Building Engineering 2025, 3(1), 1739.
https://doi.org/10.59400/be1739

Article

Effect of natural pozzolana, pozzolanic sand, and basalt on thermal and mechanical properties of green concrete

Moustafa Wassouf*, **Jamal Omran, Ali Kheirbek**

Department of Construction Management, Faculty of Civil Engineering, Tishreen University, Lattakia 041, Syria
*** Corresponding author:** Moustafa Ali Wassouf, moustafa.wassouf@tishreen.edu.sy

CITATION

Wassouf MA, Omran JY, Kheirbek A. Effect of natural pozzolana, pozzolanic sand, and basalt on thermal and mechanical properties of green concrete. Building Engineering. 2025; 3(1): 1739. https://doi.org/10.59400/be1739

ARTICLE INFO

Received: 18 September 2024
Accepted: 22 October 2024
Available online: 8 November 2024

Abstract: Green concrete, also known as sustainable concrete, is a building material that aims to reduce environmental impact by using natural, recycled, or sustainable materials in its production. One way to achieve sustainability in concrete is to replace cement with pozzolanic materials, which not only reduces the carbon footprint but also improves the performance of concrete and reduces its cost. This study aims to use natural materials that can partially or completely replace cement and conventional aggregates in concrete mixes. pozzolanic gravel (GPoz) replaced coarse aggregate, basaltic sand (SBas) and pozzolanic (SPoz) replaced fine aggregate, while ground pozzolana (PN) replaced cement. This work focuses on the experimentation and simulation of concrete mixes using the four abovementioned materials. 36 cubes were cast to conduct the thermal conductivity test by direct exposure of concrete samples, where an insulated thermal chamber was designed from thermal bricks, equipped with a heat source from the bottom and an empty space for the tested sample from the top, and then the resistance test on simple pressure was conducted for the cubic samples at the age of 28 days. Pozzolanic aggregate, when used in combination with basalt sand, showed greater thermal resistance compared to conventional concrete. Even with the replacement of 50% of the cement with ground pozzolana, we notice an increase in resistance of more than 11%, but with the replacement of basalt sand with pozzolana sand, we notice an increase in thermal resistance of more than 53%. As for the mechanical properties represented by resistance on simple pressure, we notice an acceptable decrease in resistance when replacing cement with pozzolana, with the exception of mixtures containing aggregates and pozzolana sand together, where replacing 50% of the cement with pozzolana increases the resistance on simple pressure by more than 46.4%.

Keywords: sustainable materials; natural pozzolana; green concrete; basalt; thermal conductivity; resistance to simple pressure; thermal resistance; thermal

1. Introduction

Energy consumption in the world is increasing, and, therefore, a need for taking into consideration the ongoing energy crisis and the impact it has on the environment is present. In terms of energy demand, the built environment is a net consumer of energy, demanding over 36% of the global energy and upwards to 50% of raw materials worldwide. In terms of the environmental impact, buildings are responsible for over 39% of the global greenhouse gas emissions [1,2].

Cement, the main ingredient in concrete, is produced by heating limestone and other raw materials to high temperatures, which releases large amounts of carbon dioxide into the atmosphere. It is estimated that 1 ton of Portland cement produces 0.96 ton of CO_2, and 1 ton of concrete produces 0.108 ton of CO_2. According to experts, the concrete industry is responsible for 7% to 9% of the global greenhouse gas emissions [3,4].

Hence, the need for new methods and approaches to deal with the energy crisis and reduce the negative environmental impacts caused by the construction industry. One of these approaches is to rely on environmentally friendly building materials such as green concrete, also known as sustainable concrete, which is a building material that aims to reduce environmental impact by using natural, recycled, or sustainable materials in its production [5,6]. One way to achieve sustainability in concrete is to replace cement with pozzolanic materials [7], which not only reduces the carbon footprint but also improves the performance of concrete and reduces its cost.

Sustainable materials have captured a great deal of attention from both construction industry professionals and the public as a result of the growing importance of sustainability in construction. So concrete should take the lead in the sustainable growth of the construction sector because it is one of the main building materials used globally [8]. Recently defined by the International Concrete Sustainability Council (CSC), green sustainable concrete is “concrete that increases resource efficiency and reduces environmental impact while enhancing performance and durability. (Source: CSC). It is noteworthy that it is concrete that uses waste materials in at least one of its components during the production process. It is described as an environmentally friendly concrete with high performance and life cycle sustainability.

The three main objectives of the “green” approach to concrete are the reduction of greenhouse gas emissions, the use of natural resources, and the incorporation of waste materials into concrete [9], as this concrete is produced from waste such as slag, waste from power plants, recycled concrete, metal waste, glass waste, incinerator residues, burnt soil, sawdust, combustion ash, etc. With green concrete, all stages of concrete construction are considered, including design, features, construction, and maintenance [10]. **Table 1** below shows the basic composition of conventional concrete and its replacement with green concrete:

Table 1. Results of measuring the apparent and solid volumetric weights of the tested pebbles.

