ELSEVIER

Cement & Concrete Composites 23 (2001) 65–70

Cement & Concrete Composites

www.elsevier.com/locate/cemconcomp

New lightweight composite construction materials with low thermal conductivity

Joseph Khedari, Borisut Suttisonk, Naris Pratinthong, Jongjit Hirunlabh *

Building Scientific Research Center, School of Energy and Materials, King Mongkut's University of Technology Thonburi, Bangmod Rasburana, 91 Pracha U-thit Rd., Thungkru, Bangkok 10140, Thailand

Received 18 January 2000; accepted 8 November 2000

Abstract

This paper presents an initial investigation on the use of a new lightweight construction material, composed of cement, sand and fiber of waste from young coconut (*Cocos nucifera*) and durian (*Durio zibethinus*). Thermal conductivity, compressive strength and bulk density were investigated. The experimental investigation reveals that the addition of these fibers reduces the thermal conductivity of the composite specimen and yield a lightweight. The composite satisfies the basic requirement of construction materials, and they could be used for walls and roofs. Thus, the potential for development, therefore, seems to be very promising. Finally, apart from saving energy consumption for the building, the proposed materials offer an alternative option to dispose waste of fruit industry. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Thermal conductivity; Compressive strength; Bulk density; Admixture; Matrix; Fruit; Waste; Energy

1. Introduction

A large amount of agriculture waste from food industries such as fruit peels can be disposed by several techniques. The most effective technique is to reuse this waste by processing it as a new product, which depends on user's purposes. For instance, fertilizer fuel, household product and construction materials. Chemical and physical properties of this waste have a main role on the user's decision.

Various types of agriculture waste, after being processed, have been tested by blending with the other common compounds (cement, sand and water) to make composite materials [1–10]. Although the result from those researches on mechanical properties of fiber reinforcement are satisfying, but from the point of view of energy saving other properties should also be taken into account, namely thermal conductivity.

Thailand, located in the tropical zone, has many kinds of fruits [11], Table 1. It produces a huge amount of fruit peels yearly [12]. Although, common approaches are already used, a considerable amount is left to landfill with the associated disasters. To our knowledge, only one study was conducted on palm fiber composite materials [13]. Therefore, development of composite materials for building using these peels with low thermal conductivity will be an interesting alternative which would solve simultaneously energy and environment concerns.

After a series of preliminary tests on thermal conductivity and bulk density of peels of fruits, it was found that durian (*Durio zibethinus*) and young coconut (*Cocos nucifera*) are the most interesting products as they have the lowest thermal conductivity and bulk density. Though coconut fibers have been already considered, durian, to the best of knowledge, was never considered. That is why the proposed composites are rather new products.

2. Experimental setup

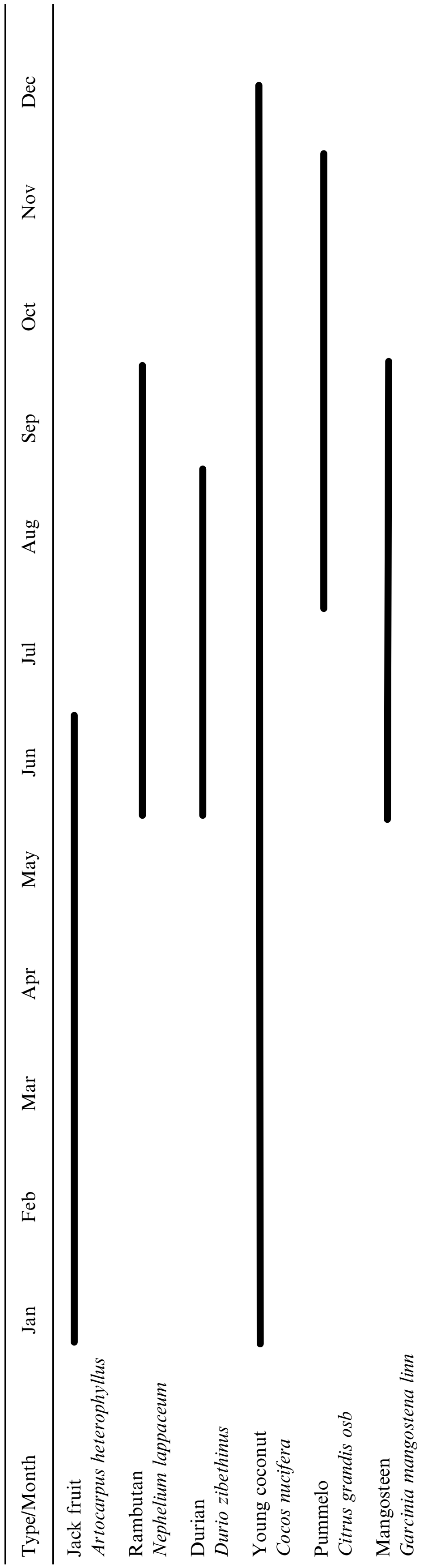
Based on general methods of fiber processing with a series of preliminary tests, fiber preparation was made following the steps given in Fig. 1.

