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EFFECTS OF WOOD-PULP FIBERS ON THE MECHANICAL PROPERTIES OF CEMENT COMPOSITES

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ABSTRACT
The application of pulp fiber in cement paste has been under consideration to improve the bearing capacities of the cement composites. Cement composites made by various types of fibers have distinct properties regarding the stability and resistance in dissimilar environmental conditions and applied loads. This behavior depends on four main factors: a) fiber type, b) mixture percentage c) fabrication manner, and d) additives. In this work, to distinguish the flexural behavior of fabricated composites with wood-pulp cellules fibers, the experimental samples designed and tested. The samples made with these fibers were compared with the no-fibrous control samples for their flexural strength and modulus of elasticity. Moreover, to characterize the microstructure properties SEM micrographs were analyzed. The results showed that the application of fibers had suitable effects on the improvement of the flexural strength related to the amount of used fibers.

Keywords: cement board, Pulp fiber, flexural strength, Modulus of elasticity, SEM micrograph

1. INTRODUCTION
All over the world, the production of the cement boards, are based on eckhatch procedure. The history for this method, back to about 100 years ago, in which was derived from paper production technology. Following this procedure, water, fibers and cement should be mixed at first and then, using a special process, this matrix converted to cement composite boards (CCB). To fabricate CCB, the cement matrix positioned on the driving belt, water-drained, and after placing the layers on each others, CCB will be formed. In original procedure, asbestos fibers were used which had good consistency with cement paste, physical and chemical properties, durability and mass-productivity specifications. The growth in production of CCB leads to increase in use and application of Asbestos material, in which, in 1985 the outmost production rate was recorded. Unfortunately clinical researches show harmful effects of this material on the humanity health [1]. Consequently, application and fabrication of the asbestos-based products were inhibited in the majority parts of construction industries. Despite this, the need for CCB motivates the researchers to find an effective solution. This solution should cover the

industrial demands production of CCB with an alternative material. The efforts were initiated in 1980's [10-2]. The solution was the mixed application of various types of cellulose, polymer, and suitable additives. The world master producers of CCB were the leaders of these research efforts. Also, several countries were looking for an appropriate and suitable materials and production techniques for their local applications. By the way, cellules and polymer based fibers (in particular Poly Vinyl Alcohol (PVA) fibers and other new products) were globally accepted as an effective material to be used. It is obvious that what is the researchers are seeking for is the economically optimized mixing proportion for production of the standard CCB. In this regard, the local fibers and domestic material and methods are recommended. For that reason, some factories in Thailand, Turkey, and Belgium succeeded to produce CCB with in access and localized materials, however, some other countries are preferred to import materials for this means. In Iran, there are many economical problems in technology transfer and on the other hand because of the dependency of the Iranian factories to PVA, these factories continue to use the asbestos in their products, despite the restricting regulations. In the recent years, with some growths in demands, 40 million tons of CCB and about 4500 km sewage and water pipes were produced with asbestos materials. Beside, the lack of intense restricting rules and regulations encouraged the continuation of the asbestos products in Iran. The first regulation concerned this issue was back to 2001 when the superior council for protecting of the living environment, puts some restrictions on the application of the asbestos materials. This states that after July 2001, the newly established factories are forbidden to use the asbestos in their products and the factories that were previously using the asbestos as a raw material have been ordered to modify their production procedure to replace the asbestos with other allowable material to completely eliminate the applications in the next 7 years.

The current study was started in early 2007 after this rules encouraged the researches seeking appropriate fibers to be replaced with asbestos materials. These fibers should be met all of the advantageous of asbestos and on the other hand these fibers should not affect the human heath. The pulp fiber produced in paper production factories were considered here with some surface treatments. These fibers were used in reinforcing the cement composite boards. After surface treatment process, their mechanical and physical properties regarding the flexural strength and young modulus were investigated. Samples were made with various fiber contents and then using SEM micrographs the micro-structural properties were studied.

