An Experimental Study on the Thermo-mechanical Properties of Cement Mortar with Textile Fibers for Building Applications

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Abstract. Developing materials with enhanced thermal properties is fundamental to reduce the energy demand in buildings and consequently energy consumption. In this study, an experimental assessment of the use of textile fiber waste in cement-based composites for building applications was addressed. In particular, both mechanical and thermal characterizations were performed to evaluate the behavior of cement mortars incorporating two types of textile fibers in different percentages after 7 and 28 days of water curing, respectively. Results show that the addition of fibers has great potential to improve the thermal insulation capacity of buildings by reducing the thermal conductivity of cement mortar by up to 52%. Moreover, the textile fibers improved the mechanical strength of the cementitious mortar, especially with a high percentage of textile and a prolonged period of curing.

Keywords: Textile fiber · Reinforced cementitious mortar · Thermal insulation · Experimental study · Building applications

1 Introduction

Nowadays, the energy demand in buildings is continuously increasing. According to the International Energy Agency (IEA), buildings account for more than 30% of global energy consumption and 27% of total energy sector emissions [1]. Conditioning spaces to maintain thermal comfort accounts for a significant portion of building-related energy use and emissions [2]. The energy needed for conditioning depends on the intensity of the heat exchange with the outdoor environment, in particular on the thermal conductivity of construction materials. To reduce heat losses, fibers were proven to be an excellent solution to decrease the thermal conductivity of building materials [3]. Several researchers studied the effects of adding fibers to cement mortar as thermal reinforcement materials instead of traditional materials such as banana fibers [4], waste coir fibers [5], Acaï [6], coconut fiber [7], or rice straw fibers [8].

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Textile Reinforced Mortar (TRM) as a fiber-reinforced cementitious compound is expected to represent a promising material based on the exceptional properties of textile fibers. Based on a literature search, the textile-reinforced mortar was evaluated for limited applications. In general, fabric meshes and textile yarn were used to improve the tensile strength, ductility, and durability of cementitious composites [9–18]. Nevertheless, there is a research gap on using textile fibers such as spinning waste as a thermal reinforcement material in cementitious composites. For instance, fabric shavings [19] were studied by Oliveira et al. for use in cementitious mortar. They reported that the fabric yarn reduced the mechanical performance of cement mortar except for the tensile adhesion strength. Moreover, subjecting the fabric yarn mortar to a thermal test at 60 °C reveals a difference of 12 °C between the inner surface and the reference face due to porosity. Other researchers [20] evaluated the possibility of incorporating textiles into building applications. The results showed that increasing the textile content increased the thermal stability of the cement mortar.

To this end, this study aims to develop a new building material with low thermal conductivity by incorporating two types of textile waste into cement-based mortars. Several textile-fiber-reinforced composites were made by replacing volume fractions of the cement mortar sand with different percentages of fiber waste. The reinforced mortars produced were characterized mechanically and thermally. If the incorporation of textile fiber waste into the cement slurry will result in properties within the limits set by the standards, it will be a promising solution to reduce the environmental impact of the textile and clothing industry.

2 Materials and Methods

2.1 Materials and Sample Preparation

To prepare the cementitious mortars, Portland cement CEM I/52.5, in accordance with the EN-197-1 standard [21], was used. Natural sand AF-R-0/2-S was used as a fine aggregate. Regarding the reinforcement materials, two types of textile fibers were added, which were discarded as waste at the end of the textile spinning process. Type I textile is made up of linen, cotton, and polyester fibers, while Type II is composed of cotton fibers only. These fibers were dispersed by injecting compressed air before adding them to the mixture. Cementitious composites reinforced with textile fibers were produced by replacing the sand of mortar with volume fractions of 10%, 20%, 30%, and 40% of one of two types of textile. Figure 1 shows the mix design used in this study. All the mixtures were produced using a mechanical mixer and following the terminology of the EN 1015-2 standard [22]. After the mixing process, the blend was poured into molds measuring 40 × 40 × 160 mm. Then, the filled molds were left to dry for 24 h at 20 °C. After demolding, some of the hardened samples (Fig. 2) were left in water for 7 days and the others for 28 days.

