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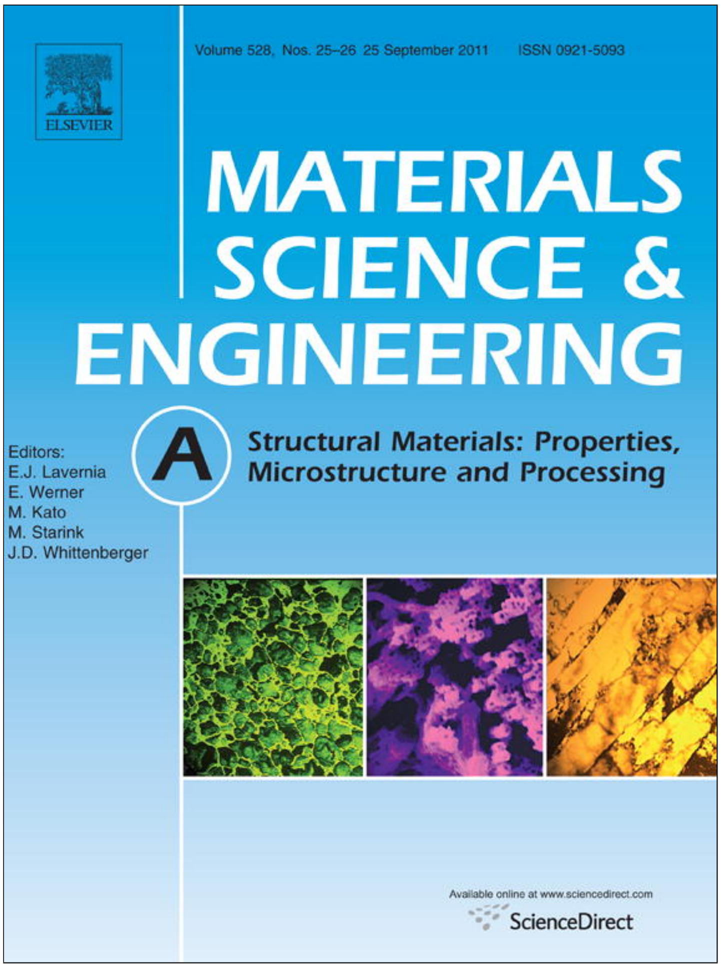

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Materials Science and Engineering A 528 (2011) 7801–7804

Contents lists available at ScienceDirect

Materials Science and Engineering A

journal homepage: www.elsevier.com/locate/msea

Fiber reinforced cement boards made from recycled newsprint paper

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ARTICLE INFO

Article history:
Received 19 June 2011
Received in revised form 5 July 2011
Accepted 6 July 2011
Available online 18 July 2011

Keywords:
Fiber–cement board
Recycled newsprint paper
Natural fiber
Building material
Calcium chloride

ABSTRACT

In this study, the reinforcing effect of recycled newsprint paper (RNP) in cement boards has been investigated. The experimental design consisted of two variable factors namely RNP and calcium chloride ($CaCl_2$). In the sample preparation, boards with density of 0.7 kg/m^3 were manufactured using fiber/cement ratios of 10:90, 15:85 and 20:80 by weight and 3% and 5% $CaCl_2$ as accelerator. At least four boards (replications) were fabricated for each treatment, and the mechanical and physical properties of the boards were evaluated. The statistical analysis showed that the differences between the mean values of the RNP and $CaCl_2$ contents among each of the groups (treatments) compared were significant. Test results showed that addition of $CaCl_2$ tends to enhance both the mechanical and physical properties of the boards. All properties of the boards were improved when the $CaCl_2$ content was increased from 3% to 5%. The rupture and elasticity moduli of the boards decreased with an increase in the RNP content, and the maximum values were obtained at RNP loading of 10%. The results also showed that as the fiber content was increased, significant increased in water absorption and thickness swelling occurred. Increasing RNP fiber content from 10% to 20% reduced both the mechanical and physical properties considerably. The optimum condition was obtained when the RNP and $CaCl_2$ contents were 10% and 5%, respectively.

