EPJ Web of Conferences **371**, 02008 (2026) https://doi.org/10.1051/epjconf/202637102008
AMT'2026

Thermal Properties of Lightweight Cement–Sand–Natural Pozzolan Moroccan Composites

Mohamed Kichouhi[1*], Khadija Hoummada[1], Rachid El Alaiji[2], Mohammed Amine Moussaoui[3], and Soufiane Derfoufi[1]

[1]Materials, Systems and Energy Engineering Laboratory, FSTT, Abdelmalek Essaâdi University, Tetouan, Morocco.
[2]Laboratory of Innovative Technologies, ENSAT, Abdelmalek Essaâdi University, Tetouan, Morocco.
[3]Laboratory of Mechanics and Energy, Mohammed First University, 60000 Oujda, Morocco.

Abstract. Thermal insulation is a key research topic due to its role in improving passive thermal comfort in buildings and reducing carbon emissions. This study investigates the development of a low-cost, thermally insulating concrete incorporating natural pozzolan aggregates (NPA) derived from a locally available mineral resource. Concrete mixtures containing different NPA proportions (0–6 $wt\%$) were prepared and experimentally evaluated. Thermal conductivity and thermal diffusivity were measured using the Hot Disk technique. The results showed that the incorporation of 6 $wt\%$ NPA reduced thermal conductivity by 15.79%, thermal diffusivity by 20.55%, and density by 5.29%. These results demonstrate the effectiveness of natural pozzolan aggregates in enhancing the thermal performance of concrete. Consequently, natural pozzolan represents a promising and environmentally friendly material for producing thermally efficient concrete for sustainable building applications.

1 Introduction

In the context of current energy and environmental challenges, reducing energy consumption in the building sector has become a key research priority, particularly through improving the thermal performance of building envelopes. Effective thermal insulation plays a crucial role in achieving passive thermal comfort, reducing energy demand, and mitigating the carbon footprint associated with buildings.

The building sector is one of the most energy-intensive industries in the world, accounting for about 35% of global energy consumption and contributing about 40% of total carbon dioxide emissions [1]. This situation has prompted increased research efforts to develop advanced building materials with improved thermal insulation performance [2]. These materials are expected to combine high thermal efficiency with environmental sustainability, cost-effectiveness, and reduced carbon emissions, in line with sustainable building goals.

* Corresponding author: kichouhi.mohamed@etu.uae.ac.ma

The development of innovative building materials can significantly improve thermal insulation performance and enhance passive heating and cooling strategies, thereby reducing the total annual energy consumption of buildings [3]. These materials are often produced by adding industrial or local by-product wastes to traditional binders such as clay, plaster and cement as additional components. In response to the growing challenges posed by climate change, the main objective of this approach is to produce building materials with better thermal properties that are both economical and environmentally friendly [4]. The use of pozzolan in thermal insulation applications has attracted considerable interest in recent studies. Several studies have focused on the thermal properties of natural pozzolan and its contribution to enhancing the energy performance of buildings [5]. Notably, Sarooj mortar, which contains pozzolan, has been extensively studied for its mechanical strength and thermal insulation performance, showing promising results compared to conventional building materials [6]. Research conducted on the compressive strength and thermal conductivity of pozzolanic concrete has also revealed its potential as a thermal insulator [7]. In addition, experimental studies have also shown that adding natural pozzolana to mortar compositions has enhanced their thermophysical properties, leading to improved overall thermal comfort in built environments [8].

In this context, the current study aims to address existing research gaps by analysing the physical, chemical, and mineralogical properties of natural pozzolan (NP) and cement. The main objective of this research is to propose new NP aggregates-based concrete materials with improved energy performance compared to ordinary concrete. The overall goal is to promote the use of local and natural materials, such as natural pozzolan, in the development of new lightweight concrete composed of cement, sand, and NPA, providing improved thermal insulation performance.

