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Free, restrained and drying shrinkage of cement mortar composites reinforced with vegetable fibres

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Abstract

Many investigations are realized to establish the basic mechanical properties of vegetable fibre reinforced composites (VFRC) but not their shrinkage and creep behaviour. Some works have been realized to establish the shrinkage of cement mortar matrices reinforced with cellulose fibres, but very few results has been published with regards to shrinkage of VFRC with short sisal and coconut fibres. In this paper a concise summary of several investigations is presented to establish the influence of sisal and coconut fibres on the free and restrained plastic shrinkage, early drying shrinkage cracking, crack self-healing and long-term drying shrinkage of mortar matrices. The free and restrained shrinkage were studied by subjecting the specimens to wind speed of 0.4–0.5 m/s at 40 °C temperature for up to 280 min. The self healing of cracks of the VFRC was studied by using the same specimens as for the study of restrained shrinkage which were kept further in a controlled environment with 100% relative humidity and temperature of 21 °C for up to 40 days. Drying shrinkage tests were carried out at room temperature with about 41% relative humidity for 320 days. The influence of curing method, mix proportions and partial replacement of ordinary Portland cement (OPC) by ground granulated blast-furnace slag and silica fume on the drying shrinkage of VFRC was also investigated. Finally, based on the obtained results on drying shrinkage an equation using the recommendation of ACI model B3 was adjusted and compared well with the obtained experimental data.

Keywords: Sisal fibres; Coconut fibres; Cement; Mortar; Composite materials; Plastic shrinkage; Shrinkage cracking; Self-healing of cracks; Drying shrinkage

1. Introduction

Plastic shrinkage is the dimensional change that occurs in all fresh cement based materials within the first few hours after placement when the mixture is still plastic and has not yet achieved any significant strength. Freshly cast concrete shrinks primarily due to water evaporation. This shrinkage has been attributed [1,2] to negative capillary pressure that leads to a volume contraction of the cement paste. The stresses are generated by a complex series of menisci which are formed in the water filled concrete pores when water is eliminated from the paste mainly by evaporation.

If concrete is restrained against shrinkage, tensile stress develops and can cause cracks. Plastic shrinkage cracks are widely evident in bridge decks, industrial and parking garage floors and highway pavement slabs, that have large thickness and exposed areas. The

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development of plastic shrinkage cracks leads to rapid deterioration of the structures when they are exposed to drying and wetting or freezing and thawing conditions [3–6].

The addition of small quantities of fibres such as steel, polypropylene and cellulose can reduce plastic shrinkage and shrinkage cracking of cement based materials [2–12]. The effectiveness of fibres in reducing early age shrinkage should be evaluated from free and restrained shrinkage tests. Reduction in free shrinkage does not necessarily give an indication of the overall reduction in crack tendency, which is a function of the plastic shrinkage and the reinforcing effect of the fibres in the fresh matrix. To establish the crack tendency, restrained shrinkage tests considering different restraint and drying conditions need to be carried out. The shrinkage and cracking potential in hardened concrete follows the same concepts as for plastic shrinkage of the fresh mixture. Here also the cracking sensitivity is a function of the shrinkage strain and the improved toughness due to fibres [7].

Practical experience has demonstrated that cracks in cement based materials maintained at high humidity, have the ability to heal themselves. The self-healing of cracks has been attributed [13] to the swelling and hydration of cement pastes, precipitation of calcium carbonate crystals, blocking of flow path by water impurities or by concrete particles broken from the surface of the crack. In vegetable fibre–cement composites the fibres can act as porous bridging elements across the cracks accelerating the autogenous healing [14,15].

Hardened cement paste has a high drying shrinkage; concrete, on the other hand, shows relatively lower shrinkage because the volume changes are largely restrained by the rigidity of the aggregates [5]. Regarding the effect of fibres on the drying shrinkage of concrete, the few results available are not conclusive [16–19]. It has been reported that steel fibres have no effect on the shrinkage of concrete [16] and that they can reduce the shrinkage by up to 40% [17]. Glass fibres have been reported [18,19] to reduce the shrinkage of mortar matrices by 20–30%. The existing data concerning the influence of sisal and coconut fibres on the drying shrinkage behaviour of cement based composites in the available literature are quite scarce. However, it is known that vegetable fibres are porous and they create moisture paths deep into the matrix which will increase shrinkage as confirmed by the authors' investigations [14,15].

An analytical model for the drying shrinkage of steel fibre reinforced cementitious composites has been developed by Mangat and Azari [20] to predict the influence of randomly oriented fibres on composite drying shrinkage. The model is based on the concept that, shrinkage of cement matrix, in any direction, is restrained by an aligned fibre of effective length parallel to the direction of the shrinkage strain. This analysis requires a knowledge of the values of coefficient of friction at the fibre matrix interface from the drying shrinkage experimental data. Recently a general expression for the drying shrinkage prediction has been proposed by Zhang and Li [21] based on the shear-lag theory developed by Cox [22] considering the properties of both fibres and matrix including free shrinkage behaviour of pure matrix, elastic moduli ratio of fibre and matrix, fibre orientation characteristic, fibre effective aspect ratio and fibre volume fraction. Both formulations are not applicable for the composite reinforced with fibres that have elastic modulus lower than that of the matrix one which is the case of this paper. To predict the drying shrinkage specifically for the vegetable fibres reinforcing cement mortar, an equation using the recommendation of ACI model B3 for concrete has been adjusted and its validity to the experimental data is examined and presented in this paper.

2. Experimental procedures

2.1. Materials

The sisal and coconut fibres used in this investigation were of Brazilian production. The maximum, minimum, mean and the coefficient of variation (CV) of the physical and mechanical properties of these fibres based on a minimum of twenty tests are given in Table 1 [14,23]. Chemical and physical properties of the ordinary Portland cement "OPC" produced in England, ground granulated blast-furnace slag "GGBS" and undensified silica fume (grade 940) are presented in Table 2. The Thames Valley sand used in the drying shrinkage tests had a fineness modulus of 2.81, a specific gravity of 2.65 and a total moisture content of 0.35%. The sand and cement employed in the free and restrained plastic shrinkage tests followed the Spanish Standard with a maximum particle size of 2 mm and OPC CEM I 42.5R, respectively. Tap water was used in all mixes.

2.2. Free plastic shrinkage

The free plastic shrinkage of sisal fibre reinforced mortar composites (SFRMC) was measured using the method proposed by Sanjuán and Moragues [24]. This method enables the measurement of horizontal deformation of fresh mortar specimens of dimensions 150 mm × 1200 mm × 15 mm using mechanical dial gauge extensometers located on the upper face of the specimens. The gauge length was 1000 mm. To accelerate the evaporation of the mix water the specimens were subjected to forced ventilation. A conventional pan mixer was used to manufacture two identical specimens. Immediately after casting, the gauges were located on