2. TESTS AND METHODS

Cement: Type 2 cement supplied by Tehran Cement Factory was used in this study. Standard laboratorial tests (based on Iranian National Standard No. 398) were executed to determine the properties of this cement, which passed the requirements.

Fibers: The major part of the fibers of this study was prepared from the

agricultural wastes. These fibers are usually used for paper production in which this paper it was named as wood-pulp. The used dimensions were wide-spread of length and thickness where would be discussed later.
Water: Tap water was used ke samplesto ma.

3. MIX DESIGN AND SAMPLE PREPARATION

The amount of wood-pulp was the major parameter of this study. These fibers were in used in the range of 0 to 14% of cement weight.

Table 1: Mix designs and naming codes

Sample	Cement (g)	Water (gr)	Fiber (gr)	Comments
Control	150	450	--	Non-fiber sample
P2	150	450	3.0	2% Cellulous-fiber
P4	150	450	6	4% Cellulous-fiber
P6	150	450	9.0	6% Cellulous-fiber
P8	150	450	12.0	8% Cellulous-fiber
P10	150	450	15.0	10% Cellulous-fiber
P12	150	450	18.0	12% Cellulous-fiber
P14	150	450	21.0	14% Cellulous-fiber

Composite cements were designed and made with a w/c ratio=3. At first fibers were mixed in rotary mixer with 15 mm horizontal blades for 5 min to be separated. This initial preparation was for untwisting the fibers to be well-dispersed in the cement mortar. Cement, water and fibers were mixed for another 5 minutes. After preparing the materials and mixing process, the prepared mixtures were poured into 8×18×15 cm molds. Excess water was drained with a 0.9 bar suction pump (Figure 1) while applying a 10 kg weight on the samples. Then the samples were dried for 1 hour and cured in a steam cabinet with 100% RH for 14 days. After curing, the samples de-molded and dried for 6 hours in 75˚C to prepare for mechanical tests.

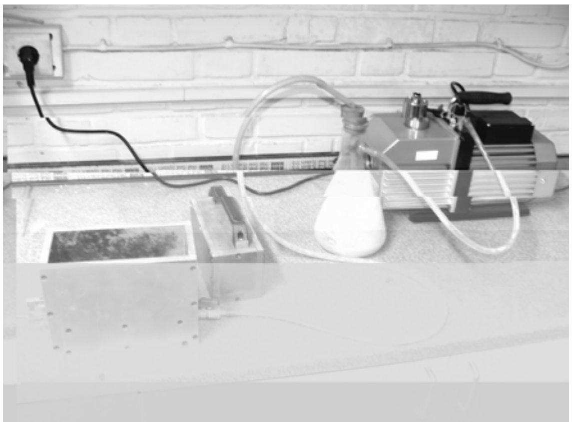

Figure 1. Set up for preparing the samples

4. TESTS

4.1. Tests for fibers

4.1.1. Freeness test

One of the important characteristics of the fiber in cement matrix is the Canadian Standard Freeness (CSF) that was designed for measuring the drainage properties of the wood-paste. The results of CSF test depend on many variables such as: the amount of fine particles and small pieces of available wood, fibrillation degree, flexibility of fibers, and the finesse modulus. The procedure for this test is as follows:

1- Specific volume of wood-paste poured into the cylinders to be drained. Accompanying liquid was brought in the conical case with two orifices one in the bottom and the other located on the side surface of the case.

2- Drained volume of liquid was measured and reported as degree of freeness after some modifications on the values of temperature coefficient and paste density.

3- In this research, the cured fibers were examined for freeness test according CSF.

4- Average measured value for CSF was 500 which were very close to results of other researches.

4.1.2. Morphological tests for fibers

Prepared fibers were poured into the test tubes and de-fibered. After fully separation, length and diameter of fibers as well the diameters of cellulose pores were measured with projectina optical microscope with 30 tries.