Eighteen coconut fiber specimens and 12 durian specimens were prepared with different fiber lengths, sizes of sand and mixing proportions (cement:sand:fiber) as described in Table 2. Two samples of different

* Corresponding author. Tel.: +66-2-470-8625; fax: +66-2-427-9062.
E-mail address: joseph.khe@kmutt.ac.th (J. Khedari).

0958-9465/01/$ - see front matter
PII: S0958-9465(00)00072-X

Table 1
Seasons of Thai fruits



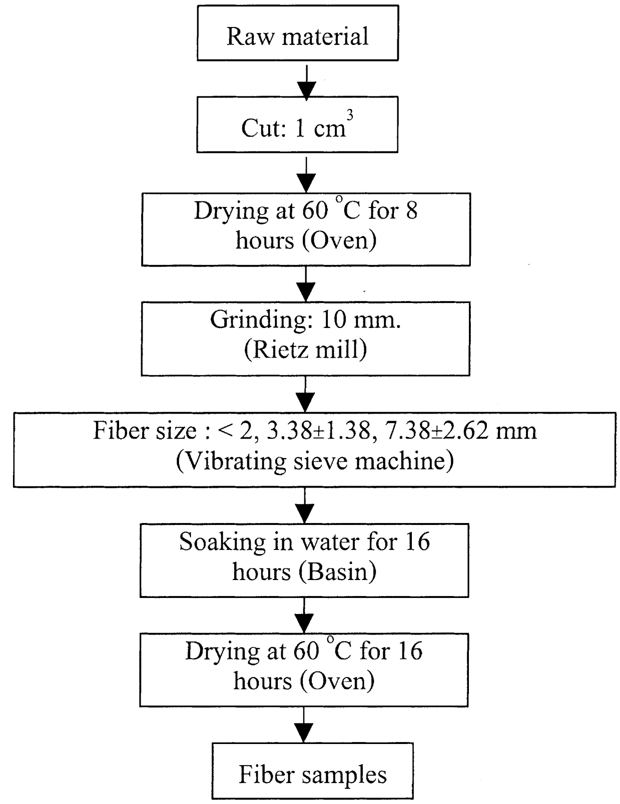


Fig. 1. Fiber preparation process.

dimensions per specimen (code) were fabricated: 5:5:5 cm^3 sample for compressive strength test and 10:5:5 cm^3 for the other tests. Ordinary Portland Cement, Elephant brand Type ONE (Thai standard), was used as the matrix material.

The procedure for preparing specimens was done as follows:

(i) Weighing cement, sand and fiber sample according to the desired ratio following Table 2, then mixing of three elements of composite material. Add exact volume of water and mix well.

(ii) Casting specimen by filling the above mixture into mold and leave it for a day at room temperature. Then removing mold leave sample for drying at room temperature.

The composite specimens were tested based on the following testing standards:

Physical properties (*dimension, shape and bulk density*): Performed according to ASTM C 134-88.

Thermal property (*thermal conductivity*): Testing according to JIS 2618. Measurement was performed after specimens drying at room temperature without incubation in water.

Mechanical property (*compressive strength*): Measured according to ASTM C 109/C 109-95. Before testing specimens have to be incubated in water for 10 days. The accuracy of equipment used is about 2–3%.