2.2 Samples Characterization Methodology

The bulk density was tested both in the fresh and in the hardened states in accordance with the European standards EN 1015-6 [23] and EN 1015-10 [24], respectively.

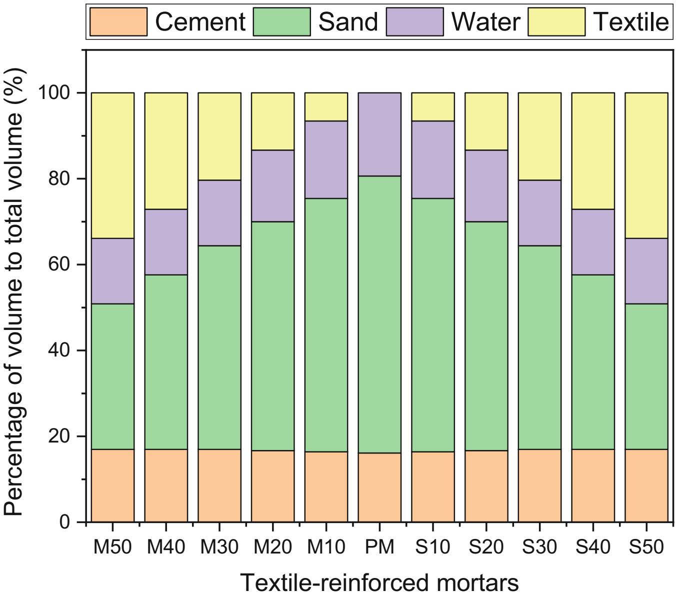

Fig. 1. Mix design of textile-reinforced mortars.

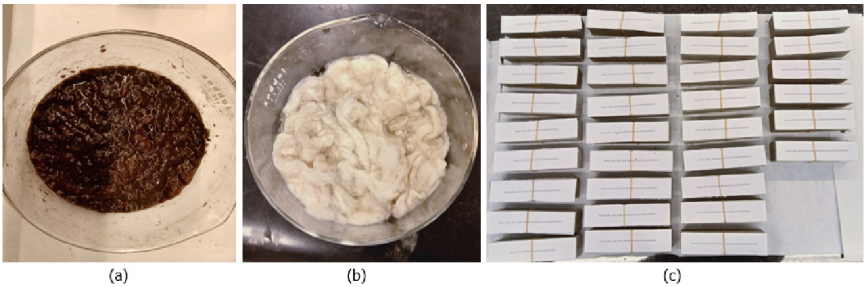

Fig. 2. (a) Type I-textile fibers (b) Type II-textile fibers (c) Textile-reinforced mortars after water curing.

In order to mechanically characterize the hardened cementitious composites, flexural and compressive strength tests were carried out according to standard EN 1015-11 [25]. A COINSA Controls Industrial double-head machine was used for both mechanical tests. Each sample was first subjected to a three-point flexion test at a load rate of 50 ± 10 N/s. Then, one of the two fragments resulting from the flexion test was subjected to the compressive strength test at a loading rate of 2400 ± 200 N/s. Both tests were carried out until the specimen broke and the breaking load was recorded. Then, the two equations below were used to determine the maximum flexural (Eq. (1)) and compressive (Eq. (2)) load of each type of fiber-reinforced mortar:

$$R_f = \frac{3}{2}\frac{F_f}{bh^2} \times 100 \tag{1}$$

$$R_c = \frac{F_c}{S} \tag{2}$$

where R_f is the flexural strength (MPa), F_f is the maximum flexural load (N), b and h are, respectively, the width and the depth of the sample, respectively, R_c is the compressive strength (MPa), F_c is the maximum compressive load (N) and S is the cross-sectional area where the load is applied.