Table 2: Morphological characteristics of fibers

Morphological characteristics	Average
Length	mm
Demeter	30.853 micron
Inside cellulose wall	4.102 micron
Pore cellules wall	22.648 micron

5. EXPERIMENTAL CURVES

In this research, the strength of samples was tested in flexural loads. The flexural samples were flat rectangular and tested with a 3-point load system according to the EN12467:2004.

Figure 2 shows the load-deflection curve for CCB with and without fibers. As it can be seen in Figure 2, the application of fibers in CCB increased the flexural bearing capacity (FBC). The maximum observed value in control sample of FBC was 54.42 N, while this enhancement for 4, 6, 8% fiber added samples were 109.75, 238.35, and 289.62, respectively. These values showed that the addition of fibers in cement paste notably increased the FBC. The effect of thickness was not evaluated in this curve, therefore, could not properly reflect the capabilities. Because the more fibers added, the more thickness of CCB appeared and so, the increase of thickness cold be affect the ultimate FBC. To eliminate this deficiency, the following relations were utilized in evaluation of the FBC of CCB:

$$\sigma = M / W \quad \text{(Eq. 1)}$$

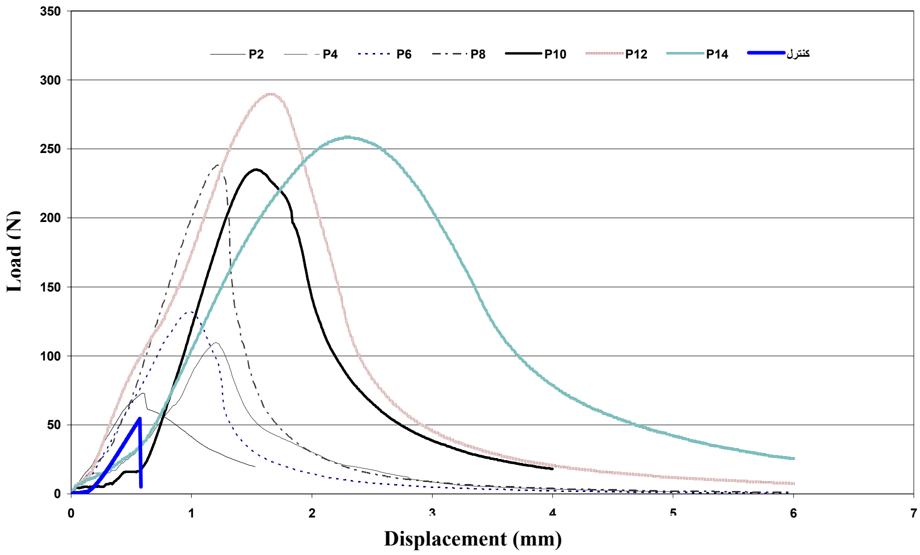

Figure 2. Load-deflection curve of CCB reinforced with cellulous fibers in comparison to the control samples

Where σ is available stress (MPa), M is flexural moment, W is the flexural capacity of the section.

$$M = PL / 4 \quad \text{(Eq. 2)}$$

P is applied concentrated load (N) and *L* is the length of sample.

$$W = BH^2 / 6 \quad \text{(Eq. 3)}$$

Where *B* is width (mm) and H is height (mm) of sample.

$$E = \sigma / \varepsilon \quad \text{(Eq. 4)}$$

Where E is modulus of elasticity (MPa) and ε is strain.
By replacing the values of *M* and *W* in Eq. (1), the stress will be attained as follows:

$$\sigma = \frac{3PL}{2BH^2} \quad \text{(Eq. 5)}$$

Deflection can be calculated by assuming the linear region as:

$$\delta = \frac{PL^3}{48EI} \quad \text{(Eq. 6)}$$

Where *I* is the moment of inertia and δ is the deflection (mm).

