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# SHRINKAGE OF CEMENT COMPOSITES REINFORCED WITH SISAL AND COCONUT FIBRES

R. D. Tolêdo Filho, Civil Engineering Department,
COPPE, Federal University of Rio de Janeiro, Brazil
*K. Ghavami, Civil Engineering Department,
Pontifical Universidade Catlike, PUC-Rio, Brazil
M. A. Sanjuán, Institute Español Del Cement y suss Aplicaciones

## ABSTRACT

The influence of sisal and coconut fibres on the free plastic shrinkage and long-term drying shrinkage of cement matrices is evaluated experimentally using factorial design. A special chamber was designed for the experimental investigation where the test specimen are exposed to a wind speed of 0.5 m/s and temperature of 40°C for a period of 280 minutes. The drying shrinkage was studied for a period of 320 days in the environmentally controlled laboratory with 21.0 ± 1.6 °C and 41.0 ± 8.6% relative humidity. In this paper the results of the research on the influence of mix proportions and the fibre types, length and their volume fractions on the drying shrinkage of cement composites with and without fibres are presented.

The inclusion of 0.2% volume fraction of 25mm sisal fibres in cement mortar significantly reduces free plastic shrinkage and up to 3% volume fraction of 25mm of vegetable fibre reinforcement increases the drying shrinkage of the matrix from 0% to 27% depending on the variables studied.

**Keywords:** sisal and coconut fibres, cement mortar, composites, factorial design, shrinkage.

## 1. INTRODUCTION

Plastic shrinkage is the dimensional change in all fresh cement based materials within the first few hours after it has been placed in the formwork. This type of shrinkage is not unacceptable in itself but it is sometimes accompanied by the development of cracks, which are unsightly and objectionable. When the cement matrix is placed, the aggregates and cement start to settle and water rises or bleeds to the surface. The disappearance of the sheen from the surface of the concrete, mortar or paste indicates the time when the rate of evaporation exceeds the rate of bleeding water rising to the surface. The time required to attain this condition will be influenced by the temperature, wind velocity and relative humidity of the air, the temperature and bleeding characteristics of the cement.

* E-mail address of the corresponding author: ghavami@civ.puc-rio.br

Plastic shrinkage cracks may develop when the surface of the cement matrix has some initial rigidity. At this stage, the matrix cannot accommodate the rapid volume change of plastic shrinkage by plastic flow because it has not developed sufficient strength to withstand tensile stress. The use of low modulus fibres at a volume fraction smaller than 0.3% is one of the effective methods to reduce plastic shrinkage and cracking [1-7].

Long-term drying shrinkage is an inherent property of all cement based materials. Hardened cement paste has a high drying shrinkage; concrete, on the other hand, shows relatively less shrinkage because the moisture movements are restrained by the rigidity of the aggregates [2]. The effect of fibres on the drying shrinkage of concrete, based on the few results available, are not yet conclusive [8-11]. For example steel fibre has very little effect on the shrinkage of concrete [8] and can reduce the shrinkage by up to 40% [8]. Glass fibre has reduced the shrinkage of cement mortar matrices between 20 and 30%[10-11]. The vegetable fibres such as sisal and coconut fibres are porous and can create moisture paths deep into the matrix and could increase the shrinkage as confirmed by the authors' investigations [1,6].

The main objectives of this paper are to determine whether low modulus sisal fibre might be useful for controlling the free early age shrinkage of mortar, to present a model for predicting the free plastic shrinkage of sisal fibre reinforced mortars and to study the influence of sisal and coconut fibres of various volume fraction and lengths on the drying shrinkage characteristics of the developed composites.

## 2. EXPERIMENTAL PROCEDURES

*2.1 Materials*

The sisal and coconut fibres used in this investigation were of Brazilian production. The sisal and coconut fibres of 25 mm long had a mean density, elastic modulus, and tensile strength of, respectively, 0.90 g/cm$^3$, 19 GPa and 577 MPa and 0.80 g/cm$^3$, 3.5 GPa and 174 MPa.

The sand and cement employed in the free plastic shrinkage tests followed the Spanish Standard with a maximum particle size of 2 mm and ordinary Portland cement "OPC" (CEM I 42.5 R), respectively. The fineness modulus of the sand employed in the drying shrinkage tests was 2.81. Tap water was used in all mixes. Chemical and physical properties of the used cements are presented in Table 1.

