Civil Engineering
Engenharia Civil

Impact of the loading of date palm fibers on the performances of mortars

http://dx.doi.org/10.1590/0370-44672022760052

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Abstract

The development of eco-friendly composites as insulating materials in buildings offers practical solutions to reduce energy consumption, which is why scientists have started in recent decades to search for more sustainable and eco-friendly materials. It is well known that building materials are among the most commonly used materials and have an obvious negative impact on the environment. Therefore, this article presents a study on the use of a new bio-composite material, composed of natural fibers of date palm, cement, and sand. The objective of this study is to assess the thermal insulation properties, as well as the water absorption and mechanical performance of this material for the construction of buildings. The percentage by weight of date palm fiber in the test samples varied from 0% to 30% for a mixture of two fiber sizes equal to 3 mm and 7 mm. The characteristics of these samples were determined experimentally in terms of compressive strength, as well as thermal conductivity. The results show that the introduction of date palm fibers in mortars causes a decrease in compressive strength and thermal conductivity. This study affirmed that the use of vegetable fibers in cementitious composites has a positive effect on the properties of insulations and on the costs.

Keywords: date palm fiber (DPF) ; bio-composite materials ; eco-friendly materials ; Mechanical performance ; thermal conductivity.

1. Introduction

A huge demand for energy in a building is one of the several factors that have an impact on the environment and our life. One of the promising alternatives to this problem is thermal insulation of the building with the use of biomaterials from vegetal and agriculture waste. These biomaterials need low energy consumption for their production, reduce CO_2 emission, and are renewable materials. In general, previous researches have shown that the presence of natural fibers in concrete can improve crack resistance, toughness, and post-crack performance. On the other hand, the use of natural fibers in concrete leads to problems related to durability in an alkaline medium (Claramunt *et al*., 2011). Presently, great efforts have been directed towards the use of natural fibers, such as hemp, coir, sisal, jute, and date palm fibers, which are abundant and without risk to the health, as insulation in building materials. They provide cost-effective and high performance insulation, promoting sustainable development (Ramakrishna, 2005; Li, 2000). Natural fibers like date palm fibers (DPF) are a good candidate for the development of effective insulating green materials compared to other materials (Agoudjil *et al*., 2011).

Mixtures reinforced with date palm fibers are now considered to have good thermal and mechanical properties, besides being lightweight. Thus, they can well be used in building components as new composite materials to improve the energy efficiency of buildings (Benmansour *et al*., 2014; Chikhi *et al*., 2013; Haddadi, 2015). World production of the date palm is constantly increasing, which indicates the importance of date palm wood. After the date fruit harvesting, important quantities of date palm rachis, and leaflet wastes are accumulated every year. Algeria has more than 710,000 metric tons (Chandrasekaran; Bahkali, 2013). The use of DPF in building technologies can improve thermal insulation performance, especially in desert regions, which can help reduce energy consumption (Abani, *et al*., 2015). Similar to other plant fibers, such as alfa and hemp, the presence of DPF in concrete leads to a reduction in concrete shrinkage (Taheri; Salwa, 2013). Djoudi *et al*., (2012) concluded that a certain vibration is essential in order to obtain suitable workability and compaction of the date palm fiber concrete. The fiber content results in a reduction in compressive and flexural strengths. Concrete density and thermal conductivity decrease with increasing fiber content and length (Benaniba *et al*., 2020; Sethuraman *et al*., 2020). In this context, some published articles have focused on new eco-friendly materials reinforced by natural fibers, such as palm fibers, (Ali; Alabdulkarem, 2017) corncob, (Laborel *et al*., 2018, Chabriac *et al*., 2016) rice straw, (Bassyouni *et al*., 2015, Ismail *et al*., 2022), and sisal fibers (Li *et al*., 2000, Ohenoja *et al*., 2016; Sağlam *et al*., 2022). The potential of this raw material is based on its sustainability, low cost, availability, low density, great quantity, and low environmental impacts. (Senthamaraikannan *et al*. 2019 ; Berardi *et al*., 2016 ; Al-Oqla *et al*., 2014). Many researchers dealt with the use of palm tree by-products in construction materials due to their high thermal insulation properties. In addition, (Sun *et al*., 2022; Chikhi *et al*. 2013) studied the effect of the petiole and rachis of palm trees on thermal conductivity and compressive and flexural strengths of gypsum-based composite materials. The effect of the same fibers on thermal conductivity and compressive strength of mortar-based composite materials has been investigated by (Benmansour *et al*., 2014). In addition, Kriker *et al*., (2005) and Benaniba *et al*., (2020) have evaluated mechanical properties of reinforced concrete with Algerian DPF. Djoudi *et al*., (2014) have studied the effect of the addition of Algerian DPF on thermal and mechanical properties of plaster concrete.

