Coventry University and
The University of Wisconsin Milwaukee Centre for By-products Utilization,
Second International Conference on Sustainable Construction Materials and Technologies
June 28 - June 30, 2010, Università Politecnica delle Marche, Ancona, Italy.
Main Proceedings ed. J Zachar, P Claisse, T R Naik, E Ganjian. ISBN 978-1-4507-1490-7
http://www.claisse.info/Proceedings.htm

Production of Cement Composite Board Using Cellulose Fibres

Eshmaiel Ganjian[a*], Morteza Khorrami[b] and Tayebeh Parhizkar[c]

[a] *Coventry University, Faculty of Engineering and Computing, Department of The Built Environment, Coventry CV1 5FB, UK. E mail: <E.Ganjian@Coventry.ac.uk>.*
[b] *Building & Housing Research Centre/Eslamshahr Islamic Azad University, Tehran, Iran, PO Box 13145-1696.E mail:< mrz_khorrami@yahoo.com.>*
[c] *Building & Housing Research Centre, Tehran - Iran P.O. Box 13145-1696. Email: <Parhizkar@bhrc.ac.ir>*

ABSTRACT

Over the past two decades, Cement Composite Boards (CCB) made of natural fibres without asbestos have been developed and used for internal and external wall, roofing, flooring, and cladding in some developed countries. Using selected natural cellulose fibres, it is possible to develop products for different uses with this new technology. This depends on the types of fibres used, its ratio in the mix design, the type, the amount of additive materials and also the method of processing and making.

In this research, different specimens made of different types of cellulose fibres were studied and their properties were determined. The results indicate that the fibre contents and types affect the flexural behaviour and fracture mechanism of composite sheets significantly.

INTRODUCTION

Over the last three decades a broad research has been carried out on the use of natural fibre reinforced cement products in the construction industry, and these investigations have shown that not only the natural fibres reinforced cement products satisfy the required specifications on strength and durability, but also possess other benefits such as renewability, good insulating properties and low energy consumption [Coutts 2005]. A report by Banfill et al. [2006] acknowledges the high performance level of fibre reinforced cement products in the construction industry and regards it as a new generation of tough and long-lasting construction materials. Natural fibres are sometimes also used in combination with synthetic fibres in cement products to improve the mechanical properties of the product for example polypropylene (PP) and polyethylene (PE) are employed in products to control cracking and improve the ductility of composite [Alva 2007].

The Kraft process is the most frequently used chemical pulping method and this process entails the cooking of wood chips with a mixture of caustic soda and sodium sulphide in a digester so as to break the lining that is linking the cellulose, pulp obtained from this process is usually used to manufacture high grade papers and other high quality materials, for example the softwood unbleached Kraft are the most widely used wood fibres in cement composite due to their characteristic strength, availability and cost [Negro et al 2006].

Previous research carried out by the authors studied some of the chemical and mechanical properties of fibres such as resistance to alkali, tensile strength, young modulus etc [Khorami et al. 2008; Ganjian et al. 2008]. The effect of fibre length and aspect ratio were also studied. In this research, the application of Kraft pulp and wheat fibres has been studied. The research focused on the use of discrete and randomly oriented fibres mixed with cement and water. The effect of different amounts of fibre proportions in the mix design was investigated. The mechanical and physical properties were measured according to relevant standards in the laboratory and the results were compared with the values of control (no fibres) cement board specimens.

LITERATURE ON CELLULOSE FIBRES IN CCB

Wood fibres are grouped into hardwood and softwood. Processing includes chemical treatment, heat treatment, mechanical brushing or refining etc. They are usually combined with other additives before being processed into paper, paper board, tissue, cardboard etc, or formed as chips for construction materials. Natural fibres are grouped according to their origin based on wood derivative cellulose obtained from plants, animals and mineral sources. They are affordable and readily available in large quantities in most tropical countries [Juarez et al. 2007]. Cellulosic fibres have been found to be suitable as reinforcement in fibre cement building products. Although, associated with certain problems like swelling in highly alkaline cement matrix and effects of climatic changes, the durability of cellulose fibres cement composite are correlated with the fibre type, fibre content, matrix type and aging methods. However, research has indicated that cellulose fibres at volumes raging from 0.06% to 0.5% significantly reduce restrained drying-shrinkage cracking in cementitious materials [Soroushian 1998].