*2.2 Methods*

The method which enables to measure accelerated horizontal deformation of fresh mortar specimens of 150 mm x 1200 mm and 15 mm, using dial gage extensometers was used in this study to determine the free plastic shrinkage of the composites [12]. A conventional pan mixer was used to manufacture two specimens of each mix. Immediately after casting, the gages were located on the samples, the chamber closed and set to hold wind speed and temperature of 0.5 m/s and 40°C, respectively, in the interior. Free plastic shrinkage tests started at this moment and measurements were recorded at regular intervals of time up to 280 min when the free plastic shrinkage was nearly complete. A complete factorial design was used to define the experimental program. The factors studied in this investigation were: a) water/cement ratio ($X_1$); b) sand:cement ($X_2$); and c) percentage of fibre ($X_3$). These factors are the common variables considered in the design of fibre reinforced cement mixes. The lower and upper levels selected for each factor are presented in the axis of Figure 1. The mix proportions are numbered and shown at the corners of the cube.

Table 1 Chemical and physical properties of the cementing materials

| Property | OPC Blue Circle | CEM I 42.5 R |
|---|---|---|
| a) Chemical properties | | |
| CaO (%) | 64.7 | 63.3 |
| $SiO_2$ (%) | 20.7 | 18.9 |
| $Al_2O_3$ (%) | 4.6 | 3.8 |
| $Fe_2O_3$ (%) | 3.0 | 3.9 |
| MgO (%) | 1.0 | 1.2 |
| $SO_3$ (%) | 3.0 | 2.9 |
| $Na_2O$ (%) | 0.13 | 0.15 |
| $K_2O$ (%) | 0.65 | 1.05 |
| Loss on ignition (%) | 1.3 | 3.17 |
| Soluble residue (%) | 0.38 | 1.89 |
| b) Physical properties | | |
| Fineness ($m^2$/kg) | 353 | - |
| Setting time (initial – min.) | 134 | - |
| Compressive strength (MPa) at 7 days | 47.2 | - |

The drying shrinkage test specimens were cast in a four-cavity plastic mould of internal dimensions 90 mm in diameter x 300 mm in length. Three pairs of studs were placed internally in each cavity before casting to allow fixing of the screws to be used as strain measurement points. Sisal and coconut fibres of 25 mm long were mixed randomly with cement mortar in a pan mixer. To produce a well homogeneous fibre cement mortar mix the following procedure was adopted. First all the sand was placed in the mixer and then 40% of the total required water was added to the running mixer. In order to avoid clumping of fibres and also to keep the mix wet enough, 35% of water and the fibres were slowly added. After placing all the fibres and the whole cementitious material the remaining water was added and the mixing process was continued for about 5 minutes to enhance fibre dispersion.

The specimens were cast in three layers using external vibration. The time of vibration was established according to recommendation made by ACI 544.2R [13]. Strains were measured over a gauge length of 254 mm using a mechanical gauge, which had a sensitivity of $2.5 \times 10^{-6}$. Readings were taken on the three gauge lengths (120° spaced) of the specimens. The temperature and relative humidity of the concrete laboratory monitored during the period of test were, respectively, 23.13°C ± 1.58°C and 41.00% ± 8.60%.

The specimens were water cured at 18°C during the first 28 days. The influence of fibre type and volume fraction and matrix composition on the shrinkage of the material was studied. The experimental program is presented in Table 2. In this Table, the following abbreviations are used to represent fibre type, fibre length, volume of fibre, cement matrices and cure condition:

M1 – cement mortar mix proportions by weight 1:1:0.4 (cement: sand: water);

M2 – cement mortar mix proportions by weight 1:2:0.4 (cement: sand: water);

S – sisal fibre;

C- coconut fibre;

Number after the fibre type - volume fraction of fibre (%);

