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The influence of date palm mesh fibre reinforcement on flexural and fracture behaviour of a cement-based mortar

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ABSTRACT

The aim of the present paper is to investigate both flexural and fracture properties of a cement-based mortar reinforced with Date Palm Mesh (DPM) fibres. In particular, three-point bending tests on DPM fibre-reinforced specimens (with different fibre volume fractions) are performed. On the basis of the experimental results, the value of flexural strength is computed as a function of the peak load according to the UNI Recommendations, whereas the value of fracture toughness is analytically determined according to the Modified Two-Parameter Model (MTPM) recently proposed by some of the present authors for quasi-brittle materials.

1. Introduction

During last years, natural fibres (such as flax, jute, sisal, coir and bamboo fibres) have been extensively used as suitable reinforcement in cement-based composites [1,2]. As a matter of fact, the desirable characteristics of such fibres, represented by low environmental impact, biodegradability, low cost, low density, and good mechanical properties [1,3,4], have led many researchers to analyse vegetable fibres as an alternative to conventional reinforcements, such as steel and polymeric fibres commonly employed in engineering applications [5–7].

Although some building materials, such as clay bricks, have already been reinforced with vegetable fibres since ancient times, these fibres have systematically been used only for about 50 years, as potential substitutes for asbestos fibres in cement production [1]. Since then, natural fibres have increasingly been used as reinforcement of cement-based composites in non-structural civil applications, such as thin-sheet products for partitions, building envelopes, roofing tiles and pre-manufactured components.

Examination of the state of the art clearly shows that a significant effort has been made by the Scientific Community in order to assess the physical-chemical and mechanical properties of natural fibre reinforcements (see reviews in Refs. [8–10]). Thanks to this large body of work, nowadays it is possible to assert that vegetable fibre reinforcements allow us to reduce both the plastic shrinkage [11] and the thermal conductivity [12], and to improve the acoustic performance by increasing the sound absorption [13]. Moreover, such reinforcements are also able to provide adequate stiffness and strength to cement-based composites due to a substantial improvement of their flexural strength, fracture toughness and impact resistance [14–16].

In the present paper, both flexural and fracture properties of a cement-based mortar reinforced with short vegetable fibres are investigated. Such fibres are extracted from the Date Palm Mesh (DPM), that is, the fibrous structure surrounding the trunk of the date palm. An experimental campaign is carried out on reinforced mortar specimens, by examining five different values of fibre volume fraction (that is, 2, 4, 6, 8 and 10% by volume). In order to analyse the fibre effect on the mechanical properties, plain mortar specimens are also tested for comparison.

The above experimental campaign consists of:

(i) three-point bending tests performed on unnotched specimens to determine the flexural strength [17];
(ii) three-point bending tests performed on edge-notched specimens to determine the fracture toughness [18–20].

On the basis of the experimental results, the value of flexural strength is computed as a function of the peak load according to the formulation reported in Ref. [17]. Moreover, the value of fracture toughness, i.e. the critical Stress-Intensity Factor (SIF), is analytically determined on the basis of the experimental load against Crack Mouth Opening Displacement (CMOD) curve, according to the modified version of the Two-Parameter Model (TPM) recently proposed by some of

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Nomenclature

a_0	notch length
B	specimen width
C_i	initial linear elastic compliance
C_u	unloading linear elastic compliance
E	elastic modulus
$K_{(I+II)C}^{S}$	critical mixed mode stress-intensity factor
L	specimen length
n	Date Palm Mesh fibre percentage
P_f	peak load related to load – deflection curve
$P_{\max}$	peak load related to load – CMOD curve
R_f	flexural strength
S	support span
W	specimen depth

Acronyms

CMOD	Crack Mouth Opening Displacement
DPM	Date Palm Mesh
MTPM	Modified Two-Parameter Model
SIF	Stress-Intensity Factor
TPM	Two-Parameter Model

the present authors [21–23].