In this study, an effort has been made to investigate the effect of the inclusion of DPF on the mechanical and thermal properties of bio-composite concrete. For this, two fiber lengths (3 and 7 mm) were chosen with contents of 3% to 15%. The results presented herein can open a production component of cement composites containing date palm fibers with good mechanical properties, low cost and reduced environmental impact.

2. Materials

Nomenclature

A : Water absorption (%)	t : Time(s)
φ : Fiber concentration (%)	L : distance between supports (mm)
R_c : Compressive strength (MPa)	F_c : Maximum load(N)
T : Temperature (°C)	b : Width of specimen(mm^2)
m (t) : weight of the sample after saturation at time t weighed in air (kg)	λ : Thermal conductivity ($W.m^{-1}.K^{-1}$)
m_s : Dry weight (anhydrous) (kg)	

The composites used consisted of cement, sand and date palm fibers (DPF). Portland cement from Algeria was used, as well as sand from Bousaada-Algeria. This sand is coarser, with a maximum diameter reaching 5 mm with a widely distributed particle size distribution. Date palm fibers are used as inclusions. It was obtained from the oasis of Biskra-Algeria. Due to environmental influences, the palm fibers were contaminated with large amounts of sand and dust. The samples were washed with fresh water and manually disassembled into bundles of fibers. Before use, the DPF meshes were washed with high pressure water to remove polluting particles. Afterwards, these fibers were first dried in the sun for two days and then in an oven at T=70°C until dry. Then, the fibers of diameter less than 0.8 mm were cut to the desired length. In this study, two fiber sample sizes equal to 7 mm (DPF7) and 3 mm (DPF3) are considered as shown in Figure 1. DPF_{Mix} (Mixture of DPF3 and DPF7) is then designed as a mixture of DPF3 and DPF7.

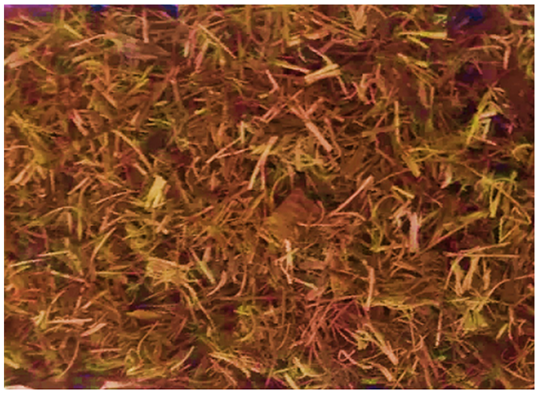

Figure 1 - Date palm fiber with different sizes (DPF_{mix}).

The SEM micrograph of a crude fiber shows the surface containing a large number of unfinished cultivated fibers that should be residual lignin and artificial impurities (sand and dust). A cross section of a single DPF reveals a large number of single hollow fibers collected and linked by a primary layer, as presented in Figure 2.

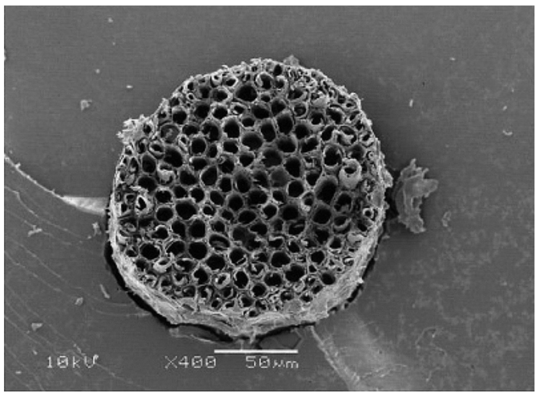

Figure 2 - SEM micrographs of raw DPF (Cross-sectional view of the fiber).

3. Composite preparation

The composites are obtained by mixing prompt Portland cement (CPJ-CEM II / A 32.5), sand and water for several concentrations by weight of DPF_{Mix} equal to 6%, 12%, 18%, 24% and 30%. Composites are made by mixing fibers, cement and sand in a blender with a velocity equal 40 rpm. Dry mixing is necessary to homogenize the mixture. The three constituents Cement, DPF and sand were then mixed. Water was added gradually and the mixing continued for 5 min. To reduce water loss by evaporation in the ambient air, the mixture was quickly poured into rectangular molds with a shape of 40 × 40 × 160 mm^3. The mold was filled with material and left in the open air for almost 24 hours. Then, the samples were immersed in water at 21±2 °C for 28 days according to standard EN 196-1 (Dhakal *et al.*, 2006). The samples were dried in the open air for 48 h in the molds and 28 days after demolding. The proportions of the materials used in the mixtures are presented in Table 1. Thus, MDP_{Mix} (Mixture of sand, cement, DPF3 and DPF7) is designed as a mixture of sand, cement, DPF3 and DPF7.

