SETTING AND HARDENING OF AGRO/CEMENT COMPOSITES

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In this study, the use of bagasse fiber (BF) and unbleached bagasse pulp (BP) in a cement matrix, as a raw material, to produce lightweight construction materials is reported. The bagasse was used as partial replacement of cement at different levels: 0% (control cement), 1%, 2% 3%, and 4% by weight. The average size of bagasse fibers was less than 2 mm. Although a reduction in the physical and mechanical strength was observed, the incorporation of either fiber or pulp increased the water of consistency and setting time. A composite containing 4% of bagasse fibers can be used for lightweight concrete. FT-IR spectra showed that the BF or BP adversely affect the rate of calcium silicate hydrate (CSH) formation by decreasing its promotion.

Keywords: Bagasse fiber; Unbleached bagasse pulp; Cement matrix; Mechanical strength

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INTRODUCTION

A large amount of agricultural wastes are produced every year around the world. The use of these wastes as a raw material to substitute mineral aggregates provides an interesting alternative to meet the challenge of disposal and support environmental sustainability. In this context, several studies have been conducted on various types of Portland cement material that has been modified with agricultural wastes (Almeida et al. 2002; Li 2004; Savastano et al. 2000; Semple et al. 2000; Karade et al. 2001). Results have indicated that the composites possess lower density, which results in greater efficiency for both acoustic and thermal insulation. While the results from studies on insulation properties of this material have been acceptable, from the point of view of the durability the main disadvantage is their sensitivity to the water absorption and dimensional instability in the presence of high relative humidity. Because construction is a material-intensive activity and consumes large amounts of materials, the utilization of such wastes in making cement-bonded construction materials offers an attractive alternative to their disposal.

Few studies have been reported on the use of bagasse fiber (BF) or unbleached bagasse pulp (BP) as a partial cement replacement material with respect to cement mortars. The agro-wastes such as rice husk ash, wheat straw ash, hazel nutshell, and sugarcane bagasse ash are used as pozzolanic materials (includes fly ash, rice ash, husk ash, and condensed silica fume increase the strength of the cement, but slow the cure time) in blended cements for the development of cement. On the other hand, the use of waste fibers as reinforcement in cement composites has enormous potential in the field of recycled materials for civil construction. Optimized recycled composites present an acceptable alternative in comparison with fiber-cement produced with virgin wood cellulose fibers (Soroushian et al. 1995). The availability of non-commercial fibrous wastes also supports their potential utilization as sustainable methods for the production of building components (Savastano et al. 2003).

Balbon et al. (2004) explored the utilization of bagasse as an alternative aggregate for structural concrete and found that the product has appreciable strength. The likely natural fiber composites of the future will include many alternative fiber sources rather than just wood; these fiber sources may include hemp, wheat straw, and sugarcane bagasse.

Inorganic bound composites using wood and any combination of natural and/or recycled fiber will also gain in popularity. These products have the benefit of proven biological durability and have proven themselves as durable sidings and as materials suitable for sound-absorbing barrier systems. When used in concrete, fibers are discontinuous, discrete units and find their greatest use in crack control of concrete flatwork, especially slabs on grade (Merrit and Ricketts 2001).

In India and other parts of the world, bagasse ash has been found to possess good pozzolanic characteristics, and nearly two-thirds of the silica is carried in the amorphous state (Banaag et al. 2005). A study shows that quick-setting material is obtained by mixing bagasse ash, 10 % cement, and 4% gypsum, which gives a material suitable for use as mortar and plaster (Banaag et al. 2005). Thus, the main objective of the present study is the possibility of using bagasse pulp and fiber in blended cement. The effect of these fine fibers on the physico-mechanical properties of the cement was investigated.

EXPERIMENTAL

Chemical Composition of the Raw Materials:

The raw materials used in this work were Type I-Ordinary Portland cement (OPC) having a Blaine surface area of 3300 cm^2/g. This was provided by Tourah cement Co., Egypt. The chemical analysis of OPC is shown in Table 1. The mineralogical composition of the OPC sample was C_3S, 55.10 %, β-C_2S, 16.72 %, C_3A, 6.43 % and C_4AF, 12.08 % as calculated from Bogue's equations (Hewlett 1998).

The local agricultural waste samples of bagasse fiber (LAB) and unbleached bagasse pulp (UBP) were from Edfo Sugar Milling Co., Egypt. The cellulosic waste (0.8 mm length) was prepared by grinding the pretreated sample with boiling water for 30 minutes, washing, and then air drying. Unbleached bagasse pulp was ground also to a fine sample. The chemical analyses of BF and BP are shown in Table 2.