Table 2
Composite specimens' specification for young coconut (*Cocos nucifera*) and durian (*Durio zibethinus*) fiber cement

Fiber length (mm)	Size of sand (mm)	Mass ratio of samples (W/C ratio: 1.5:1)		Specimen code	
		Cement:sand:coconut fiber (F/C ratio, %)	Cement:sand:durian fiber (F/C ratio, %)	Coconut	Durian
<2	<0.71	1:1:10	1:1:10	C01	D01
		1:1:20	1:1:15	C02	D02
		1:1:30	1:1:40	C03	D03
	0.855 ± 0.145	1:1:10	1:1:10	C04	D04
		1:1:20	1:1:15	C05	D05
		1:1:30	1:1:30	C06	D06
3.38 ± 1.38	<0.71	1:1:10	1:1:10	C07	D07
		1:1:15	1:1:15	C08	D08
		1:1:20	1:1:20	C09	D09
	0.855 ± 0.145	1:1:10	1:1:10	C10	D10
		1:1:15	1:1:15	C11	D11
		1:1:20	1:1:25	C12	D12
7.38 ± 2.62	<0.71	1:1:10	–	C13	–
		1:1:15	–	C14	–
		1:1:20	–	C15	–
	0.855 ± 0.145	1:1:10	–	C16	–
		1:1:15	–	C17	–
		1:1:20	–	C18	–

3. Results and discussion

To facilitate comparison, Table 3 groups all results of measurements.

3.1. Effect of fiber length and fiber content on thermal conductivity of specimen

The variation of thermal conductivity for coconut and durian composite specimens with different fiber contents (% by mass) and for different fiber lengths is plotted in Figs. 2 and 3. The thermal conductivity of porous medium is inversely proportional to the voids in the specimen. These voids are occurring from packing of fibers. In general, short fibers are more difficult to align and pack densely than the longer one [1]. Thus, for a given fiber content the short fiber length makes a lot of voids leading, therefore, to low thermal conductivity of specimen. Also, the thermal conductivity is a close function of fiber content. Hence, the thermal conductivity decreased when the quantity of fiber content increases [5,14].

The thermal conductivity of new specimens is in the range of data reported in [15] on lightweight aggregate concrete, which varies 0.3–0.6 W/m K for similar density. This indicates a high and promising potential for development.

In addition, the more the voids' ratio, the lighter the specimen and the lower its thermal conductivity. This relationship is shown in Fig. 4. It can be assumed that heat-insulating efficiency of material is opposite to its density [2].

3.2. Effect of fiber length and fiber content on compressive strength of specimen

Fiber-based cement products are generally loaded in compressive strength with regard to construction purpose. During the mixing and casting of the composite, the rheological properties of mix will naturally depend on how close the fiber get to each other.

The influence of fiber length is very significant for straight fibers. Figs. 5 and 6 show the effect of fiber length and fiber content on compressive strength of composites for different sizes of sand. The results are based on $5 \times 5 \times 5$ cm^3 mould. The compressive strengths are proportional to the fiber length. This observation agreed with that formulated by Krenchel [4,16,17] about fiber spacing in specimen.

The compressive strength decreases when the fiber content increases [4,5]. This is due to the fact that increasing fiber content yields a low density of specimen. In fact, if the fiber is stiff, then packing of the fiber becomes difficult at high fiber content and voids are introduced into the product. Thus, the specimen density decreases at a greater rate than it would be expected with more flexible fibers (wood) which are more readily packed together at high loading [18].

The relationship between the compressive strength and the density of specimens is shown in Fig. 7. As

Table 3
Summary of results

Specimen (code)	Thermal conductivity (W/m K)	Bulk density (kg/m^3)	Compressive strength (MPa)
C01	0.6544	1410	4.77
C02	0.2543	959	2.46
C03	0.1903	864	1.81
C04	0.6631	1400	6.07
C05	0.2802	1062	3.16
C06	0.1753	770	1.97
C07	0.6518	1502	7.96
C08	0.5359	1440	3.61
C09	0.3827	1161	2.90
C10	0.7557	1422	6.89
C11	0.5916	1297	4.49
C12	0.4293	1106	2.53
C13	0.6736	1504	8.52
C14	0.5486	1464	6.69
C15	0.4687	1239	4.43
C16	0.9333	1561	7.43
C17	0.8056	1462	5.56
C18	0.4613	1129	4.46
D01	0.3506	1456	3.29
D02	0.2874	1346	0.86
D03	0.1751	1315	0
D04	0.3831	1369	3.14
D05	0.2746	1202	0.78
D06	0.1890	950	0.20
D07	0.6369	1709	3.51
D08	0.3731	1536	1.37
D09	0.2806	1350	0.08
D10	0.7961	1832	3.21
D11	0.3616	1461	1.37
D12	0.2524	1180	0.20