By increasing the load P, the value of δ could be measured in real time. If the linear region was assumed, it would be computed as:

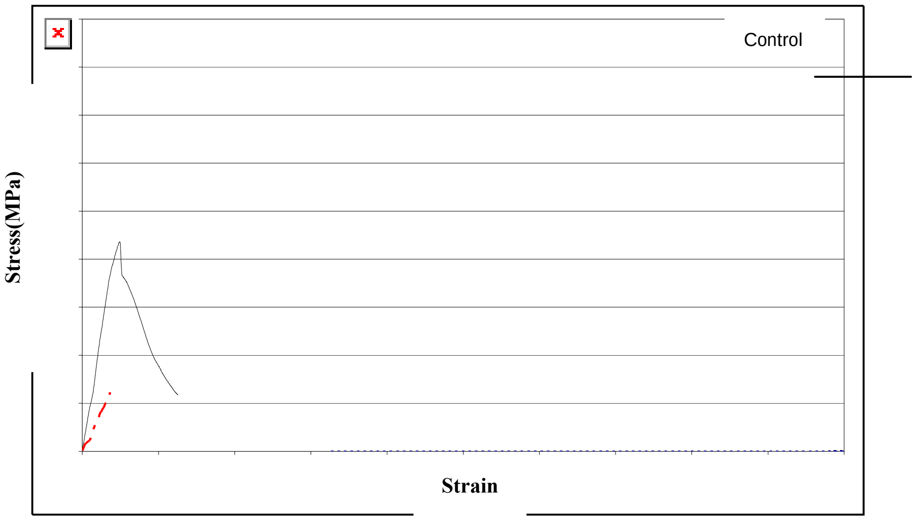

Figure 3. Stress-strain curve of cement composites reinforced by pulp or plant fibers in comparison to the reference sample

$$E = \frac{PL^3}{48\delta I} \quad \text{(Eq. 7)}$$

Where

$$I = \frac{1}{12} BH^3 \quad \text{(Eq. 8)}$$

Using the Eq. 7, the value of ε can be gained:

(Eq. 9)

Based on these relations, flexural strength of CCB samples were evaluated as shown in Figure 3.

For more analysis, the stress-strain curves are plotted in Figure 3. As it can be seen, application of fiber upgrades the maximum yielding stress. Moreover, by increasing the fibers, the area under the stress-strain curve has been increased that is related to the energy absorption properties of boards.

6. FLEXURAL STRENGTH

Figure 4 demonstrates the results of flexural strength of samples. The results proved that the addition of fibers resulted in improvement of flexural strength of CCB. Obviously, the rate of enhancement depends on the type and amount of added fibers and various percentages of fiber replacements affect the mechanism of failure in CCB. Assessment of stress-strain curves of CCB guided us to classify the CCB based on the type and amount of fiber replacements into three groups:

Group 1: Samples with 0-6% fiber replacement
Group 2: Samples with 8-10% fiber replacement
Group 3: Samples with 12-14% fiber replacement
In group 1, as depicted in Figure 4, the flexural strength enhanced slightly with and increase in the fiber amount, whereas the minor enhancement, the failure mechanism of the samples was totally different which varied from brittle to ductile.

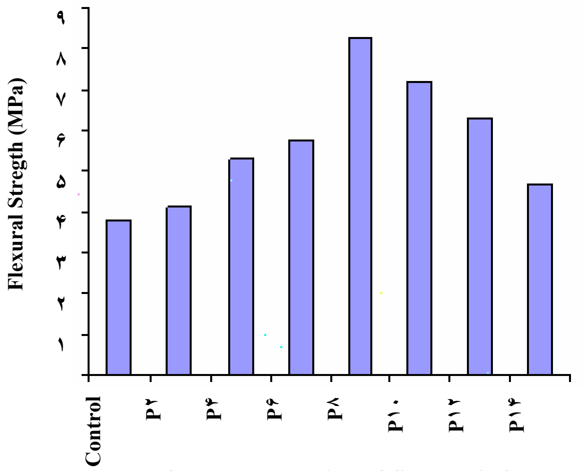

Figure 4. The maximum flexural capacity of fiber-reinforced cement composite boards in comparison to the non-fibrous reference samples