Wood cellulose fibres are used in the manufacture of flat sheets and non pressure pipes. Jute is a common reinforcement material in India and elephant grass reinforced mortars are also used for low cost housing projects in Asia. Natural fibres such as Bagasse, bamboo, barley, banana, coir, cotton, flax, hemp, jute and straw, are currently being investigated for use in fibre cement products, to manufacture low cost building materials.

Cellulose natural fibres enhance the mechanical properties of cementitious materials such as flexural strength, toughness, tensile strength, thermal shock, impact and resistance to fatigue in concrete and cementations materials [Savastano et al. 2003; 2004; Marikunte et al. 1994] and they are currently being investigated as reinforcement for cast-in-place concrete.

Fibre dispersion was also found to determine the effectiveness of the composite in terms of reinforcement and also affects the rheological properties of fresh cement, mortar or concrete. Thus if fibres clump, little reinforcement is provided in the material. But if fibres are uniformly dispersed, maximum reinforcement is provided with minimum number of fibres in adequate length and diameter of about 0.4 -3%, sufficient strength and elasticity required to withstand bending and fractural behaviour of the composite is produced.

Further research still confirms, that both fibre pull-out and fibre fracture contributes to failure in wood fibre cement composite and that the strength of adhesion between the fibre and matrix which is dependent on the structure and polarity of these materials can alter the mechanical performance of the cement composite as well as varying fibre length.

Soroushian et al. [1994], after comparing neat cement with wood fibres cement composite, reported that in spite of the increase in freeze-thaw cycles of wood cement composite, its dynamic modulus of elasticity remained reasonably constant, and the flexural strength and toughness value were much higher than that of neat cement which experienced reduction in dynamic modulus of elasticity and a low flexural strength and toughness compared to that of wood fibres cement composite.

Pehannich et al. [2004] presented a report on the effect of potassium silicate, sodium silicate and silane treatment on newspaper and unbleached Kraft fibre cement composite compared to untreated wood fibre cement composite. Both wood fibres were chemically treated with aqueous solution. They concluded that aqueous chemical treatments enhance the mechanical properties of the treated wood fibre- cement composites.

MATERIALS USED AND MIXTURE DESIGN

Table 1 shows the mixture design used. Portland cement is represented as (C), cellulose pulp fibres is represented as (P), wheat stalk fibres as (W).

Table 1: Mix Designs of Cement Composite Boards.

Mix	Mix Code	Cement (gr)	wheat fibres (gr)	pulp fibres (gr)
1	Control	200	0	0
2	P2	200	0	4
3	P4	200	0	8
4	P6	150	0	9
5	P8	150	0	12
6	W2	200	4	4
7	W4	200	8	8

Each material is added in percentage of cement weight. For example P2 means 2% cellulose fibre by Cement weight in mixture shown in Table 1.

The cellulose waste cardboard fibres were beaten for about five minutes before being added to the matrix in order to reduce fibres length and to create micro fibrils within the cellulose fibres so as to enhance the bonding strength between the fibres and cement matrix.

EXPERIMENTAL PROCEDURE

Dry cement powder was added to a mixing bowl containing water according to the mix design given in table1. The cellulose fibres were beaten for about 5 minutes; they were then dispersed in water for an extra minute before being added to the mixture of cement and water. This was mixed thoroughly again with a double blade mixer at minimum speed for about 5 minutes. Wheat stalk fibres were also dispersed in water.