2 Materials

2.1 *Natural Pozzolan (NP)*

Natural pozzolan was used as a lightweight additive in the production of environmentally friendly lightweight concrete. The NP was obtained by crushing volcanic rocks extracted from Oujda, Morocco. Scanning electron microscope (SEM) images of granular NP shown in Figure 1 reveal irregular, non-spherical shapes of NP particles containing pores of various sizes. The particle sizes of NP aggregates used in this study ranged from 2000 to 6000 μm, as shown in Figure 2.

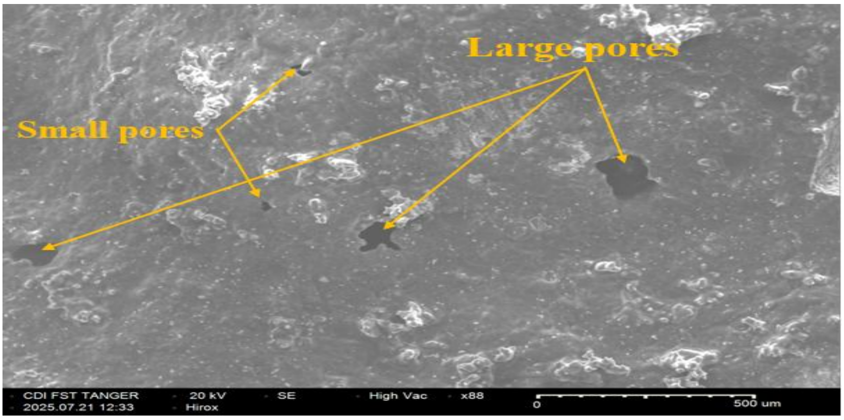

Fig. 1. SEM micrograph analysis of natural pozzolan (NP).

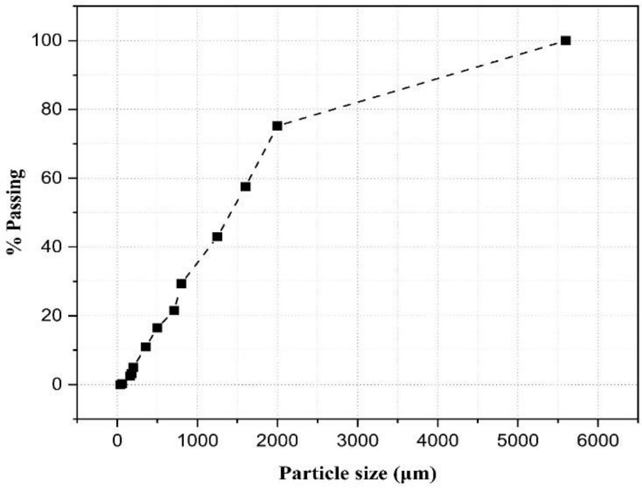

Fig. 2. Particle size distribution of natural pozzolan aggregates (NPA).

2.2 *Sand*

Sand is a fine granular material widely used in mortar and concrete mixtures due to its low cost, making it one of the cheapest materials used in construction. The most important function of sand is to fill voids and provide the necessary volume for the mixture. In this study, locally available Moroccan sand was used as the fine sand material. Figure 3 shows the particle size distribution of the sand used in the study, indicating that most of the sand used is smaller than 2500 μm. In this study, a sand-to-cement ratio of 0.33 (1:3) was used during the concrete preparation process as a fixed ratio to achieve a suitable mix design.