Table 1 - Proportions of the materials used in mixtures.

DPF7 (%)	3	6	9	12	15
DPF 3 (%)	3	6	9	12	15
Cement (%)	68	64	59	55	51
Sand (%)	26	24	23	21	19

4. Measurements methods

4.1 Water absorption of DPF

This test consists of drying the samples in an oven for 24 hours at a temperature of 70 ± 2°C to ensure a complete loss of moisture, and then immediately weighed to the nearest 1mg. This weight is designated as ms by using a Sartorius balance with a PT150 model. Then, the samples were immersed in water at room temperature for different periods equal to 5 minutes. After that, they were removed and the water droplets on their surfaces were cleaned with a dry system. Before returning the samples to the water for saturation, we have measured the new weight designed by m(t). Thus, the percentage of water absorption in the samples was calculated by the difference in mass between the samples immersed in water and dry samples using the following equation (Boumhaout *et al.*, 2015):

$$A(\%) = \frac{m(t) - m_s}{m_s} \qquad (1)$$

4.2 Thermal conductivity of composites

The thermal conductivity of the test pieces was measured under laboratory conditions of 50% RH and 20°C by using the hot-wire method after drying of samples for 28 days. This transient method is the classic method of measuring the thermal conductivity of insulating materials. The method involves placing a thermal shock probe sandwiched between the two samples to be characterized (Dupain *et al.*, 2009). The probe locally produces a weak heating of the material to a few degrees above ambient temperature. Evaluation of thermal conductivity and volume heat capacity is based on periodically recording of the sample temperature as a function of time. By mathematical processing of this signal integrated in the software provided, the thermal conductivity is identified.

4.3 Mechanical testing

The compressive strength device is illustrated in Figure 3. At 28 days, the compressive strength was tested on a half-prism obtained after rupture of the samples according to standard EN 196-1 (Taoukil *et al.*, 2011). The mechanical properties obtained from the tests are carried out on five test samples. The compressive strength of mortars is determined from the maximum load using the following equation:

$$R_c = \frac{F_c}{b^2} \qquad (2)$$

Figure 3 - Compressive strength test device of the MDP_{Mix}.

5. Results and discussion

5.1 Water absorption tests of MDP_{Mix}

Figure 4 presents the water absorption of composites samples. It shows that the addition of fibers in the mortar produces an important increase in the water absorption. At first, it was noted that the water absorption coefficient of vegetable fibers was very high. They are able to absorb a mass of water greater than their own mass. We can explain this by the fact that the DPF is a hygroscopic material. (Chikhi *et al.*, 2013) studied the effect of water on gypsum composites filled with DFF and found that the water content in the composites strongly depends on the water absorption capacity of DFF. In addition, (Toukil *et al.*, 2012; Kessal *et al.*, 2022) investigated the effect of water on a sandy solution filled with wood wool and discussed similar behavior. They also found that the high hygroscopicity nature of wood wool is a disadvantage that results in high shrinkage and swelling of the composites. This can lead to damages that can affect the durability of building materials.

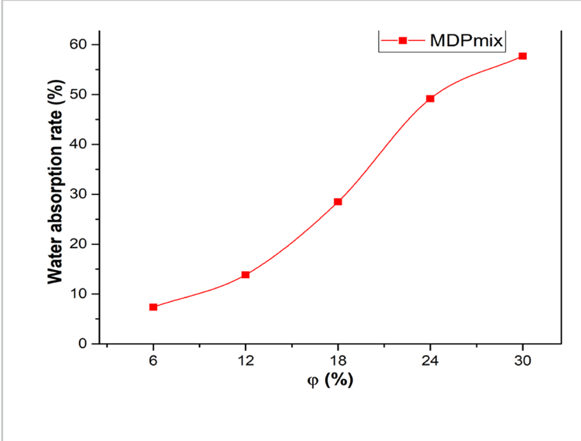

Figure 4 - Water absorption as function of fibers content.