During mixing, a perforated stainless steel plate with filter paper on was placed inside the casting mould and the vacuum pump was switched on to vacuum the chamber for about 5 minutes and then switched off. Then, after careful mixing the slurry was poured into the mould and the pump was switched on again. This time the perforated plate with filter paper on retains cement mixture with fibre particles while the excess water is drained off through suction by the pump. After 8-15 minutes when water is drained, a fibre cement sheet is formed. It is notable that the higher fibre content slurries tend to take longer to drain off the water. When the water is drained off the pump is switched off again and a weight of about 10kg is uniformly applied to compact the paste inside the mould while the pump is switched on again. This lasts for about 5 minutes to drain the remaining excess water so as to form a fibre cement sheet paste that is not too wet. Then the specimen is demoulded and kept in an about 95 ± 5 percent RH and 20 ± 2 °C environment to cure. Figure 1 shows the mould and dewatering process set up used.

Fig. 1: Mould and a Slurry Vacuum De-watering Process Set-up.

TESTS CARRIED OUT

1) Flexural test

Flexural test was carried out at 7 and 21 days according to BS EC 12467standard on a JJ Lloyds Machine applying the load with a constant rate of deflection, driving at a speed of 20 mm/min.

The set up includes a specimen (cement sheet) measuring about 184mm x 82mm x 9mm thick. For a rectangular specimen under a load in a three-point bending setup:

$$\sigma = \frac{3FL}{2bd^2} \qquad \ldots(1)$$

Where; F is force at the fracture point, L is length of the support span, b is width and d is thickness of the specimen.

3) Moisture movement

Moisture movement is the linear variation in length and width of test specimen, with change in moisture content. This test is used to determine the serviceability of products in areas of high humidity and exposure to moisture. Moisture movement test was carried out according to ASTM C1185. Each specimen was conditioned to practical equilibrium at a relative humidity of 30 ± 2 % and a temperature of 20 ± 2°C. Practical equilibrium is defined as the state of time change in weight where, for practical purposes, the specimen is neither gaining nor losing moisture content more than 0.1 wt. % in a 24-h period The length of each specimen was measured using a micrometer with the accuracy of 0.01 mm. Then the specimens were conditioned to practical equilibrium at a relative humidity of 95 ± 5 % and a temperature of 20 ± 2°C. The lengths of the specimens were measured again. The linear change in moisture content is the percentage change in length based on the length at relative humidity change of 30 to 90 i.e.

$$Linear\ change\ (\%) = \frac{length\ at\ 90\ \% - length\ at\ 30\%}{length\ at\ 30\%} \times 100 \qquad \ldots\ (2)$$

4) Water absorption

Water absorption test is done to determine the tendency of a product to absorb water and sometimes determine uniformity of the product. The increase in mass of the test specimen expressed as a percentage of its dry mass after immersion in water for a specified period of time is determined. The test was carried out according to ASTM C1185. Each specimen was dried to constant weight in a ventilated oven at a temperature of 90 ± 2°C and cooled to room temperature in a desiccator before being weighed. Then the specimens were submerged for 48 ± 8 h in clean water at 23 ± 3°C. Each specimen was then removed from the water, wiped with a damp cloth, and weighed. i.e. the water absorption percentage is:

$$(W_s - W_d)/W_d \times 100 \qquad \ldots(3)$$

Where; W_s is weight of saturated specimen in grams and W_d is weight of dry specimen in grams.

5) Moisture content

The percentage of moisture content of the fibre-cement product when conditioned at 50 ± 5 % RH and a temperature of 23 ± 2°C was determined according to ASTM C1185. The test specimen from the flexural test was used for this test. After equilibrium conditioning, each specimen is weighed (w). Each specimen is then dried to constant mass in a circulated oven at a temperature of 90 ± 2°C and cooled to room temperature in a desiccator and the final mass when oven-dried (F) is recorded. Moisture content percent is given by:

$$M = 100 \times [(W - F)/F] \qquad \ldots(4)$$

TEST RESULTS AND DISCUSSION

1) Flexural test results and analysis

The results of the tests are shown in the graphs of figure 2 for the pulp fibres specimens. This results show that as expected the modulus of elasticity of P2 to P8 specimens are less than the control specimen and with increasing pulp fibre content, the maximum flexural strength is increased. Figure 2 shows that as expected, the fracture deflection of the specimens with fibres are increased profoundly (to over twice of that for the control specimen). The fibres change the fracture mechanism from brittle in control specimen, to ductile behaviour in pulp specimen. This is due to the fibres bridging effect following the initial micro crack appearance. The figure shows that fibres contribute to sustaining of the flexural stresses right from the beginning of the loading. This is clear from the lower gradients of the curves at the beginning and the end of loading; unlike the control specimen (the dotted line in the graph) they do not have sudden brittle fracture.