2. Cement-based composites reinforced with date palm fibres

Among vegetable fibres, those obtained from date palm (Phoenix Dactylifera, one of the most cultivated palm around the world) have been proved to be good candidates for reinforcement of cement-based composites [24–27].

The date palm tree is composed by: (a) a long trunk; (b) a mesh, surrounding the trunk; (c) leaves; (d) reproductive organs; (e) fruit bunches (Fig. 1). The mesh is characterised by a fibrous structure, which creates a natural woven mat of crossed fibres of different diameters, and is considered as a ligno-cellulosic material [27].

The date palm is commonly found in North Africa, Middle East, India and USA (California). There are about 100 million date palm trees in the world, and each tree can grow for more than 100 years [25].

In Algeria, there are more than 18.7 million trees, and the annual trimming operations produce enormous quantities of agricultural wastes, which are usually thrown away, except small quantities used for artisan products [26].

Such wastes can represent an abundant source of low-cost raw material for industrial purposes. Therefore, the development of cement-based composites reinforced with this agricultural material represents an excellent solution for efficient utilization of such wastes as a renewable resource.

Some attempts to valorise Date Palm Mesh (DPM) fibres as reinforcements in cement-based composites are available in the literature [24–27]. For instance, Kriker et al. [24] examined four types of DPM fibres aiming to determine their mechanical and physical properties. More precisely, the performance of such fibres (with length equal to 15–60 mm) was analysed by including them in a cement-based concrete with fibre content equal to 2–3% by volume. It was observed that, by increasing both the fibre length and the percentage, post-cracking flexural strength and toughness coefficients were improved, whereas an opposite trend was observed for both first cracking resistance and compressive strength [24].

The effect of DPM fibres on the properties at both early stage and hardened stage of self-compacting concrete in hot-dry conditions has been investigated by Tioua and co-workers [27]. In particular, the addition of a low fraction of DPM fibres to hot-dry cured specimens was found to be effective in reducing both the early stage shrinkage and the cracking risk. Conversely, a low inclusion of DPM fibres did not significantly modify the concrete performance in the hardened state, that is, neither mechanical nor physical properties of concrete.

To the best knowledge of the present authors, no studies related to the fracture behaviour of cement-based composites reinforced with DPM fibres are available in the literature. Therefore, this paper deals with the fracture toughness of a cement-based mortar reinforced with short DPM fibres.

3. Experimental campaign

3.1. Materials and mixture proportion

The DPM fibres used in the present study are obtained from Deglet-Noor date palms (Deglet-Noor date is one of the most appreciated variety in the world) from the oasis of Tolga (Biskra, Algeria).

After removing the leaves, the fibres are pulled out from the date palm trunk in a form of nearly rectangular sheets (Fig. 2(a)). Then the mesh sheets are manually separated into single fibres and washed with fresh water. Finally, such fibres are dried at room temperature for one week and cut to the desired length, that is, 7–10 mm (Fig. 2(b)).

Since the fibres here employed have the same geographical origin of those used in the experimental campaign performed by Kriker et al. [24], it is reasonable to assume that the DPM fibres are characterised by similar physical properties (see Table 1).

The cement-based mortar matrix consists of a limestone Portland cement (42.5 CEM II/A-LL type) and a silica sand with a grain size distribution determined according to the UNI EN 196–1:2005 European Recommendation [17].

For the specimen casting, the mixture proportions adopted for both plain and reinforced cement-based mortar are cement:water:sand (by weight) = $1:0.55:3$. The ratio between water and cement is fixed after performing a workability test with the flow table according to the UNI EN 1015–3:2007 European Recommendation [28]. In particular, the content of water in the mixture shall be enough to produce a flow of about 110% by jolting the flow table 15 times in approximately 15s.

The above mortar mix design is prepared according to UNI EN 196–1:2005 European Recommendation [17], and the mortar mixture composition is listed in Table 2.

3.2. Specimen preparation and curing condition

Specimen preparation and curing condition are performed

Fig. 1. Components of the date palm tree.