Table 1. Chemical Composition of the Raw Materials, wt %

Oxides Materials	L.O.I	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	Blaine S. Area,cm^2/g
OPC	2.64	20.12	5.25	3.38	63.13	1.53	0.55	0.3	2.54	3300

Table 2. Chemical Analysis of Bagasse Fiber and Pulp

Sample	Ash%	Lignin%	Pentosan %	Holo-Cellulose %	α-Cellulose %	Extractives %	W.R.V. %
Bagasse fiber	1.7	22.7	23.6	75.6	48.4	2.6	104.6
Bagasse pulp	0.75	5.95	26.8	-----	63.6	----	106

Batches Preparation and Methods

Five Portland cement–cellulosic fiber and pulp composites were prepared by mixing the cement with 1, 2, 3, and 4 wt.% (denoted by the symbols: M0, M1, M2, M3 and M4). Mixes were mechanically blended in a porcelain ball mill (Lab. monomill, Pulverisette 6- FRITSCH, Germany) for one hour using 3 balls to assure the complete homogeneity.

The standard water of consistency as well as setting time of the prepared cement pastes were directly determined by a Vicat apparatus to obtain the same workability for all mixtures (ASTM 1993 a & b). The cement pastes were mixed and moulded into one inch cubic stainless steel moulds, and vibrated manually for two minutes and on a mechanical vibrator for another two minutes. The moulds were stored inside a humidity cabinet for 24 hours at 23 ±1 °C and 100 % R.H, then demoulded and cured under water until the time of testing for compressive strength after 1, 3, 7, 28, and 90 days. Compressive strength (ASTM 1993 c) was carried out using a hydraulic testing machine of the Type LPM 600 M1 SEIDNER (Germany) having a full capacity of 600 KN. The loading was applied perpendicular to the direction of the upper surface of the cubes. The combined water content (Wn) of the hydrated samples predried at 105 ºC for 24 hours was determined based on ignition loss at 1000 ºC for 30 minutes (El-Didamony et al. 1978).

The phase compositions of some selected samples were investigated using infrared spectroscopy (IR) and scanning electron microscopy (SEM) techniques. The IR analysis was carried out using a Perkin Elmer FT-IR spectrometer in the range of 4000-400 cm^{-1}. The SEM images were obtained by JEOL-JXA-840 electron analyzer at an accelerating voltage of 30 KV. The fractured surfaces were fixed on Cu-stubs by carbon paste and then coated with a thin layer of gold

RESULTS AND DISCUSSION

Water of Consistency and Setting Times

The water of consistency and setting times (initial and final) of cement pastes blended with variable ratios of fiber and treated pulp are represented in Figs. 1 and 2, respectively. It is clear that the water of consistency increased gradually with the incorporation of both fiber and pulp, but with higher rates in the pulp than in fiber. The water requirement increased with increase in cellulose fiber volume fraction. Higher volume fraction of fibers implies higher surface area, and hence more water to wet the surfaces. Also, cellulose fibers absorb water from the mixture, reducing the workability (Soroushian and Marikunte 1991). Cellulose fibers were observed to reduce the unit weight of fresh cement based materials. This is probably because of the fact that the air content increases with addition of cellulose fibers. The increase in air content could be attributed to the difficulty of compacting cement composites incorporating high volumes of fibers. On the other hand, the setting times (initial and final) also increased with fiber and pulp contents. This could be because of the fact that some constituents of the fiber and pulp can act as set retarders (Soroushian and Marikunte 1990). Furthermore, the initial setting time tended to be stable at fiber content more than 3%, while the final setting time seemed to be stable at pulp content more than 3 %.

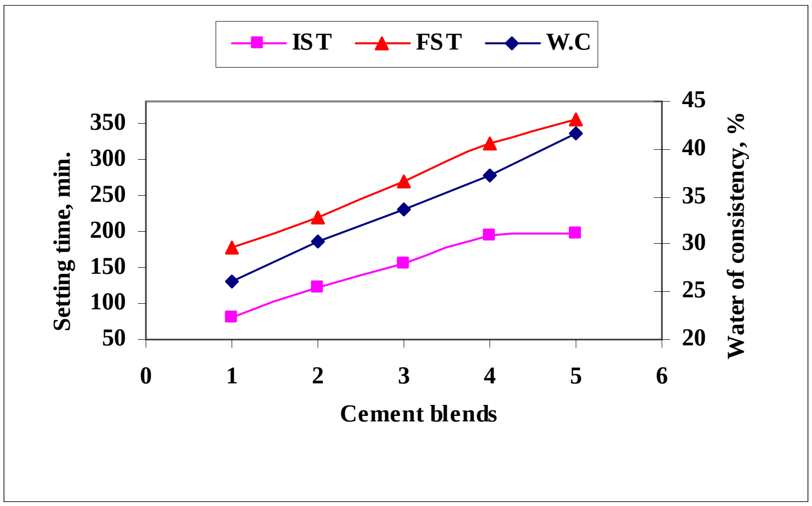


Fig. 1. Water of consistency and setting times of cement pastes blended with variable amounts of fiber

