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Characterization of Hammam Boughrara Perlite for Thermal and Acoustic Insulation Feasibility in Concrete for Sustainable Building Materials

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Abstract
Perlite is a material widely used in the construction industry to enhance insulation performance of materials building. The current study investigates the feasibility of recycling Hammam Boughrara perlite as building material for enhanced thermal and acoustic insulation of concrete. This research investigates all properties affecting the performance of concrete, including durability, tensile strength, and compressive strength, through a range of mechanical, physical, and chemical tests with a mixture ratio involving raw perlite. It highlights the exceptional insulating properties of perlite, its lightness, and its environmentally friendly nature. The methodology used is detailed, along with the research objectives and expected results. Also, this work provides an overview of the knowledge to be gained and helps to better understand the benefits of using perlite in the field of thermal and acoustic insulation of concrete. Thermal treatment of mortar samples took place at various temperatures including 200°C, 400°C, and 600°C, followed by tests including thermal conductivity, ultrasonic pulse velocity, and compressive strength. Confirmed that addition of perlite increased insulation power of concrete yet allowed sufficient integrity for extreme conditions. The importance of this research lies in its contribution to both: the insulation potential of perlite which responds to the needs of the architectural community in modern building activity, and in addition the economic valorization of natural components found in the immediate surroundings. The results illustrate the opportunity for identification of green, energy-efficient, and lightweight building materials designed to meet environmental issues and regional social-economic demands.
Keywords: Raw perlite. Mortar. Concrete. Pozzolana. Thermal conductivity. Ultrasound. Compressive strength.

1. Introduction

Perlite is a material widely used in the construction industry to enhance the thermal and acoustic insulation of materials such as concrete (Alexa-Stratulat et al., 2024a; Hrbek et al., 2016; Kapeluszna et al., 2021; Kotwica et al., 2016; L. Wang & Wang, 2024; X. Wang et al., 2021)(García-Vera et al., 2018).

Perlite is an amorphous volcanic glass that expands to multiple times its original volume, when it is heated. Its properties, such as low density, high porosity, thermal insulation, and pozzolanic activity, have gained attention in concrete technology for lightweight and specialized concrete applications (Demirboğa et al., 2001; Fletcher et al., 2007; Lanzón & García-Ruiz, 2008; Sengul et al., 2011; Top et al., 2020; Topçu & Işikdağ, 2008).

The expanded form of perlite is commonly used as a lightweight aggregate in concrete, significantly reducing its density without drastically compromising compressive strength. Lightweight perlite concrete is beneficial in prefabricated panels, high-rise buildings, and especially bridge decks (Okuyucu et al., 2011; Sengul et al., 2011; Tawfik et al., 2024; L. Wang & Wang, 2024).

The high porosity of expanded perlite causes excessive water absorption, which can change the water-to-cement ratio and impair the workability and strength of concrete (García-Vera et al., 2018; Giarma et al., 2024; Guenanou et al., 2019, 2019, 2019; Kapeluszna et al., 2020; Li et al., 2004; Thanaraj et al., 2020).

Through this study, we aim to specifically characterize Hammam Boughrara perlite by closely examining its physical, chemical, and mechanical properties. The ultimate goal is to determine the potential of this raw perlite as an effective and durable insulator (Davraz et al., 2020, 2020; Guenanou et al., 2019; Pichór et al., 2015; L. Wang & Wang, 2024).

In a context where the demand for advanced insulation materials is constantly increasing, it is essential to meet the growing requirements for building energy efficiency and acoustic comfort. A comprehensive understanding of the unique properties of Hammam Boughrara perlite could contribute to the development of innovative new applications in insulation, thus offering sustainable and environmentally friendly solutions for the construction industry (Alexa-Stratulat et al., 2024a, 2024b; Chen & Ni, 2018; Giarma et al., 2024; Rashad, 2016; Thanaraj et al., 2020; Xiong et al., 2021).

In parallel, this study also holds significant importance for the valorization of local natural resources and the promotion of socio-economic development in the Hammam Boughrara region. By better understanding the perlite from this area, we can contribute to the creation of new economic opportunities and improve the living conditions of the local population.

2. Materials Used

The different concrete compositions used are provided in Table 1. Concrete consists of cement, sand, raw perlite aggregates (Figure 1), and water.

Table 1 – Composition of concretes

	Concrete constituents			
Dosage	**Sand 0/3(Kg)**	**Perlite 3/8 (Kg)**	**Ciment (Kg/m^3)**	**Mixing Water (L)**
G1	60	920	150	75
G2	330	650	200	120
G3	750	350	300	180

2.1. Perlite

Perlite is a natural volcanic rock formed from siliceous lava. Due to rapid cooling, the lava solidifies into a glassy rock. Over tens of thousands of years, perlite softens when it reaches temperatures between 850 and 900°C. The water trapped within the material's structure vaporizes and escapes, causing the material to expand by 4 to 20 times its original volume (Figure 1).