5.2 Effect of the concentration of DPF on thermal conductivity

Figure 5 shows the evolution of the thermal conductivity as a function of fiber content. From these results, it has been noted that the addition of the DPF into the mortar matrix reduces the thermal conductivity of the composite. This decrease is expected because date palm fibers have a lower thermal conductivity than the mortar matrix. In addition, it is interesting to remark that the fibers embedded in the composite tend to generate porosity and air in the matrix and reduce the density. Therefore, the first benefit of using natural fibers is to lighten the composite. The thermal conductivity of porous materials is determined by the voids in the samples. These voids occur due to the packing of the fibers. In general, short fibers are harder to align and pack denser than larger fibers (Khedari *et al.*, 2001; Chiker *et al.*, 2021; Dridi *et al.*, 2022). Thus, for given fiber content, a mortar filled with short fibers leads to an increase in the number of voids, which leads to low thermal conductivity and lower density of the composites. For $\varphi > 24\%$, it is clear that the influence of the fiber content on the thermal conductivity of the composite is negligible. Thereby, according to the obtained results, the decrease of thermal conductivity is about 87% for the samples MDP_{Mix}, for the fibers content of 30%. This decrease is due to the significant difference between the thermal conductivity of the fiber and matrix materials used and the insulating nature of the fibers, which have a thermal conductivity of 0.083 $W\ m^{-1}\ K^{-1}$ (Ledhem *et al.*, 2000; Al Rim *et al.*, 1999).

Indeed, it has been observed that beyond approximately 24% of date palm fibers loading, the decrease of the thermal conductivity of composite was relatively low. For this reason, it has proven useful to limit the fiber content around this value. In fact, from the results achieved in this study, we can clearly assume that the addition of date palm fibers could significantly improve the thermal insulation of composites with a decrease in effective thermal conductivity.

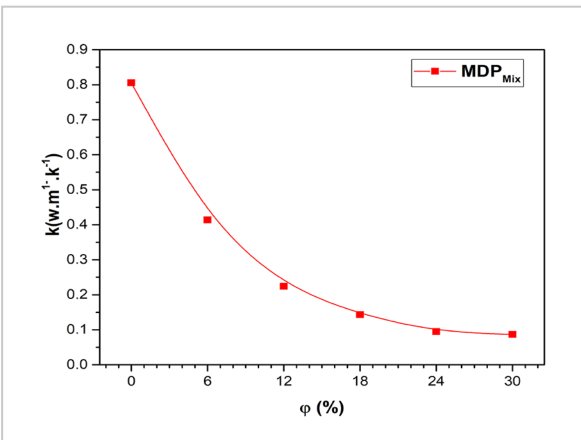

Figure 5 - Thermal conductivity as a function of concentration of DPF for composite MDP_{Mix}.

5.3 Effect of the density on thermal conductivity

Figure 6 shows the relationship between the thermal conductivity and the density of the composites. From these results, it can be seen that the thermal conductivity of composites increases when the density increases. Indeed, there has been observed a direct relationship between the density of the composites and thermal conductivity. An increase in air voids leads to a decrease in the density of composites, which leads to a decrease in resistance and a decrease in thermal conductivity. The relationship between conductivity and density is always tested on materials with a mineral matrix and plant fibers according to Alrim *et al.*, (1999); Khedari *et al.*, (2004), and Belkadi *et al.*, (2022) where they used a clay matrix and Portland cement, respectively. Thus, it is important to preserve the fact that the influence of the concentration of DPF has a stronger effect on the thermal conductivity and density of the composites. In addition, the presence of water reduces the insulating capacity of our composites.

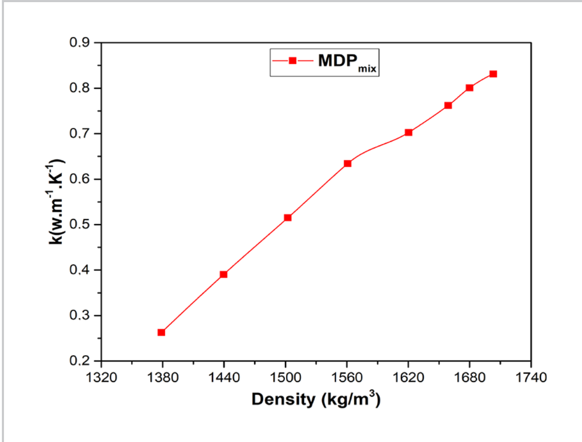

Figure 6 - Thermal conductivity of the composites as a function of the density.

5.4 Compressive strength tests

Figure 7 shows the variation of the compressive strength of the studied concrete samples as a function of the date palm fiber content after 28 days of hardening.

The values range between 6.83 MPa and 28.88 MPa, which represent the lowest and the highest MDP_{Mix} compressive strength having a fiber content of 30% and 6%, respectively. Indeed, it has been noted that the compressive strength decreases with the increase of date palm fiber content. In fact, for 6% and 30% of date palm loading, the compressive strength of composites decreases by about 18% and 80.51%, compared to the mortar without fibers 0%. This behavior is due to the increase of fiber content that leads to a low density of the samples. In fact, at high content, if the fiber is stiff, the packing of the fiber becomes difficult, and voids are introduced into the composite. A relationship between date palm fiber content and compressive strength appears clearly. The higher the date palm fiber content, the lower the compressive strength. This relationship is consistent with several studies performed on concrete reinforced with vegetal fibers. Thus, the use of vegetal fibers does not increase the compressive strength of concrete, as they increase the volume of voids and decrease the compactness of the composite (Bahloul *et al.*, 2009; De Pellegrin *et al.*, 2021). Theoretically, the addition of DPF to a cement matrix will reduce the compressive strength of the composite. Therefore, the increase in the porosity of the composite material as a result of the addition of fibers is the main factor responsible for the decrease in compressive strength. These results are in accordance with literature (Aruniit *et al.*, 2011; Belkadi *et al.*, 2018).