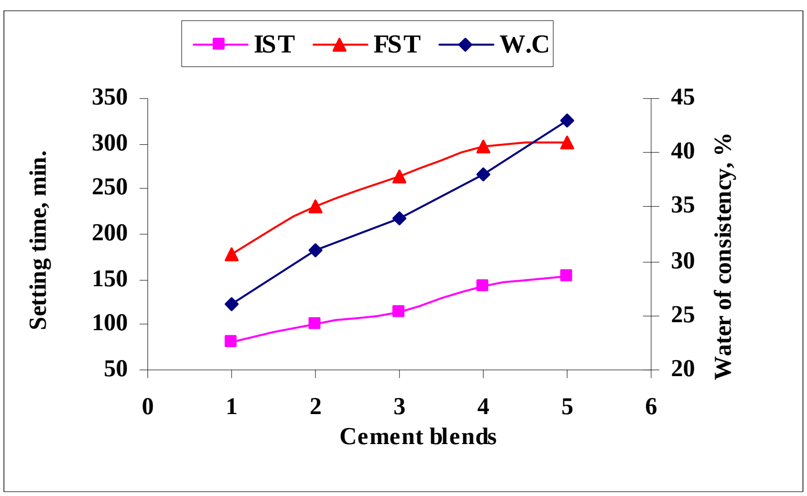


Fig. 2. Water of consistency and setting time of cement pastes blended with variable amounts of pulp

Bulk Density and Total Porosity

The bulk density and total porosity of cement pastes blended with variable ratios of fiber and pulp are plotted as a function of curing time in Figs. 3, 4, 5, and 6, respectively. The bulk density of the hardened cement pastes of the control mix increased gradually with curing time up to 90 days, while the total porosity decreased. This is mainly attributed to the hydration process, where some hydration products are formed and were directly deposited into the pore structure of the hardened cement pastes. As a result, the total porosity decreased, whereas the bulk density increased (Banaag et al. 2005).

On the other hand, the bulk density of the cement pastes containing 1-2% fiber or pulp increased slightly with curing time up to 90 days, while with 3-4% increased only up to 7 days and then decreased. So, higher amounts of either fiber or pulp are undesirable due the adverse effect on cement properties. Furthermore, the values of bulk density of the cement pastes incorporated either fiber or pulp were much lower than those of the control, and the total porosity were much higher, noticing that the results with the bagasse pulp were better than with fiber. This is mainly due to the fact that both fiber and pulp are light in weight, and therefore they decrease the bulk density of the hardened cement pastes. So, the total porosity increases, i.e. they open the structure to a greater degree.

