Use of Textile Fiber Waste to Improve the Thermal and Mechanical Performance of Cement-Based Mortar

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Abstract. Improving the thermal properties of materials used in buildings is crucial to reducing energy demand and consumption. This study investigated the use of textile fiber waste in cement-based composites for construction applications. Mechanical and thermal characterizations were carried out to assess the behavior of cement mortars with different percentages of two types of textile fibers after 7 and 28 days of water hardening. The results show that the incorporation of fibers can significantly improve the thermal insulation capacity of buildings by reducing the thermal conductivity of cement mortar by up to 52%. In addition, the use of textile fibers can improve the mechanical strength of the cement mortar, especially with a high fiber content and a longer curing time.

Keywords: Textile fiber · Cement mortar · Thermal insulation · Experimental study · Building applications · Mechanical performance

1 Introduction

The energy demand in buildings is currently increasing steadily. According to the International Energy Agency (IEA), buildings are responsible for more than 30% of global energy consumption and 27% of total emissions [1]. A significant portion of this energy use and associated emissions is attributed to the need to condition spaces to maintain thermal comfort [2]. The intensity of heat exchange with the outside environment and the thermal conductivity of building materials play a crucial role in determining the energy required for space conditioning. To counteract heat loss, the incorporation of fibers into building materials has proven to be an effective solution for reducing thermal conductivity [3]. Many researchers have studied the effects of adding fibers to cement mortar as a thermal reinforcement material, including banana fiber [4], coir scraps [5], acai [6], coconut fiber [7], and rice straw fiber [8].

Textile Reinforced Mortar (TRM) is a fiber-reinforced cementitious compound and is considered a promising material owing to the exceptional characteristics of textile fibers. However, based on a literature review, the use of textile-reinforced mortar was

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restricted to certain applications. Fabric mesh and textile yarn have been employed to improve the tensile strength, ductility, and durability of cementitious composites in general [9–18]. However, there is a research gap in the application of textile fibers, such as spinning waste, as thermal reinforcement material in cement-based composites. Oliveira et al. [19] studied the use of fabric shavings in cement mortar and reported that the inclusion of fabric yarn resulted in a decrease in the mechanical performance of the cement mortar, with the exception of bond strength. In addition, a thermal test of the fabric yarn mortar at 60 °C showed a temperature difference of 12 °C between the inner surface and the reference surface due to the porosity. Other researchers [20] also examined the integration of textiles in construction applications and found that increasing the textile content improved the thermal stability of the cement mortar.

The aim of this study is to create a novel building material with low thermal conductivity by integrating two types of textile waste into a cement-based mortar. The study involved the creation of various textile fiber-reinforced composites by substituting sand in the cement mortar with different proportions of fiber waste. The resulting reinforced mortars were then subjected to mechanical and thermal characterization. If the incorporation of textile fiber waste into the cement slurry leads to standard-compliant properties, this could prove to be a promising solution for reducing the environmental impact of the textile and clothing industry.

2 Materials and Methods

2.1 Materials and Sample Preparation

Portland cement CEM I/52.5 according to standard EN-197-1 [21] was used to produce the cement mortars. Natural sand AF-R-0/2-S was used as a fine aggregate. Two types of textile fibers were included as reinforcement materials, which were disposed of as waste at the end of the textile spinning process. Type I textiles consisted of linen, cotton, and polyester fibers, while Type II consisted of only cotton fibers. The fibers were dispersed by blowing in compressed air before adding them to the mixture. Textile fiber-reinforced cementitious composites were prepared by replacing the sand in the mortar at 10%, 20%, 30%, and 40% volume fractions of one of the two types of textile. All mixtures were prepared according to the terminology of standard EN 1015-2 [22] as fully described in [23]. Some of the prepared samples (Fig. 1) were cured in water for 7 days while the others stayed for 28 days.