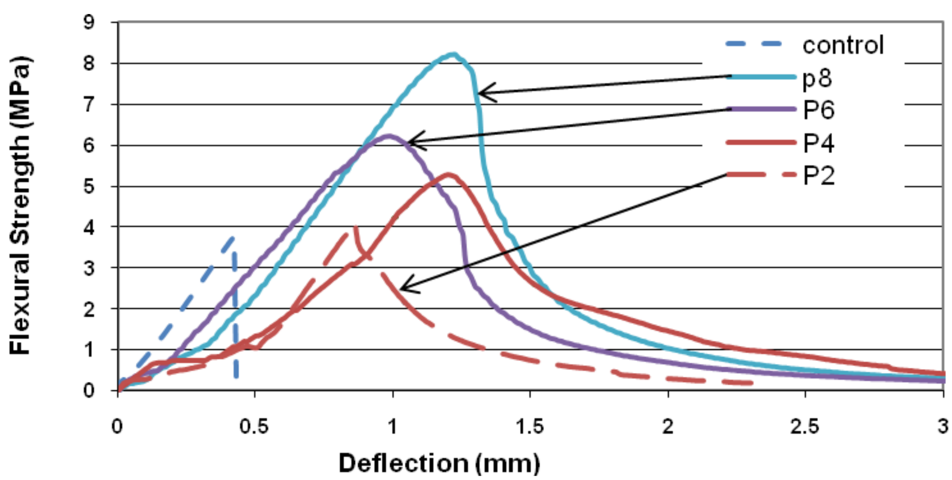

Fig. 2: Flexural Results for Pulp Cellulose Fibre Specimens.

Figure 3 shows the flexural results for the wheat stalk specimens. In specimens made with wheat fibres containing more than 4 % by weight, the fibres floated on the top of the slurry mix and separated from the cement paste. The wheat fibres were not uniformly dispersed in the cement matrix for these mixes. For this reason only 2% and 4% by weight were cast and tested.

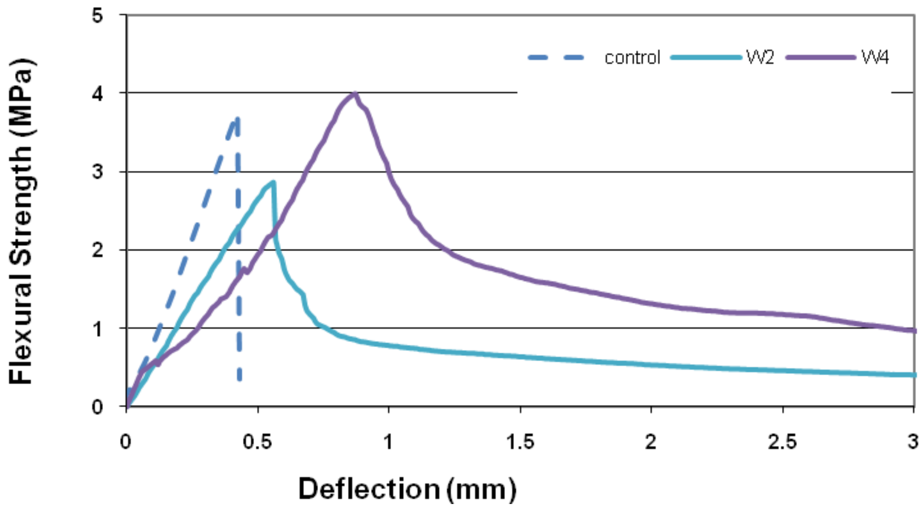

Fig. 3: Flexural Results for Wheat Stalk Cellulous Fibre Specimens.