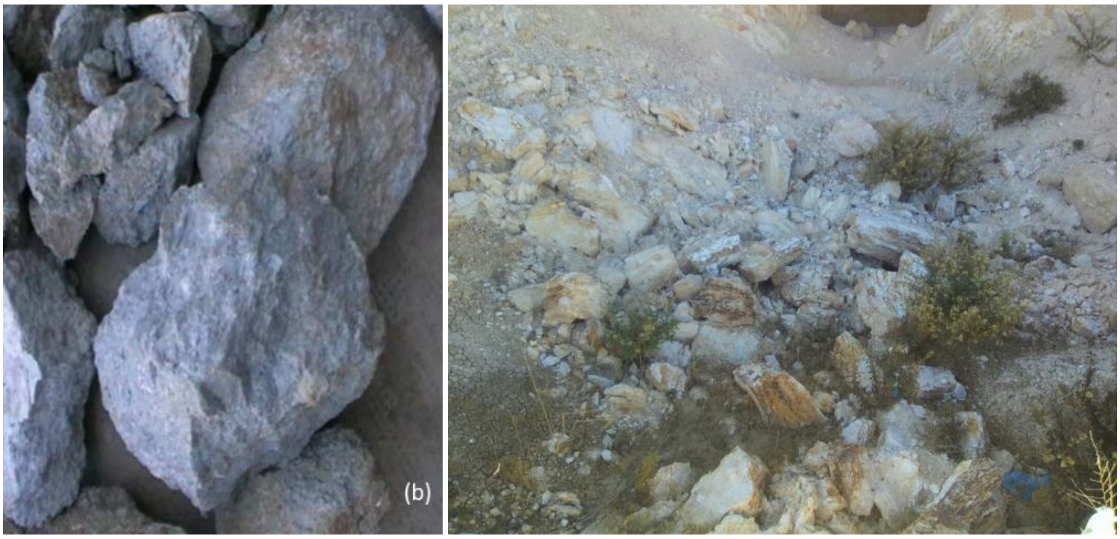

Figure 1 – The Figure 1. Raw perlite from Hammam Boughrara

2.2. Thermal Treatment

The various samples underwent thermal treatment to observe the behavior of perlite aggregates under the effects of temperature (Belhadj et al., 2023; Hager, 2013; Mohammed Belhadj et al., 2016). The following graph (Figure 2) shows the temperature cycle used in this study.

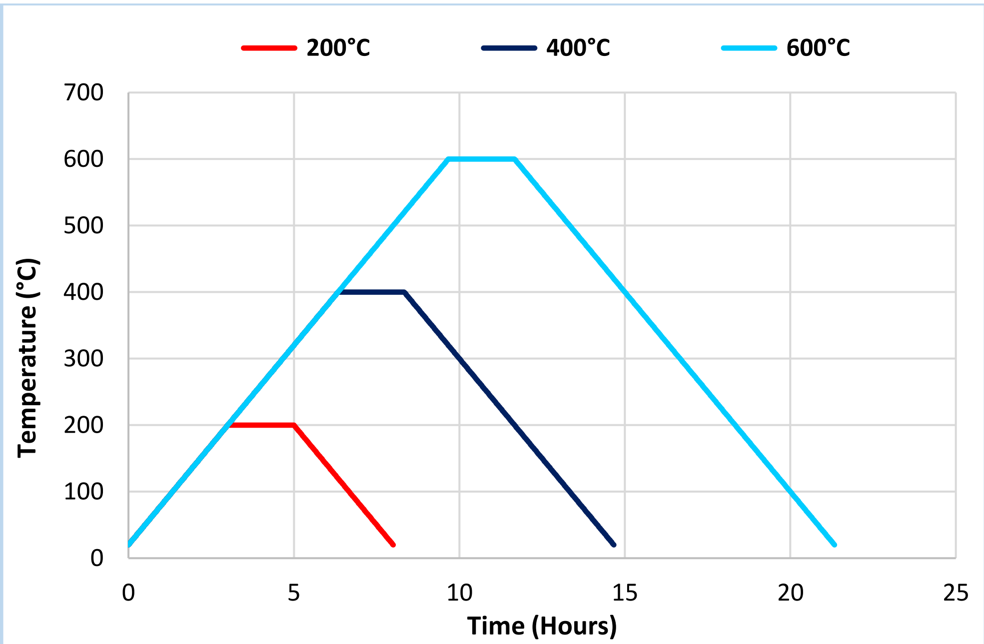

Figure 2 – Figure 2. Heating and cooling cycle

3. Results

Several tests were conducted on the different concrete samples, including compressive strength tests, thermal conductivity tests, and ultrasound tests.