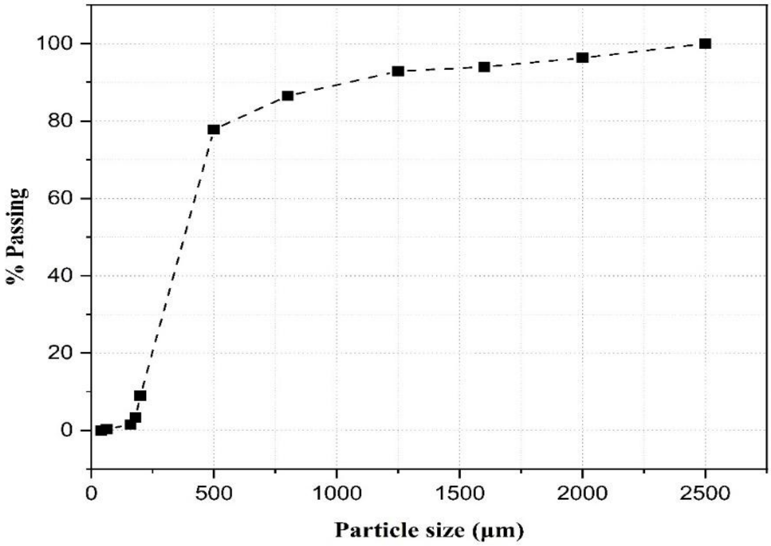

Fig. 3. Granulometric distribution of the sand used for concrete preparation.

2.3 Used matrix: Cement

Ordinary Portland cement (OPC 35), supplied by Lafarge Holcim Morocco, complies with European standards and is ISO 9001 certified [9]. It is an essential material in the construction industry and mainly contains silicates and oxides. When moistened, it turns into a paste that later hardens, giving it great mechanical strength. As the main component of the so-called binder in the production of concrete and mortar, cement plays an important role in enhancing the durability and structural integrity of buildings. Figure 4 shows the amount of cement produced in different countries along with the associated carbon dioxide emissions [10]. China is the emerging leader as the largest producer of most carbon dioxide emissions in this sector. As a result, a range of strategies and technologies have been proposed to mitigate these emissions. Among the most important is the partial replacement of cement with industrial, plastic, or plant waste [11], thereby reducing carbon dioxide emissions.

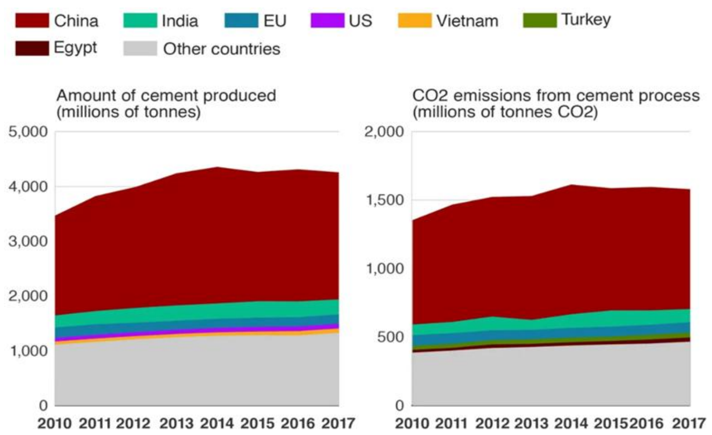

Fig. 4. Cement production and associated CO_2 emissions.

2.4 Sample preparation

Figure 5 illustrates how the concrete samples were prepared, formed, and cured in sequence. The concrete samples were prepared according to precisely defined proportions with dimensions of 5 × 5 × 5 cm^3. Table 1 shows the constituent materials and their quantities in the mixtures studied. All compositions adhered to a sand/cement ratio of 1:3 and a water/cement ratio of 1:2. A total of 8 samples were produced, consisting of two samples for each concrete mixture. At a constant temperature of 20 ± 3 °C and relative humidity above 95%, after 28 days, we will conduct tests on the samples.