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1. Introduction

New materials and composites with both economic and environmental benefits are being considered for applications in the building, automotive, furniture, and packaging industries [1,2]. Mineral fillers and fibers are used frequently in the cement industry to achieve desired properties or to reduce the cost of the final products. After banning asbestos fibers due to its hazardous effects on human health, finding alternatives fibers has drawn the researcher's attention [3]. The investigations for a replacement of asbestos fibers resulted in many synthetic and natural fibers being examined in numerous laboratories around the world [4]. Several studies have shown natural or lignocellulosic fibers can be considered as one of the most important candidates for asbestos fiber in fiber–cement board because of the individual characteristics, availability and economic aspects [5,6]. Fiber reinforced cement board products are suitable for almost any light, non-load bearing or load bearing structures. They are also suitable for condition where properties of other materials are exceeded, such as resistance to fire, acoustics, durability, and lightness [7–9].

Studies on the lignocellulosic fibers suggest that these fibers have the potential for use as reinforcing agent in cement composites [8,9]. The primary advantages of using lignocellulosic fibers as additives in cement are the low density, low cost, nonabrasive nature, high filling levels possible, low energy consumption, and wide variety of fibers available throughout the world. The two main disadvantages of using lignocellulosic fibers in cement are the high moisture absorption of the fibers and composites and the low compatibility between fiber and cement [10,11]. Lignocellulosic fibers contain a wide range of carbohydrates such as hemicellulose and extractives (including starch, sugar, tannins, phenols, lignins, etc.) which are known to inhibit normal setting and strength development properties of the cement matrix [12]. Extensive research, however, shows that using chemical admixtures under controlled compaction and temperature conditions can lead to a wide range of fiber reinforced cement composites with excellent durability properties and with very satisfactory levels of long-term performance under internal and external exposure conditions [13,14].

On the other side, faced with an increasing worldwide shortage of wood resources, there has been a strong trend to produce composite products using recycled paper, non-wood plant materials and agricultural residues [12]. Among the possible alternatives, the development of pulp and paper industries and bio-composites using recycled paper is currently at the center of attention [13–15]. It is excellent alternative waste materials to substitute wood because it is plentiful, widespread, and easily available. In addition to abundance and renewability, utilization of recycled paper has advantages for economy and environment [16,17].

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doi:10.1016/j.msea.2011.07.005

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Table 1
Chemical and morphological properties of used RNP fibers.

Characteristics	
α-Cellulose (%)	53.2 ± 2.4
Hemicellulose (%)	17.2 ± 1.3
Lignin (%)	20.7 ± 1.3
Extractives (%)	5.8 ± 0.5
Ash (%)	1.6 ± 0.2
Fiber length (mm)	0.87 ± 0.42
Fiber width (μm)	24.3 ± 7.6
Aspect ratio	37.1 ± 3.2
Freeness (CSF)	560

When paper waste is used as secondary fibers for papermaking, it requires extensive stages for deinking, cleaning, and refining. Unlike papermaking process, when recycled paper, especially recycled newsprint paper (RNP), is used for the manufacture of cement composites, it does not require extensive preparation. This greatly reduces the potential cost of manufacturing. Although many investigations have already been carried out on the use of lignocellulosic fibers in cement in the world, there is very limited information in the scientific literature concerning RNP as reinforcement in fiber–cement [18]. The main objective of this work was to find out the possibility of using RNP for making cement composite products. In addition, the effects of RNP and a chemical admixture (calcium chloride) contents on some selected mechanical and physical properties of the boards produced have been investigated.

2. Experimental procedures

2.1. Materials

The lignocellulosic raw material for this study was recycled newsprint paper (RNP) which was collected from a local recycling company. The chemical and morphological characteristics of the RNP are shown in Table 1. Further, distributions of fiber length and width are presented in Fig. 1.

The binding agent employed was commercial grade of Portland cement, Type I. Calcium chloride ($CaCl_2$) was used as cement setting accelerator. It was an analytical grade from Merk Co., Germany.