	Raw materials	**Replacement of concrete materials**
1	Bonding dough	Solid fly ash, recycled glass, silica smoke
2	Coarse aggregate (gravel)	Waste recycling, waste prepared for mixed concrete, glass waste
3	Fine aggregate (sand)	Fine recycled aggregate, demolished brick waste, mine dust, marble powder waste

By using alternative binders or reducing the amount of cement in the mixture, the carbon footprint of concrete can be significantly reduced. Studies have shown that the use of alternative binders such as fly ash or slag can reduce the carbon footprint of concrete by up to 80% compared to traditional Portland cement mixtures [11]. Studies have also proven that reducing the amount of cement in concrete can lead to more sustainable environmental properties [12], that is, when concrete is produced with fewer cement materials, we have reduced the potential environmental impact of carbon emissions.

Pozzolana can be defined as siliceous and aluminous materials that do not individually have binding qualities, but when finely ground and in the presence of water, they react chemically with the presence of calcium hydroxide $Ca(OH)_2$ at normal temperatures to form compounds with binding properties. Pozzolana may be found in nature as volcanic ash, opaline shales, rocks trays (cherts), or prepared industrially such as burnt clay and coal ash. It is provided that the silicates contained in pozzolana are in amorphous form because the effectiveness of crystalline silicic oxides is low. Pozzolanic materials reduce the rate of rapid acquisition of resistance to concrete in the early times and increase it in the late age, which in turn reduces the speed of rehydration heat emission [13]. Some researchers have studied the effect of replacing Portland cement with ground pozzolana on the simple pressure resistance of bituminous cubes with dimensions of 15 × 15 × 15 cm, where different replacement ratios of 10%, 20%, 30%, and even 50% have been studied. The further increase in replacement led to an increase in compressive strength until the maximum strength was reached when replacing OPC by 30%, and with an increase in this percentage, the resistance to simple compaction decreased, and it was also noticed that the strength of concrete increases with age [14].

The use of natural pozzolans leads to a reduction in carbon dioxide emissions associated with Portland cement production. Replacing 50% of Portland cement with natural pozzolan means halving greenhouse gas emissions in cement production [15].

Previous research has shown the importance of using natural pozzolana as a substitute for siliceous sand in the production of lightweight cement mortar with a resistance to simple pressure ranging from 170–400 kg/cm^2 and a lower density (1920 kg/m^3). The results showed that the use of natural pozzolana offers a set of features, the most important of which is reducing the density of the mortar and then producing a light mortar that can be used in structural elements when its resistance to simple pressure exceeds 170 kg/cm^2 [16].

This research deals with the study of replacing Portland cement with ground pozzolana according to different replacement ratios ranging between 10%, 30%, and 50%, as most research studies discuss the effect of replacing Portland cement with factory waste materials such as fly ash and furnace slag and their effect on mechanical properties in the presence of natural materials that can be used as an alternative to Portland cement. Another section of studies did not address the study of the thermal effect of concrete manufactured from pozzolanic materials and gravel, which constitutes a knowledge gap that this research attempts to fill. In addition, the combination of these materials (pozzolana and basalt) in the binding paste and gravel structure to produce environmentally friendly concrete is considered new and unusual, as the objectives of the research are summarized in studying the physical properties (thermal conductivity) and mechanical properties (resistance to simple pressure) of green concrete produced from natural materials with the aim of reducing the environmental footprint and improving thermal performance.

The research paper was organized to include first a description of the materials used and the laboratory experiments that were conducted on them, including measuring the solid and apparent volumetric mass, in addition to measuring the sand equivalent to ensure its cleanliness before using it in the mixtures and conducting granular gradation experiments for the gravel, i.e., separating the different sizes of the sample from each other to determine the extent of the volumetric distribution of the gravel particles. After that, the mixtures were designed using the method (Dreux-Goriss) and clarifying the mixing ratios for each of the three groups with variable parameters in each mixture, then the samples were poured into the mold with dimensions (10 × 10 × 10 cm) and unscrew it the next day and put the samples in the water for 28 days in preparation for both thermal and mechanical resistance empirical tests, and ended with a presentation of the results and discussions. **Figure 1** shows a schematic diagram of the investigation.

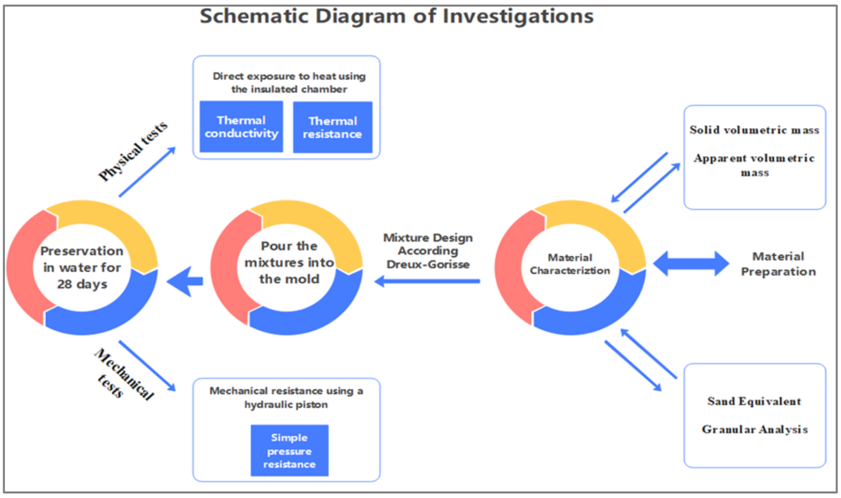

Figure 1. shows a schematic diagram of investigation.