Moreover, the thermal conductivity characterization was performed using the TEMPOS thermal properties analyzer. This analyzer is based on a transient line heat source method, where thermal conductivity is measured using a probe consisting of a needle with a built-in heater and temperature sensor. The heater is activated by passing an electrical current through it, and the system measures the temperature of the sensor over time. The time-dependent temperature changes of the sensor when the probe is immersed in the material to be tested are evaluated to determine the thermal conductivity of the material [26]. The second residual fragment from the flexural test was drilled with a rotary hammer. First, the hole of each sample was cleaned with compressed air and filled with thermal paste. Then, the sensor needle was inserted into the hole. For accurate measurements, good thermal contact between the sensor and the sample was ensured. Finally, the thermal conductivity of each mortar was tested in the climatic chamber at a temperature of around 20 °C.

3 Evaluation of Characterization Results

Several tests were conducted on the fresh and the cured states of the TRM composites to evaluate the effect of adding the two different types of textile fibers on the thermos-mechanical performance of cement mortar. Each test was performed in three samples of the same composition to ensure repeatability and the mean value was calculated and reported in the sections below.

3.1 Bulk Density Testing

The variation in bulk density of the textile-reinforced composites versus the proportion of reinforcing materials is illustrated in Fig. 3. As shown in the graph, plain mortar has a higher apparent density both in the fresh and in the dry state and reaches a value of 1900 kg/m^3. The incorporation of both fiber types in cementitious mortar caused a drop in the bulk density. In fact, the fresh bulk density dropped until it attained values of 1585 kg/m^3 and 1710 kg/m^3 for Type I-textile mortar and Type II-textile mortar, respectively. Compared to the baseline mortar, the addition of 40% textile reduced the dry bulk density, achieving a difference of about 300 kg/m^3 and 150 kg/m^3 for Type I-textile mortar and Type II-textile mortar, respectively. In summary, Type II textile-reinforced composites exhibit higher bulk density values than Type I textile-reinforced composites in both fresh and dry states. This drop in density suggests that these textilized materials would be suitable for thermal insulation applications.

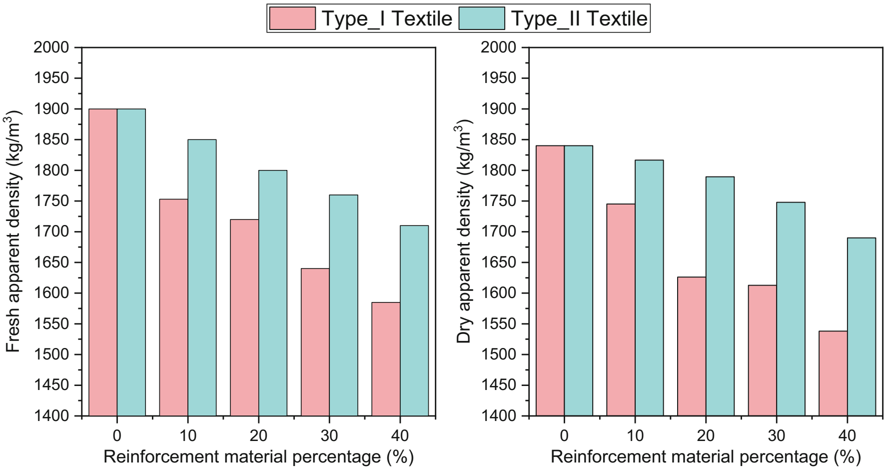

Fig. 3. Fresh and Dry bulk densities of the textile-fiber-reinforced mortars.

3.2 Mechanical Characterization

The compressive and flexural strength results of all mortar types after 7 and 28 days of water curing are shown in Fig. 4 and Fig. 5. As shown in the graphs, the mechanical performance of all the cementitious mixtures was improved by increasing the curing period. Compared to the 7-day compressive strength, the plain mortar gains around 13% in strength after 28 days of curing. Regarding the bending test, the flexural strength of the control sample increased by 34% between the 7^{th} and the 28^{th} day. Figure 4 shows the variation in the compressive strength of cement mortar after the incorporation of two different types of textiles. It is worth mentioning that the Type II-textile-reinforced samples showed higher compressive strength values than the Type I-textile-reinforced samples after both 7 and 28 days. Regardless of the curing period, the addition of the Type I textile to the cementitious mortar slightly reduced the compressive strength. After 7 days of curing, the integration of 40% of the textile decreased the compressive strength until achieving a difference of about 33% compared to plain mortar. However, curing the same mixture for 28 days only shows a drop of around 9% compared to the 28-day control mortar. However, the incorporation of cement mortar with Type II textile fibers led to a slight increase in compressive strength values compared to ordinary mortar. For the mixture with 40% Type II-textile fibers, the 7-day compressive strength was increased by 16%, while a 21% increase in 28-day compressive strength was observed compared to the textile-free mixture. The mechanical compression test results show that the two types of fibers exhibit superior mechanical performance compared to previously tested materials, such as rice husk ash [27], expanded polystyrene [28], vegetable synthetic sponges [29], and crumb rubber [30].

