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Virtual manufacturing and mechanical properties of synthetic fiber-reinforced mortars

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Abstract

The composition of mortars was improved since ancient times, even using natural fibers, or natural polymers. The physico-chemical, mechanical and elastic properties of the fiber-reinforced cement-based materials depend on the fiber's properties (shape, contents and orientation) and the properties of the matrix. Given the wide range of fibers available for experimental use which can be embedded in the cementitious matrix, an important aspect is to estimate the properties of the composite before investigating. Virtual manufacturing reduces the need for laboratory tests and thus saves raw materials, but special computer programs are needed for the preliminary simulation of the behavior of newly-designed materials. This paper introduces a computer modeling approach to simulate the effect of the different types of short fibers on the traditional cement-based mortar properties and to compare the obtained values with the experimental test results.

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Keywords: cementitious composite; multiphase materials; fiber-reinforced mortar; polypropylene; virtual manufacturing; Finite-Element method.

1. Introduction

A major concern in all areas of engineering, including civil engineering is the development of durable materials, which must simultaneously meet the economic and environmental requirements. This results in a need to research

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new materials that meet all aspects of these requirements and have adequate properties, created efficiently using clean processes and technologies, if possible. The composition of mortars was improved since ancient times, even using natural fibers or natural polymers. In Egypt the principal building material was clay, used in the construction of housing walls and later it was used in the form of raw bricks made of Nile alluvium in admixture with waste vegetables. Modern development and early use of fiber dates back to the early 1960s with a rising demand for firm and stiffer materials, which are also strong and lightweight. New requirements led to the revival of the concept and application of these materials, which has been the subject of intense development in several areas to this day.

Due to the wide range of types of fibers available for cement-based construction materials, virtual testing was developed in order to achieve the composite's properties using different types of fibers. The results obtained were compared with experimental test data as well in order to analyze the methodology's applicability, feasibility and accuracy in case of mortars with dispersion of discontinuous, small fibers. As the fiber materials, polypropylene and steel were chosen due to their properties, the ubiquitous research data on them and last but not least, due to the wide range of their applicability.

1.1. Theoretical background

A new way used in different areas in order to save raw materials was using computer programs for the preliminary simulation of the behavior of the newly-designed materials or reducing the specimen number. Each new material composition requires serious and costly investigation, involving significant amounts of raw materials at the same time. This direction seeks the simulation of composite material behavior, which can be used to determine their performance with a certain accuracy and whether the new material meets the requirements. This means significantly reduced testing time or considerable savings in all points of view. The key to increasing the performance of traditional cement-based construction materials is the appropriate choice of reinforcement fibers. The choice of the reinforcing materials requires knowledge of the conditions to be met: tensile, flexure and impact strength greater than that of the matrix in which it is embedded, the chemical resistance, satisfactory adhesion to the matrix etc. The fiber-reinforced mortar (FRM) can be defined as a composite material made of a cementitious matrix and a dispersion of discontinuous, small fibers. On a smaller spectrum it may be defined as a composite of hydraulic cement paste, fine aggregate and fibers [1]. The discontinuous fibers are used in principle to diminish the brittle behavior of cement-based materials such as mortars or concrete, to close small cracks and to provide a higher mechanical resistance. Due to the discontinuous fibers which allow stress redistribution, the deformability of the system increases more or less, depending on the amount of fibers and the fiber material properties. In order to simulate the behavior of FRM based on the pre-phase material properties and the interaction of the constituent phases, a multi-scale modeling was used. [2][3][4]

This paper aims to study the influence of the minimum reinforcement percentage on the properties of a composite. In order to do that the minimum recommended quantity of fibers was established at 15 kg/m^3 in case of steel fibers, and 1 kg/m^3 in case of polypropylene, and of course, the traditional mortar mixture (matrix) used as a reference. Due to the method's feasibility (computer modeling techniques and software), several mixtures were tested.

2. Experimental methodology

2.1. Materials and mixture's proportions

Experimental investigation is focused on tensile strength and flexural strength response of traditional cement-based mortar and three different type of fiber reinforced mortar. Their physical and mechanical properties are shown in Table 1. The mixtures composition was made with constant cement and sand ratio of 1:3. Portland cement CEM II 42.5 was used as binding.

Traditional cementitious mortar (MT) has been improved using different types of fibers (see Fig. 1.) such as steel fibers or polypropylene, in order to determine the composite's properties, particularly tensile strength and elastic modulus. As mentioned, the minimum manufacturer recommended fiber content was used: 15 kg/m^3 in case of steel,