Eco-friendly isolant composite mortars based on natural pozzolan, fly ash and plastic fibers

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Abstract. Thermal insulation in buildings has gained significant attention recently due to the clear benefits of selecting appropriate insulation materials for energy conservation. This study presents experimental research conducted to evaluate the thermal properties of mortar based natural Moroccan pozzolan and fly ash, both of which serve as alternatives to cement powder. Unlike cement, which requires energy-intensive extraction, natural pozzolan is an abundant volcanic material, and fly ash is a powdery residu generated as a byproduct during the combustion of coal in thermal power plants. The aim of this research is to explore the potential of these materials for thermal insulation and to address the environmental concern of plastic waste management through recycling. Twenty different mortar mixes were synthesized and evaluated, with a constant 10% of fly ash and varying percentages (10%, 20%, 30%, 40%) of natural pozzolan replacing cement. Additionally, 1% of plastic fibers based on the mortar volume were included. Thermal conductivity and heat capacity of the cured mortar mixtures were measured after 7 and 14 days using a TPS1500 hot disc Analyzer, which is currently the most precise and useful method for studying thermal transport parameters. To ensure consistent conditions, all samples were preconditioned to eliminate moisture before testing. The test results indicated the potential of using plastic fibers, fly ash, and natural pozzolan as effective thermal insulation materials. These materials demonstrated reduced thermal conductivity and increased specific heat capacity, making them desirable for building applications. From an economic and environmental standpoint, incorporating them as cement substitutes for sustainable cement production in thermal insulation is the most favorable approach.

Index Terms— Fly ash, Hot disk Analyser, Natural pozzolan, Thermal capacity, Thermal conductivity, TPS1500, Sustainable environment, Natural resources management.

1 Introduction

The cement sector represents currently a significant energy and high-pollution activity[1]. In addition to being a significant CO2 emitter [2], it is crucial for national development. Given the adverse effects of these emissions on global warming, numerous studies are underway to identify solutions and promote sustainability within the cement sector.

One promising approach to mitigate CO2 emissions involves maintaining the same performance qualities of Portland cement while employing alternative raw materials for cements. Essentially, clay and limestone are used as the primary raw materials in the production of clinker. However, extensive research has shown that various waste materias, such as paper pulp wastes [3], ceramic wastes [4], weathered basalt [5], blast furnace [6] and fly ash [7], may be used in the cement industry. These findings highlight the potential for employing these alternative materials as substitutes, reducing the environmental impact of cement production.

The topic of thermal insulation in buildings has gained significant traction due to its potential for reducing energy consumption[8]. A highly effective strategy to achieve this is through the exploration of new construction materials with enhanced insulation properties.

The primary objective of this study is to draw attention to the global environmental issues surrounding the cement industry and construction. Our objective is to develop environmentally friendly and energy-efficient materials by reducing the reliance on cement. This is accomplished by partially replacing cement with natural Moroccan pozzolan and fly ash, while also incorporating fibers to minimize environmental pollutants..

Natural pozzolan, which is utilized as a supplementary cementing material and possesses pozzolanic capabilities [9], can provide significant ecological and economic benefits [10]–[12].

After burning coal or other fossil fuels, power plants release fly ash, a powdery substance [13], [14]. Due to its strong pozzolanic activity, fly ash is a highly well-liked component in the building sector [15]–[18].

In the field of civil engineering, plastic waste has been employed extensively[19]–[22]. Among the popular ways to enhance the properties of composite materials made of cement is by using fibers as a reinforcement [22].

The importance of this research lies in several key aspects: it addresses the global environmental challenges posed by the cement industry and construction sector, which are significant contributors to energy consumption and greenhouse gas emissions. By exploring alternative materials and approaches, the research aims to reduce the environmental impact of these industries.

2 Materials and Methods

2.1 Materials

Composite Cement CPJ 35 is the type of cement used in this investigation. While natural pozzolan (PZ) was extracted from the Middle Moroccan Atlas and fly ash (FA) was sourced from Jorf Lasfar Energy Company, a power plant in Morocco. The physical and chemical composition of both raw materials is shown in Table 1.