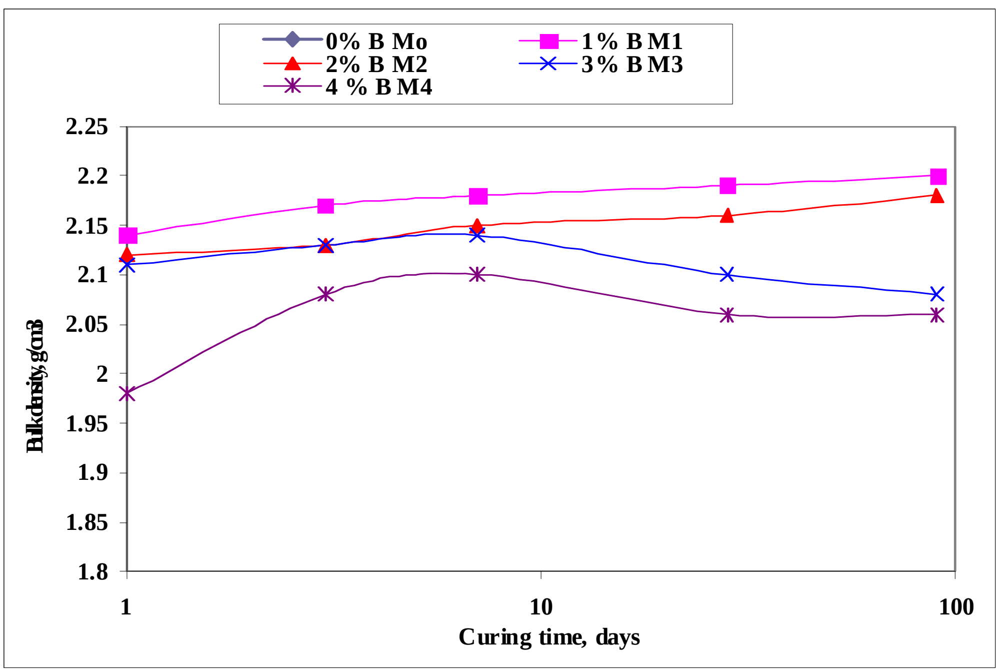


Fig. 3. Bulk density of cement pastes blended with variable amounts of fiber cured up to 90 days

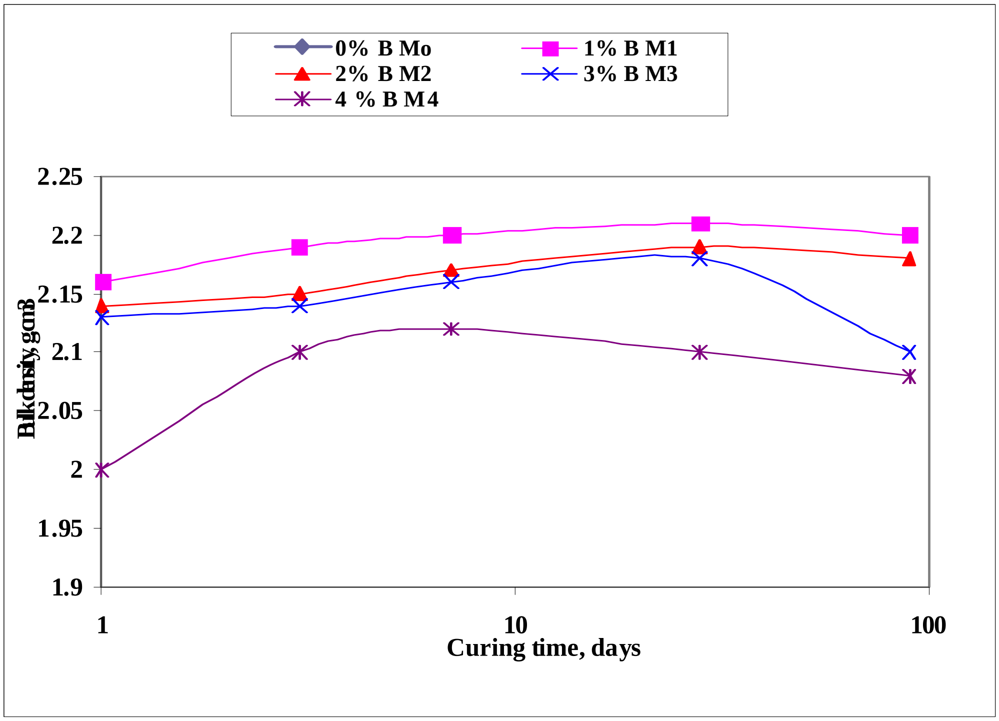


Fig. 4. Bulk density of cement pastes blended with variable amounts of pulp cured up to 90 days

