Mechanical Characterization of Sisal Fiber Reinforced Cement Mortar

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Abstract The purpose of this work is to evaluate the mechanical characteristics of sisal fiber reinforced cement mortar. The composite material was produced from a mixture of sand, cement and water in the proportions of 1:1:0.4, respectively. Sisal fibers, amounting to 3% of the weight of cement, were added to the mixture in two different lengths, namely 25 and 45 mm. Mechanical characterization of both the composite and the plain mortar was carried out by means of three point bend, compression and impact tests. Specimens containing parallel sided notches of different root radii were loaded in three point bending in an effort to determine the effect of the fibers on the fracture behavior of the material in the presence of discontinuities. The results obtained indicate that, while fiber reinforcement leads to a decrease in the ultimate compressive strength, J integral calculations at maximum load for the different notch root radii have indicated, particularly for the case of long fibers, a significant superiority of the reinforced material in comparison with the plain cement mortar, in consistence with the impact test data.

Keywords Composite material, Impact energy, Fracture initiation, J-integral

1. Introduction

It is well known that the presence of short randomly dispersed fibers in a cementitious matrix can result in an appreciable improvement in the mechanical behavior of the produced composite. This improvement is clearly manifested by the significant superiority of the composite´s toughness in comparison with that of the plain matrix. The increase in toughness, due to the incorporation of fibers, can be attributed, largely, to the fiber bridging mechanism, whereby the fibers take an active part in supporting tensile loading, in controlling matrix microcracking and in reducing the rate of crack propagation. The fiber reinforced concrete will, therefore, exhibit a pseudoductile behavior, maintaining considerable load carrying capacity after cracking of the matrix.

Starting early seventies, a number of studies [1-4] have been made regarding the use of natural fibers, such as sisal and bamboo, as reinforcing elements in cement mortars and in concretes. The focus in these works has been on the evaluation of the mechanical properties of the resulting composites as a function of the characteristics of their constituents, and the results obtained have indicated the viability of using natural fibers as reinforcing agents in cementitious matrices.

The present work was initiated with the purpose of evaluating the effect of sisal fibers on the compressive strength and fracture resistance of hardened cement mortar. Taking into account their potential use in structural applications, the evaluation of the notch sensitivity of sisal fiber reinforced mortar, in comparison with that of plain mortars, is considered to be an important undertaking. Accordingly, the J-integral approach was adopted and specimens containing deep notches of different root radii were cast in appropriate molds, cured and then loaded in three point bending. The J-integral values at maximum load were calculated and correlated with the notch root radius, for both plain and reinforced mortars. Finally, the J-integral results are also correlated with the impact energy of unnotched prismatic bars having the Charpy dimensions.

2. Materials and Experimental Procedure

The mortar mixture used in the present study was composed of Portland cement PC 32, washed dry sand and tap water, in the proportions of 1:1: 0.4, respectively. The sand had fineness modulus of about 3.33, a maximum particle size of 2 mm and an apparent density of 1.6 g/cm^3.

As to the production of the reinforced mortar, sisal fibers, in an amount of 3% to the cement weight, were added to the mixture in two different lengths, namely 25 and 45 mm. The fibers had average mechanical properties of 670 MPa tensile strength, 4% elongation and 30 GPa elastic modulus.

Compressive strength of the materials was determined making use of cylindrical specimens (50 mm in diameter and 100 mm in length) which were cast from the plain and reinforced mortar mixtures. The specimens were loaded at room temperature (23 ºC) in a universal testing machine with a cross-head speed of 10^{-5} m/s.

In order to determine the load-displacement (P-δ) curves of the materials, notched prismatic specimens (50x50x300 mm) with 270 mm loading span were submitted to three point bending with a test speed of $2x10^{-5}$ m/s at room temperature. The specimens were cast from the plain and fiber reinforced mortar mixtures containing a 25 mm deep parallel sided notch with 0.5, 1, 1.5, 2 and 2.4 mm root radius. Unnotched specimens with identical geometry were also tested in three point bending.

Impact testing was carried out on unnotched prismatic specimens (10x10x50 mm), using a low capacity Charpy type impact machine appropriate for low toughness brittle materials.

3. Results and Discussion

3.1. Compressive Strength

The tests pointed that the plain mortar specimens loaded in compression suffered a highly unstable mode of failure, whereas the fiber-reinforced mortars exhibited a more stable behavior, characterized by larger deformations with a gradual drop in the applied load. Table 1 presents the compressive strength calculated from the ultimate load. From this table it can be verified that the presence of sisal fibers has a deleterious influence on the strength level. Moreover, this influence turns out to be more significant for the long fibers in comparison with the shorter ones. This can be attributed to a decrease in the mortar’s density, associated with an increase in its porosity [5-6]. However, it should be mentioned that the specimen integrity was preserved over a wider deformation range in the presence of longer fibers.