Figure 4 shows the maximum stress experienced by each specimen before fracture or failure. This shows that that the modulus of rupture gradually increases as cellulose fibres content increased in all cellulose fibres specimens. As the pulp fibres have a potential for uniform dispersion in the cement matrix, the pulp specimens were able to be made with higher percentage of fibres up to 8 percent. The 8 percent pulp fibre specimen shows more than twice flexural strength when compared to control specimen. This specimen is classified as class 2 in the BS EN 12467 -07 classifications.

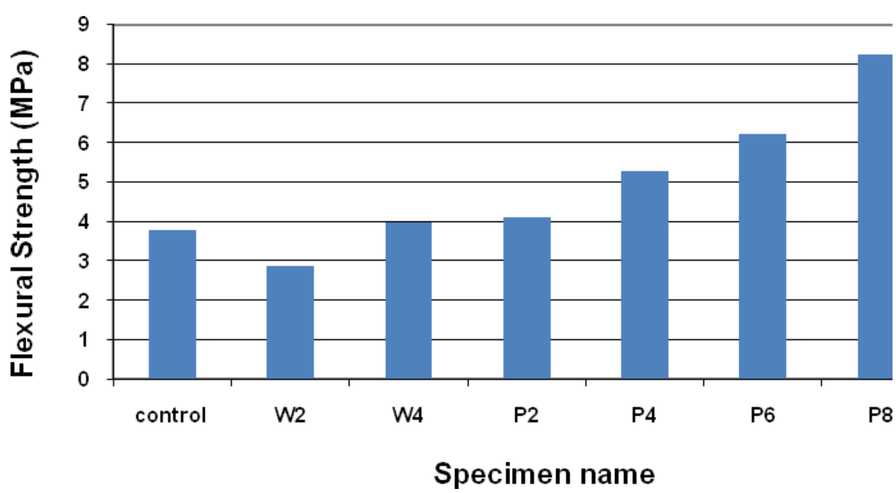

Fig. 4: Maximum Flexural Strength at 21 Days for all Specimen.

2) Moisture movement results and analysis

The results of the moisture movement are shown in figure 5. It should be noted that due to limitation of precession of the measuring equipment of 0.01 mm, the results are presented in the range of 0, 0.13 and 0.24 percent. Although the results show minimal expansion due to moisture movement but in general increasing fibre content, leads to elongation of the length of specimens up to 0.25% which is however insignificant. This can be due to two main reasons; the first is due to the orientation of the fibres in the slurry mix. In pouring the slurry in the mould, some fibres may stand in vertical or incline position. Since the shapes of fibres are laminar, the vertical oriented fibred will cause the apparent minute elongation on the specimens. The second reason is due to moisture. As cellulose fibres have pores in their structures in case of moisture absorption the volumetric increase will be in the thickness direction and hence their length elongation cannot be significant.

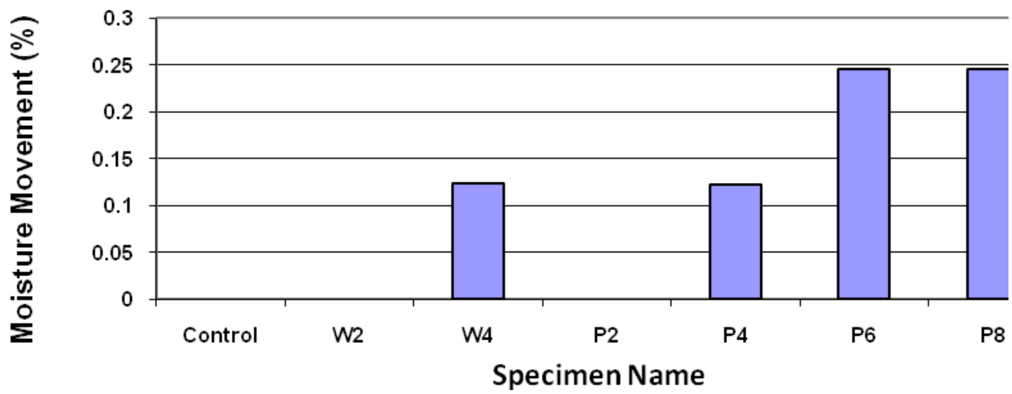

Fig. 5: Moisture Movement Results for the CCBs Studied.