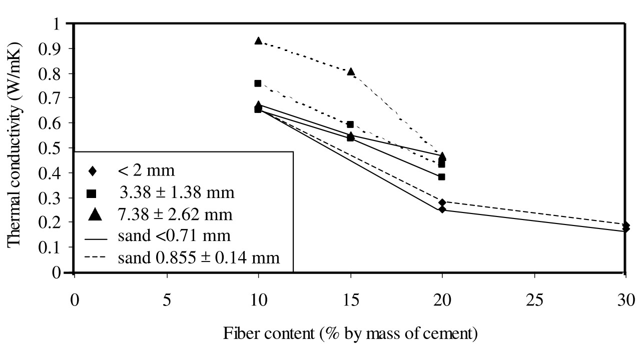


Fig. 2. Effect of young coconut fiber content on thermal conductivity of composites for different fiber lengths and sizes of sand.

expected from previous discussion, the denser is the specimen, the higher the compressive strength.

3.3. Effect of size of sand on thermal conductivity and compressive strength

Two sizes of sand commercially available were considered: <0.71 mm and 0.855 ± 0.145 mm. It was found

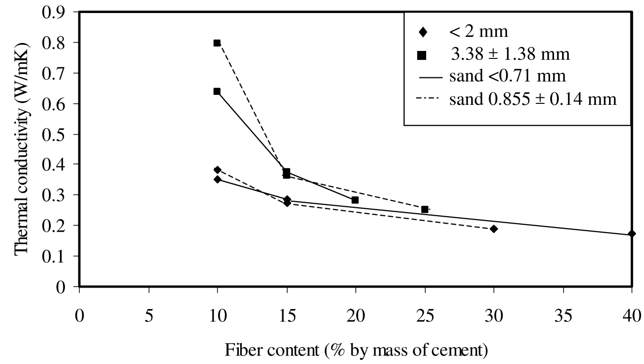


Fig. 3. Effect of durian fiber content on thermal conductivity of composites for different fiber lengths and sizes of sand.

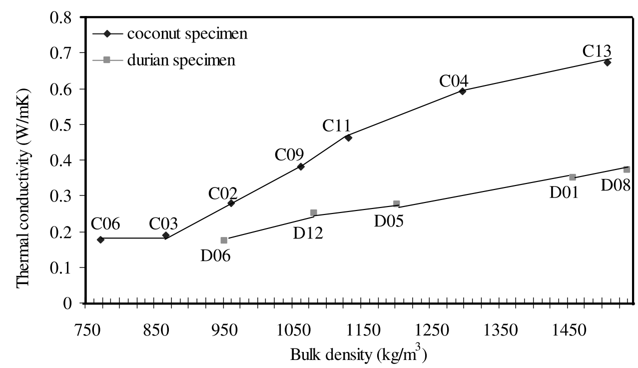


Fig. 4. Bulk density and thermal conductivity of young coconut and durian fiber reinforced composites.

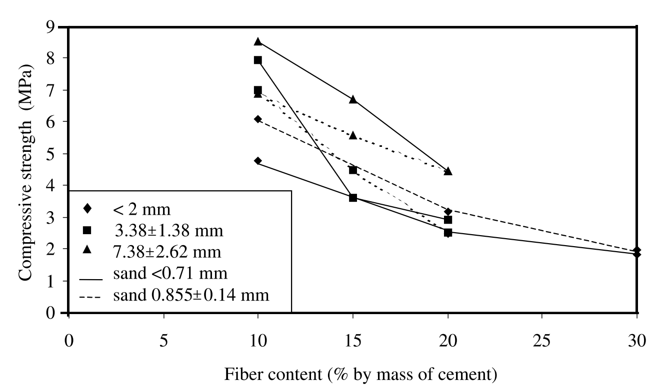


Fig. 5. Compressive strength of composites vs. fiber content for different young coconut fiber lengths and sizes of sand.

that the thermal conductivity of specimen is proportional to the size of sand. For <2 mm fiber length (Figs. 2 and 3 and Table 3), the size of sand is practically without any effect on the specimen's thermal conductivity. When the fiber length increases, the effect becomes more significant, namely with 7.38 ± 2.62 mm fiber length.