2.2. Preparation of boards

Table 2 presents the formulations and abbreviations of the boards produced. All the boards were made with 10:90, 15:85 and 20:80 weight ratios for RNP/cement, and a 1.00:0.60 weight ratio for cement/water. The chemical admixture was used at a dosage of 3% and 5% by weight of cement, primarily to counteract the retardation effect of the RNP, accelerate the hydration process, and also to enhance the strength development of the cement composite. The RNP for each board was first sprayed evenly with the dilute aqueous solution of calcium chloride ($CaCl_2{\cdot}H_2O$). Consequently, the cement and RNP were uniformly hand-blended and then immediately transferred to a steel mould measuring 450 mm × 450 mm × 15 mm. The mat was evenly spread and flattened using a wooden block, the mould removed and a piece of plywood placed on top of the mat. The resulting assemblage was pre-pressed to reduce its height while the mat for the next board was mixed. This stack of mats was placed between two steel plates and pressed at 2 MPa for 3 min. The pressed mats were kept under compression for 24 h by bolting the two steel plates together using four 15 mm thick bolts. After 24 h, the boards were declamped, stacked vertically and conditioned for 28 days at 20 ± 1 °C and 65 ± 5% RH to allow the cement to cure and gain strength. The boards were conditioned in a controlled room for 28 days at 25 °C and 65% RH to reach the equilibrium moisture content of 12%. The edges of the panels were trimmed to obtain the final board size of 400 mm × 400 mm.

Table 2
The mixing ratios of raw materials and their abbreviations.

Board type	Fiber (%)	Cement (%)	$CaCl_2$ (%)
Control	0	100	0
A_1B_1	10	90	3
A_1B_2	10	90	5
A_2B_1	15	85	3
A_2B_2	15	85	5
A_3B_1	20	80	3
A_3B_2	20	80	5

2.3. Test procedure

Mechanical and physical properties were determined following ISO 8335:1987. It is a procedure for boards of Portland or equivalent cement reinforced with fibrous wood particles.

2.3.1. Mechanical properties

Conditioned boards were sawn into test samples for modulus of rupture (MOR, MPa) and modulus of elasticity (MOE, GPa). Three-point flexural testing was carried out using an Instron Universal Testing Machine, with a span of 180 mm and cross-head, bearer diameter of 25 mm and loading speed of 5 mm/min. The MOR and MOE were measured as:

$$\mathrm{MOR} = \frac{3Pl}{2bd^2} \quad (1)$$

$$\mathrm{MOE} = \frac{ml^3}{4bd^3} \quad (2)$$

where P is the maximum load carried by the specimen, l the support span, b and d are the specimen breadth and depth, respectively, measured at the nearest undisturbed location to the region of failure, and m is the slope of the load-deflection curve during elastic deformation.

2.3.2. Water absorption and thickness swelling

The specimens for water absorption (WA) and thickness swelling (TS) were completely submerged horizontally under distilled water maintained at 25 °C for 2 h and 24 h. After soaking, the samples were drained on paper towels for 10 min to remove excess water. The WA and TS were calculated from the increase in weight and thickness of the specimen during submersion, respectively. At least three specimens of every board were tested to obtain a reliable average and standard deviations.

2.4. Statistical analysis

The experimental design consisted of two treatments (including RNP and $CaCl_2$ contents) and their interactions. Data for each treatment were statistically studied by analysis of variance (ANOVA). When the ANOVA indicated a significant difference among factors and levels, a comparison of the means was done employing Duncan's multiple range test (DMRT) to identify the groups that were significantly different from others groups at 99% and 95% confidence levels.

3. Results and discussion

The results of the mechanical and physical tests, with statistical analysis, are shown in Tables 3–5 for all the fabricated materials. For easier comparison between the mechanical and physical per-

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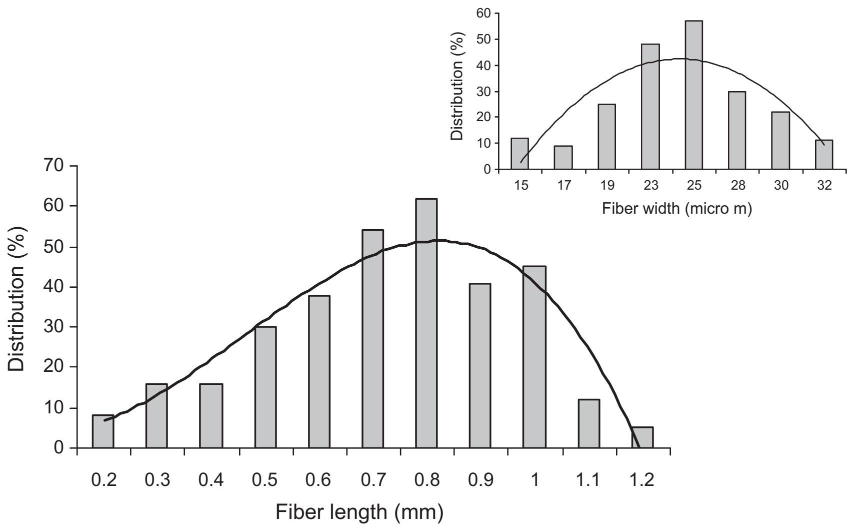

Fig. 1. Distibuations of fiber length and width.