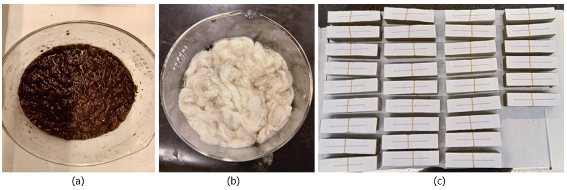

Fig. 1. (a) Type I-textile fibers; (b) Type II-textile fibers; (c) Textile-reinforced mortars after water curing.

2.2 Samples Characterization Methodology

The fresh and cured state of the cement-based composites were tested for bulk density according to the European standards EN 1015-6 [24] and EN 1015-10 [25], respectively. To evaluate the mechanical properties of the cured cementitious composites, flexural and compressive strength tests according to the EN 1015-11 [26] standard were carried out using a COINSA Controls Industrial double-head machine. The three-point bending test was performed on each specimen at a load rate of 50 ± 10 N/s, followed by a compressive strength test on one of the two resulting fragments at a load rate of 2400 ± 200 N/s. In addition, the TEMPOS thermal property analyzer was used to perform thermal conductivity characterization. A probe consisting of a needle with a built-in heating element and temperature sensor was used to measure thermal conductivity based on a transient line heat source method. In fact, an electrical current is passed through the heater and the temperature change of the sensor is measured over time [27]. The thermal conductivity of each mortar was determined by analyzing these temperature changes. The second residual fragment from the bending test was drilled out with a hammer drill and filled with thermal paste before the sensor needle was inserted. To ensure accurate measurements, good thermal contact between the sensor and the sample was ensured. Then, the thermal conductivity of each mortar was tested in the climate chamber at a temperature of around 20 °C.

3 Characterization Results

Various tests were carried out both in the fresh and in the cured state of the cement mortars reinforced with textile fibers in order to evaluate the influence of the incorporation of two different types of fibers on the thermo-mechanical properties of the composite material. To ensure consistency and accuracy, three samples of the same composition were tested for each test and the mean was calculated and presented in the subsequent section.

3.1 Density Testing

The graph presented in Fig. 2 shows the changes in bulk density of cement mortar reinforced with the two types of fibers. With a value of 1900 kg/m^3, the plain mortar shows the highest density both in the fresh and in the dry state. However, the addition of Type I and Type II fibers in different proportions resulted in a drop in bulk density. With type I textile mortar, the fresh bulk density decreased to 1585 kg/m^3, while with type II textile mortar it dropped to 1710 kg/m^3. In addition, the dry bulk density of composites with 40% textile fibers was reduced by approximately 300 kg/m^3 and 150 kg/m^3 for Type I and Type II textiles, respectively, compared to the ordinary mortar. Notably, Type II textile-reinforced composites exhibit higher bulk density values than Type I textile-reinforced composites in both the fresh and dry states. These results suggest that the incorporation of textile fibers can potentially produce materials suitable for thermal insulation applications.

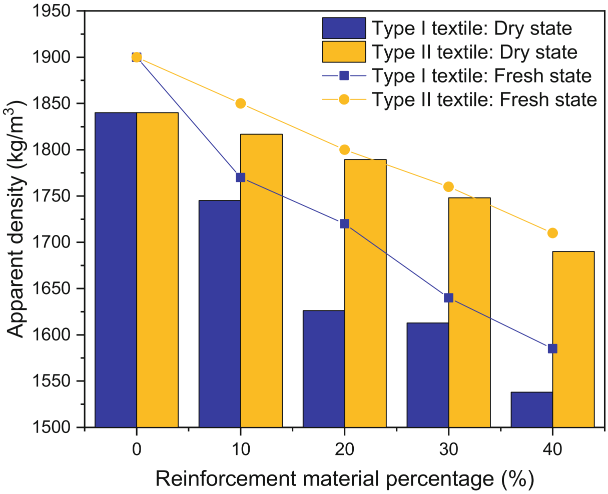

Fig. 2. Fresh and dry bulk densities of the textile fiber-reinforced mortars.