3) Water absorption results and analysis

Figure 6 shows the results of water absorption. As it can be seen the water absorption of the CCBs do not follow a general trend but the increasing fibre content, increases the water absorption slightly when compared to the control specimen. This can be due to the orientation of the fibres in the cement matrix during the manufacturing of the fibre cement sheets which caused increased porosity of the specimen as the vacuum system might not have been efficiently removing the air between the fibres and the cement matrix. Increasing the time or suction power of the vacuum may reduce the porosity and the water absorption

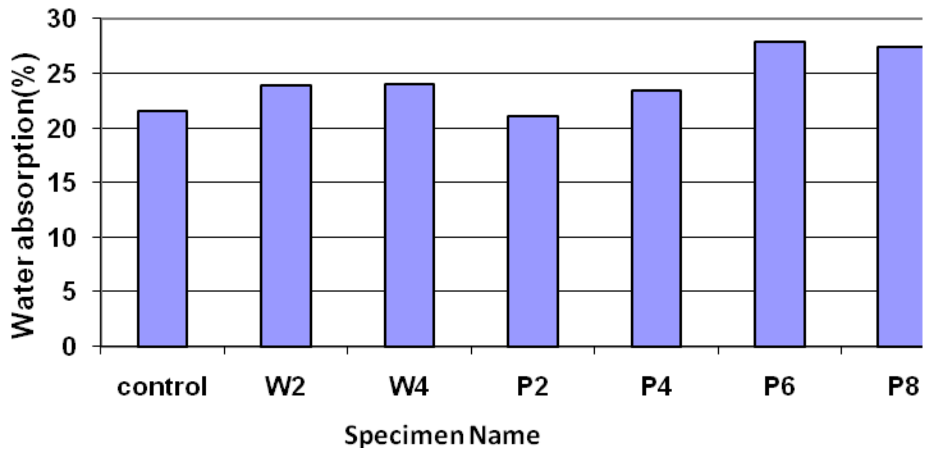

Fig. 6: Water Absorption Results for the CCBs Studied.

4) Moisture content results and analysis

The moisture content values are shown in figure 7. As expected the results show that fibres specimen have higher moisture content than the control specimen with no fibres. In general, cellulose fibres are hydrophilic and show typically about 10 percent weight increase in moisture content. However, the cement paste matrix limits the moisture absorption of the fibres and reduces the moisture content increase to 2.5 to 3.2 percent only. (i.e. much closer to cement paste values). The manufactures of CCB usually spray a resin on to the surfaces of the products to prevent the ambient moisture content to penetrate.

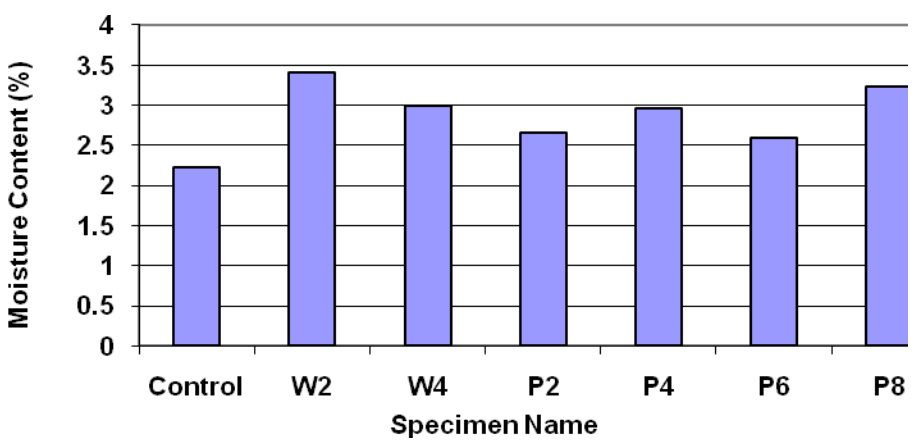

Fig. 7: Moisture Content Results for the CCBs Studied.