The samples where placed in group 2, have the most flexural capacities in contrast to the reference samples. In some samples in this group, the enhancement reached up to two folds. Moreover, the flexible failure mode was observed for all of samples in this class. In this situation, well-dispersion of fibers with good bond formation between cement paste led to good development of flexural strength of these samples.
In group 3, with increasing the fibers, the more decrease in flexural strength was observed that it is expected to continues up to 14% fiber addition. Assessment of failure mechanism showed that the ductility of samples in this group is higher than other groups. It should be noted that the higher amount of fiber in this group lead to for an unfavorable appearance due to high concentration of fibers at the outer surface of CCB. Moreover, after breaking the samples under load, the balled-shape fibers are visible in some parts of matrix that leads to missed-dispersion of fibers inside the matrix eventually leads to decreasing the flexural strength of this group.
To verify the behaviour and effects of paper-pulp fibers, SEM photographs were analyzed and showed in Figures. 5 and 6. The microstructure of paper-pulp fibers represents the rough surface with good fibrillation. Well ionfibrilizat of fibers forms the numerous fibrils around the outer surface that could help the friction bond strength with cement matrix. On the other hand, the high aspect ratio (10.23) and smaller diameter (30.85 μm) assist in friction strength. The matter will be more important at the interfacial zone of fiber-cement paste and increasing the effective

bond between them. In these pictures very tiny particles associated with the fibers are gibleinegl. Therefore at the sites of cement paste that these materials stanceexi can be interpreted as defects that decrease the strength. Consequently, the existence of these particles in lower amounts could restrict the weak regions inside the cement paste. But other important factor influencing the cement composite with fibers is the fibers orientation in the cement paste. Figure 6 shows the distribution and performance of fiber in cement paste. It is considerable that the fibers are dispersed uniformly throughout the samples. Moreover, the existence of cement particles around the fibers demonstrates the establishment of well interaction between fibers and cement paste. This shows a good bond development between fiber and cement paste.