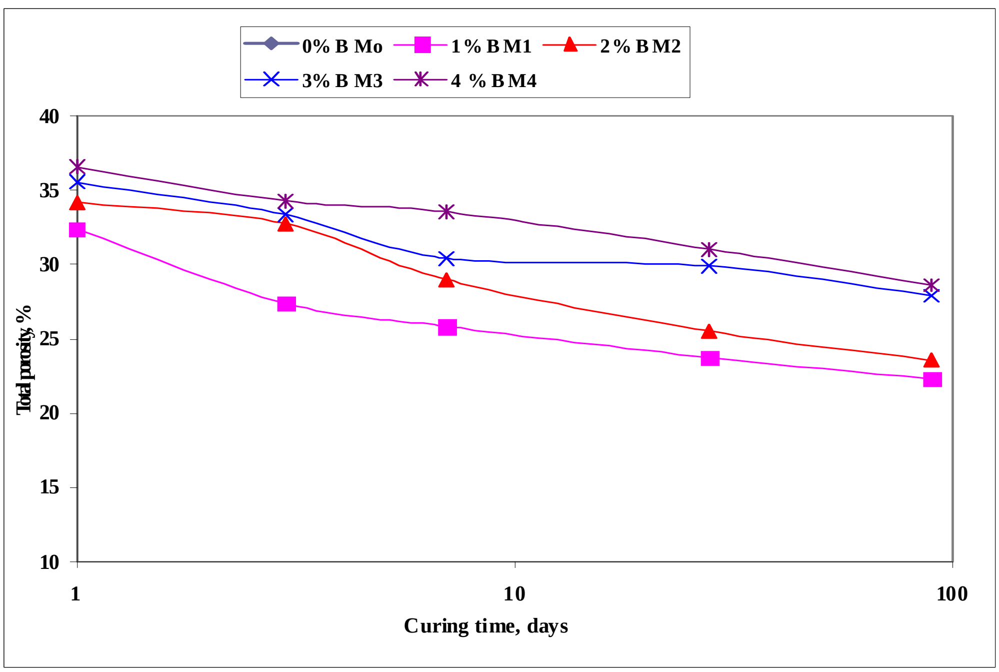


Fig. 5. Total porosity of cement pastes blended with variable amounts of fiber cured up to 90 days

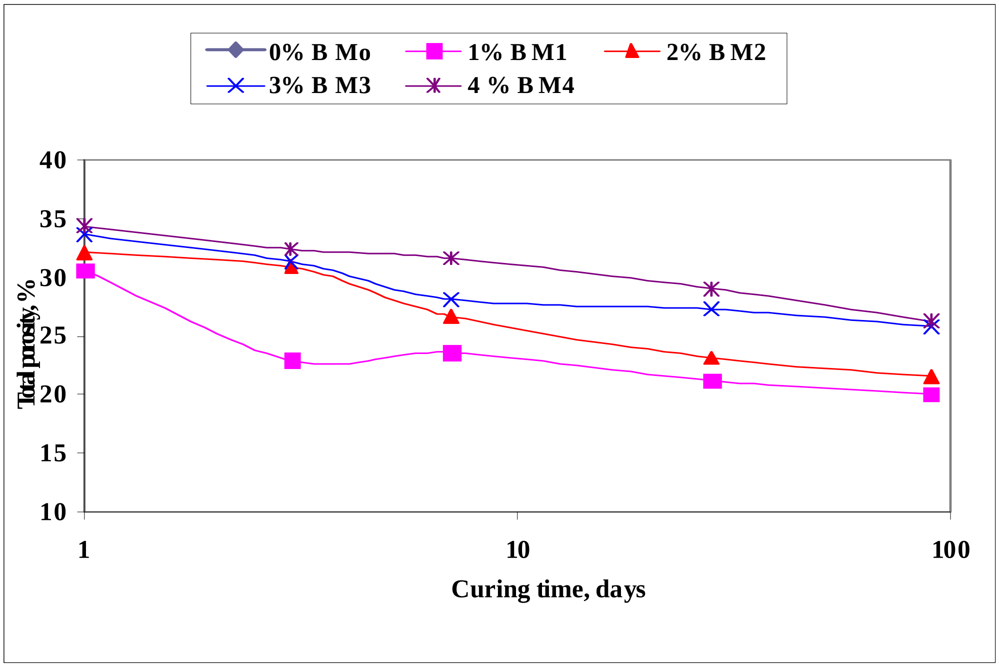


Fig. 6. Total porosity of cement pastes blended with pulp cured up to 90 days

Compressive Strength

The compressive strength of cement pastes blended with variable ratios of fiber and pulp are represented in Figs. 7 and 8, respectively. As a general trend, the compressive strength increased with curing time up to 90 days. This is mainly attributed to the fact that as the curing time proceeds, hydration products are formed. The formed hydration products are deposited into the pore system of the hardened cement pastes. As a result, the total porosity decreased while the bulk density increased. The compressive strength also increased (Banaag et al. 2005), while the compressive strength of bagasse-cement composites vary, depending on the fiber volume fraction and the type of fibers used. It has been reported that the compressive strength decreases with increase in fiber or pulp content (3-4%) (Wolfe and Gjinolli 1996; Blankenhorn et al. 2001), while noting that the compressive strength was better with pulp than with fiber. The decrease of compressive strength is mainly attributed to the fact that both fiber and pulp are light in weight and therefore they decrease the bulk density of the hardened cement pastes. So, the total porosity increases, i.e. they open more structure. It is worth mentioning that the values of compressive strength at 1 and 3 days are near or close to zero. Thus, it can be concluded that the addition of either fiber or pulp adversely affect the mechanical strength, particularly at early ages of hydration. This is essentially due to the fact that these materials separate the cement particles and prevent their hydration. Accordingly, these materials can be applied as isolators (thermal, electrical, and sound insulator).