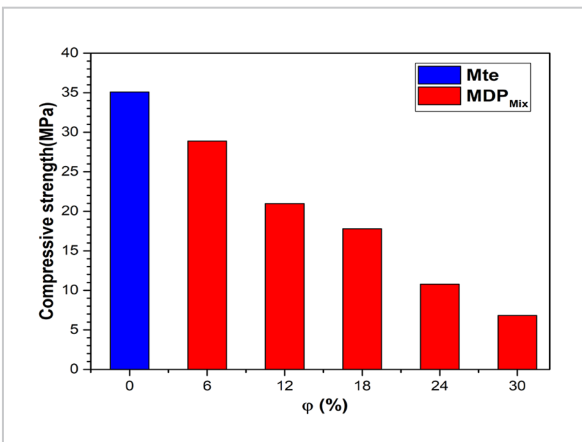

Figure 7 - Compressive strength as a function of the concentration of the fibers.

5.5 Correlation between conductivity and density

Figure 8 represents the correlation between resistance to conductivity and the density of mortars made with date palm fibers. The experimental results show that the conductivity increases significantly with increasing density. Good dispersion was noted with a correlation coefficient R^2 equal to 0.99. The correlation proposed from the present study is of the form:

$$\lambda = 0.018\Phi - 2.177 \quad (3)$$

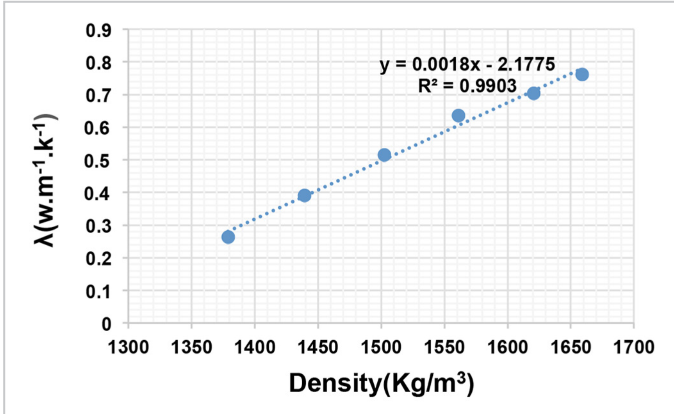

Figure 8 - Evolution of the conductivity versus the density.

5.6 Correlation between conductivity and water absorption

Figure 9 represents the correlation between resistance to conductivity and the water absorption of mortars made with date palm fibers. A polynomial relationship has been observed between the results of water absorption and thermal conductivity of mortars made with date palm fibers. The increase in capillary water absorption leads to a remarkable decrease in conductivity. The polynomial correlation proposed from the present study is of the form:

$$\lambda = 0.0002\ \Phi^2 - 0.0193\ \Phi + 0.5073 \quad (4)$$

With a correlation coefficient $R^2 = 0.9257$.

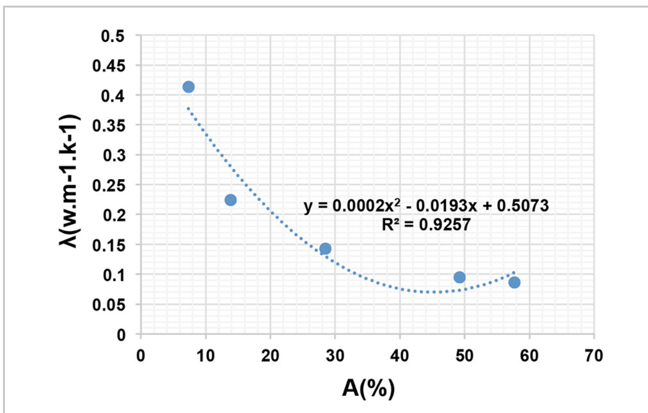

Figure 9 - Evolution of the conductivity versus the water absorption.