Table 3
ANOVA table of RNP, $CaCl_2$ and their interaction effects on the mechanical properties.

Source of variations	df	MOR			MOE		
		SS	MS	*F*	SS	MS	*F*
RNP	2	3.496	1.748	41.042**	8819785.6	4409892.8	99.25**
$CaCl_2$	1	0.404	0.44	9.48**	321727.6	321727.65	13.61*
RNP × $CaCl_2$	2	0.117	0.058	1.368ns	30000.08	15000.44	2.22ns
Error	12	0.511	0.43		54692.05	4557.67	
Total	17	4.572			9226206.1		

df, degree of freedom; MS, mean of squares; SS, sum of squares; *F*, *F* value.
* Significant difference at the 5% level ($p \le 0.05\%$).
** Significant difference at the 1% level ($p \le 0.01\%$).
ns Not significant.

Table 4
DMRT for the effects of variable factors on studied properties.

Properties	RNP			$CaCl_2$	
	10%	15%	20%	3%	5%
MOR	1.88	1.17	0.83	1.14	1.44
MOE	2383	1202	717	1300	1568
WA 2-h	44.3	44.4	52.8	45.7	41.9
WA 24-h	38.6	46.7	58.4	49.7	46.3
TS 2-h	0.67	0.84	1.31	0.97	0.91
TS 24-h	1.2	1.4	1.96	1.56	1.47

formance of the various composites, the results are presented in Figs. 2 and 3.

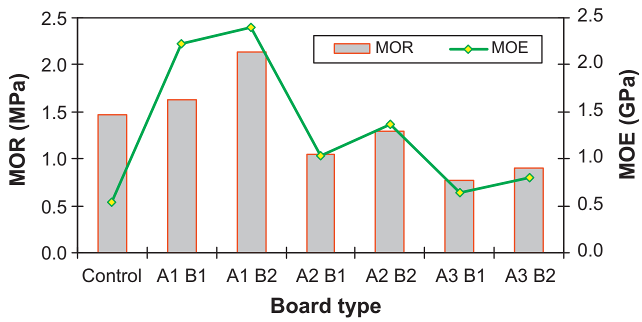

Fig. 2. MOR and MOE of various board types.

3.1. Static bending behavior

In general, statistical analysis showed that the mechanical properties in terms of MOR and MOE of the boards were significantly influenced by the RNP and $CaCl_2$ contents (Tables 3 and 4). However, the interaction of above-mentioned variable factors was not significant. According to the DMRT, the differences between the mean values of the studied properties within and among each of the groups compared were significant. All boards made with 10% RNP had the highest values among the other types of specimens. In addition, all mechanical properties of the boards were improved when the $CaCl_2$ was increased from 3% to 5% (Fig. 2).

The unsatisfactory results in bending behavior at higher RNP content can be explained as follows. The development of strength properties in fiber–cement board mostly depends on the forma-

Table 5
ANOVA table of RNP, $CaCl_2$ and their interaction effects on the physical properties.

Source of variations	df	WA 2-h			WA 24-h			TS 2-h			TS 24-h		
		SS	MS	*F*	SS	MS	*F*	SS	MS	*F*	SS	MS	*F*
RNP	2	1035.503	517.75	83.95**	1165.86	582.93	88.33**	1.304	0.652	252.94**	1.847	0.92	62.97**
$CaCl_2$	1	63.319	63.31	10.26**	51.68	51.68	7.83*	0.014	0.014	5.388*	0.048	0.48	78.5*
RNP × $CaCl_2$	2	2.15	1.077	0.175ns	3.27	1.63	0.24ns	0.002	0.001	0.422ns	0.01	0.005	0.53ns
Error	12	74.05	6.167		79.9	6.599		0.31	0.003		0.114		
Total	17	1174.980			1300.01			1.351			2.019		

df, degree of freedom; MS, mean of squares; SS, sum of squares; *F*, *F* value.
* Significant difference at the 5% level ($p \le 0.05\%$).
** Significant difference at the 1% level ($p \le 0.01\%$).
ns Not significant.