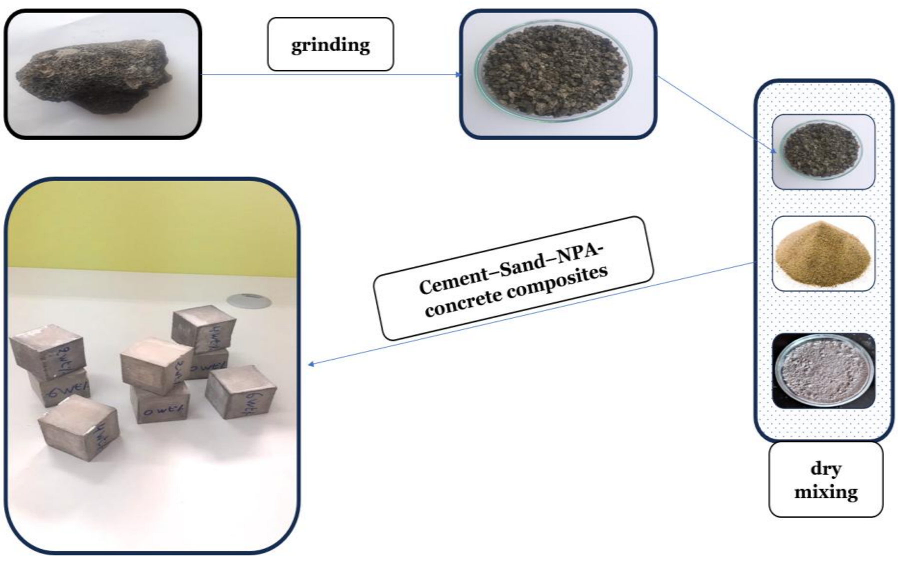

Fig. 5. NPA-concrete sample preparation.

Table 1 Composition of NP-incorporated concrete (NPC) samples.

Sample name	NPA content	Cement	Sand	E/C
NPA	***wt*%**	***wt*%**	***wt*%**	**ratio**
NPA0	**0**	**100**	**33**	**0.5**
NPA2	**2**	**100**	**33**	**0.5**
NPA4	**4**	**100**	**33**	**0.5**
NPA6	**6**	**100**	**33**	**0.5**

3 Methods

3.1 Structural Analysis Using X-ray Diffraction (XRD)

X-ray diffraction (XRD) is one of the fundamental research techniques for determining the crystalline structure of materials. This study was conducted using a D8 ADVANCE ECO diffractometer (Bruker) located at the Development and Innovation Center of the Faculty of Science and Technology in Tangier (FSTT) using Cu-Kα radiation (λ = 1.5406 Å). In this experimental setup, high-energy photons were produced by the X-ray source and passed through the NP sample and cement (C35) to see the structure for each sample.

3.2 Hot Disk Technique

The One method of measuring thermal properties, including thermal conductivity and thermal diffusivity, is the Hot Disk THB (Transient Hot Bridge), which complies with ISO 22007-2 [12]. It uses a nickel sensor that acts as both a heat detector and a heat source. The sensor is electrically heated while in contact with the sample, and the thermal response is recorded. This simple and accurate technique allows for precise evaluation of thermal properties when used with a properly prepared sample and specialized software, as shown in Figure 6. The measurements in this research were performed using electrical power ranging from 70 to 100 mW and a heating time of 80 seconds.

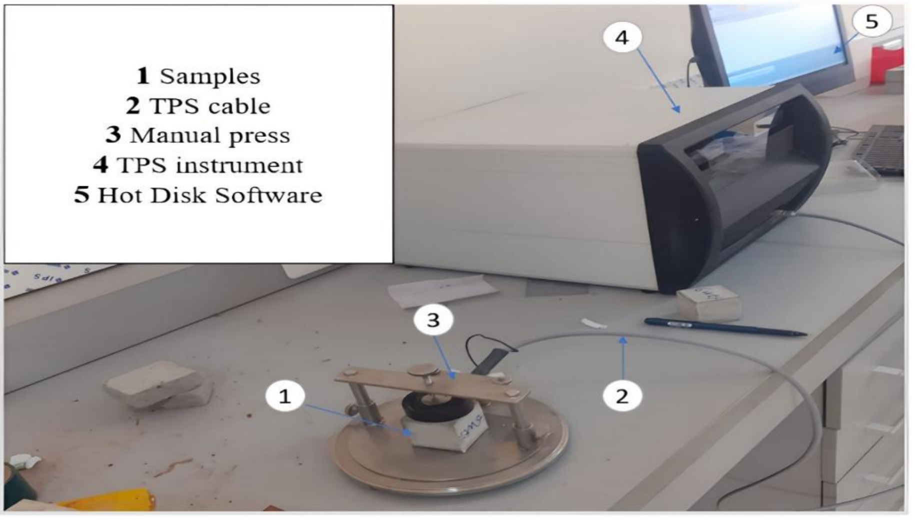

Fig. 6. Experimental arrangement for thermal measurements using the Hot Disk method.