2. Materials and methods

To investigate the possibility of producing sustainable concrete using pozzolanic aggregates, basaltic sand, and pozzolanic sand in the aggregate structure with replacement of Portland cement by ground pozzolana in the binding paste in proportions up to 50%, a series of laboratory experiments were conducted, where different concrete mixes were prepared using varying proportions (10%–50%) of ground pozzolana as replacement of Portland cement and natural aggregates with basaltic and pozzolanic aggregates. Then the mechanical and physical properties of the resulting concrete mixes were tested, including compressive strength and thermal conductivity.

All parameters were stabilized with a change in the gravel structure at the group level. The first group (natural gravel), the second group (pozzolana gravel with basalt sand), and the third group (pozzolana gravel and sand). The only variable at the level of one group is the ratio of cement replacement with ground pozzolana in the bonding paste, where the performance of concrete mixtures of each of the three groups was compared with the performance of conventional concrete mixtures to assess the effectiveness of the use of pozzolana in the production of ecological concrete.

The research was based on the experimental approach to study the effect of using natural pozzolana and basalt on concrete samples manufactured from these materials, using analytical and mathematical methods to study the changes in mechanical and physical indicators with different replacement ratios of Portland cement with pozzolana and natural aggregate with pozzolanic and basalt aggregate. For this purpose, the concrete samples from all mixtures were subjected to physical and mechanical tests for cubic samples with dimensions of 10 × 10 × 10 cm. The thermal conductivity test was conducted by directly exposing the concrete samples to heat using an insulated thermal chamber made of thermal bricks with dimensions of 10 × 10 cm and a height of 20 cm. The chamber was equipped with a heat source at the bottom and an empty space at the top for the tested sample. The design of the chamber and the heat source allowed heating the sample from one side only to measure the heat transfer from this side to the other side after a period of time. Subsequently, a resistance test was carried out on the simple compressive strength of the cubic samples at the age of 28 days.

3. Results and discussion

A sufficient amount of Syrian natural pozzolana was brought from the "Tel Shihan" site located about 70 km southeast of Damascus and 15 km northwest of Sweida governorate, which is widely covered by Hurriya al-Sham, a volcanic field with an area of about 45,000 km^2 covering parts of Jordan and Saudi Arabia [17]. Therefore, the natural pozzolana found at the Tel Shihan site is of volcanic origin. The main oxides that make up NP are as follows: SiO_2: 44.9%, Al_2O_3: 16.5%, Fe_2O_3: 8.9%, Cao: 9.6%, MGO: 8.4%, and alkali oxides: 4.4%, in order to be processed in a laboratory before being described and used in the process of manufacturing laboratory samples [18]. **Table 2** shows the results of measuring the apparent and solid volumetric weights of the materials used in the manufacture of concrete cube models.

Table 2. results of measuring the apparent and solid volumetric weights of the tested pebbles.

Solid volumetric mass kg/L	Virtual volumetric mass kg/L	The sample
1.728	0.705	Pozzolanic gravel
2.32	1.257	Pozzolanic sand
2.374	1.127	Basalt sand
2.55	1.338	Fine sand
2.68	1.57	Coarse sand
2.74	1.439	Natural gravel

The sand equivalent values for the types of sand used were 85% for fine siliceous sand originating from Nabk, 68% for coarse calcareous sand, pozzolan sand 84%, and basalt sand 88%. Ordinary Portland cement of Type 1 and Class 32.5 from the Tartus plant was used for pouring concrete. **Figure 2** shows the different types of fine and coarse gravel, cement, basalt, and pozzolana used in mixtures:

Figure 2. Materials used in concrete mixtures.

For the preparation of laboratory models of green concrete, the mixture had to be designed based on the results of grain grading of natural, pozzolanic, and basalt aggregates. The French design method (Dreux-Goriss) was adopted. Below we show the design stages of these mixtures and the final proportions obtained for the various mixtures. 12 concrete mixtures were adopted, divided into three groups with different replacement ratios for each of the aggregates (natural, pozzolanic, and basalt), as well as the replacement of cement with ground pozzolana in the following weight ratios (10%, 30%, 50%). **Figure 3** shows grain grading curves for gravel used in concrete mixtures.