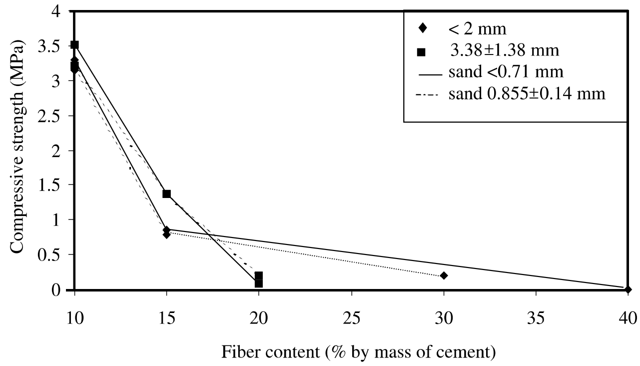


Fig. 6. Compressive strength of composites vs. fiber content for different durian fiber lengths and sizes of sand.

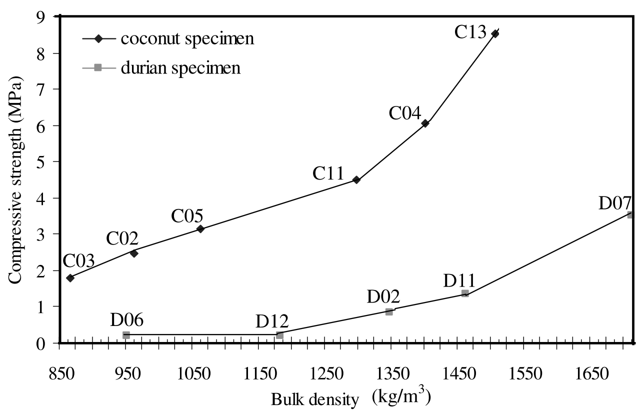


Fig. 7. Compressive strength and bulk density for young coconut and durian fiber reinforced composites with different sizes of sand.

With sand size <0.71 mm, the thermal conductivity of sample is lower than that with 0.855 ± 0.145 mm. In fact, fine sand can insert into matrix between fibers. The result is that fibers are aligned to be distant from each other. Therefore, it creates voids and gets low density and low thermal conductivity. The opposite is true with the other size of sand.

The size of sand is significant to the structure of specimen. Figs. 5 and 6 and Table 3 indicate that the compressive strength is fairly dependent on the size of sand. It seems that increasing the size of sand decreases the compressive strength of specimen except with <2 and 3.38 ± 1.38 mm (at 15% fiber length) young coconut fiber length. This effect, therefore, needs to be investigated again as the difference between the two sizes of sand used here is rather small.

4. Conclusion

The experimental investigation on the possibility of utilization of coconut (*C. nucifera*) and durian (*D. zibethinus*) fibers to reduce the thermal conductivity of mortar to construct wall and other building components showed that it is a very interesting option. The investigation reveals that the addition of these fibers can reduce the thermal conductivity of sample and yield a lightweight. The optimum ratio of young coconut fiber component is 20% of cement while that of durian fiber is 10% of cement. For both composites, the optimum fiber length is <2 mm and the size of sand is <0.71 mm. The coconut specimen gets thermal conductivity of 0.2543 W/m K, a compressive strength of about 2.4 MPa (when incubated in water for 10 days) and bulk density of about 958 kg/m^3. The durian specimen properties are as follows: thermal conductivity of 0.3506 W/m K, compressive strength of about 3.3 MPa (incubate in water for 10 days) and bulk density of 1456 kg/m^3.

When compared to standards of the common construction material "mortar", Table 4, we can conclude that fruit peel fiber mortar advantages are follows:

1. The thermal conductivity of young coconut and durian fiber cements is lower than common mortar by about 85% and 79%, respectively. Therefore, it could be used to prevent heat transfer into building and therefore to save energy.
2. The compressive strengths of these fiber-mortars are less than mortar, but are still in the standard range for hollow non-load bearing concrete masonry units (2 Mpa ; ASTM C 109/C 109-95). Therefore, it is possible to construct wall, ceiling and roofing of housing.
3. The bulk densities of coconut fiber and durian fiber are lower than mortar by 52% and 27%. Hence, it is also convenient to deliver.