4 Results and discussion

4.1 XRD analysis

X-ray diffraction (XRD) was used to determine the mineral composition of both natural pozzolan and cement using a SHIMADZU XRD-6000 device. The diffraction pattern of cement (C35) in Figure 7 indicated that it consists of alite, quartz, and gypsum, with most of the dominant phase at 2θ = 29.520 in alite. This confirms the conformity and suitability of the cement used in this study. In contrast, the XRD analysis demonstrates that the NP is composed of crystalline minerals, as shown in Figure 8. The main identified phases correspond to albite ($NaAlSi_3O_8$), spinel (Al_2MgO_4), and cristobalite (SiO_2).

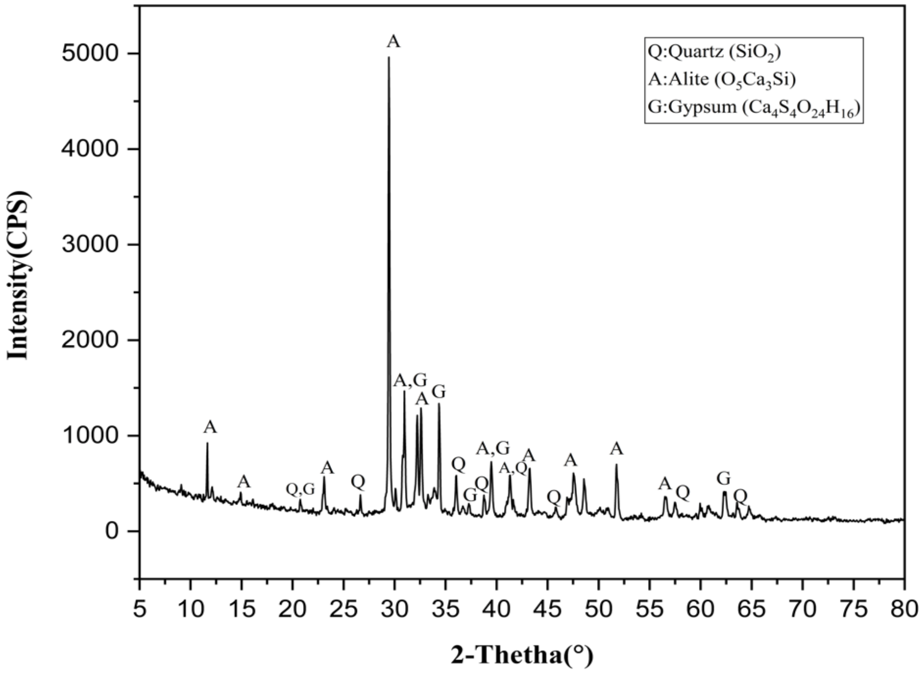

Fig. 7. XRD pattern of cement.

