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The impact of Jordanian natural zeolite and silica fume on concrete performance sustainability

Tamara Hussein Bani Ata[1*], Asma Thamir Ibraheem[2]
[1,2] Civil Engineering Department, Al-Nahrain University. Baghdad, Iraq; tamara.pciv22@ced.nahrainuniv.edu.iq (T.H.B.A.) asma.th.ibraheem@nahrainuniv.edu.iq (A.T.I.)

Abstract: This study evaluates the combined impact of Jordanian natural zeolite and silica fume as additional cementitious materials (SCMs) on concrete mixtures. A normal mix, special concrete with natural zeolite, and other concrete with zeolite and silica fumes were prepared, focusing on various cement replacement percentages. The research emphasizes sustainability through efficient energy use and environmental preservation. Concrete specimens were tested for tensile splitting, compressive, and flexural strengths at 7 and 28 days to evaluate mechanical properties. Additionally, the study assessed permeability (water absorption), durability (sulfate resistance), and carbon footprint reduction using environmental impact assessment (EIA) methods for better performance investigation. Results showed that a 10% cement replacement with natural zeolite significantly improved permeability and durability compared to the normal mix. In contrast, combining silica fume and zeolite in concrete adversely affected concrete strengths. Microstructural analysis using scanning electron microscopic images and X-ray diffraction analyzed mixture compositions with a significant reduction in microcracks. These results highlight the challenges of SCMs to improve concrete durability and strength in rigid pavement applications, presenting realistic paths for the development of sustainable infrastructure with high-performance concrete.

Keywords: *Concrete Performance and EIA, Jordanian Natural Zeolite, Silica Fume, Sustainability.*

1. Introduction

One of the most often used materials for construction in the world. It is essential in the development of modern structures, infrastructure, and many other applications. The need to create more environmentally friendly concrete mixtures that can lower carbon emissions while preserving performance qualities has grown as a result of the impact on the environment. Concrete's durability is influenced mainly by cement type, aggregate quality, and curing techniques. Moreover, it is a flexible construction resource; it is easily formed into a wide variety of shapes. So, the water-cement ratio, admixture usage, and construction methods all affect how workable it is.

The main construction material utilized in rigid pavement systems is concrete. Rigid pavement, also known as concrete pavement, is one of the most crucial applications of concrete. The surface layer is composed of a concrete slab with Portland cement as composite material formed from cement, aggregates (fine and coarse), and water that mix well together to produce strong, durable, and adaptable material for construction. It has been properly designed and placed due to its long service life, chemical attack resistance, and abrasion wear.

Concrete pavement is preferred because of its durability, low rehabilitation needs, high strength, and long-life service, which are associated with material use, construction, and crack patterns like crack spacing and width. So, high crack spacing has the potential to cause horizontal cracking, and wider cracks result in severe distress. Moreover, long-term shear stress transfer between adjacent slab

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* Correspondence: tamara.pciv22@ced.nahrainuniv.edu.iq

segments is improved by smaller crack widths, which are caused by heavy traffic loads. The applied loads are distributed throughout the underlying foundation layers. It is usually used on runways and highways to control heavy traffic due to its high yield and tensile strength. Rigid pavement design aims to improve concrete slab stiffness and increase the effectiveness of load transfer across cracks.

Airfield pavement consists of a varied layout of structural layers; this arrangement distributes the aircraft's loads and transfers them into the subgrade. Runways are subjected to high mechanical stresses and environmental conditions, so high-performance materials are required to ensure the pavement's life span and durability. Concrete pavement is preferred for runways due to its superior load distribution properties; it is usually applied with reinforcement bars located at the concrete cross-section. The main aim of the airfield runway structure is to balance the internal forces of the slab surface with the variations in loadings to minimize the possibility of random crack formation in the concrete slab and extend its service life.

The growing demand for sustainable, durable, and environmentally friendly concrete, especially in pavements, has led to supplemental cementitious materials (SCMs) use such as silica fume and natural zeolite. This is one of the most applicable pozzolan approaches to use in specific amounts in place of cement in high-stress situations that enhance the sustainability of concrete performance.

Previous research showed that natural zeolite with crystalline aluminosilicate minerals can increase concrete's mechanical properties by improving its pozzolanic reaction. Also, silica fume, a by-product of small particle size and high reactivity of silicon and ferrosilicon, is another SCM that has been extensively studied for its potential to optimize concrete performance and sustainability, which contributes in increasing concrete's strength and resilience with less permeability. So, the individual use of natural zeolite and silica fume has shown promise in improving concrete's mechanical properties and sustainability.

