate of burning test (30% wt. loss)	10	10.0 x 1.25
	Rate of burning test (70% wt. loss)	Same as above	
	Total no. of samples for the four tests	28	
	Grand total no. of samples for four loading levels	28x4=112	

Statistical analyses were carried out using SPSS package**.**

3. Results and discussion

Table 3 gives the mean times obtained for the three fire retardant tests performed in the study. One way ANOVA was carried out on these data sets (Table 2). The results revealed that all the three properties studied show significant differences between different loading levels of nanoclay. Therefore, Duncan’s homogeneity tests were carried out for each parameter and the results are included in table 3.

Table 2 ANOVA table for fire retardance test of particle boards at different loadings of nanoclay

Property	Source of variation	df	F	Sig.
Flammability Test	Nano-Clay loading level	3	7.655	0.001
	Error	32		
Flame Penetration Test	Nano-Clay loading level	3	3.844	0.019
	Error	32		
Rate of Burning Test	Nano-Clay loading level	3	4.429	0.009
	Error	36		
	Nano-Clay loading level	3	7.729	<0.001
	Error	36		

Table 3 Fire retardance test of particle boards at different loadings of nanoclay

Nano-Clay %	Flammability		Flame Penetration		Rate of burning			
					30%		70%	
	Time (min)	SD	Time (min)	SD	Time (min)	SD	Time (min)	SD
N0	22.8^{b}	4.2	5.3^{d}	1.0	2.2^{e}	0.3	4.4^{h}	0.6
N1	35.8^{a}	7.6	6.3^{c}	1.1	2.2^{e}	0.5	5.1^{g}	1.1
N2	26.8^{b}	8.0	5.7^{cd}	0.7	2.0^{e}	0.2	4.1^{hi}	0.5
N3	23.5^{b}	5.5	4.9^{d}	0.9	1.7^{f}	0.4	3.5^{i}	0.5

*alphabets represent significant differences obtained through Duncan's subsets

3.1. Flammability test

Average ignition time looks to be higher in nano-clay loaded boards than control boards (p = 0.001). It took 13.0 minutes more for N1 boards to get ignited compared to control boards. The time of 35.8 min. is more than the 30 min. that is prescribed in the standard [8]. However, Duncan's test revealed that only N1 boards took significantly longer time to get ignited (Table 3). Nano-fillers have very high efficiency as flame retardant compared to traditional flame retardants. It has been reported that the addition of 3-5% of nano particles shows a better or the same fire resistance as polymer materials loaded with 30-50% traditional flame retardant [9]. In an experiment on exposing model structures of oriented strand board (OSB) and plywood, it has been reported that there would be high-heat areas of different sizes due to the exposure to ground forest fire [10]. Shi et al. [11] studied the effect of nano-silica along with coupling agents and fire retardants mixed in urea formaldehyde on *Populus* t*omentosa* and found that they enhanced the fire retardance of the wood. Nanoclay has shown to significantly enhance the ignition retarding properties of the polymer/nano-composites [12,13]. In fire retardants, the reduction of flammability is associated with the loss of mechanical properties; whereas the mechanical properties are improved in the composites containing nanoclay [14,15,12]. Nanoclay could improve the curing performance of the UF resin and physical and mechanical properties of bamboo-based composites [16]. In the present study, the Duncan's test (Table 3) revealed that NI boards exhibited significantly longer time to get ignited. On the other hand increasing the nano-loadings level does not improve this property. This observation is supported by Nemati et al [17] who observed that the thermal properties of the composite were higher with smaller nanoclay concentrations.

3.2. Flame penetration test

Average time required for the flame to penetrate the control board was 5.3 minutes. It took 6.3 minutes, 5.7 minutes and 4.9 minutes for 1%, 2% and 3% nano-clay loaded boards respectively for the flame to penetrate. A p-value of 0.019 (Table 2) suggests statistical difference between these flame penetration times. Boards with 1% nano-clay showed longer penetration time than boards with other loading levels. Duncan's homogeneity test grouped two nanoclay loaded

(N1 and N2) in a single group where as control was placed along with N3 and N2 (Table 3). Wang et al. 2007 reported improvement in flame-retardant efficiency of the intumescent nano-composite coating by 1.5% well-distributed nanoclay particles [18]. However, 3% nanoclay produced a negative effect on the fire performance of the coating. A similar result was observed in the present experiment where 3% loading level brought the flame penetration to same level as that of controls. In montmorillonite added polymers, barrier effects due to exfoliation of lamella of the clays in the polymer matrix are reported to prevent the diffusion and decomposition of the product [19].