Table 1. Compressive strength of the plain and reinforced mortars

Mortar	Compressive Strength (MPa)
plain	28 ± 1
reinforced with 25 mm sisal fibers	25 ± 1
reinforced with 45 mm sisal fibers	22 ± 1

3.2. Fracture Resistance

The values of the maximum loads obtained during the bending tests according to the notch root radius (ρ) of the specimens are presented in Tables 2, 3 and 4 for the different types of mortars. In these tables, the maximum load corresponds to the average of three tests.

Table 2. Maximum load to the notch root radius for the plain mortar

ρ (mm)	Maximum Load (N)
unnotched	1539.1 ± 17.3
0.5	359.1 ± 20.6
1.0	368.5 ± 15.3
1.5	391.9 ± 16.1
2.0	397.1 ± 6.4
2.4	437.2 ± 51.6

Table 3. Maximum load to the notch root radius for mortar reinforced with 25 mm fibers

ρ (mm)	Maximum Load (N)
unnotched	2195.2 ± 66.5
0.5	801.0 ± 60.1
1.0	845.9 ± 99.7
1.5	858.4 ± 81.1
2.0	992.1 ± 52.2
2.4	1074.0 ± 83.9

Table 4. Maximum load to the notch root radius for mortar reinforced with 45 mm fibers

ρ (mm)	Maximum Load (N)
unnotched	2453.2 ± 47.0
0.5	1014.8 ± 44.4
1.0	1127.9 ± 26.7
1.5	1190.6 ± 28.9
2.0	1225.4 ± 35.2
2.4	1494.9 ± 31.9

The load carrying capacity of all mortars considered in the present study decreased with the presence of notches in the specimens. Concerning the notched bend specimens for all mortar conditions, the ultimate load was found to decrease as the notch became sharper. However, the incorporation of sisal fibers by the mortar was associated with an appreciable increase of the ultimate load during the tests, with the long fibers being more effective in promoting mortar resistance than the 25 mm fibers.

The J-integral values at maximum load (J_m) were calculated from the integrated energy (U) under the load displacement curve, using the Rice estimation formula [7]. The variation of J_m with the notch root radius for the plain mortar is presented in Fig. 1.

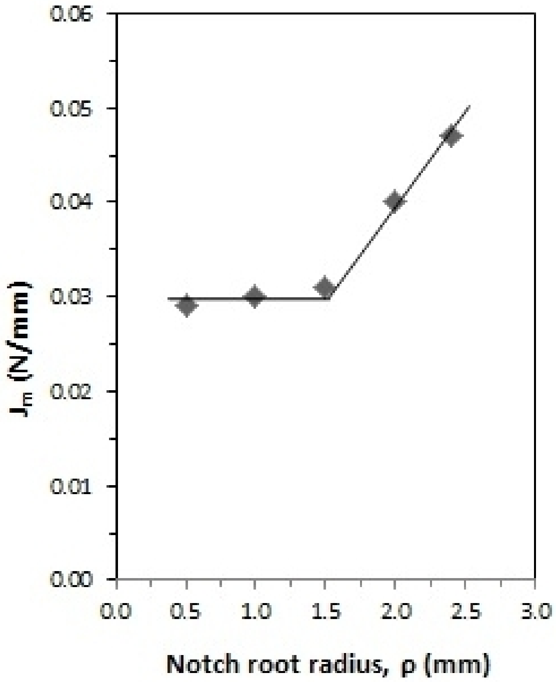

Figure 1. Variation of J-integral at maximum load with the notch root radius for the plain mortar

One may observe that the variation of J_m with ρ is in agreement with the effect normally detected for metallic and nonmetallic materials, where the J-integral value at fracture initiation varies linearly with the root radius. As fracture initiation in the plain mortar occurs essentially at the maximum load, J_m can, therefore, be considered a good estimate of the J-integral value corresponding to the event of failure initiation in the mortar. For small root radii ($\rho \leq 1.5$ mm), though, J_m becomes independent of ρ, remaining at a constant level discriminated as J_{Ic} and considered as a material characteristic. The limiting root radius, which is equivalent approximately to 1.5 mm, is also considered a material constant of microstructural significance, apparently compatible with the fact that the sand, used as a constituent of the mortar mixture, had a maximum particle size of 2 mm.

As to the reinforced mortars, the variation of J_m with the notch root radius is presented in Fig. 2, for both the 25 and 45 mm sisal fibers, in comparison with the J_m level of the plain mortar. In addition to the extremely beneficial effect of fibers on the mortar's fracture resistance, the figure also indicates that a better fracture resistance of the mortar was associated with the use of 45 mm sisal fibers.