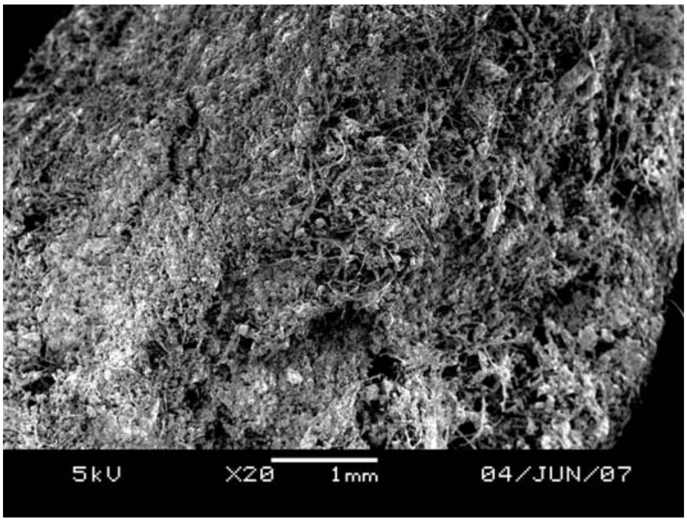

Figure 5. SEM Micrograph of cement paste with Kraft fiber

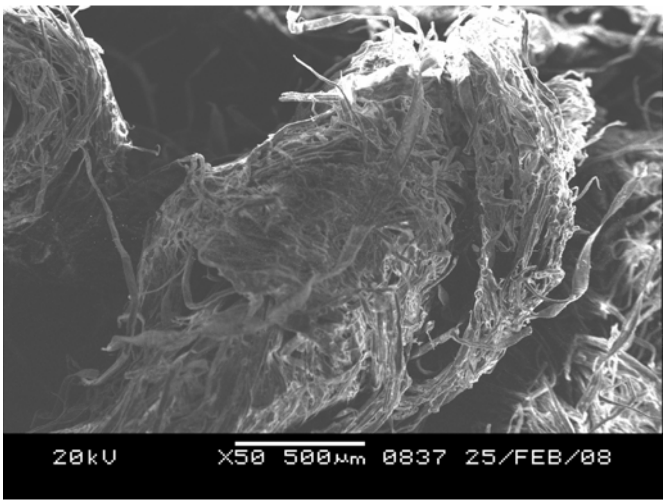

Figure 6. SEM Micrograph of Kraft fiber

7. MODULUS OF ELASTICITY

The modulus of elasticity (ME) is computed for ascending branch of stress-strain curves and the values are depicted in Figure 7. As it can be seen, the modulus of elasticity in all of the samples is lower than reference sample and with increasing the amount of fiber, it will be reduced. Many factors are involved in this property. If the cement composite is considered as a two-phase material (fiber and cement) then ME of the fibers can be effective in overall modulus of elasticity of cement composite so that the more or lesser ME of fibers the more or lesser ME of cement composites will be gained.

It should be noted that the amount of fiber in reinforcing the cement composite is very determinative. To verify this phenomena, the following relation that proposed by Allen [11]which was used to compare with the results of experimental modulus of elasticity of cement composites.

$$E_c = E_m(1-V_f) + E_f V_f \qquad \text{(Eq. 10)}$$

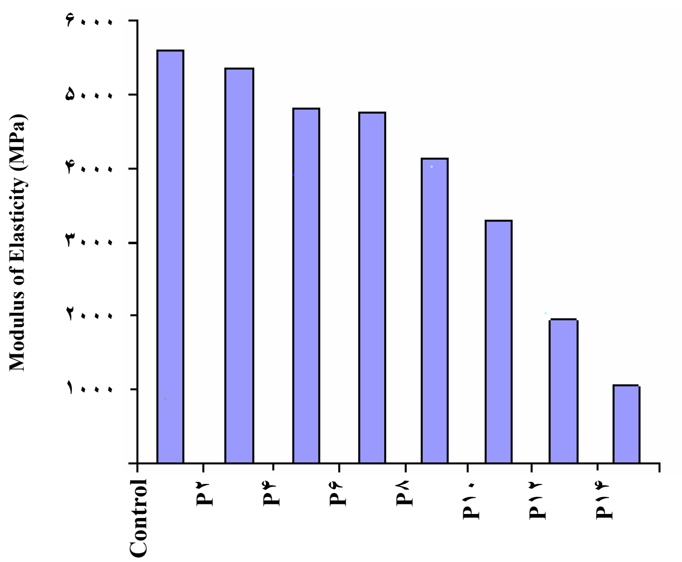

Figure 7. Modulus of elasticity of cement composite boards with and without fibers

Where E_c, E_m, E_f, are the composite, cement matrix and fibers modulus of elasticity respectively and V_f is the volumetric percentage of fiber in the composite.

Experimental results of modulus of elasticity are:

Cement modulus of elasticity = 8.788 GPa

Average modulus of elasticity of pulp= 85.36 GPa

Using the composite component's ME yields great values for in calculated ME for composite material while the experimental observation do not agree with these findings. So it is supposed that the Allen formula is proper when the composite is considered in an ideal condition. Researchers showed [11,5-6] that with application of fiber in cement paste resulted in increase of voids in cement matrix and consequently the micro defects extended. Then generally the modulus of elasticity of cement composite with fiber would we more less that the samples without fibers. Allen [11] proposed a formula regarding this concern as follows:

$$E_m = E_{mo}(1-p) \quad \text{(Eq. 11)}$$

Where E_{mo} is cement matrix ME without fiber, p is the amount of voids in the composite in percent. Moreover, Allen [11] showed that p is as a part of fiber in percent and could be calculated as follows:

$$p = 0.0522 + 3.7407\, V_f \quad \text{(Eq. 12)}$$

It seems that the Eqs.11 and 12 is very reliable and could reflect the experimental observations.