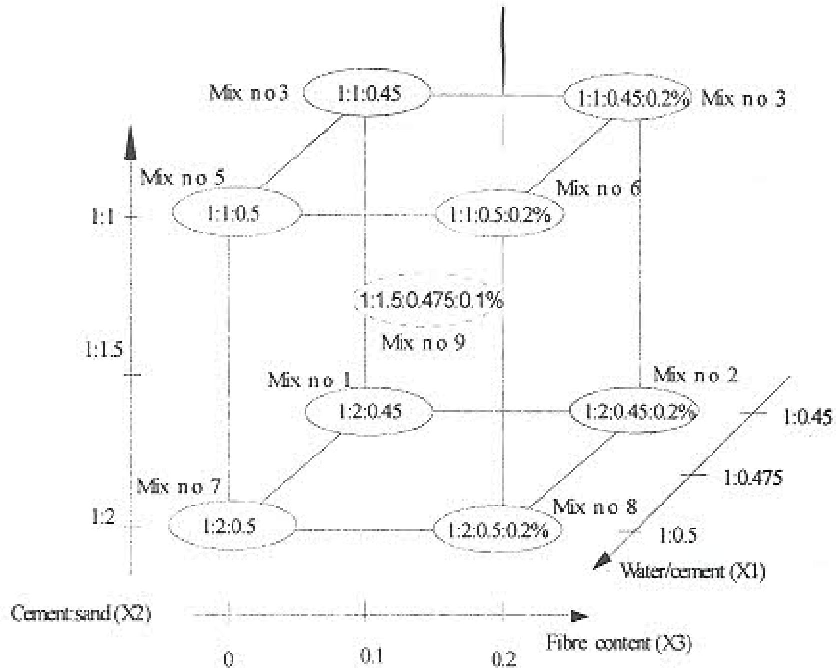



Figure 1 Factorial design $2^3$

Table 2 Experimental mixes used for studying the drying shrinkage of the composites

| Mix | Mortar mix proportions (by weight) | Fibre Type | Fibre Volume (%) | *l* (mm) |
|---|---|---|---|---|
| M1 | 1:1:0.4 | - | - | - |
| M2 | 1:2:0.52 | - | - | - |
| M1S325 | 1:1:0.4 | Sisal | 3 | 25 |
| M1S225 | 1:1:0.4 | Sisal | 2 | 25 |
| M1C325 | 1:1:0.4 | Coconut | 3 | 25 |
| M1C225 | 1:1:0.4 | Coconut | 2 | 25 |
| M2S225 | 1:2:0.52 | Sisal | 2 | 25 |

## 3. RESULTS AND DISCUSSION

### *3.1 Plastic shrinkage*

Figure 2 presents the mean values and the coefficient of variation of the free shrinkage of the composites. The results can be combined in seven different ways to estimate the main effects and interactions of the variables. The average effect of fibre content ($X_3$) on the free plastic shrinkage of mortars is a reduction of 769.5 $\mu\varepsilon$ in its value as given in Table 3 and Figure 2. This reduction is greater with w/c ratio of 0.5 than with w/c ratio of 0.45. This fact shows that the factors $X_3$ and $X_1$ do not present an additive behaviour and that there is an *interaction* between them.

An analysis of variance was performed to show which effects are significant. The significance of each effect was tested at confidence levels of 99% using the F test. The results indicated that the main factors and the interacting factor $X_2 \, x \, X_3$ are significant. A multiple linear regression analysis was carried to the set of experimental data producing equation 1.

$$FPS = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon \quad (1)$$

Table 3 Main effects and interactions

| Main effects ($\mu\varepsilon$) | | | Interactions ($\mu\varepsilon$) | | | |
|---|---|---|---|---|---|---|
| $X_1$ | $X_2$ | $X_3$ | $X_1 x X_2$ | $X_1 x X_3$ | $X_2 x X_3$ | $X_1 x X_2 x X_3$ |
| 178 | -220 | -769 | 16.5 | -73.5 | -163.8 | 23.8 |

In this equation: FPS is the free plastic shrinkage; $\{\beta_i\}$ are the unknown regression coefficients; $\{X_i\}$ are the factors and $\{\varepsilon\}$ represents the random error. The fitted model is given by equation 2.

$$FPS = 2370 + 622 W/C - 110.25 S/C - 2200\% sisal \quad (2)$$

Hyperplane in the three dimensional space of the independent variables $\{X_i\}$ of equation 2, is unlikely to be a reasonable approximation of the response surface over the entire space of the independent variables, but for the relatively small region of practical application studied, the errors observed were smaller than 15% and are well acceptable.