Figure 5 presents the flexural test results of all fiber-reinforced-cement composites. Similar to the compressive strength results, the Type-II textile-reinforced mortars show higher mechanical performance compared to the Type-I textile-reinforced mortars after both 7 and 28 days of curing. However, increasing the proportion of both fiber types

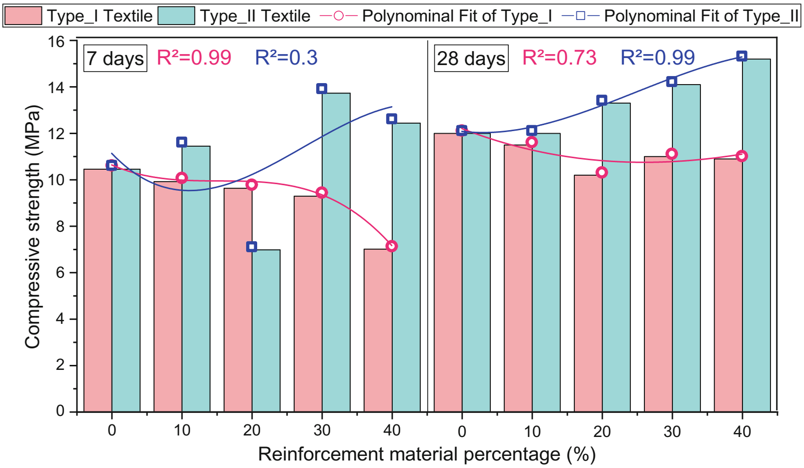

Fig. 4. Compressive strength of textile-reinforced mortars after 7 and 28 days of water curing.

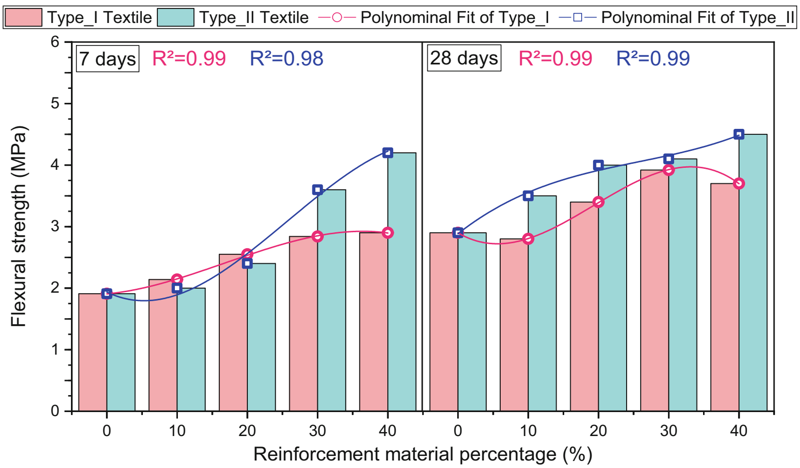

Fig. 5. Flexural strength of textile-reinforced mortars after 7 and 28 days of water curing.

increased the flexural strength regardless of cure time. The increase in the 7-day flexural strength is approximately 34% and 55% for the 40% Type-I textile mortar and 40% Type-II textile mortar, respectively, compared to the control sample. While 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.