To manufacture mortars, both materials were steamed for 24 hours at 105°C and milled to a thickness of 80 μm. Drinking water and sea sand were included. Plastic fibers were inserted as reinforcement.

Table 1. Chemical and physical properties of raw materials.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	Na_2O	P_2O_5	K_2O	MnO	LOI
PZ	42.54	16.60	10.57	10.29	8.060	2.396	2.006	1.416	0.92	0.167	4.240
FA	52.33	23.16	7.098	2.625	1.22	0.818	0.824	0.312	1.127	0.06	9.238

	Specific density (g/cm^3)	Bulk density (g/cm^3)
PZ	2.22	1.03
FA	2.67	1.32
Cement	2.5	0.97
Sand	2.7	1.22

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2.2 Preparation and sample conditioning

20 mixtures were synthetized to prepare prismatic samples of (40x80x120 mm) containing a constant percentages of 10% of fly ash and natural pozzolan added at different weight percentages (10%-20%-30%-40%) as a partial substitution for cement .according to the volume of mortar, 1% of plastic was added. In all mixtures a constant water to binder ratio of 0.6 was used. A day after casting, the prismatic specimens were left in ambient air until the test age.

2.3 Methods

(40x80x120 mm) samples were tested for thermal conductivity determined after 7 and 14 days with a TPS 1500 hot disc analyser .The Transient Plane Source (TPS) method is recently the most accurate and practical technique to study thermal transport properties. In accordance to ISO 22007-2, this technique offers data on the material under study's thermal conductivity as well as its specific heat per unit volume.

The Kapton sensor, which serves as both a heat source and a temperature sensor to measure temperature changes over time, is sandwiched between two samples of 40x80x120 mm. Fig 3 describes the methodology followed on this study.

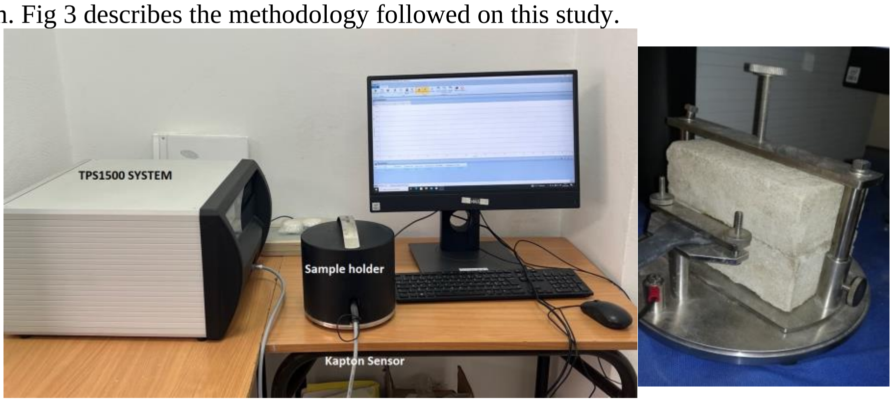

Fig 1. TPS 1500 Hot disc Analyser

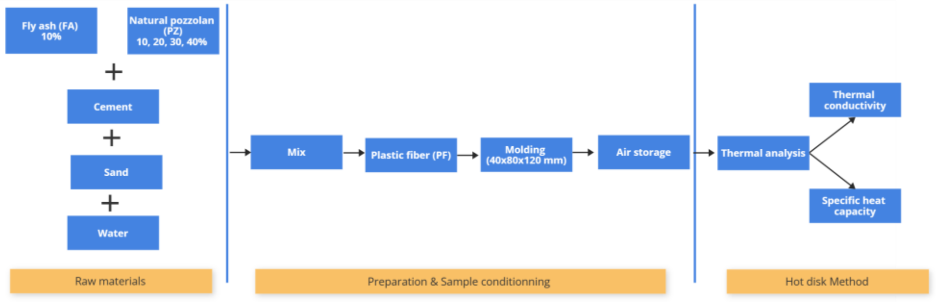

Fig 2. Methodology of the experimental study

3 Results

To eliminate any moisture content, the samples were subjected to a drying technique in an oven at 105°C for 24h [20].