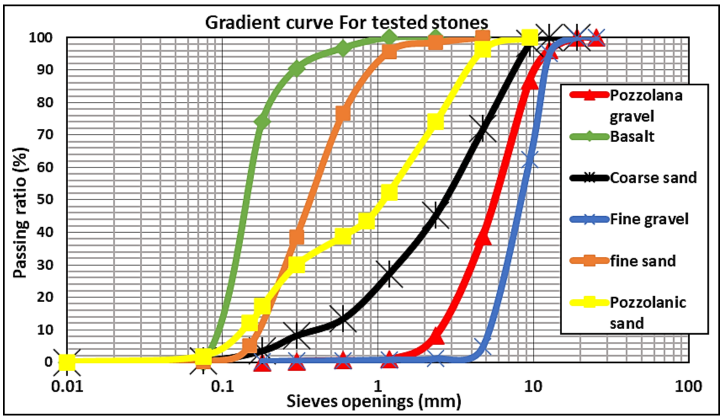

Figure 3. Grain size distribution curve for the tested pebbles.

The ratio of water to cement was fixed in each group of mixtures to prevent interference of parameters affecting the properties of the resulting concrete, and the ratio was adopted $W/C = 0.6$ and also $G = 0.35$, gravel coefficient, air volume 10 L/m^3. We show below the composition of some of these mixtures:

1) Mixture (NC) consists of 100% Portland cement and natural aggregates.
2) The mixture ($GCP_{10\%}$) consists of 90% Portland cement, 10% pozzolana, and natural aggregates.
3) Mixture (NC_{PS}) consists of: 100% Portland cement, 100% pozzolana aggregates, and 100% pozzolana sand.

4) The mixture ($GCS_{P10\%}$) consists of 90% Portland cement, 10% pozzolana, 100% pozzolana aggregates, and 100% pozzolana sand.
5) Mixture (NCP) consists of: 100% Portland cement, 100% pozzolana aggregates, and 100% basalt.
6) The mixture ($GCP_{P10\%}$) consists of: 90% Portland cement, 10% pozzolana, 100% pozzolanic aggregates, and 100% basalt.

It turns out **Tables 3–5** of the results of the design of concrete mixtures:

Table 3. Results of designing mixtures for the first group for 1 m^3.

Mixture components (kg/m^3)	Mixtures of the first group			
	NC	$GCP_{10\%}$	$GCP_{30\%}$	$GCP_{50\%}$
Normal average stones	1042	1042	1042	1042
Fine sand	390	390	390	390
Lenticular coarse sand	385	385	385	385
Pozzolana	0	35	105	175
Cement	350	315	245	175
water	210	210	210	210

Table 4. Mixture design results for the second group for 1 m^3.

Mixture components (kg/m^3)	Mixtures of the second group			
	NCP	$GCP_{P10\%}$	$GCP_{P30\%}$	$GCP_{P50\%}$
Lenticular coarse sand	385	385	385	385
Pozzolana	0	35	105	175
Cement	350	315	245	175
Water	210	210	210	210
Pozzolanic gravel	665	665	665	665
Basalt sand	352	352	352	352

Table 5. Mixture design results for the third group for 1 m^3.

Mixture components (kg/m^3)	Mixtures of the third group			
	NC_{PS}	$GCS_{P10\%}$	$GCS_{P30\%}$	$GCS_{P50\%}$
Pozzolanic sand	680	680	680	680
pozzolana	0	35	105	175
Cement	350	315	245	175
Water	210	210	210	210
Pozzolanic gravel	665	665	665	665

In casting bionic mixes, we relied on manual mixing, where each component of the dry mix was weighed independently, and then the molds were cast with dimensions (10 × 10 × 10 cm) as in **Figure 4** and unscrewed the next day and put the samples in water for 28 days. The samples were poured into molds in two layers using the shaking table. Then levelling the surfaces of the samples in preparation for their subsequent preservation in water.

Figure 4. Casting samples in molds.

3.1. Physical properties of concrete

These properties included thermal conductivity by the method of direct exposure to cubic concrete samples, as in **Figures 5** and **6**, and **Table 6** showing the results of thermal conductivity of the three groups:

Figure 5. Measuring the deference in temperature for the first group of mixtures ($GCS_{P50\%}$).

Figure 6. Measuring the deference in temperature for the first group of mixtures ($GCS_{P30\%}$).

Table 6. Results of measuring thermal conductivity of concrete mixtures.

The mixture	Thickness (m)	Change in temperature (°C)	Amount of thermal energy transferred (W)	Thermal conductivity *λ* (W/mk)	Thermal resistance *R* (mk/W)
NC		66	37.37	1.102	0.907
GCP10%		64	36.85	1.093	0.915
GCP30%		64	36.64	1.087	0.920
GCP50%		64	35.52	1.054	0.949
NCP		76	22.23	0.637	1.570
GCPP10%		74	22.45	0.647	1.546
GCPP30%	0.1	67	20.41	0.600	1.666
GCPP50%		65	19.48	0.576	1.735
NCPS		137	25.12	0.613	1.632
GCSP10%		108	20.88	0.548	1.825
GCSP30%		77	15.12	0.432	2.315
GCSP50%		68	13.66	0.401	2.496

Figure 7 shows the relationship between thermal resistance and the percentages of cement replacement with pozzolana for the three concrete mixtures:

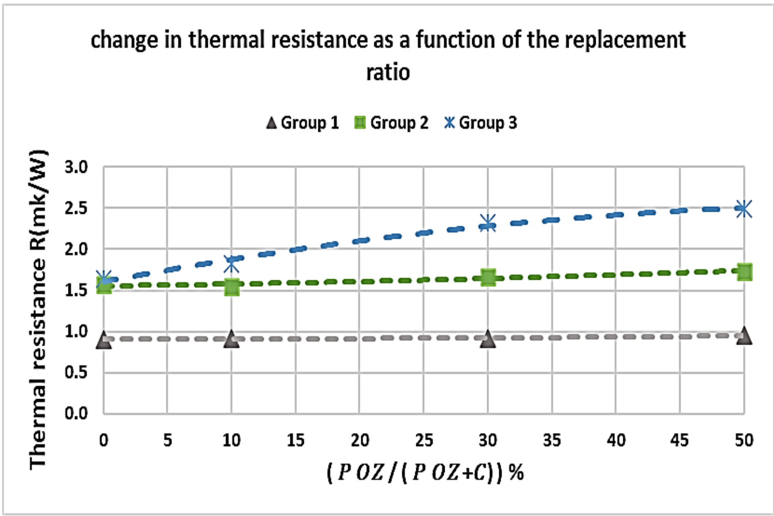

Figure 7. Change in thermal resistance as a function of replacement ratio.

From the results, it can be noted that with an increase in the percentage of replacing cement with pozzolana, the thermal resistance of concrete increases. Replacing cement with an equal mass of pozzolana leads to a decrease in thermal conductivity by 5% when using natural pebbles. As pozzolana pebbles appear when used with basalt sand, thermal resistance is greater compared to the samples of the first group. Even with the replacement of 50% of cement with ground pozzolana, we note an increase in resistance of more than 11%, but with the replacement of basalt sand with pozzolana, we note thermal resistance increased by more than 53%, as the thermal resistance of these samples reached 2.496 mk/W.

The reason is that the pozzolan pebbles used in the mixtures of the second and third groups reduce the hoarding of the mixture because its density is lower than natural pebbles (mixtures of the first group), and therefore the porosity increases, that is, its ability to absorb air, which will increase its thermal resistance. In addition, pozzolana is a porous sedimentary rock, where the size of the porous voids reaches 50% of its total volume and are in the form of channels with openings ranging from 3.0 to 0.8 Nm [19].

Comparing the thermal performance between the group containing basalt sand and the group containing pozzolan sand, we note that the grains of basalt sand reduce porosity [20], that is, increase the compactness of the mixture and thus reduce the thermal insulation property, and this is explained by the low values of thermal resistance of the second group compared to the third group. **Figure 8** shows the size of the pores between the mixture containing pozzolan sand and the mixture containing basalt sand.

Figure 8. The size of the pores between the mixture containing pozzolan sand and the mixture containing basalt sand.

3.2. Mechanical properties of concrete

To determine the resistance to the simple pressure of concrete samples, at the age of 28 days, we applied a force to their surface, where the resistance to the simple pressure of the samples is calculated by calculating the pressure force that leads to the collapse of the sample and calculating the surface exposed to that force. **Table 7** shows the results of the simple compressive strength of concrete samples:

Table 7. Results of measuring resistance to simple compression of concrete mixtures.

The mixture	$\left(\frac{POZ}{POZ+C}\right)\%$	Resistance to slight pressure kg/cm^2
NC	0	330
$GCP_{10\%}$	10	244
$GCP_{30\%}$	30	180
$GCP_{50\%}$	50	162
NCP	0	143
$GCP_{P10\%}$	10	132.5
$GCP_{P30\%}$	30	112.5
$GCP_{P50\%}$	50	77.5
NC_{PS}	0	194

Table 7. (*Continued*).

The mixture	$\left(\frac{\mathbf{POZ}}{\mathbf{POZ+C}}\right)\%$	Resistance to slight pressure kg/cm²
$GCS_{P10\%}$	10	186
$GCS_{P30\%}$	30	155
$GCS_{P50\%}$	50	154

We represented the relationship between the cubic resistance of the cast samples (10 × 10 × 10 cm) at simple pressure and the replacement ratios as follows, as shown by **Figure 9**:

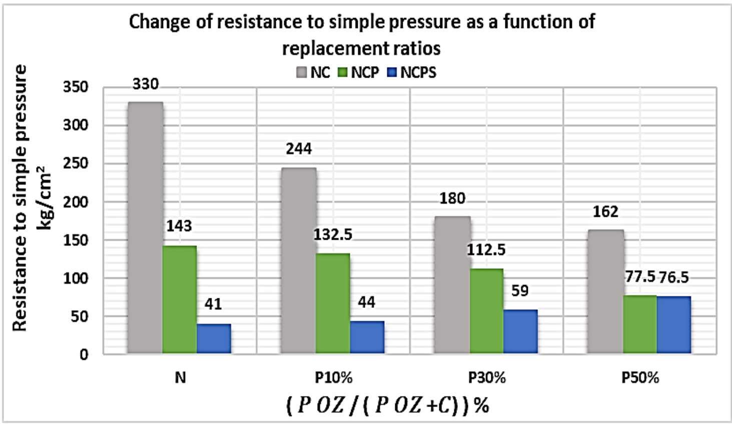

Figure 9. The relationship between the simple pressure resistance of concrete and the replacement ratios.