3.3 Thermal Characterization

Figure 6 presents the thermal conductivity of all textile-reinforced composites after 7 and 28 days of curing. Regardless of the type of textile fibers added, increasing the proportion of reinforcing material resulted in a decrease in thermal conductivity. The 40% reinforced mixture of each category had the lowest thermal conductivity of all the mortars of the same category. In the comparison between the plain mortar and the composite reinforced with 40% Type I textile, a decrease in 7-day thermal conductivity with increasing addition of fibers is observed, reaching a difference of about 46%. Moreover, compared to the 10% Type I textile sample, the 10% Type-II textile reinforced mortar shows a higher drop in 7-day thermal conductivity reaching a value of 1.08 W/m K. However, increasing the inclusion of Type-II fibers from 10% to 40% slightly reduced the thermal conductivity with a difference of 16%. Regarding the 28-day thermal conductivity, both textile types show a similar result, reaching values of 0.75 W/m K and 0.8 W/m K for 40% Type-I fiber mortar and 40% Type-II fiber mortar, respectively. This improvement in thermal conductivity due to the addition of textile fibers is consistent with previous studies that have identified improved insulation resistance with increased fibrous material [31]. Moreover, Both types of textile fibers improved the thermal performance of cement mortar more effectively compared to previously tested materials such as polymer-coated perlite [32].

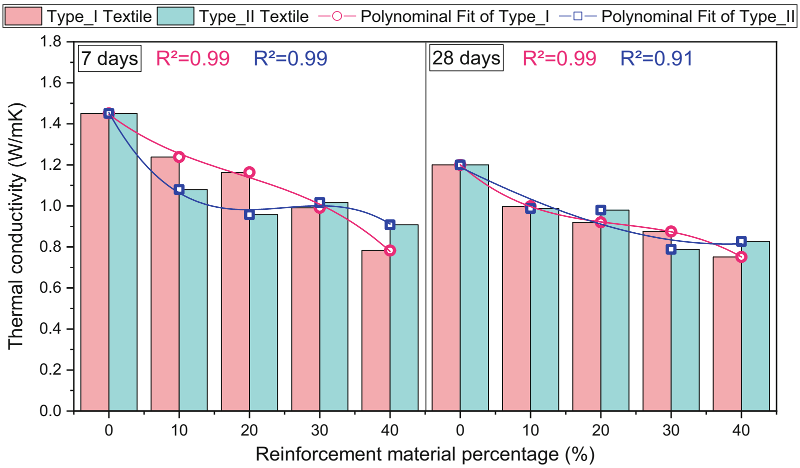

Fig. 6. Thermal conductivity of the textile-reinforced mortars.

These observations demonstrate the high thermo-mechanical performance of both Type-I textile and Type-II textile fibers reinforced mortars and help to conclude that both are suitable for thermal insulation applications.

4 Conclusions

In this study, the effect of adding two different types of textile fibers on the thermos-mechanical properties of cementitious mortar was evaluated experimentally. The following conclusions were drawn:

– The incorporation of both fiber types in cementitious mortar leads to a drop in bulk density and the Type II textile-reinforced composites exhibit higher bulk density values than the Type I textile-reinforced composites both in fresh and dry states.

– Increasing the curing period increases the compressive and flexural strength of textile fibers reinforced cement composites.
– The Type II-textile-reinforced samples showed higher compressive strength values than the Type I-textile-reinforced samples after both 7 and 28 days. The addition of the Type I textile slightly reduced the compressive strength of the plain cement mortar, while the Type II textile fibers led to a slight increase in its value.
– Increasing the addition of both fiber types resulted in an increase in flexural strength, but the Type-II textile-reinforced mortars show higher strength compared to the Type-I textile-reinforced mortars after both 7 and 28 days of curing.
– Increasing the proportion of both types of textile fibers led to a decrease in the thermal conductivity of cement mortar.