5.7 Correlation between compressive strength and water absorption

Figure 10 represents the correlation between the compressive strength versus the water absorption of mortars made with date palm fibers. For all mixes, the increased water absorption causes a remarkable decrease in compressive strength. A good dispersion was noticed with a correlation coefficient R^2 equal to 0.9572. The expression of the polynomial relation is of the form:

$$R_C = 0.0029A^2 - 0.5782\ A + 31.162 \quad (5)$$

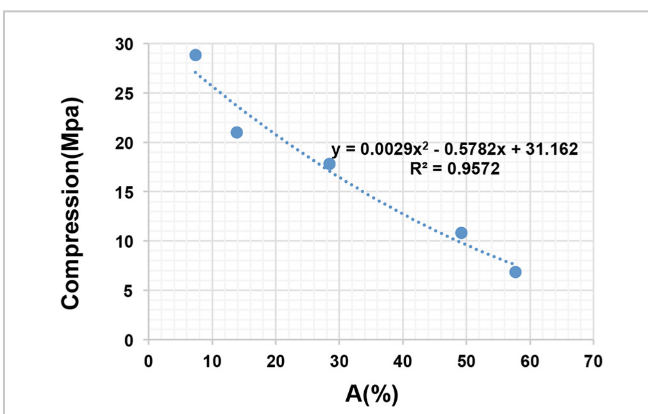

Figure 10 - Evolution of the compressive strength versus water absorption.

6. Conclusion

In this article, we are interested in the experimental study of the effect of the inclusion of DPF on the mechanical and thermal properties of bio-composite concrete. From the experimental results, we conclude that the use of the date palm fibers allows reinforcing concrete yields with the modification of some characteristics of the concrete:

• The experimental investigations indicated that the increase of DPF content allows lightening of the mortar by decreasing its density and increases the insulating capacity of mortar by decreasing its thermal conductivity with about 87% for the MDP_{Mix} samples with a fiber content of 30%.

• The resulting behavior shows a rapid increase in thermal conductivity with the absorption of water.

• The incorporation of DPF in the matrix does not improve in any case the mechanical compressive strength of concrete, where the values range between 6.83 MPa and 28.88 MPa, which represent the lowest and the highest MDP_{Mix} compressive strength having a fiber content of 30% and 6%.

• Thus, the compressive strength is significantly reduced due to the inhomogeneous dispersion of the fibers, which can form clusters.

• Therefore, an increase in the porosity yields to the increase in the volume of voids, affecting the compactness of the composite.

These outcomes will be considered in the future by using the industrial and agro-industrial materials for sustainable building construction.

References

ABANI, S.; HAFSI, F.; KRIKER, A.; BALI, A. Valorisation of date palm fibers in sahara constructions. ***Energy Procedia,*** v. 74, p. 289–293, 2015.

AGOUDJIL, B.; BENCHABANE, A.; BOUDENNE, A.; IBOS, L.; FOIS, M. Renewable materials to reduce buildings heat loss: characterization of date palm wood. ***Energy and Buildings,*** v. 43, n. 2-3, p. 491-497, 2011.

AL RIM, K.; LEDHEM, A.; DOUZANE, O.; DHEILLY, R.M.; QUENEUDEC, M. Influence of the proportion of wood on the thermal and mechanical performances of clay-cement-wood composites. ***Cement and Concrete Composites,*** v. 21, n. 4, p. 269-276, 1999.

ALI, M. E.; ALABDULKAREM, A. On thermal characteristics and microstructure of a new insulation material extracted from date palm trees surface fibers. ***Construction and Building Materials,*** v. 138, p. 276–284, 2017.

AL-OQLA, F .M.; SAPUAN, S. M. Natural fiber reinforced polymer composites in industrial applications: feasibility of date palm fibers for sustainable automotive industry. ***Journal of Cleaner Production,*** v. 66, p. 347-354, 2014.

ARUNIIT, A.; KERS, J.; TALL, K. Influence of filler proportion on mechanical and physical properties of particulate composite. ***Agronomy Research Biosystem Engineering,*** n. 1, p. 23-29, 2011. Número especial.

BAHLOUL, O.; BOURZAM, A.; BAHLOUL, A. Utilisation des fibres végétales dans le renforcement de mortiers de ciment (Cas de l'alfa). INTERNATIONAL CONFERENCE ON SUSTAINABLE BUILT ENVIRONMENT INFRASTRUCTURES IN DEVELOPING COUNTRIES, 1. ***Proceedings*** [...]. 2009.

BASSYOUNI, M.; WAHEED, U. L.; HASAN, S. The use of rice straw and husk fibers as reinforcements in composites. ***Biofiber reinforcements in composite materials,*** p. 385-422, p. 2015.

BELKADI, A. A.; AGGOUN, S.; AMOURI, C.; GEUTTALA, A.; HOUARI, H. Effect of vegetable and synthetic fibers on mechanical performance and durability of Metakaolin-based mortars. ***Journal of Adhesion Science and Technology,*** v. 32, n. 15, p. 1670-1686, 2018.