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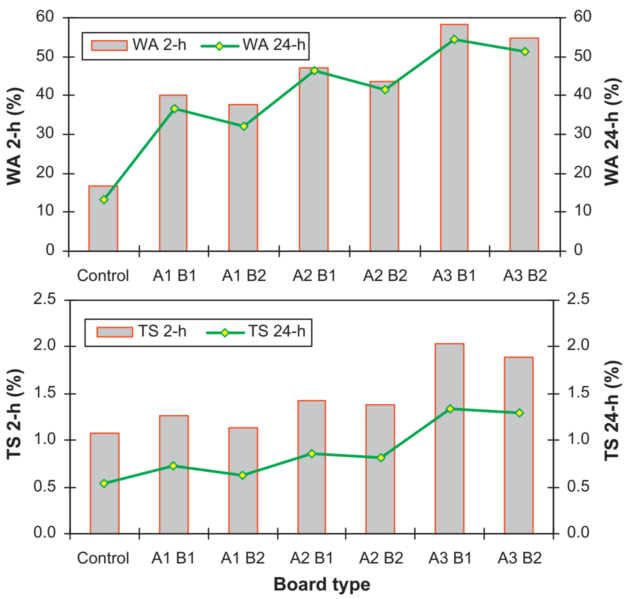

Fig. 3. Effects of RNP and $CaCl_2$ contents on the WA and TS of boards.

tion of fiber–matrix, matrix–matrix and fiber–fiber bonds, i.e. their ability to bond to matrix and/or to each other. The bonding can be affected by dimensions, surface conditions and number of fibers present in a given volume of material [19]. In addition, the low specific gravity of the RNP (about 0.45) causes fibers to float on top of the slurry and it creates a lack of homogenous mixture in the composite so that the top surface of the composite fills with accumulated fibers.

The data in Table 3 and Fig. 2 show that both mentioned properties of the boards were improved when the $CaCl_2$ content was increased from 3% to 5%. This may be due to the fact that the compatibility of the RNP with cement was improved considerably.

3.2. Water absorption and dimensional stability

The ANOVA and DMRT results of the 2-h and 24-h water-soaking test for water absorption and thickness swelling of the fiber–cement composites are shown in Tables 4 and 5. Results indicate that as the amount of RNP increases, the WA and TS of the boards increases significantly. Average WA of the samples ranged from 32 to 54% and 38 to 59% for 2-h and 24-h immersion, respectively. The board A_1B_1 had the lowest average WA and TS values at the both levels of $CaCl_2$. It was observed that there is a sharp increase in water absorption when the RNP content in the mix is more than 10% by weight. There are at least three possible reasons for this phenomenon. One is that the lower bonding strength between the RNP and cement led to a tendency for more springback after 2-h and 24-h of water immersion. Another possible reason is that like other woody materials, the RNP has high hemicellulose content (17.2%) resulting in a high water absorption rate. This then affects the WA could be considered an important reason for the reduced dimensional stability of boards. The third possible reason could be attributed to low bulk density of RNP which causes more void space in the board [9,20].

In addition, it was observed that $CaCl_2$ treated composites generally absorbed less water at 2 h and 24 h, respectively. This is most probably due to changes in the fiber structure that rendered them stiffer and tougher by the creation of high cement–to–cement bonds and cement–wood bonds.

4. Conclusions

Based on the results of this work the following conclusions can be drawn:

1. RNP fibers had significant effects on the mechanical and physical properties of the composites.
2. Analysis of variance showed that there was statistically significant difference between the control sample and treated samples relating to content of $CaCl_2$. Therefore, it can be concluded that the effect of $CaCl_2$ contents was a cause for the improvement of all studied properties.
3. Use of DMRT indicates that the differences in the mean values of tear index within and among the compared groups are significant at the 95% confidence level.
4. The results showed that as the fiber content was increased, significant increased in water absorption and thickness swelling occurred.
5. The optimum condition was obtained when the RNP and $CaCl_2$ contents were 10% and 5% by weight, respectively. Further increase in RNP content had adverse effect on the samples and results in lower than expected strength properties.

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