That natural pozzolanic substances react with calcium hydroxide (which is produced during the hydration of cement) to form additional binding compounds such as calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H). This reaction consumes calcium hydroxide, which reduces the amount available for hydration of cement particles. In addition, the coefficient of effectiveness of ground pozzolana is lower than that of cement. As a result, the resistance to simple pressure decreases when replacing cement with pozzolana, as in the mixtures of the first group (natural pebbles) and the second (pozzolanic pebbles with basalt sand), except for the third group containing pozzolanic pebbles and sand, where with the replacement of 50% of the cement with pozzolana, the resistance to simple pressure increases by more at 46.4% due to pozzolanic sand, as the particle size and distribution also affect the compressive strength of concrete. The appropriate size and distribution of pozzolanic sand particles helps facilitate the wetting process and increases the overall strength of the concrete.

The particle size of pozzolanic substances is important because microparticles have a larger surface area and can react more effectively with calcium hydroxide. Mixing different pozzolanic materials can also adjust the properties of green concrete, such as strength, permeability, and resistance to chemical attack, as well as the use of basalt particles as a substitute for siliceous sand in green concrete to reduce the environmental impact of concrete production. We note that the particle size of basalt aggregates affected the strength of concrete and its thermal conductivity, where smaller particles usually lead to higher strength, but increased the compactness of the mixture and reduced porosity, which negatively affected the physical properties of thermal conductivity.

It is clear that the percentage of replacement of Portland Cement with ground pozzolana in the bonding paste should not exceed 50% because increasing the replacement rate will negatively affect the mechanical properties, which is one of the limitations identified by the study. As for the replacement in the gravel structure, we note that there are no challenges or restrictions imposed by the study.

3.3. Economic analysis

The availability of natural pozzolana in the market plays a crucial role in controlling costs in the construction industry. Pozzolana is a natural volcanic ash that is found in nature and markets in large quantities, with the amount of pozzolana in Syria estimated at about one billion tons [18]. It is a very effective alternative to conventional cement, and offers many benefits such as improved strength, durability and thermal resistance.

An analysis of the prices of materials used in concrete mixes will be conducted in both traditional and environmental cases (complete replacement of gravel with pozzolana or basalt and replacement of 50% of cement with grounded pozzolana in the binding paste) as shown in **Tables 8** and **9**, respectively required to produce one cubic meter of concrete. The price analysis guide presented by the Ministry of Local Administration and Environment in Syria 2024 was relied upon.

The prices of materials included in conventional concrete were graphically represented as in **Figure 10** and compared with the prices of materials included in green concrete as in **Figure 11**.

Table 8. Regular concrete materials price analysis.

Regular concrete materials' price analysis		**Price**	**Ratio**
Materials	Cement price with transportation	595,000 SYP	50%
	Gravel price with transportation	133,000 SYP	11%
	Sand price with transportation	133,000 SYP	11%
Machinery	Mold wages with all supplies	100,000 SYP	8%
Labor	Labor wages	100,000 SYP	8%
Profits and expenses		120,000 SYP	10%
Production cost 1 m^3		1,181,000 SYP	

Table 9. Green concrete materials price analysis.

Green concrete materials' price analysis		**Price**	**Ratio**
Materials	Cement price with transportation	297,500 SYP	59%
	Price of ground pozzolana with transportation	50,000 SYP	10%
	Price of pozzolanic gravel with transportation	15,000 SYP	3%
	Price of pozzolanic or basalt sand with transportation	15,000 SYP	3%

Table 9. (*Continued*).

Green concrete materials' price analysis		**Price**	**Ratio**
Machinery	Mold wages with all supplies	40,000 SYP	8%
Labor	Labor wages	40,000 SYP	8%
Profits and expenses		50,000 SYP	10%
Production cost 1 m^3		507,500 SYP	

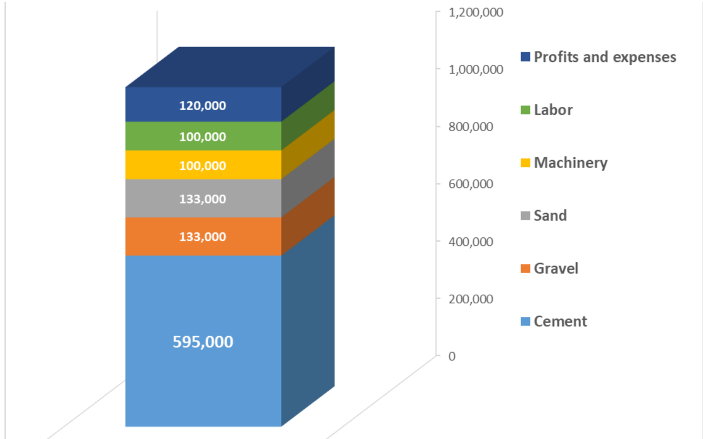

Figure 10. Graphical representation of the prices of materials included in conventional concrete.