BELKADI, A. A.; KESSAL, O.; CHIKER, T.; ACHOUR, Y.; ROUABHI, A.; MESSAOUDI, O.; KHOUADJIA, M. L. K. Full factorial design of mechanical and physical properties of eco-mortars containing waste marble powder. ***Arabian Journal for Science and Engineering,*** p. 1-14, 2022.

BENANIBA, S.; DRISS, Z.; DJENDEL, M.; RAOUACHE, E.; BOUBAAYA, R. Thermo-mechanical characterization of a bio-composite mortar reinforced with date palm fiber. ***Journal of Engineered Fibers and Fabrics,*** v. 15, p. 1-9, 2020.

BENMANSOUR, N.; AGOUDJIL, B.; BOUDENNE, A.; GARNIER, B. Numerical investigation of heat transfer of silver-coated glass particles dispersed in ethylene vinyl acetate matrix. ***International Journal of Thermo-physics,*** v. 35, n. 9-10, p. 1803-1816, 2014.

BENMANSOUR, N.; AGOUDJIL, B.; GHERABLI, A.; KARECHE, A.; BOUDENNE, A. Thermal and mechanical performance of natural mortar reinforced with date palm fibers for use as insulating materials in building. ***Energy and Buildings,*** v. 81, p. 98-104, 2014.

BERARDI, U.; IANNACE, G. Acoustic characterization of natural fibers for sound absorption applications. ***Building and Environment,*** v. 94, p. 840-852, 2015.

BOUMHAOUT, M.; BOUKHATTEM, L.; HAMDI, H.; BENHAMOU, B.; AIT NOUH, F. Thermomechanical characterization of composite materials: mortar reinforced by date palm fibers mesh of Marrakesh. INTERNATIONAL RENEWABLE AND SUSTAINABLE ENERGY CONFERENCE - IRSEC, 3, 2010. ***Proceedings*** [...] p. 1-5.

CHABRIAC, P. A.; GOURDON, E.; GLE, P.; FABBRI, A.; LENORMAND, H. Agricultural byproducts for building insulation: acoustical characterization and modeling to predict micro-structural parameters. ***Construction and Building Materials,*** v. 112, p. 158-167, 2016.

CHANDRASEKARAN, M.; BAHKALI, A. H. A review on valorization of date palm (Phoenix dactylifera) processing by-products and wastes using bioprocess technology. ***Saudi Journal of Biological Sciences,*** v. 20, n.2, p. 105-120, 2013.

CHIKER, T.; BELKADI, A. A.; AGGOUN, S. Physico-chemical and microstructural fire-induced alterations into metakaolin-based vegetable and polypropylene fibred mortars. ***Construction and Building Materials,*** 276, 122225, 2021.

CHIKHI, M.; AGOUDJIL, B.; BOUDENNE, A.; GHERABLI, A. Experimental investigation of new bio-composite with low cost for thermal insulation. ***Energy and Buildings,*** 66, p. 267-273, 2013.

CLARAMUNT, J. *et al.*. The hornification of vegetable fibers to improve the durability of cement mortar composites. ***Cement and Concrete Composites,*** v. 33, n.5, p. 586-595, 2011.

DE PELLEGRIN, M. Z.; ACORDI, J.; MONTEDO, O. R. K. Influence of the length and the content of cellulose fibers obtained from sugarcane bagasse on the mechanical properties of fiber reinforced mortar composites. ***Journal of Natural Fibers,*** v. 18, n. 1, p. 111-121, 2021.

DHAKAL, H. N.; ZHANG, Z.Y.; RICHARDSON, M. O. W. Effect of water absorption on the mechanical properties of hemp fiber reinforced unsaturated polyester composites. ***Composites Science and Technology,*** v. 67, n. 7-8, p. 1674-1683, 2007.

DJOUDI, A.; KHENFER, M. M.; BALI, A.; BOUZIANI, T. Effect of the addition of date palm fibers on thermal properties of plaster concrete: experimental study and modeling. ***Journal of Adhesion Science and Technology,*** v. 28, n. 20, 2100-2111, 2014.

DJOUDI, A.; KHENFER, M. M.; BALI, A.; KADRI, E. H., DEBICKI, G. Performance of date palm fibres reinforced plaster concrete. ***International Journal of Physical Sciences,*** v. 7, n. 21, p. 2012, p. 2845-2853 2012.

DRIDI, M.; HACHEMI, S.; BELKADI, A. A. Influence of styrene-butadiene rubber and pretreated hemp fibers on the properties of cement-based repair mortars. ***European Journal of Environmental and Civil Engineering,*** p. 1-20, 2022.

DUPAIN, R.; LANCHON, R.; SAINT-ARROMAN, J. C. ***Granulats, sols, ciments et bétons – caractérisation des matériaux de génie civil par les essais de laboratoire.*** 4. ed. 2009.