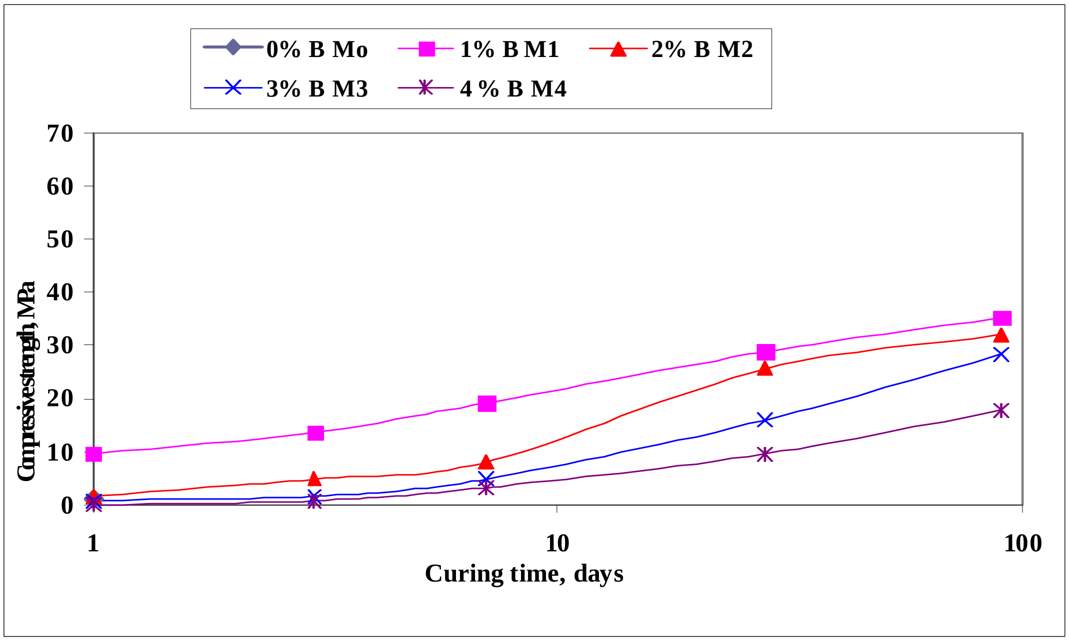


Fig. 7. Compressive strength of cement pastes blended with variable amounts of fiber cured up to 90 days

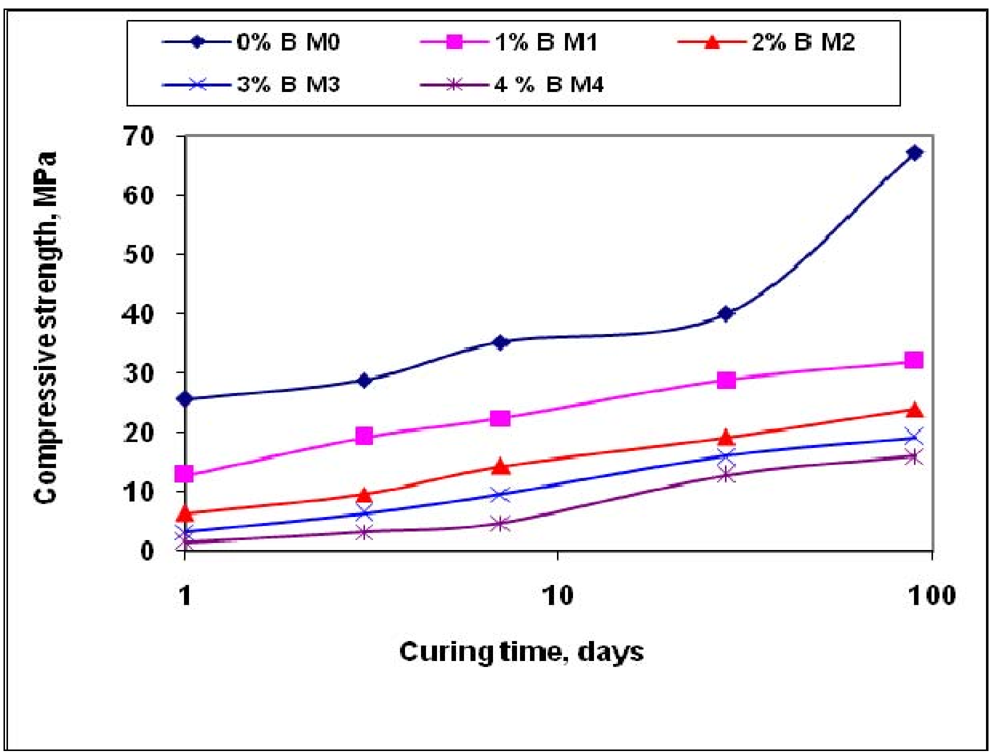


Fig. 8. Compressive strength of cement pastes blended with variable amounts of pulp cured up to 90 days