3.1. Compressive Strength

The compressive strength tests of the concretes yielded the following results:

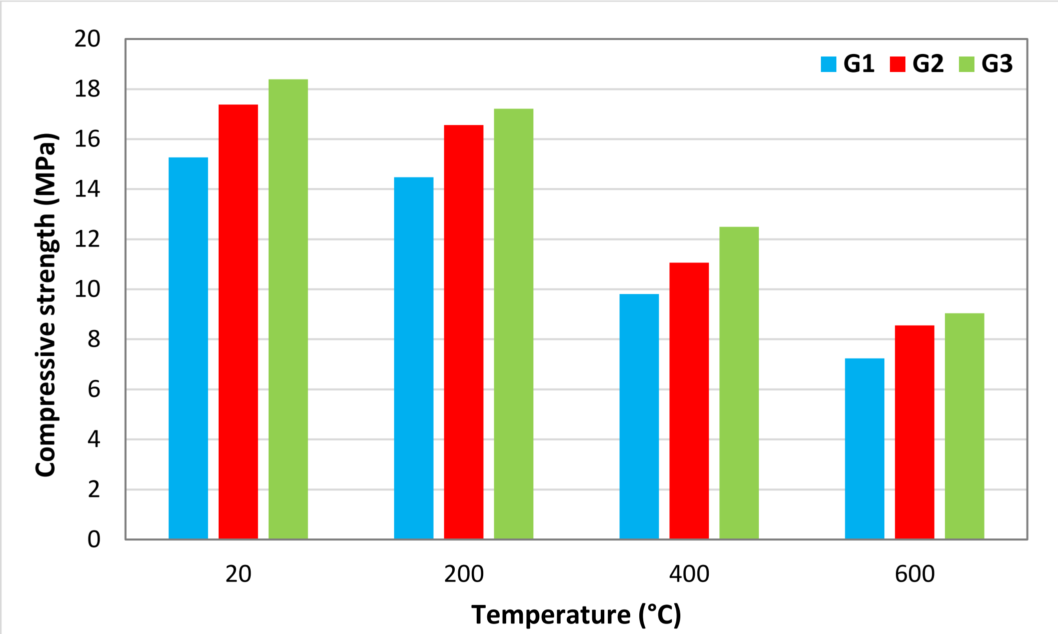

Figure 3 – Compressive strength of concrete as a function of temperature

From Figure 3, we compared the strengths of concrete at different ages for the three types of samples as a function of temperature. It was observed that the different types of concrete experienced a decrease in strength due to damage caused by temperature elevation, particularly at 600°C, where the reduction reached approximately 50% compared to ambient temperature strength (Bahrami & Nosier, 2007; Hager, 2013).

It was also noted that the mix G3 produced better results compared to other mixes, which is logical given its cement dosage of approximately 300 kg/m³.

3.2. Thermal Conductivity

The higher the thermal conductivity of a material, the more it conducts heat and the less it insulates. Thermal conductivity primarily depends on the nature of the material and temperature, but other factors such as humidity and pressure also play a role.