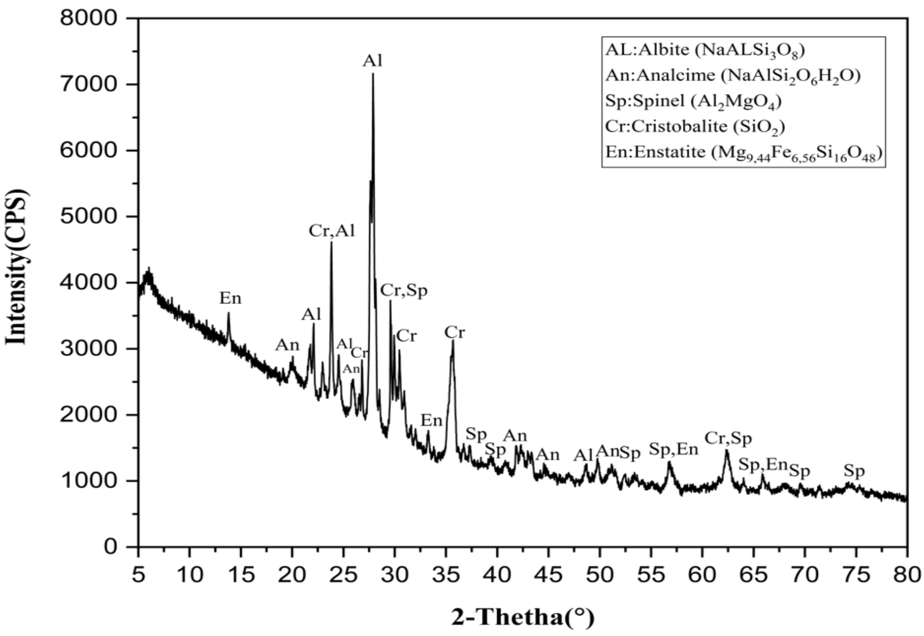

Fig. 8. XRD pattern of the natural pozzolan (NP).

4.2 Experimental Results of Density

Lightweight materials integration in the construction sector has weighty environmental and economic benefits, including reduction in human labor and logistical costs. Moreover, constructions have lower mass, thus increasing their resilience to seismic damages, which has been supported by a previous study [13]. Figure 9 illustrates the density of NPA-based concrete. A progressive decrease in density is observed with increasing NPA content. Moreover, the particle size of NPA plays a significant role in this reduction. The addition of 6 $wt\%$ NPA caused a density decrease of 5.29%. Therefore, the experimental data were fitted using a linear regression model in Origin software. The obtained fitting shows a high degree of accuracy, with a coefficient of determination ($R^2 = 0.99$), and is described by the equation presented in Figure 9.

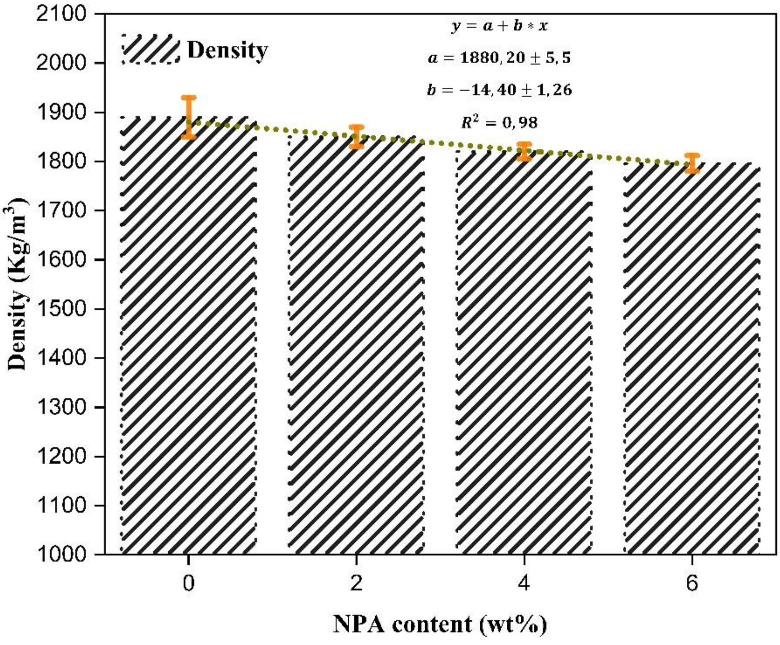

Fig. 9. Effect of NPA content on the bulk density of the samples.