3.1 Thermal conductivity W/mk

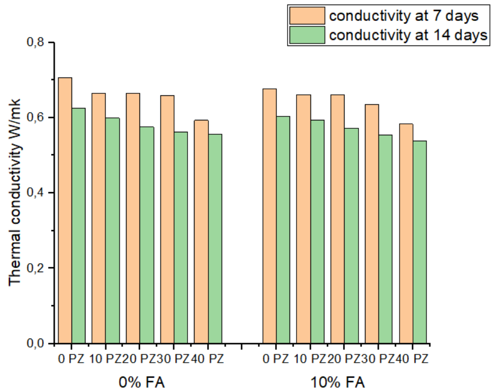

Fig 3. Thermal conductivity of various mixtures with 0%PF

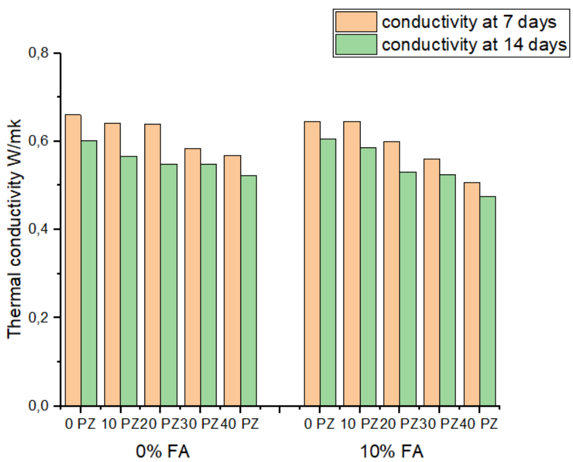

Fig 4. Thermal conductivity of various mixtures with 1%PF

The graph in Fig 2 and Fig 3 illustrates the changes in thermal conductivity of the mortars at different ages. It is evident that at 7 and 14 days, the thermal conductivity decreases in relation to the rate of cement replacement.

Increasing the partial substitution of cement with PZ from 0% to 40% led to a reduction of thermal conductivity in eco-friendly mortars. Specifically, the thermal conductivity decreased from 0.62 W/mK to 0.55 W/mK after 14 days without the addition of fly ash. When fly ash was added, the thermal conductivity decreased from 0.60 W/mK to 0.55 W/mK. Additionally, the incorporation of plastic fibers also contributes to a decrease in thermal conductivity.