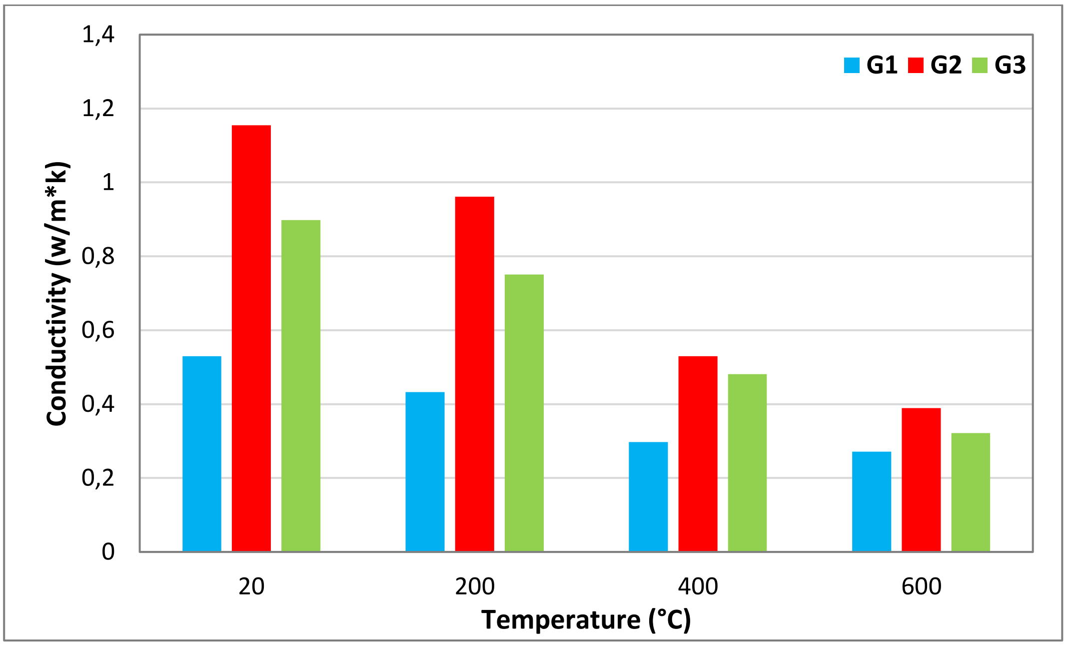

Figure 4 – Thermal conductivity of concrete as a function of temperature

From Figure 4, it was observed that thermal conductivity decreased with temperature, which indicates that at 600°C, the concrete exhibited good thermal conductivity. This can be attributed to the presence of raw perlite. Additionally, it was noted that the G1 mix containing more perlite produced concrete with better thermal conductivity, indicating good insulating properties.

3.3. Ultrasound

The principle of the ultrasound method involves measuring the propagation time of ultrasonic pulses through the concrete of a structure without sampling by coring.

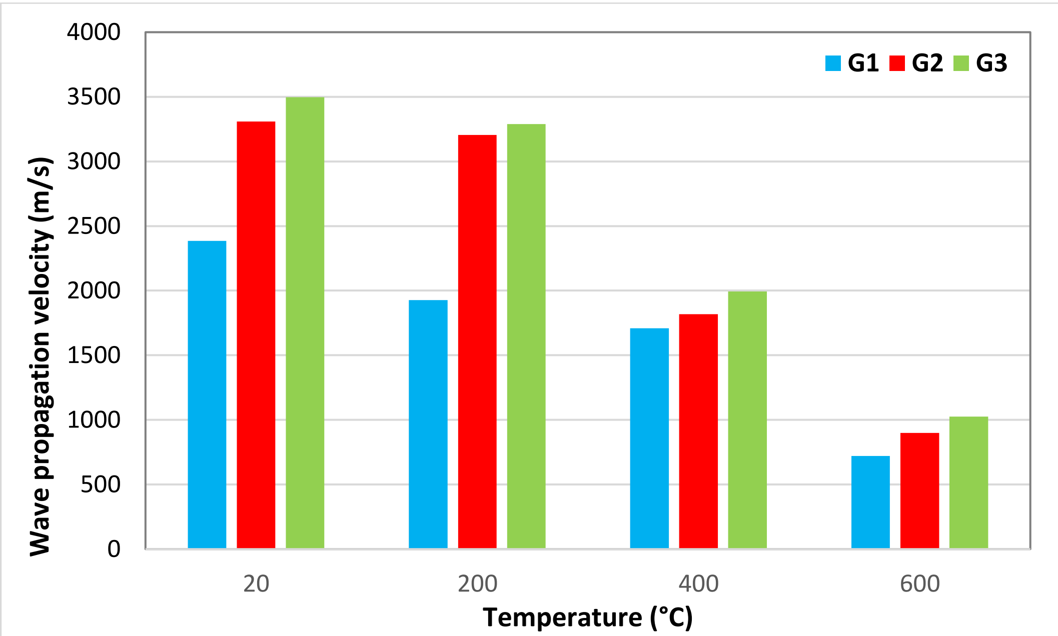

Figure 5 – Wave propagation velocity in concrete as a function of temperature

Research indicates a direct relationship between wave propagation velocity in concrete and its quality. Table 3 provides a classification:

Table 3 – Concrete quality as a function of ultrasonic wave propagation velocity

Concrete Quality	Wave Propagation Velocity (m/s)
Excellent	> 4200
Good	3700-4200
Doubtful	3200-3700
Poor	2500- 3200
Very Poor	< 2500

From Figure 5, a variation in wave propagation velocity was observed depending on the type of concrete. Referring to Table 3, it was noted that concrete at ambient temperature exhibited good quality in terms of strength. However, in terms of insulation, the thermally treated concretes yielded better results. This can be explained by the presence of perlite in these concretes and the effect of temperature on raw perlite, leading to its expansion and subsequent improvement in insulation characteristics.

4. Conclusion

This study allowed us to draw the following conclusions:

- The use of raw perlite in concrete production is a major advantage due to the insulating properties provided by raw perlite, particularly under extreme conditions such as during a fire.
- Dynamic auscultation tests are extremely effective for concrete quality control, particularly for assessing homogeneity and detecting cracks or internal imperfections. However, their use for resistance evaluation remains dependent on numerous parameters, with a deviation of approximately 40% between actual resistance and estimated resistance using this method, which remains significant.
- Laboratory experiments revealed that raw perlite is a natural insulating material capable of completely replacing quarry gravel to produce lightweight concrete with thermal and acoustic insulation properties.

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