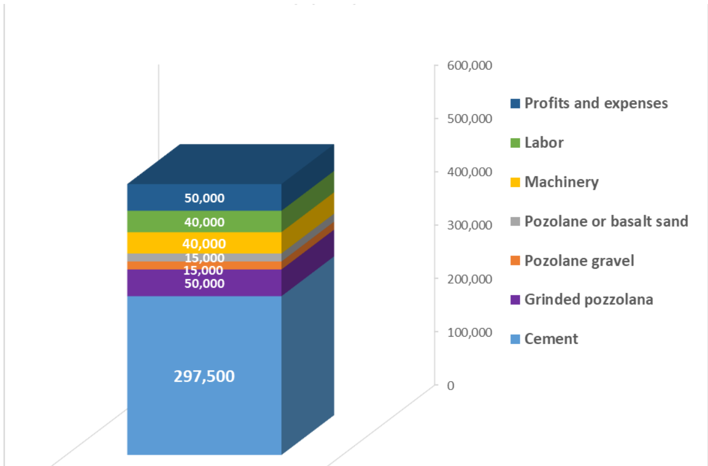

Figure 11. Graphical representation of the prices of materials included in green concrete.

From the results of the analysis of green concrete materials prices, we note that the largest proportion of the cost is due to cement, despite its replacement by 50%. As for the costs of pozzolana and basalt, they are low and are represented only in their transportation costs, while their production costs are zero, unlike Portland cement, which requires processing and burning in a kiln at a temperature of (1200–1300 °C) in addition to the negative impact of its production on the environment represented by carbon emissions [21], which makes its replacement or considering other alternatives a matter of utmost importance.

In conclusion, **Figures 10** and **11** clearly show the significant price difference between materials used in regular concrete mixes and green concrete. The costs of materials such as cement, aggregates, and water are notably lower in green concrete, making it a more economical and sustainable option for construction projects. These results are consistent with recent reference studies, which have also highlighted the cost benefits and environmental advantages of using green concrete [22,23].

4. Discussion and conclusion

In the light of these results obtained by us of the effect of replacing Portland Cement with ground pozzolana and natural pebbles with pozzolanic and basalt pebbles on the physical (thermal conductivity) and mechanical (resistance to minor compression) properties of concrete produced with the aim of reducing the environmental footprint, the following points can be recorded as conclusions of this research:

1) Increasing the percentage of replacement of Portland Cement with natural pozzolana, the thermal resistance of the resulting bitumen increases.
2) Resistances on simple pressure decrease with increasing proportions of cement replacement with ground pozzolana in mixtures.
3) The values of resistance to simple compression of cubic samples exceed the minimum limits of the standard specification for cement blocks; this will allow the manufacture of cement blocks using pozzolanic gravel with the possibility of replacing cement with ground pozzolana according to different replacement ratios.
4) When used with basalt sand, pozzolan gravel showed greater thermal resistance compared to conventional concrete; even with the replacement of 50% of cement with ground pozzolana, we note an increase in resistance of more than 11%, but with the replacement of basalt sand with pozzolan sand, we note an increase in thermal resistance of more than 53%.
5) From the economic aspect Replacing half of the cement in concrete with natural pozzolanic materials can have several economic implications. Since the cost of this material is zero, and therefore the overall cost savings on cement can be significant.
6) The role of pozzolanic and basalt particle size and material blending in green concrete is to optimize the mix design to achieve the desired properties, such as strength, durability, workability, and sustainability. By carefully selecting and blending these materials, concrete producers can create more environmentally friendly concrete mixes that meet performance requirements.
7) One of the main reasons why the availability of natural pozzolana is important is because it helps reduce the overall production costs of concrete. By using pozzolana as a partial replacement for cement, construction companies can lower their expenses on raw materials without compromising on the quality of the final product. This cost-saving measure can significantly impact the overall project budget, making it more feasible for contractors to take on larger and more complex construction projects. Furthermore, the availability of natural pozzolana provides a sustainable solution for the construction industry. Traditional cement production is known to be energy-intensive and environmentally damaging, leading to high levels of carbon emissions and depletion of natural resources. By

incorporating pozzolana into concrete mixes, companies can reduce their carbon footprint and promote eco-friendly construction practices. This not only benefits the environment but also helps meet regulatory requirements and improve the overall reputation of the construction industry.

One of the future research directions we propose to explore the effects of pozzolan materials in green concrete:

1) Studying the long-term durability and performance of concrete incorporating pozzolanic materials under different environmental conditions, such as freeze-thaw cycles and exposure to aggressive chemicals.
2) Investigating the effects of different types and dosages of pozzolanic materials on the properties of concrete, such as compressive strength, permeability, and resistance to cracking.
3) Exploring the potential synergies between pozzolanic materials and other supplementary cementitious materials, such as fly ash, slag, and silica fume, in order to optimize their combined benefits in concrete mix design.
4) Conducting life cycle assessments to evaluate the environmental impact of using pozzolanic materials in concrete compared to traditional cement-based mixes.
5) Developing guidelines and specifications for the use of pozzolanic materials in concrete to ensure consistent performance and quality in construction projects.