On the other hand, in the mixing procedure of cellules fiber and cement paste with water, some bubbles and spumes would appear on the surface of mortar which could be lead to increase the thickness of the samples with fibers. Thus the results obtained from laboratorial study could be comparable and reliable. The reason for producing the bubbles or spumes is the application of alkaline stuffs in chemical process for production of the pulp. When these chemicals components are contacted with oil used to lubrication of the molds, these bubbles or spumes are formed. As a result, though ME of fiber is greater than the cement paste, but because of these process (bubbles or spumes formation) resulted in increment of porosity of composite leads to decrease in reduction of composite ME. Increase in fiber amount would cause to extending the porosity and finally expansion of samples based on Eq.12 then, in all samples with fiber ME would be reduced by increase in fiber amount.

8. CONCLUSION

From the results obtained in the effect of wood-pulp fibers in mechanical properties of cement composites, the following conclusions can be drawn:

1- Cellulose-fibers extracted from the brief-preparation of pulp has good consistency with cement paste and could be dispersed inside the cement matrix and finally have well bonding with cement paste.

2- By increasing the fiber amount up to 8% of cement, the flexural strength of cement boards would be increase and in the range of 8 to 10% this is constant or has very low decreases. With addition of fiber more than 12%, the flexural strength development would have descendent slop.

3- The main reason for decrease of strength of cement composites, are: a) thickening of the samples because of porosity and b) miss dispersion or non-uniform distribution of fiber in cement paste in which fibers want to be like clew and twisting or miss dispersion inside the matrix.

4- Existence of fibrils could aid in binding and uniformity of fibers with cement paste and eventually leads to enhancing the flexural strength.

5- Modulus of elasticity of composites got more affection from the bonding and continuity of the fibers with cement paste than its components like cement or fibers; does the more bonding strength the more modulus of elasticity would be exist.

REFERENCES

1. WHO meeting: "Occupational Exposure Limit for Asbestos", Oxford, United Kingdom, 10-11 April 1989.
2. R.S.P. Coutts, "A review of Australian research into natural fibre cement composites", Cement & Concrete Composites 27 (2005) 518-526.
3. Coutts RSP. Flax fibres as a reinforcement in cement mortars. Int J Cem Compos 1983;5(4):257-262.
4. Bentur A., Midness S., Fiber Reinforced cementitious composites, Elsevier, 1990.
5. Coutts R. S. P., "A review of Australian research into natural fiber cement composites", Cem. Comcr. Comp, 27(2005) 518-526.
6. Bentur A, Akers SAS. The microstructure and ageing of cellulose fiber reinforced cement composites cured in a normal environment. lnt J Cem Compos 1989;11:999109.
7. Aziz, M.A., Paramasivam, P. & Lee, S. L., Concrete reinforced with natural fibers. In concrete Technology and Design, Vol. 2: New Reinforced Concretes, ed.R.N. Swamy. Surrey University Press, 1984, pp.107-40.
8. Kaufmann J.; Winnefeld F. and Hesselbarth D., "Effect of the addition of ultrafine cement and short fiber reinforcement on shrinkage, rheological and mechanical properties of Portland cement pastes", Cem. Concr. Comp., 26(2004) 541-549.
9. Mohr B. J.; Nanko H. and Kurtis K. E., "Aligned kraft pulp sheets for reinforcing mortar", Cem. Concr. Comp., 27(2005) 554-564.
10. Andonian, R., Mai, Y.W. & Cotterell, B., Strength and fracture properties of cellulose fiber reinforced cement composites. Int. J. Cem. Comp, 1(1979) 151-8.
11. Allen H.G., "Tensile properties of seven asbestos cements", Composites, 2(2)(1971) 98-103.