3.3. Rate of Burning

For 30% loss in weight, average time required for burning of control board was 2.2 minutes whereas it was 2.2 minutes, 2.0 minutes and 1.7 minutes respectively for 1%, 2% and 3% nano-clay loaded boards as shown in Table 3. The times required to char the boards to record 30% weight loss are similar with 1% and 2% nanoclay loading and is comparable with the control boards. However, 3% loading resulted in faster burning. For 70% loss of weight, average time required for burning of control board was 4.4 minutes whereas it was 5.1 minutes, 4.1 minutes and 3.5 minutes respectively for 1%, 2% and 3% nanoclay loadings (Table 3). Duncan's post hoc analysis grouped N0, N2 and N3 in overlapping two subsets. However, N1 recorded significantly higher time to burn 70% of the mass. Nikolaeva and Karki [19] stated that the exfoliated clay layers collapse into intercalated structure and turn into carbonaceous-carbonate structure. The carbonaceous char develops on the surface during the combustion and protects underlying material.

The importance of assessing full-scale studies on charring rates of engineered wood products like Laminated Veneer Lumber (LVL), Cross Laminated Timber (CLT) etc. with different types of adhesives was emphasized in an extensive review article. [20]. As described in the methods section, it is important to look at the time taken for mass loss from 30% to 70% [7]. Table 3 indicates that this time duration is different for different concentrations of the nanoclay. Hence these were calculated for each of the ten samples. The means of time durations for mass loss from 30% to 70% were 2.1 min. for controls (N0), 2.7 min. for N1, 2.0 min. for N2 and 1.5 min. for N3 samples. Thus it is evident that N1 samples took 1.8 times longer time than N3 and about 1.3 times more time than controls. The one-way ANOVA of these durations indicated significant differences (p=0.001). Hence Duncan's homogeneity test was performed on this set of data also. The results are illustrated in figure 1.

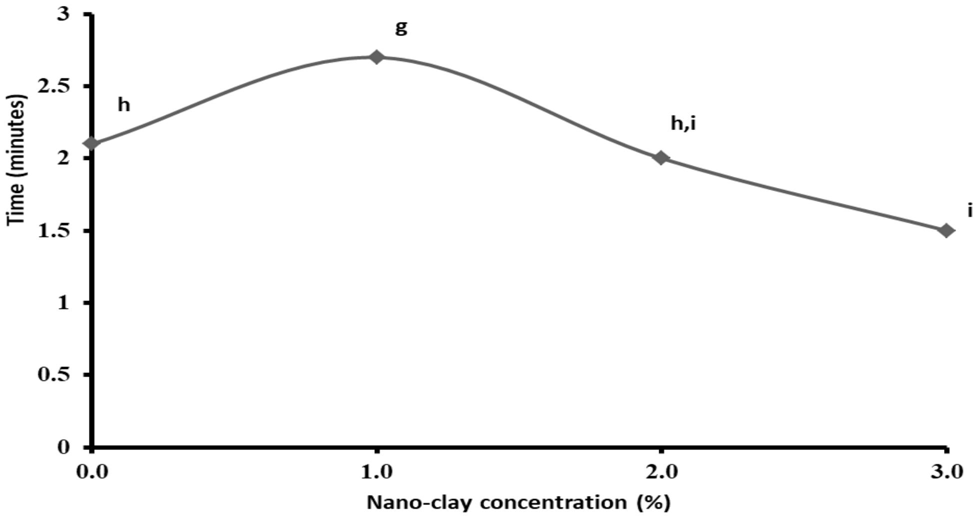

Figure 1 Time for weight loss from 30% to 70%

Fig. 1 clearly indicates that 1% nanoclay addition has significantly reduced the burning rate by taking more time to lose weight. It is pertinent to mention that particleboards treated with 16% boric acid not only exhibited very good fire-retardant properties in terms of weight loss, flame spread rate and after-flame time but also improved the internal bond and thickness swelling [21].

On the whole it can be inferred from the present study that 1% addition of nano-clay into UF resin helps in promoting fire retardancy of the particle boards prepared. There is even a report on co-incorporation of nano-fillers leading to improvement in the mechanical performances of the wood polymer composites containing combination of ammonium polyphosphate (APP) with phytic acid as flame retardant [22].

4. Conclusion

Addition of nanoclay into UF resin to prepare particle boards offers them the opportunity of being considered as fire resistant products. It was noticed that with addition of 1% nanoclay, ignition, flame penetration and rate of burning were delayed compared to controls. The other two loading levels of 2% and 3% did not improve the fire-resistance properties of the boards. It can be inferred that nanoclay used in the present study offers fire retardant effects at 1% concentration level.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of Interest among any parties in this research article.

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