In general, we suggest that more research is needed to fully understand the benefits and limitations of incorporating pozzolan materials into green concrete and to optimize their use in sustainable and high-performance construction practices.

Author contributions: Conceptualization, MW and JO; methodology, AK; software, MW; validation, MW, JO and AK; formal analysis, AK; investigation, JO; resources, MW; data curation, AK; writing—original draft preparation, MW; writing—review and editing, MW; visualization, AK; supervision, JO; project administration, AK; conducting laboratory experiments, MW. All authors have read and agreed to the published version of the manuscript.

Conflict of interest: The authors declare no conflict of interest.

References

1. Santamouris, M. and K. Vasilakopoulou, Present and future energy consumption of buildings: Challenges and opportunities towards decarbonisation. e-Prime-Advances in Electrical Engineering, Electronics and Energy, 2021. 1: p. 100002.
2. Омран, Д.Ю. and М.А. Вассуф, Использование информационного моделирования строительных объектов (BIM) с целью изучения ориентации здания при проектировании для достижения их большей устойчивости. Вестник МГСУ, 2024. 19(3): p. 436-455.
3. Andrew, R.M., Global CO 2 emissions from cement production, 1928–2018. Earth System Science Data, 2019. 11(4): p. 1675-1710.
4. Guo, R., et al., Global CO2 uptake of cement in 1930–2019, Earth Syst. Sci. Data Discuss. 2020.
5. Sivakrishna, A., et al., Green concrete: A review of recent developments. Materials Today: Proceedings, 2020. 27: p. 54-58.
6. Xing, W., et al., Life cycle assessment of sustainable concrete with recycled aggregate and supplementary cementitious materials. Resources, Conservation and Recycling, 2023. 193: p. 106947.
7. Alghamdi, H., A review of cementitious alternatives within the development of environmental sustainability associated with cement replacement. Environmental Science and Pollution Research, 2022. 29(28): p. 42433-42451.

8. Ngew, S.H., The Awareness of Green Concrete among Property Developers in Klang Valley. 2018, Tunku Abdul Rahman University College.
9. Das, S., et al., Geopolymer concrete: Sustainable green concrete for reduced greenhouse gas emission–A review. Materials Today: Proceedings, 2022. 60: p. 62-71.
10. Soni, A., et al., Challenges and opportunities of utilizing municipal solid waste as alternative building materials for sustainable development goals: A review. Sustainable Chemistry and Pharmacy, 2022. 27: p. 100706.
11. Althoey, F., et al., Advancements in low-carbon concrete as a construction material for the sustainable built environment. Developments in the Built Environment, 2023: p. 100284.
12. Mohamad, N., et al., Environmental impact of cement production and Solutions: A review. Materials Today: Proceedings, 2022. 48: p. 741-746.
13. Abdullah, H.H., N.A. Al-Saadi, and K.A. Maala, Natural Iraqi pozzolana found in Anjana area, southern Hamrin Mountain, central Iraq. Iraqi Bulletin of Geology and Mining, 2006. 2(2).
14. Osei, D. and E. Jackson, Compressive strength and workability of concrete using natural pozzolana as partial replacement of ordinary Portland cement. Advances in Applied Science Research, 2012. 3(6): p. 3658-3662.
15. Ekolu, S.O., R.D. Hooton, and M.D.A. Thomas, Studies on Ugandan Volcanic ash and Tuff, in Proceedings from the International Conference on Advances in Engineering and Technology, J.A. Mwakali and G. Taban-Wani, Editors. 2006, Elsevier Science Ltd: Oxford. p. 75-83.
16. Kheirbek, A. and N.A. , Study the Influence of Replacement the Aggregates of Mortar with Natural Pozzolana on its Fresh and Hardened Properties. Tishreen University Journal for Research and Scientific Studies - Engineering Sciences Series, 2014. 36(3).
17. al-Swaidani, A.M., Use of micro and nano volcanic scoria in the concrete binder: Study of compressive strength, porosity and sulfate resistance. Case Studies in Construction Materials, 2019. 11: p. e00294.
18. Al-swaidani, A.M., Natural pozzolana of micro and nano-size as cementitious additive: resistance of concrete/mortar to chloride and acid attack. Cogent Engineering, 2021. 8(1): p. 1996306.
19. Bordeian, G.S., Characterisation and properties of alkali activated pozzolanic materials. 2000: Sheffield Hallam University (United Kingdom).
20. Ponzi, G.G.D., et al., Basalt powder as a supplementary cementitious material in cement paste for CCS wells: chemical and mechanical resistance of cement formulations for CO2 geological storage sites. International Journal of Greenhouse Gas Control, 2021. 109: p. 103337.
21. Abdelgader, H.S., et al., Cement kiln dust, in Sustainable Concrete Made with Ashes and Dust from Different Sources. 2022, Elsevier. p. 451-479.
22. Kumar, A. and A. Kumar, Comparative Study on Green and Conventional Concrete. 2024.
23. Yongsheng, J. Costs and Pricing of Green Buildings. 2024. p. 181-191.