Table 4
Comparison between new materials and mortar

Properties	Mortar	Fiber-cement		Standards for buildings
	Cement:2.75 Sand:Water (0.6 W/C ratio)	Coconut fiber (C02)	Durian fiber (D01)	
Thermal conductivity (W/m K)	1.6452	0.2543	0.3506	JIS R2618
Compressive strength (MPa)	22.0[a]	2.46[a]	3.29[b]	ASTM C 109-90
Bulk density (kg/m^3)	2000	959	1456	ASTM C 134-94

[a] Incubate in water for 10 days.
[b] Incubate in water for 10 and 13 days in air later.

4. As they utilize agriculture waste, management of the waste, especially, of fruit industry which produce millions of tons of fruit peels annually, will be also achieved.

It is also envisagable to produce cellulose-cement sheets as substitutes for a great variety of asbestos-cement sheets for building boards and cladding panels [16,18]. In addition we should mention about the good workability. Fruit fiber mortar is suitable for use in both developing and industrialized countries. Its properties are also well-suited to renovation purpose.

References

[1] Morrissey FE, Coutts RSP, Grossman PUA. Bond between cellulose fibers and cement. Int J Cement Compos Lightweight Concr 1985;7(2):73–80.
[2] Salas J, Alvarez M, Veras J. Lightweight insulation concrete with rice husk. Int J Cement Compos Lightweight Concr 1986;8(3):171–80.
[3] Hannant DJ, Fiber cements and fiber concretes. Department of Civil Engineering, University of Surrey, New York: Wiley, 1978. p. 8–37.
[4] Paramasivam P, Nathant GK, Das NC. Coconut fiber reinforced corrugated slabs. Int J Cement Compos Lightweight Concr 1984;6(1):19–27.
[5] Swamy RW. Natural fiber reinforced cement and concrete. Department of Mechanical Engineering, University of Sheffied, London, UK: Blackie Glasgow, 1988.
[6] Balaguru PN, Shah SP. Fiber-reinforced cement composites. Singapore: McGraw-Hill, 1992. p. 110–14.
[7] Mawenya AS. Development in sisal fiber reinforced concrete, appropriate building materials for low cost housing, Africa Region. In: Proceeding of a symposium held in Nairobi, Kenya, from 7 to 14 November 1983. p. 90–8.
[8] Sulaiman M, Mansoor N, Khan K. Development in sisal fiber reinforced concrete appropriate building materials for low cost housing, Africa Region. In: Proceeding of a symposium held in Nairobi, Kenya, from 7 to 14 November 1983. p. 107–16.
[9] Omer ME. Fageiri. Development in sisal fiber reinforced concrete appropriate building materials for low cost housing, Africa Region. In: Proceeding of a symposium held in Nairobi, Kenya, from 7 to 14 November 1983. p. 167–75.
[10] Soroushian P, Marikunte S. Reinforcement of cement-based materials with cellulose fibers thin-section fiber reinforced concrete and ferrocements SP-24. Detroit, Michigan: American Concrete Institute, 1990. p. 99–124.
[11] Ministry of Agriculture and Co-op. Statistic of Planting of Fruit Trees, Data Processing Sub-Division, Department of Agricultural Extension, 1999. p. 30.
[12] Ministry of Industry, Department of Industrial Factory, Juice Plant from Fruit, Vegetable and Food Preservation, 1997. p. 35.
[13] Nimitryongsakul P, Suwanasinphun S. The properties of palm fiber and mixing to cement composites. Academy J 1989;1: 76–92.
[14] Krenchel H. Fiber spacing, specific fiber surface. In: RILEM symposium. Great Britain: The Construction Press Ltd, 14–16 September 1975. p. 69–79.
[15] Neville AM. Properties of concrete, 4th ed. Malaysia: Longman, 1996. p. 706–7.
[16] Litherland KL, Maguire P, Proctort BA. A test method for the strength of glass fibers in cement. Int J Cement Compos Lightweight Concr 1984;1:39–44.
[17] Akihama S, Suenge T, Banno T. Mechanical properties of carbon fiber reinforced cement composites. Int J Cement Compos Lightweight Concr 1986;8(1):21–33.
[18] Ragsdale LA, Raynham EA. Building materials practice. London: Edward Arnold Publishers Ltd, 1964. p. 1–21.