HADDADI, M. ***Transport properties of heterogeneous materials with natural reinforcement***: experimental approach and numerical modeling. Tese (Doutorado) - University of Hadj Lakhdar-Batna, Algeria. 2015.

ISMAIL, F. S.; MOHAMED ASA'ARI, A. Z.; MOHD YUSSOF, N. A.; CHIN HAO, L. MOHAMMAD PADZIL, F. N.; HUA, L. S.; JAWAID, M. Physical and mechanical properties of paper made from beaten empty fruit bunch fiber incorporated with microcrystalline cellulose. ***Journal of Natural Fibers,*** v. 19, n.3, p. 999-1011, 2022.

KESSAL, O.; ACHOUR, Y.; NOUI, A.; BELKADI, A. A.; BENOUADAH, A.; BELAGRAA, L.; BENAMMAR, A. Bio-fiber reinforced roller compacted concrete designed for road construction: feasibility of date palm fibers in pavements. ***European Journal of Environmental and Civil Engineering,*** p. 1-23, 2022.

KHEDARI, J.; NANKONGNAB, N.; HIRUNLABH, J.; TEEKASAP, S. New low-cost insulation particle boards from mixture of durian peel and coconut coir. ***Building and Environment,*** v. 39, n. 1, p. 59-65, 2004.

KHEDARI, J.; SUTTISONK, B.; PRATINTHONG, N.; HIRUNLABH, J. New lightweight composite construction materials with low thermal conductivity. ***Cement and Concrete Composites,*** v. 23, n.1, p. 65-70, 2001.

KRIKER, A.; DEBICKI, G.; BALI, A.; KHENFER, M. M.; CHABANNET, M. Mechanical properties of date palm fibers and concrete reinforced with date palm fibers in hot-dry climate. ***Cement and Concrete Composites,*** v. 27, n. 5, p. 554-564, 2005.

LABOREL-PRÉNERON, A.; MAGNIONT, C.; AUBERT, J. E. Characterization of barley straw, hemp shiv and corn cob as resources for bio aggregate based building materials. ***Waste and Biomass Valorization,*** v. 9, n. 7, p. 1095-1112, 2018.

LEDHEM, A.; DHEILLY, R. M.; BENMALEK, M. L.; QUÉNEUDEC, M. Properties of wood based composites formulated with aggregate industry waste. ***Construction and Building Materials,*** v. 14, n. 6-7, p. 341-350, 2000.

LI, Y.; MAI,Y. W.; YE, L. Sisal fiber and its composites: a review of recent developments. ***Composites Science and Technology,*** v. 60, n.11, p. 2037-2055, 2000.

OHENOJA, K.; TANSKANEN, P.; WIGREN, V.; KINNUNEN, P.; KÖRKKÖ, M.; PELTOSAARI, O.; ÖSTERBACKA, J.; ILLIKAINEN, M. Self-hardening of fly ashes from a bubbling fluidized bed combustion of peat, forest industry residuals and wastes. ***Fuel,*** 165, p. 440-446, 2016.

RAMAKRISHNA, G.; SUNDARARAJAN, T. Studies on the durability of natural fibers and the effect of corroded fibers on the strength of mortar. ***Cement and Concrete Composites,*** v. 27, n. 5, p. 575-582, 2005.

SAĞLAM, S.; GÜZELÇIMEN, F.; BINGÖL, D.; ÖZKAN, U. Y.; EKICI, B. An evaluation on acoustic behavior of untreated tree trunks depending on bark physical properties and fiber cell structure. ***Journal of Natural Fibers,*** v. 19, n. 4, p. 1507-1521, 2022.

SENTHAMARAIKANNAN, P.; SANJAY, M.R.; BHAT, K.S.; PADMARAJ, N. H.; JAWAID, M. Characterization of natural cellulosic fiber from bark of Albizia amara. ***Journal of Natural Fibers,*** v. 16, n. 8, p. p. 1124-1131, 2019.

SETHURAMAN, B.; SUBRAMANI, S. P.; PALANIAPPAN, S. K.; MYLSAMY, B.; ARUCHAMY, K. Experimental investigation on dynamic mechanical and thermal characteristics of Coccinia Indica fiber reinforced polyester composites. ***Journal of Engineered Fibers and Fabrics*** 15, p. 1-6, 2020.

TAOUKIL, D.; ALBOUARDI, A;, AJZOUL, T;, EZBAKHE, A. H. Effect of the incorporation of wood wool on thermos-physical properties of sand mortars. ***KSCE Journal of Civil Engineering,***v. 16, n. 6, p. 1003-1010, 2012.

Received: 30 August 2022 - Accepted: 19 November 2022.