FT-IR Spectra

The FT-IR spectra of the OPC pastes (a) as well as fiber and pulp composites (b and c), respectively are shown in Fig. 9. The sharp absorption band at wave number 3644 cm^{-1} is from the free OH^{-1} group coordinated to Ca^{2+} (free lime). The intensity of the 3644 cm^{-1} absorption band of the free CH of M0 (a) decreased with fiber (b) or pulp (c) content due to the isolation of cement particles from each other, which in turn decreases the rate of hydration. The broad absorption band at wave number 3434-3450 cm^{-1}, which is due to the OH^{-1} group associated to H^+ bond, i.e. related to the symmetrical stretching frequency of water, decreased also with fiber or pulp content due to the fact that the hydration products could not be processed in their normal way. The two absorption bands at 1690-1684 and 1395-1380 cm^{-1} are related to the main silicate band and involve Si-O stretching vibration bands of CSH and/or CAH. The intensity of the triplet absorption band at 1300-710 cm^{-1} characterizing CO_3^{2-} and/or SO_4^{2-} is irregular due to the rate of carbonation or sulphonation of CSH and /or CAH.

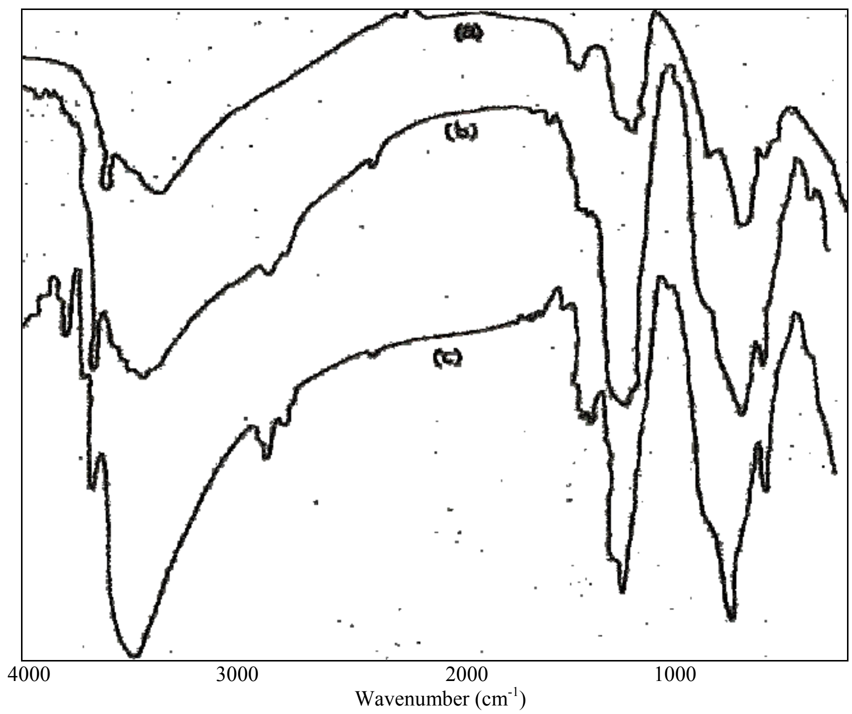
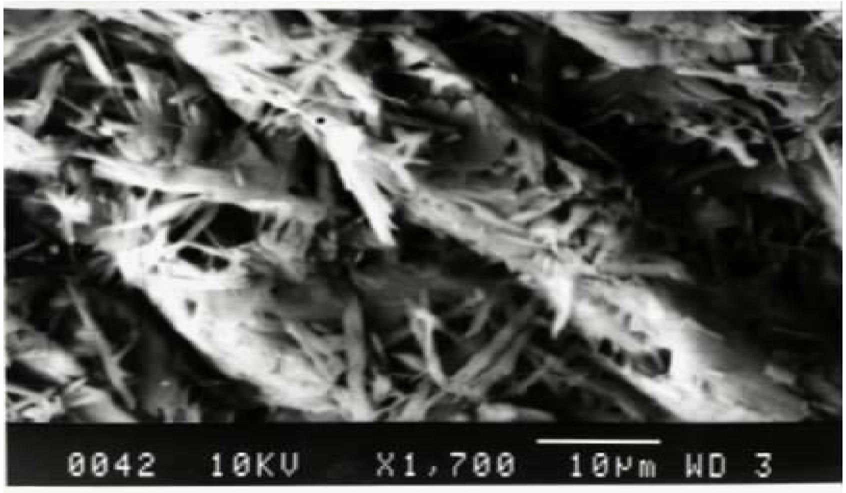