This research evaluates the combined impact of using Jordanian natural zeolite and silica fume materials together on concrete mechanical characteristics and durability performance for a long service time. It sheds light on the best mixture design performance and predicts concrete sustainability as one of the most important revolutions in the construction world through the partial replacement of cement weight. It hasn't been studied yet using this type of zeolite and silica fume in concrete. The chosen research subject addresses a construction demand for sustainable and environmentally friendly concrete applications due to climate change and the carbon footprint phenomenon. The impacts of those supplementary materials on the mechanical properties of concrete were examined through compression, tensile splitting, and flexural tests. In addition, scanning electron microscopic pictures were used to evaluate the microstructure of concrete specimens with those supplementary materials.

2. Literature Review

The use of sustainability in business and operations management is becoming more prevalent among agencies, companies, organizations, institutes, and governments. This concept is to prioritize important environmental, social, and economic aspects while making decisions.

Sustainability has led to quantifying pavement performance in a more structured and systematic manner, so highway infrastructure maintenance, rehabilitation, and expansion need to prioritize sustainability. Yudi, et al. [1] defined pavement sustainability as the ability to attain the engineering standards and requirements in pavement structures and materials, improve the surrounding ecosystems, ensure the economical use of resources, and provide serviceability to users.

Prior research and studies focused on the benefits of using the individual effects of silica fume and natural zeolite as supplementary cementitious substances on concrete behavior for structure sustainability. Najimi, et al. [2] performed natural zeolite as an additional cementitious material to concrete pavement as an extremely effective natural pozzolan. Durability and mechanical concrete properties with natural zeolite were compared to those with fuel ash. They found that compressive strength increased and surface absorption was reduced by zeolite rather than others.

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Tran, et al. [3] studied natural zeolite material in a concrete mixture of pavements. They explained the basic characteristics and structural properties of natural zeolite and how it can be used as pozzolan in the construction of concrete. They understood the impact of zeolite addition on concrete strength, workability, durability, and permeability. The results showed an ideal mixture performance with noticeable improvement in concrete structure, durability, and mechanical characteristics with a resulting model between the average compressive strength ratio and various percentages of zeolite content of cement mass.

Shaikh and Karvekar [4] studied the properties of zeolite material and its effect on rigid pavement, especially to improve concrete resistance to CO2 during production. They showed that zeolite added to concrete-tested rigid pavement for heavy traffic loads, increased pavement resistance to carbon dioxide, and minimized its environmental variation. Moreover, Rajnivas, et al. [5] explained zeolite concrete mechanical properties and its absorption of carbon. They showed that zeo-concrete is an eco-friendly mix.

Krassowska, et al. [6] studied the presence of natural zeolite in hardened and fresh concrete mixtures with the presence of reinforcing bars. The results with a comparative analysis between both reference specimens and those with the additives indicated that active pozzolanic additives in a concrete mixture with zeolite improved the adhesion of reinforced bars more than others.

Waghmare and Ghadvir [7] studied the natural zeolite effect on concrete strength properties used in rigid pavements. Strength prediction was achieved by statistical regression analysis. They showed that concrete blended with zeolite was validated by significant environmental and economic returns when used in concrete mix design.

Shekarchi, et al. [8] presented a comprehensive evaluation of numerous previous studies to present a state-of-the-art review of the literature on zeolite. The main goal is to get in-depth knowledge of how zeolite affects the workability, strength, and durability of concrete mixtures. Moreover, they showed the advantages and disadvantages of natural zeolite that open the door for more applications involving this type of supplemental material.

Yadav and Saxena [9] used the partial substitution of zeolite powder for cement in concrete to promote the supplement product as a construction material with varying proportions of zeolite powder in concrete mixtures for cube casting. They found that the concrete's compressive strength was lower than that of reference after 7 days of curing. On the other hand, after 28 days of curing and 10% cement replacement with zeolite powder, the compressive strength of zeolitic concrete reached the optimum level.

Pranav, et al. [10] tested silica fume material used in concrete mixtures for pavement sustainability. They supported researchers in selecting suitable material combinations to present sustainable mechanical qualities to those conventional in concrete. They discussed silica fume benefits and limitations for concrete pavement resilience, including self-compacting and ordinary concrete. In addition, Reddy, et al. [11] investigated the impact of adding SF to concrete mixtures. The inclusion of SF can improve concrete's performance in corrosive environments, which is where it matters most. The building sector can use silica fume as a cost-effective option to increase strength due to the study's findings.

Yudi, et al. [1] and Hamada, et al. [12] discussed silica fume physical, chemical, and mechanical properties and its microstructure in concrete depend on flexural, tensile, and compressive strength tests and its concentration in the mix. They noticed that high-strength concrete with high performance was developed in the presence of silica fume as a by-product from the ferrosilicon and silicon alloy manufacturing.