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References

1. International Energy Agency. Net Zero by 2050: A Roadmap for the Global Energy Sector. Int Energy Agency **224** (2021)
2. González-Torres, M., Pérez-Lombard, L., Coronel, J.F., Maestre, I.R., Yan, D.: A review on buildings energy information: Trends, end-uses, fuels and drivers. Energy Rep. **8**, 626–637 (2022). https://doi.org/10.1016/J.EGYR.2021.11.280
3. Cintura, E., Nunes, L., Esteves, B., Faria, P.: Agro-industrial wastes as building insulation materials: A review and challenges for Euro-Mediterranean countries. Ind. Crops. Prod. **171**, 113833 (2021). https://doi.org/10.1016/J.INDCROP.2021.113833
4. Akinyemi, B.A., Dai, C.: Development of banana fibers and wood bottom ash modified cement mortars. Constr. Build. Mater. **241**, 118041 (2020). https://doi.org/10.1016/J.CONBUILDMAT.2020.118041
5. Kochova, K., Gauvin, F., Schollbach, K., Brouwers, H.J.H.: Using alternative waste coir fibres as a reinforcement in cement-fibre composites. Constr. Build. Mater. **231**, 117121 (2020). https://doi.org/10.1016/J.CONBUILDMAT.2019.117121
6. de Azevedo, A.R.G., Marvila, M.T., Tayeh, B.A., Cecchin, D., Pereira, A.C., Monteiro, S.N.: Technological performance of açaí natural fibre reinforced cement-based mortars. J. Build. Eng. **33**, 101675 (2021). https://doi.org/10.1016/j.jobe.2020.101675
7. Quiñones-Bolaños, E., Gómez-Oviedo, M., Mouthon-Bello, J., Sierra-Vitola, L., Berardi, U., Bustillo-Lecompte, C.: Potential use of coconut fibre modified mortars to enhance thermal comfort in low-income housing. J. Environ. Manage. **277**, 111503 (2021). https://doi.org/10.1016/J.JENVMAN.2020.111503
8. Awoyera, P.O., Akinrinade, A.D., de Sousa Galdino, A.G., Althoey, F., Kirgiz, M.S., Tayeh, B.A.: Thermal insulation and mechanical characteristics of cement mortar reinforced with mineral wool and rice straw fibers. J. Build. Eng. **53**, 104568 (2022). https://doi.org/10.1016/J.JOBE.2022.104568