3.2 Mechanical Characterization

Figure 3 and Fig. 4 show the findings of the compressive and flexural strength tests performed on all mortar types after 7 and 28 days of water curing, respectively. It can be noticed that increasing the curing time resulted in an improvement in the mechanical performance of all cementitious mixes. For example, after 28 days, the plain mortar experienced a compressive strength increase of about 13% compared to 7 days of curing. Likewise, the flexural strength of the control sample increased by 34% between days 7 and 28, as shown in Fig. 4. Figure 3 illustrates the changes in the compressive strength of cement mortar after the integration of the two types of textiles. Notably, the Type II textile-reinforced samples exhibited higher compressive strength values compared to the Type I textile-reinforced samples, regardless of curing time. In contrast, the incorporation of Type I textile into the cementitious mortar led to a slight decrease in compressive strength. The addition of 40% of this textile resulted in a reduction in compressive strength of approximately 33% after 7 days of curing compared to plain mortar. However, when the same mix was cured for 28 days, it showed a decrease of about 9% compared to the 28-day control mortar. However, when Type II textile fibers were added to the cement mortar, there was a slight improvement in compressive strength values compared to ordinary mortar. In particular, the mix containing 40% Type II textile fibers showed a 16% increase in 7-day compressive strength and a 21% increase in 28-day compressive strength compared to the mixture with no fibers. In addition, the mechanical compression test results imply that both types of fibers exhibit superior mechanical performance compared to previously tested materials such as rice husk ash [28], expanded polystyrene [29], vegetable synthetic sponges [30], and crumb rubber [31].

Figure 4 shows the outcomes of the bending tests conducted on all the fiber reinforced-cement composites. Similar to the compressive strength results, the Type-II textile-reinforced mortars show higher mechanical performance than the Type-I textile-reinforced mortars after both 7 and 28 days of curing. However, increasing the amount

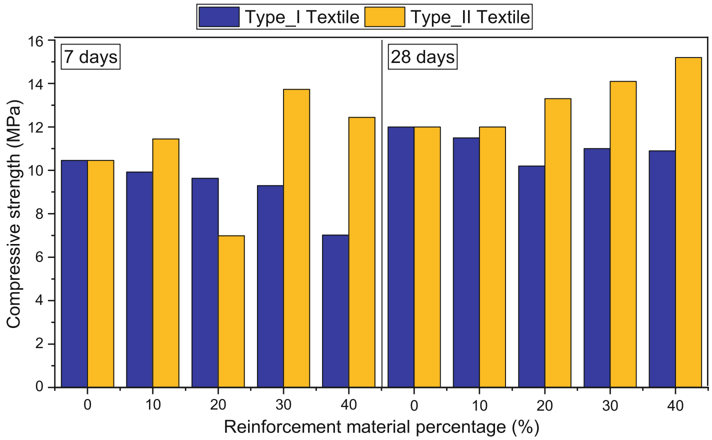

Fig. 3. Compressive strength of textile-reinforced mortars after 7 and 28 days of water curing.

of both fibers resulted in an increase in flexural strength regardless of the curing time. The samples with 40% Type-I textile and 40% Type-II textile showed approximately 34% and 55% increase in 7-day flexural strength, respectively, compared to the ordinary sample. In addition, the 28-day flexural strengths of the 40% Type-I textile sample and Type-II textile sample were increased by 22% and 36%, respectively, compared to the plain sample.

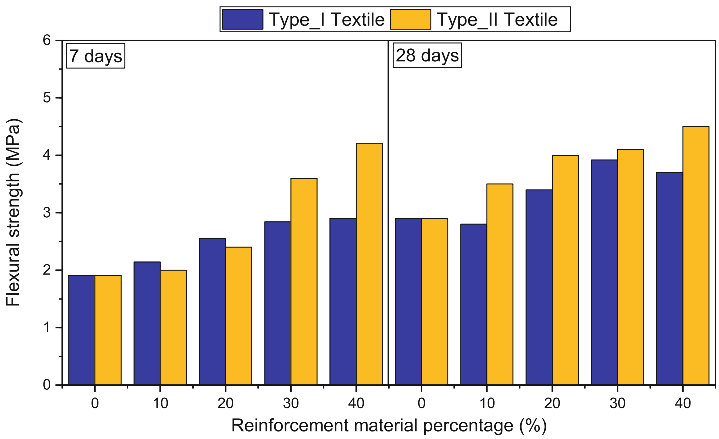

Fig. 4. Flexural strength of textile-reinforced mortars after 7 and 28 days of water curing.