4.3 Thermal characterization

Thermal conductivity and thermal diffusivity are key factors in determining the choice of insulation materials, as they measure a material's ability to transfer heat. Therefore, lower thermal conductivity indicates better insulation performance. Table 2 and figure 10 present the thermal diffusivity and thermal conductivity of the samples determined experimentally. The NPA concrete in Figure 10 has a much lower thermal conductivity compared to concrete that does not contain NPA. This decrease in thermal conductivity can be explained by the fact that the material containing NPA has become more porous, as confirmed by SEM observations (Fig. 1). When $6wt\%\ NPA$ is compared with the reference sample without additives, its thermal conductivity is reduced from 1.33 to 1.12 W/ (m.K), corresponding to a 15.79% reduction in thermal conductivity. In addition, the thermal diffusivity decreases to 0.58 mm^2/s, indicating a 20.55% reduction in heat transfer efficiency. Due to the porous structure, similar behavior has been reported in other studies investigating the incorporation of natural aggregates such as granular cork [14], which contribute to the formation of a porous structure within the resulting composite material. The thermal behavior of naturel pozzolan granules composites is consistent with findings reported in previous studies. Annaba et al. [15] demonstrated that the incorporation of natural pozzolan granules with particle sizes ranging from 7 to 20 mm significantly enhances the thermal performance of a developed multilayer mortar, leading to a 37% reduction in thermal conductivity compared with the reference material without pozzolan.

Table 2. Thermophysical properties of NPAC samples (average values ± standard deviation).

Samples	**NPA content (wt%)**	$\lambda[W/mK]$	$\alpha[mm^2/s]$
NPAC0	**0**	1.33 ± 0.02	0.73 ± 0.01
NPAC2	**2**	1.23 ± 0.02	0.80 ± 0.01
NPAC4	**4**	1.15 ± 0.02	0.59 ± 0.01
NPAC6	**6**	1.12 ± 0.02	0.58 ± 0.02

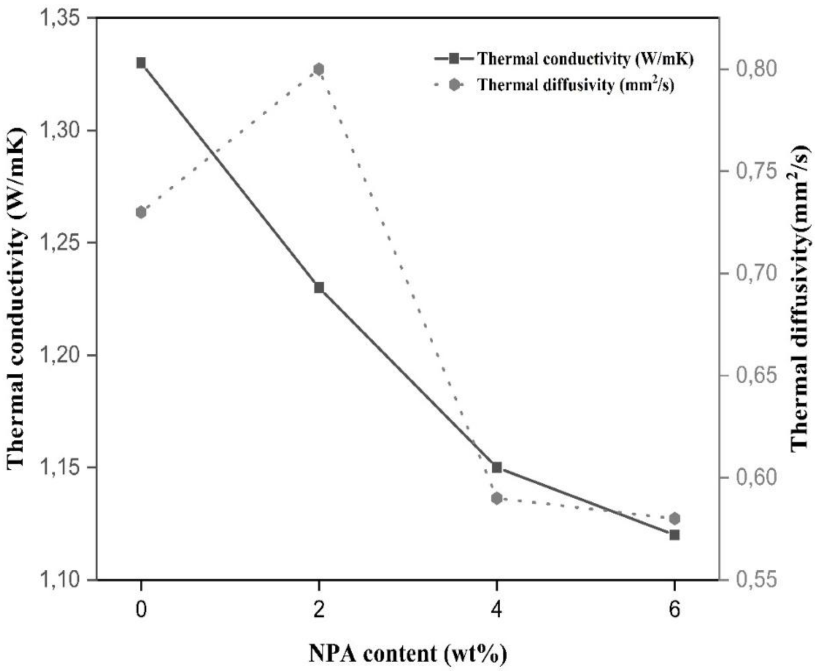

Fig. 10. Effect of NPA content on thermal transport properties.

5 Conclusion

In this research, the authors focus on promoting the use of local and environmentally friendly additives to develop lightweight building materials with superior thermal performance. The study's hypothesis is based on using pozzolan in its natural granular form, exploiting the porosity of this substance to produce lightweight insulating concrete. The authors therefore conducted an empirical study to determine the thermal properties of a lightweight concrete matrix composed of natural Moroccan pozzolanic aggregates and other concrete constituents. The experimental results obtained in this study can be summarized as follows:

- The incorporation of $6wt\%$NPA resulted in a significant decrease in concrete density to 1790 kg/m³, representing a 5.29% reduction relative to the reference sample.
- An increase in NPA content led to a substantial decrease in thermal conductivity, reaching a maximum reduction of 15.79% at $6wt\%$NPA.
- The developed materials can be used in insulating linings and filling applications, particularly in partition wall elements and blocks.