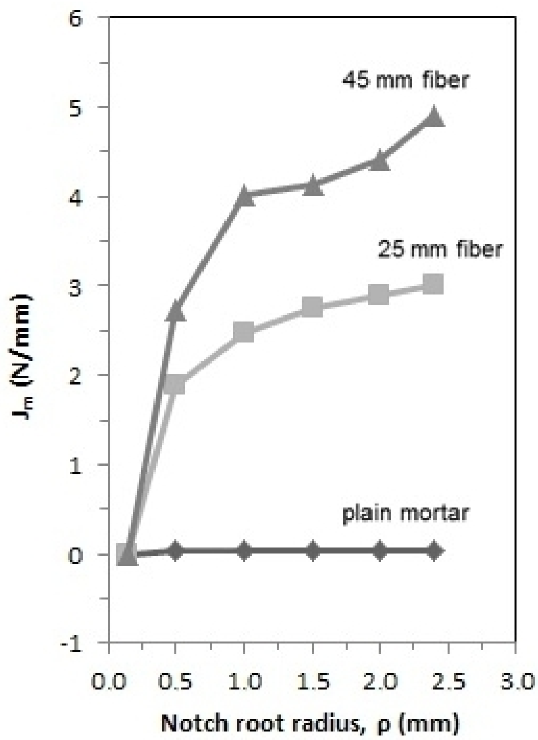

Figure 2. Variation of J-integral at maximum load with the notch root radius for the plain and reinforced mortars

The impact energy results are presented in Table 5, for the three mortars conditions. The individual energy levels shown in the table correspond to the average of five tests with a standard deviation of about 12%.

Table 5. Impact energy of the plain and reinforced mortars

Mortar	Impact Energy (J)
plain	0.45 ± 0.05
reinforced with 25 mm fibers	2.04 ± 0.22
reinforced with 45 mm fibers	3.28 ± 0.35

One can therefore conclude that the use of sisal fibers as a reinforcing element in mortar results in a considerable increase in the impact resistance and that such an increase is considerably more significant for the longer fibers. This beneficial influence is attributed to the fact that, even as the matrix cracks, the load carrying capacity is replenished by invoking fiber loading. This maintains the specimens' integrity as they continue to deform and hence to absorb more energy. The superiority of long fibers in promoting impact resistance is related to the higher load carrying capacity, as well as deformability, of the mortars reinforced with such fibers.

The correlation between the impact energy levels and J-integral results is presented in Fig. 3, whereby an essentially linear relationship is seen to exist between the two parameters.

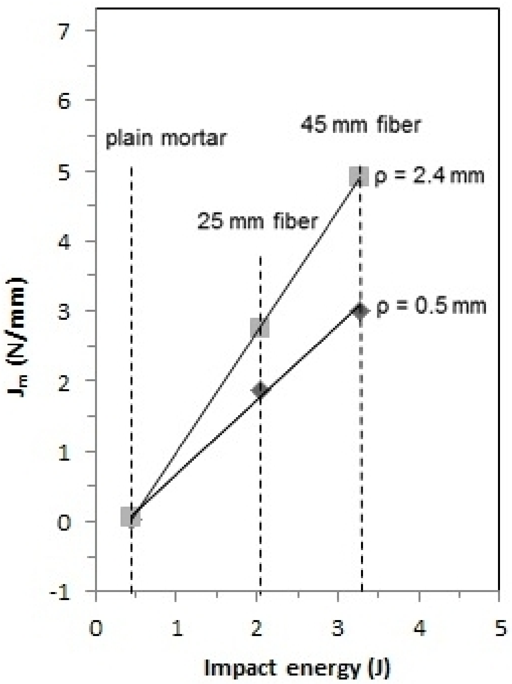

Figure 3. Correlation between J-integral at maximum load and impact energy for the reinforced mortars with notch root radius of 0.5 and 2.4 mm

4. Conclusions

Regarding the study described herein, the evaluation of the effect of sisal fibers on the compressive strength and fracture resistance of hardened cement mortar, the following conclusions can be drawn:

- The use of sisal fibers decreases the mortar's compressive strength. However, the fiber-reinforced mortars exhibit retardation during the failure process, characterized by larger deformations and gradual drop in the applied load, when compared with the plain mortar.
- The deleterious influence of sisal fibers on the compressive strength of reinforced mortar seems to be more significant for long fibers than for shorter ones.
- The presence of sisal fibers in cement mortar considerably improves its fracture resistance. This improvement is manifested by an increase in the J-Integral values determined at maximum load in the presence of deep notches with different root radii.
- Results of impact tests on unnotched specimens indicate a pronounced improvement in impact energy levels due to sisal fibers incorporated to cement mortar.
- Longer sisal fibers are seen to be more effective than shorter ones in promoting fracture resistance of reinforced mortars.

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