Moghadam and Izadifard [13] investigated concrete compressive and tensile strength in a temperature range of 28 to 800°C in hot situations. They investigated the effects of using silica fume and zeolite on certain portions of the conventional cement to decrease the environmental implications of cement consumption. The results indicated that the partial replacement of cement gave a better understanding of pozzolanic behavior in concrete structures and met both engineering and environmental aspects.

Yudi, et al. [1] and Hamada, et al. [12] discussed silica fume's physical, chemical, and mechanical properties with its effect on concrete durability. They examined how the concentration of silica fume in the concrete mixture positively impacted flexural, tensile, and compressive strengths. Also, they noticed that silica enhanced the pore size which increased drying shrinkage within the pozzolanic reaction through microstructure analysis.

Verma, et al. [14] developed concrete mixes with the use of silica fume for the manufacturing of sustainable concrete with good durability properties as compared to reference concrete. They prepared concrete mixtures by partially replacing cement with silica fume in different proportions of 5%, 10%, and 15%. The results of the study revealed that 10% replacement of silica fume with cement produced sustainable, durable concrete characteristics.

Vellaichamy, et al. [15] provided the ideal percentage of silica fume based on experimental research conducted to produce concrete cost-effectively and sustainably. They found that when silica fume is used in place of cement, the proper amount is 15% (by weight). Also, the addition of silica fume significantly raises the strength and reduces the workability of the concrete.

Sudarsono, et al. [16] studied the impact of additives on the concrete mixture; one choice is natural zeolite. Concrete samples were tested with variations of the zeolite mixture of 0%, 15%, and 25% using cement type V. The findings compared with the results of other studies using different types of cement. Based on comparative studies of zeolite concrete tests with various cement types, the ideal zeolite proportion is between 10% and 20% of the cement weight in order to obtain the best compressive strength value.

The mechanical characteristics of Portland cement and geopolymer paste, mortar, and concrete, including ground granulated blast-furnace slag (GGBS) and activated zeolite, were examined for compressive strength geopolymer mortar and concrete using [17].

Girskas, et al. [18] showed the effect of synthesizing zeolite with mineral gibbsite in concrete compressive strength properties by substituting 10% of the cement with zeolite. The results showed that using zeolite reduces water absorption by up to 1.5% and increases compressive strength by up to 28.6% after 28 days of specimen curing.

Ahmed and Ibraheem [19] evaluated the effect of zeolite in cement components in the enhancement of zeo-cement production through clinker blending and grinding with various natural zeolite percentages. They revealed that a 15% zeolite results in an optimal mix design tending to a noticeable increase in compressive strength of concrete and tensile splitting properties.

3. Research Methodology

3.1. Materials

Jordanian natural zeolite contains significant components of chemicals and minerals investigated by the X-ray spectrometric analysis test in XRF laboratory of the Quality Directorate at the Ministry of Energy and Mineral Resources as shown in Table 1. This type of natural zeolite hasn't been studied for its impact on concrete performance with other supplementary materials while the other global one was. Its unit weight and specific gravity were 1010 kg/m³ and 1.9, respectively. In addition, its grain size is from 5 to 1 cm, its chloride content (Cl) of 0.035% and the loss of ignition is 5%.

Table 1.
XRF of natural zeolite components percentages.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_2	CL	LOI
39.7%	10.8%	12.89%	10.97%	9.23%	1.63%	1.39%	0.16%	0.035%	10.04%

Source: XRF laboratory of the Quality Directorate at the Ministry of Energy and Mineral Resources.

Jordanian natural zeolite used in this research is the result of a grinding process by a laboratory ball mill, then sieving analysis for zeolite particles that passed sieve #200. On the other hand, silica fume is the other highly reactive pozzolan used in this research as supplementary material by cement weight in concrete meeting the requirements of ASTM C1240. The chemical and physical requirements are presented in Figure 1.

Chemical Requirements	
SiO_2, min, %	85.0
Moisture content, max, %	3.0
Loss on ignition, max, %	6.0

Physical Requirements	
Oversize:	
Percent retained on 45-µm (No. 325), max, %[A]	10
Percent retained on 45-µm (No. 325), max variation from average, percentage points[B]	5
Accelerated pozzolanic strength activity index:[C]	
With portland cement at 7 days, min percent of control	105
Specific surface, min, m^2/g	15

Figure 1.
Chemical and physical requirements of silica fume.