3.3 Thermal Characterization

Figure 5 shows the change in thermal conductivity of all the textile-reinforced composites after being cured for 7 and 28 days. Regardless of the type of textile fibers used, an increase in the proportion of reinforcing material led to a decrease in thermal conductivity. Of all the mortars in the same category, those reinforced with 40% of each textile type had the lowest thermal conductivity. Comparing the plain mortar to the composite reinforced with 40% Type I textile, it can be noticed that the 7-day thermal conductivity decreases as more fibers are added, resulting in a difference of about 46%. In addition, the 10% Type II textile-reinforced mortar shows a greater reduction in 7-day thermal conductivity compared to the 10% Type I textile sample, which falls to a value of 1.08 W/m K. However, increasing the integration of Type II fibers from 10% to 40% only slightly reduced the thermal conductivity, with a difference of 16%. As for the 28-day thermal conductivity, both textile types showed similar results with values of 0.75 W/m K and 0.8 W/m K for the 40% Type I fiber mortar and the 40% Type II fiber mortar, respectively. This improvement in thermal conductivity due to the incorporation of textile fibers is consistent with previous studies showing that increasing the amount of fiber material improves thermal resistance [32]. Furthermore, the thermal performance of cement mortar was significantly enhanced by both Type-I and Type-II textile fibers, exceeding the performance of previously tested materials such as polymer-coated perlite [33]. These findings indicate the superior thermo-mechanical abilities of these fibers in reinforcing mortars, and imply that both types are well-suited for use in thermal insulation applications.

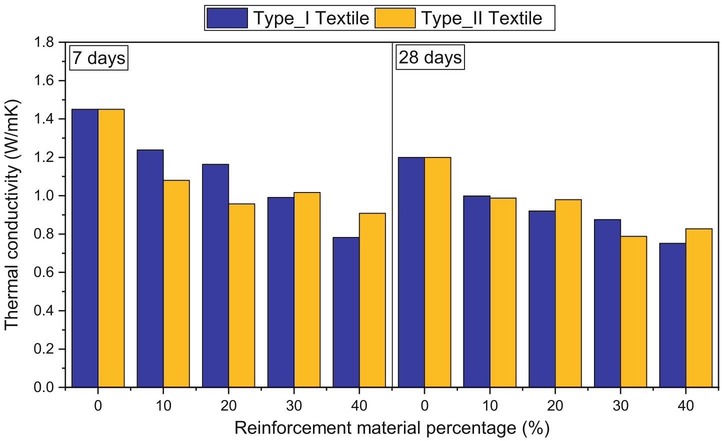

Fig. 5. Thermal conductivity of the textile-reinforced mortars.

4 Conclusions

Through experimental evaluation, this study investigated the effect of incorporating two distinct textile fibers into a cement-based mortar on its thermo-mechanical properties. The study found that:

– Both fiber types caused a decrease in bulk density, with Type II textile-reinforced composites exhibiting higher values than Type I composites in both fresh and dry states.

– Longer curing periods increased compressive and flexural strengths.
– Type II textile-reinforced mortars showed higher compressive strength than Type I samples after 7 and 28 days. Moreover, Type I fibers slightly decreased compressive strength and Type II fibers slightly increased it, compred with plain mortar.
– Increasing the percentage of both fiber types resulted in an increase in flexural strength. However, Type II textile-reinforced mortars showed greater flexural strength than Type I mortars after 7 and 28 days.
– Increasing the proportion of both types of fiber led to a decrease in the thermal conductivity of cement mortar.

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