9. Koutas, L.N., Papakonstantinou, C.G.: Flexural strengthening of RC beams with textile-reinforced mortar composites focusing on the influence of the mortar type. Eng. Struct. **246**, 113060 (2021). https://doi.org/10.1016/J.ENGSTRUCT.2021.113060
10. Zhang, H.Y., Liu, H.Y., Kodur, V., Li, M.Y., Zhou, Y.: Flexural behavior of concrete slabs strengthened with textile reinforced geopolymer mortar. Compos. Struct. **284**, 115220 (2022). https://doi.org/10.1016/J.COMPSTRUCT.2022.115220
11. Adheem, A.H., Kadhim, M.M.A., Jawdhari, A., Fam, A.: Confinement model for concrete wrapped with fiber reinforced cementitious mortar. Constr. Build. Mater. **312**, 125401 (2021). https://doi.org/10.1016/J.CONBUILDMAT.2021.125401
12. Dinh, N.H., Van, T.H., Choi, K.K.: Direct shear behavior of cementitious mortar reinforced by carbon fiber textile. Constr. Build. Mater. **249**, 118760 (2020). https://doi.org/10.1016/J.CONBUILDMAT.2020.118760
13. Brazão Farinha, C., de Brito, J., Veiga, R.: Incorporation of high contents of textile, acrylic and glass waste fibres in cement-based mortars. Influence on mortars' fresh, mechanical and deformability behaviour. Constr. Build. Mater. **303**: (2021). https://doi.org/10.1016/j.conbuildmat.2021.124424
14. Shamseldein, A., Elgabbas, F., Elshafie, H.: Tensile behavior of basalt textile-reinforced mortar (BTRM). Ain Shams. Eng. J. **13**:101488 (2022). https://doi.org/10.1016/J.ASEJ.2021.05.003
15. Mercimek, Ö., Ghoroubi, R., Özdemir, A., Anil, Ö., Erbaş, Y.: Investigation of strengthened low slenderness RC column by using textile reinforced mortar strip under axial load. Eng. Struct. **259**, 114191 (2022). https://doi.org/10.1016/J.ENGSTRUCT.2022.114191
16. Guo, L., Deng, M., Chen, H., Li, R., Ma, X., Zhang, Y.: Experimental study on pre-damaged RC beams shear-strengthened with textile-reinforced mortar (TRM). Eng. Struct. **256**, 113956 (2022). https://doi.org/10.1016/J.ENGSTRUCT.2022.113956
17. Dong, Z., Deng, M., Dai, J., Ma, P.: Diagonal compressive behavior of unreinforced masonry walls strengthened with textile reinforced mortar added with short PVA fibers. Eng. Struct. **246**, 113034 (2021). https://doi.org/10.1016/J.ENGSTRUCT.2021.113034
18. Pinto, J., Peixoto, A., Vieira, J., Fernandes, L., Morais, J., Cunha, V.M.C.F., et al.: Render reinforced with textile threads. Constr. Build. Mater. **40**, 26–32 (2013). https://doi.org/10.1016/J.CONBUILDMAT.2012.09.099
19. de Oliveira, E.M., Machado de Oliveira, E., de Oliveira, C.M., Dal-Bó, A.G., Peterson, M.: Study of the incorporation of fabric shavings from the clothing industry in coating mortars. J. Clean. Prod. **279**: 123730 (2021). https://doi.org/10.1016/j.jclepro.2020.123730
20. Briga-Sá, A., Gaibor, N., Magalhães, L., Pinto, T., Leitão, D.: Thermal performance characterization of cement-based lightweight blocks incorporating textile waste. Constr. Build. Mater. **321** (2022). https://doi.org/10.1016/j.conbuildmat.2022.126330
21. EN 197-1. Cement - Part 1: Composition, specifications and conformity criteria for common cements (1992)
22. EN 1015-2. Methods of testing mortars for masonry - Part 2: bulk sampling of mortars and preparation of mortars for testing (1999)
23. EN 1015-6. Methods of test for mortar for masonry - Part 6. Determination of bulk density of fresh mortar (n.d.)
24. EN 1015-10. Methods of test for mortar for masonry - Part 10: Determination of dry bulk density of hardened mortar (n.d.)
25. EN 1015-11. Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strength of hardened mortar (2020)
26. METER_Group. TEMPOS Thermal Properties Analyzer (n.d.)
27. Selvaranjan, K., Gamage, J.C.P.H., De Silva, G.I.P., Navaratnam, S.: Development of sustainable mortar using waste rice husk ash from rice mill plant: Physical and thermal properties. J. Build. Eng. **43**, 102614 (2021). https://doi.org/10.1016/J.JOBE.2021.102614

28. Ayed, R., Baddadi, S., Dellagi, A., Bouadila, S., Lazaar, M.: Thermal behavior improvement of building materials using expanded polystyrene. In: 2022 13th International Renewable Energy Congress (IREC 2022), pp. 13–16. IEEE (2022). https://doi.org/10.1109/IREC56325.2022.10002016
29. Salem, T., Fois, M., Omikrine-Metalssi, O., Manuel, R., Fen-Chong, T.: Thermal and mechanical performances of cement-based mortars reinforced with vegetable synthetic sponge wastes and silica fume. Constr. Build. Mater. **264**, 120213 (2020). https://doi.org/10.1016/J.CONBUILDMAT.2020.120213
30. de Souza, K.C., Dutra Schneider, S., Aguilera, O., Albert, C.C., Mancio, M.: Rendering mortars with crumb rubber: Mechanical strength, thermal and fire properties and durability behaviour. Constr. Build. Mater. **253**, 119002 (2020). https://doi.org/10.1016/j.conbuildmat.2020.119002
31. Briga-Sá, A., Nascimento, D., Teixeira, N., Pinto, J., Caldeira, F., Varum, H., et al.: Textile waste as an alternative thermal insulation building material solution. Constr. Build. Mater. **38**, 155–160 (2013). https://doi.org/10.1016/J.CONBUILDMAT.2012.08.037
32. Akyuncu, V., Sanliturk, F.: Investigation of physical and mechanical properties of mortars produced by polymer coated perlite aggregate. J. Build. Eng. **38**, 102182 (2021). https://doi.org/10.1016/J.JOBE.2021.102182