References

1. IEA, " Energy Efficiency: Buildings The global exchange for energy efficiency policies, data and analysis," (2019), Available: https://www.iea.org/topics/energyefficiency/buildings/.
2. M. Charai, H. Sghiouri, A. Mezrhab, and M. Karkri, "Numerical Study of the Impact of Clay-Straw Walls on the Energy Performance of a Residential Building," in 2018 6th International Renewable and Sustainable Energy Conference (IRSEC), 2018, pp. 1-5: IEEE.
3. H. Sghiouri, M. Charai, A. Mezrhab, and M. Karkri, "Comparison of passive cooling techniques in reducing overheating of clay-straw building in semi-arid climate," in Building Simulation, pp. 1-24: Springer.
4. NASA. (15 june 2008). Global Climate Change: Evidence. Available: https://climate.nasa.gov/evidence/.
5. Hamadache, M.; Mouli, M.; Bouhamou, N.; Benosman, A.S.; Dif, F.; Chaib, O. The Thermal Properties of Natural Pozzolan-Based Cement Mortar. Energy Procedia 2017, 139, 201–207.
6. Meddah,M.S.; Benkari, N.; Al-Saadi, S.N.; Al Maktoumi, Y. Sarooj Mortar: From a Traditional Building Material to an Engineered Pozzolan—Mechanical and Thermal Properties Study. J. Build. Eng. 2020, 32, 101754.
7. Al-Rbaihat, R.; Eayal Awwad, K.Y. Thermal and Mechanical Characteristics of Pozzolana Concrete. IOSR J. Mech. Civ. Eng. 2021, 18, 28–35.
8. Bari¸s, K.E.; Tanaçan, L. Performance of Natural Pozzolan-Based Geopolymer Reinforced with Banana Fibers. J. Green Build. 2024, 19, 51–76.
9. Lafarge Holcim Maroc, Information Note, Holcim (Morocco)., No. Cdvm, 2013.
10. L. Rodgers, "Climate change: The massive CO2 emitter you may not know about," BBC News, 2018.
11. A. Bràs, M. Leal, P. Faria, Cement-cork mortars for thermal bridges correction. Comparison with cement-EPS mortars performance, Construct. Build. Mater.49(2013) 315–327, https://doi.org/10.1016/j.conbuildmat.2013.08.006.
12. I. 22007-2, Plastics — determination of thermal conductivity and thermal diffusivity — Part 2: Transient plane heat source (hot disc) method [Online]. Available: https://www.iso.org/obp/ui/#iso:std:iso:22007:-2:ed-2:v1, 2015.

13. F. Colangelo, I. Farina, M. Travaglioni, C. Salzano, R. Cioffi, et A. Petrillo, Innovative Materials in Italy for Eco-Friendly and Sustainable Buildings, Materials, vol. 14, no 8, p. 2048, avr. 2021, doi: 10.3390/ma14082048.
14. El Wardi FatimaZohra, Cherki Aboubaker, Mounir Soumia, Khabbazi Abdelhamid, Maaloufa Youssef.(2019)." Thermal characterization of a new multilayer building material based on clay, cork and cement mortar". Energy Procedia. 157:480–91.
15. Khadija. Annaba, Fatima. Zohra. Elourdi, Khalid. Ibaaz, Azzeddine. Bouyahyaoui, Moha. Cherkaoui, Bennaceur Ouaki Safaa.Oubanmouh. (2022) "Thermomechanical characterization and thermal simulation of a new multilayer mortar and a light-weight Pozzolanic concrete for building energy efficiency." Construction and Building Materials Volume 346: 128479.