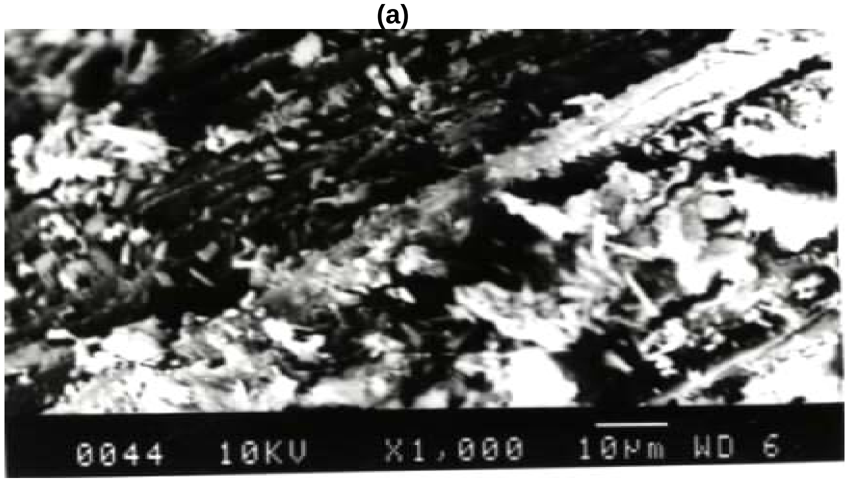
Fig. 9. The FT-IR spectra of the OPC pastes (a) as well as fiber (b) and pulp (c) composites hydrated up to 28 days

Scanning Electron Microscopy

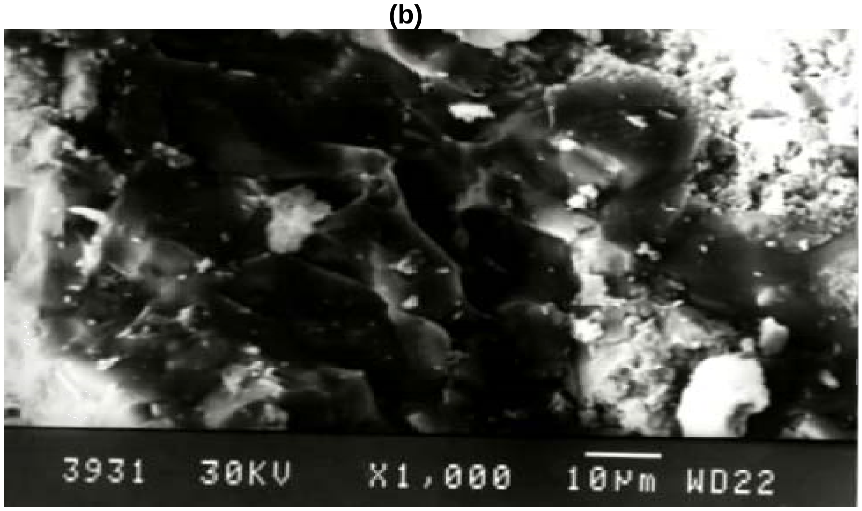
The SEM micrographs of the OPC pastes (a) as well as cement fiber (b) and pulp (c) composites hydrated up to 28 days are shown in Fig. 10. It is obvious that the normal phases as ettringitte, monosulphate, Ca $(OH)_2$, and CSH are detected due to hydration (a). Also, the fibers are clearly shown as embedded threads. The presence of these threads is responsible for the decrease of mechanical strength**.**



(a)



(b)



(C)

Fig. 10. The SEM images of the OPC pastes (a) as well as fiber (b) and pulp (c) composites hydrated up to 90 days

CONCLUSIONS

The gradual replacement of bagasse fiber (BF) or unbleached bagasse pulp (BP) at the expense of Portland cement increased the water of consistency as well as the setting time. Moreover, the partial substitution of either BF or BP affected the specific properties of the cement adversely. This means that the rate of hydration was diminished and the amount of hydration products were substantially decreased at all curing ages of hydration. The FT-IR spectra indicated that the rate of hydration and CSH were reduced. Accordingly, these materials cannot be used as a substituted material for cement systems, but cellulose fibers have the potential to serve as porous, flexible inclusions in cement mortar, so it can only be used as an isolating material. However, it is noted that composites containing 4% of bagasse fibers can be used for light-weight concrete.

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Article submitted: July 26, 2009; Peer review completed: July 30, 2009; Revised version accepted: November 7, 2009; Published: Nov. 9, 2009.