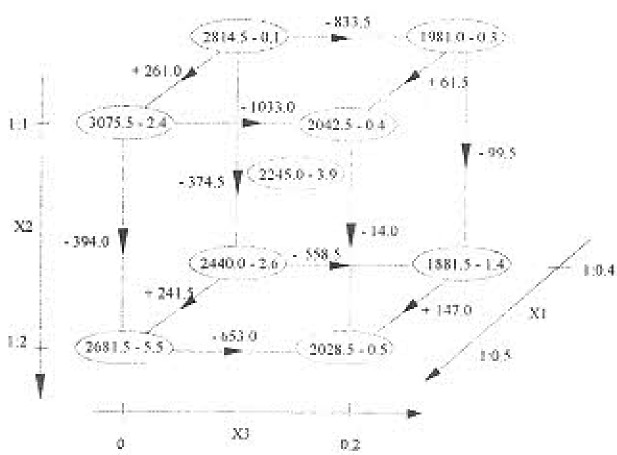



Figure 2 Free plastic shrinkage test results

### *3.2 Drying shrinkage*

Shrinkage and loss of mass measurements were started at the age of 28 days. Influence of fibre type and volume fraction on the drying shrinkage of the matrices can be seen in Figure 3. The density of the specimens after 28 days of curing and the loss of mass due the drying shrinkage after 320 days are given in Table 4.

The shrinkage of the matrix increases when vegetable fibres are present in the mixture. The higher percentage of fibres added, the higher is the shrinkage. This trend could be attributed to the porosity of vegetable fibres, which create more moisture paths into the matrix. The porous nature of the vegetable fibres can be seen in Figure 4 from the scanning electron micrograph of the sisal fibre. Specimens reinforced with sisal fibre shrank more than those reinforced with coconut fibre. This difference increased with the increase of the amount of fibre present in the mix. For example, specimens reinforced with 2% and 3% of sisal fibre present values of shrinkage 0.3% and 8.2% higher than those observed from specimens reinforced with, respectively, 2% and 3% of coconut fibre. The higher water absorption of sisal fibre, 230% compared to 100% of coconut fibres, may be the reason for the higher drying shrinkage of the composites reinforced with sisal fibres.

Table 4 Specimen density after 28 days of curing and shrinkage and loss of mass after 320 days of drying.

| Mix | Density after 28 days of curing ($kg/m^3$) | Drying shrinkage After 320 days of drying ($\mu\varepsilon$) | Loss of mass per specimen after 320 days of drying (g) |
|---|---|---|---|
| M1 | 2275 | 1285.00 | 216.25 |
| M1C225 | 2180 | 1412.50 | 228.75 |
| M1C325 | 2163 | 1511.67 | 235.75 |
| M1S225 | 2175 | 1416.00 | 226.75 |
| M1S325 | 2160 | 1636.67 | 242.25 |
| M2 | 2266 | 935.00 | 252.50 |
| M2S225 | 2118 | 1239.17 | 253.00 |

When sisal and coconut fibres were added to the mix the mass loss due to drying of the matrix slightly increased (Table 4). For example, composites reinforced with 2% and 3% of sisal fibre and cured in water increased the loss of mass of the matrix in, respectively, 4.4% and 12% after 320 days of drying. For the same condition, the increase in the shrinkage of the matrix was more significant. Composites reinforced with sisal fibres exhibited a slightly higher mass loss as compared with those reinforced with coconut fibres

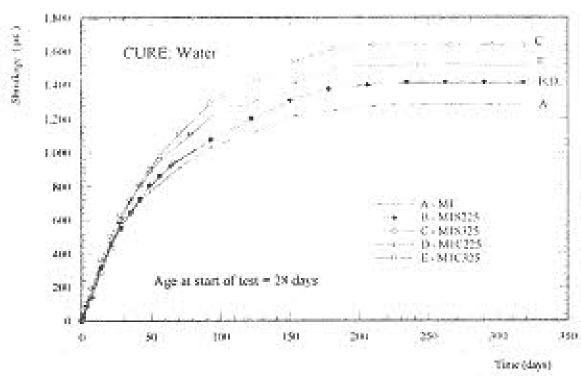
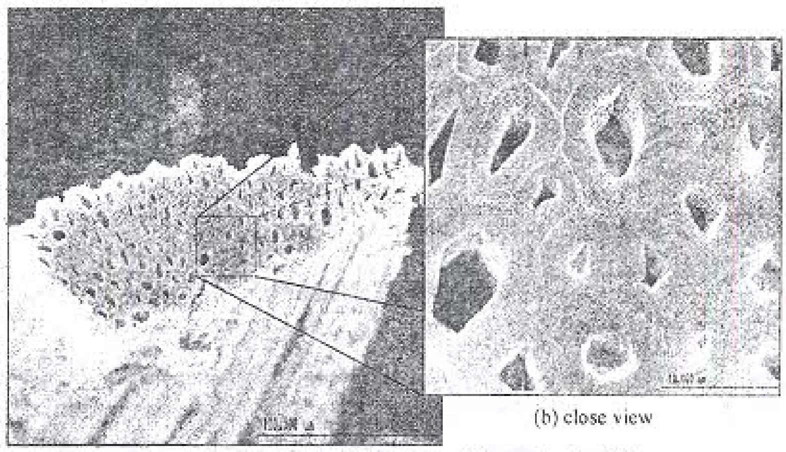