CONCLUSIONS

Based on the results and discussion presented, the following conclusions are drawn:

- Natural cellulose fibres have beneficial effect on physical and mechanical characteristics of CCBs. The flexural strength, energy absorption, moisture movement and water absorption of cement boards increases with increasing fibres content.
- The flexural strength enhancement varies depending on the type and the amount of fibres used. The fibre contents and types affect the flexural behaviour and fracture mechanism of composite sheets significantly.
- The 8 percent Kraft pulp specimen achieved the best results of flexural and toughness compared to other specimens. This specimen is classified as class 2 in the BS EN 12467 classifications.
- The Kraft pulp was more homogenously dispersed in the cement matrix and had better bonding and higher contact surfaces within the cement matrix than wheat fibre.

REFERENCES

Alva, P. (2007). “Pre-Tensioning of Fabrics in Cement-based Composites”, *Cement and Concrete Research*, 37(5), 805-813.

ASTM C1185-08. “Standard Test Methods for Sampling and Testing Non-Asbestos Fiber-Cement Flat Sheet, Roofing and Siding Shingles, and Clapboards”. *ASTM International, West Conshohocken*, PA.

Banfill, G., Starrs, G., Derruau, G., McCarter, J., and Chrisp, M. (2006). “Rheology of low carbon Fibres Cement mortar”, *Cement and Concrete Composites*, 28(9), 773-780.

BS EC 12467 (2007). “Fibre-cement flat sheets. Product specification and test methods”, *British-Adopted European Standard* / 13-Dec-2004 / ISBN: 0580450481.

Coutts, R. S. P. (2005). "A review of Australian research into natural fibre cement composites", *Cement & Concrete Composites*, 27,518-526.

Ganjian, E., Khorami, M., and Sadeghi-pouya, H. (2008). “Application of kraft and acrylic fibres to replace asbestos in composite cement sheets”, *11th International Inorganic – Bonded Fiber Composites Conference*, Madrid, Spain, Nov 2008, 52-61.

Juarez, C., Alejandro, D., Pedro, V., and Gerardo, F. (2007). “Performance of Agave Lecheguilla Natural Fibre in Portland Cement Composites Exposed to Severe Environmental Conditions”, *Building and Environment*, 42 (3), 1151-1157.

Khorrami, M. Ganjian, E., and Khalili, M. (2008). “Improvement of characteristics in cement composite sheet with agriculture waste fiber”, *International Conference on Concrete Construction*, *Excellence in concrete construction through innovation*, Kingston University, London, UK, 567-575, 9 -10th September 2008.

Marikunte, S., and Soroushian, P. (1994). “Statistical Evaluation of Long-Term Durability Characteristics of Cellulose Fibre RCC”, *ACI Mater Journal*, 91(6), 607-616.

Negro, C., Blanco, A., San Pio, I., and Tijero, J. (2006). “Methodology for Flocculent Selection in Fibre Cement manufacture”, *Cement and Concrete Composite*, 28(1), 90-96.

Pehanich, J. L., Blankenhorn, P. R., and Silsbee, M. R. (2004). “Wood Fibre Surface Treatment Level Effects on Selected Mechanical Properties of Wood fibre Cement Composites”, *Cement and Concrete Research*, 34(1), 59-56.

Savastano, H. P., Warden, P. G. and Coutts, R. S. P. (2003). “Potentials of Alternative Fibre cements as Building Materials for Developing Areas”, *Cement and Concrete Composites*, 25(6), 585-592.

Soroushian, P., and Ravanbakhsh, S. (1998). "Control of Plastic Shrinkage Cracking with Specialty cellulose Fibres", *ACI Journal*, 95(4), 429-435.

Soroushian, P., Marikunte, S., and Won, J. (1994). "Wood Fibre Reinforced cement composites Under Wetting Drying and Freezing Thaw Cycles", *Civil Engineering Journal Material*, 6(4), 595-611.

Savastano, H., Warden, G., and Coutts, P. (2004). "Evaluation of Pulps from Natural Fibrous Material in Cement Product", *Material & Manufacturing processes*, 19(5), 963-978.