3.2 Heat capacity J/kgK

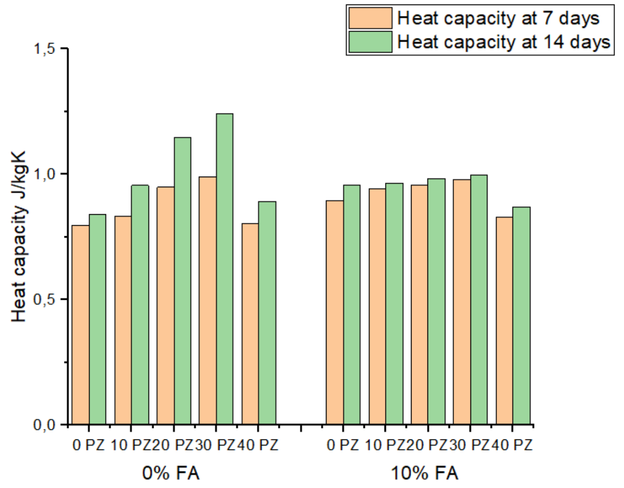

Fig 5. Specific heat capacity of various mixtures with 0%PF

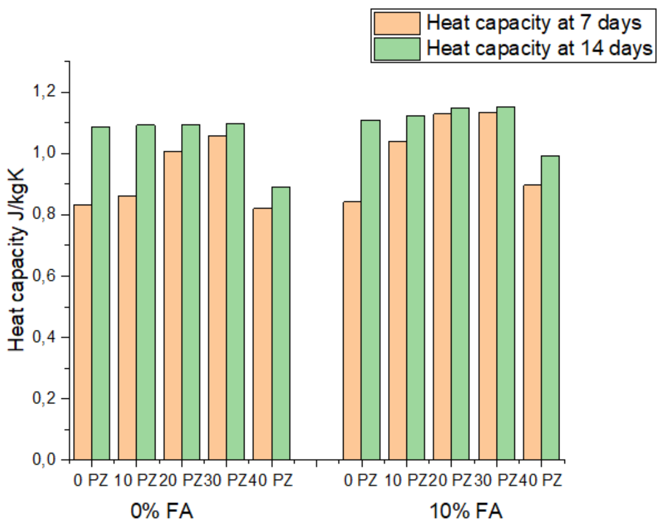

Fig 6. Specific heat capacity of various mixtures with 1%PF

According to Fig 5 and 6, in most mixtures, the thermal capacity of mortars based on natural pozzolan exceeds that of the reference mortar. At 14 days, the thermal capacity increases in accordance with the rate of additions. By incorporating pozzolan, there was a notable increase in thermal capacity, rising from 0.83 to 1.24 J/KgK. However, the inclusion of fly ash slightly reduces the heat storage of the mortars. Nonetheless, the inclusion of plastic fibers restores and enhances the thermal capacity.

4 Discussion

4.1 Thermal conductivity

The Fig 3 and 4 clearly demonstrates the decrease in thermal conductivity as natural pozzolan (PZ) is added. The inclusion of fly ash further contributes to the reduction in thermal conductivity. This can be ascribed to the inherently low thermal conductivity of natural pozzolan (0.075 W/mK) compared to cement mortar (1.4 W/mK)[23] [24]. Sisman [25], support the finding that thermal conductivity decreases with increasing natural pozzolan content.

The addition of plastic fiber has a significant effect on the thermal conductivity of mortars. This reduction can be ascribed to the poor heat conductivity of plastic (0.15 W/mK)[26].

In line with existing literature[27], [28], it is observed that for a 10% replacement of fly ash (FA), there is a 10% reduction in thermal conductivity compared to the control mortar when using 40% natural pozzolan and 1% plastic fibers. It is important to note that lower thermal conductivity corresponds to higher thermal resistance in materials.

4.2 Heat capacity

In the majority of mixtures, mortars based on natural pozzolan exhibit higher thermal capacity compared to the reference mortar. This indicates an improvement in the heat storage capacity when cement is mixed with pozzolan, as demonstrated in the study conducted by Yasemin [29]. However, the addition of fly ash and plastic fibers only results in marginal enhancements to the thermal capacity.

It is important to note that a higher thermal capacity in a material indicates a greater ability to store heat energy.

5 Conclusion

The thermal properties of mortars can be assessed through the application of the transient plane method, enabling the determination of thermal conductivity and specific heat capacity values. In this study, the focus is on evaluating the effectiveness of composite mortars that incorporate locally sourced natural pozzolan, fly ash, and plastic fibers. The investigation aims to shed light on the impact of these materials on the thermal characteristics of the mortars.

The findings of the study lead to a compelling conclusion: the utilization of natural pozzolan, fly ash, and plastic fibers as substitutes for cement in the production of eco-friendly and insulating materials proves to be an optimal solution from both economic and environmental perspectives. Notably, these materials are abundantly available, ensuring their accessibility and viability for widespread use. By employing these substitutes, the study highlights the potential for reducing the environmental impact associated with cement production while promoting more sustainable construction practices.

Overall, the research emphasizes the significance of utilizing natural pozzolan, fly ash, and plastic fibers to create composite mortars with improved thermal characteristics. This approach offers a promising avenue for enhancing energy efficiency, reducing carbon footprint, and advancing environmentally friendly building materials.

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