Figure 3 Influence of fibre type and volume fraction on the drying shrinkage of the matrices

Aggregate content in concrete or mortar is one of the most important factors affecting drying shrinkage. Keeping the water/cement ratio constant, an increase in the aggregate content will result in a reduction of shrinkage strains. For the same cement:sand ratio an increase of the water/cement ratio is also known to increase the shrinkage of the material [14]. In Figure 5 it can be seen that the shrinkage of the mix M1 is considerably higher than that of the mix M2. At the age of 320 days, the shrinkage of the mix M1 was 27% higher than that observed for the mix M2. This is mainly due to the smaller volume of cement paste in mix M2. The presence of 2% of sisal in the mix did not change this trend but slightly reduced the difference. The mix M1S2S1 exhibited shrinkage 15% higher than the mix M2S225.



(b) close view

(a) Cross-section of sisal fibre

Figure 4 Porous nature of sisal fibre microstructure

Referring to Figure 6 which shows the shrinkage-loss of mass curves for the mixes M1, M2, M1S225 and M2S225 it can be seen that for the same loss of mass, the shrinkage of the mix M1 is higher than that observed for the mix M2. This is related to the amount of aggregate and cement paste in the mix. To have the same composite shrinkage, the mix with lower content of paste needs to produce more shrinkage in its paste and thus it needs to lose more water.

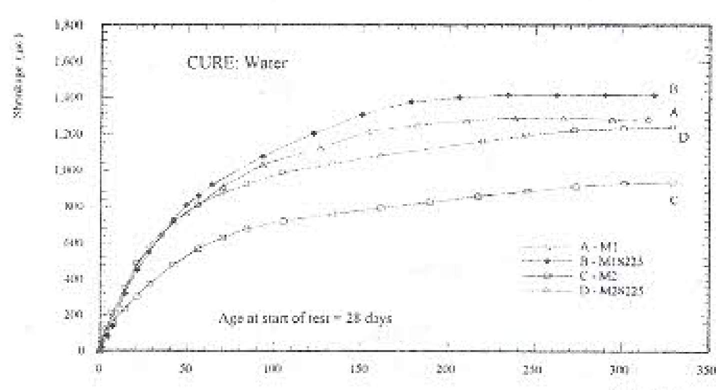



Figure 5 Influence of the mix proportions on the drying shrinkage of the material

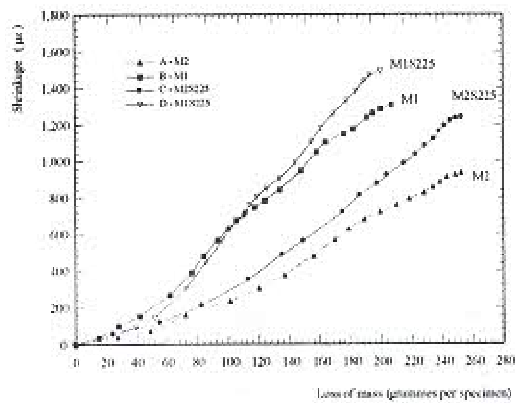



Figure 6 Loss of mass-shrinkage curves for the mixes M1, M2, M1S225 and M2S225

## 4. CONCLUSIONS

The free plastic shrinkage of composites reinforced with sisal fibre has been studied using a factorial design of experiments. This technique saves time, resources and investigation costs and leads to a mathematical model resulting in good correlation with the experimental ones in the range of factors investigated. Low volume sisal was found to be extremely effective in reducing free plastic shrinkage of cement mortar mixes.

Drying shrinkage is increased up to 27% by the presence of up to 3% volume fraction of sisal or coconut fibres. The presence of vegetable fibres appears to create moisture paths deep into the mortar which enhance the route of moisture loss and aid the development of higher drying shrinkage strains.

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