Portland cement with appropriate limits on composition is used with certain chemical and physical properties according to ASTM C150. The coarse aggregate has a maximum size of 12.5 mm with a specific gravity of 2.60 and sulfate SO_3 content of 0.083%. Moreover, sand is a natural material with well-rounded particles, it has a fineness modulus of 2.60, a specific gravity of 2.70, and a sulfate content of 0.048%.

Those aggregate types are used based on ASTM C33 specifications and requirements for aggregate grading. The superplasticizer (S.P.) was polycarboxylic polymers with a specific gravity of 1.05-1.08. The brand name is Max C600 for high-strength, sustainable, and durable concrete performance.

Normal high-strength concrete mixtures were designed, including a control conventional mix with 100% Portland cement. The other design trial involved the replacement of Portland cement weight with zeolite, and the others involved varying percentages of both natural zeolite and silica fume at the same time. The w/c was varied based on the required mix design for each blend.

Concrete mixture trials with certain supplementary material percentages used for the study were tabulated and summarized as shown in Table 2 while Figure 2 illustrates a schematic overview of the experimental study.

Table 2.
Concrete mix design analysis in the research.

Mix. no.	Normal concrete mix	Special concrete with zeolite mix (SCZ)	Special concrete with zeolite and silica fume mix (SCZSF)
1	100%	0%	0%
2	90%	10%	0%
3	85%	15%	0%
4	85%	10%	5%
5	80%	10%	10%
6	75%	15%	10%

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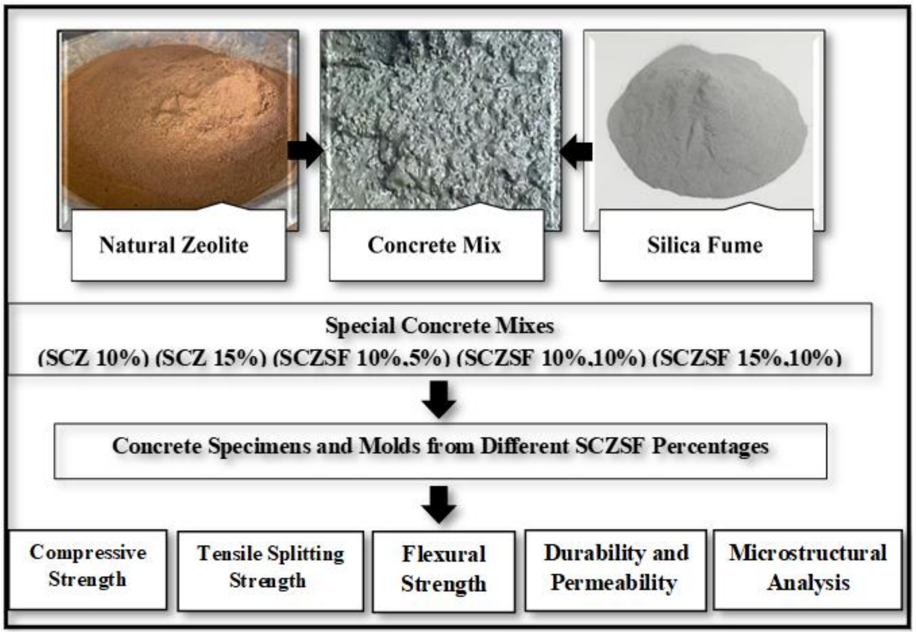

Figure 2.
Schematic overview of the experimental study.

To verify homogeneity, each mix was produced in a laboratory mixer using conventional procedures and compared with reference Portland cement mix with the desired proportions of cement, fine aggregate, coarse aggregate and water. Then, specimens for special concrete zeolite silica fume (SCZSF) mixture proportions were cased under conventional conditions into the molds for various testing with slump test checking and finally cured for 7 and 28 days in a water chamber at room temperature until they were getting ready for testing.

3.2. Experimental Work Methods

3.2.1. Samples Preparation

Concrete mixtures and sample preparation procedures are described in this section of the work. Four different types of mixtures were designed in various percentages of natural zeolite and silica fume materials and employed with a reference concrete mixture of Portland cement.

Plain concrete specimens were cast after a 400 kg/m^3 concrete mixture prepared with a combination of weighted coarse aggregates, sand, and cement added in its dry state. Fifty percent of the total water content was added to the mixer for a mixing time of 90 seconds. Extra 30 seconds of mixing for ensuring homogenization after adding a superplasticizer to the mix. A slump test was done for fresh concrete workability and consistency measurements before it was set. Then, the mixture was collected and cast in a cubic, cylinder, and prism specimens' molds for later concrete test evaluation. After 24 hours, concrete samples were taken out of molds and kept to cure for seven and twenty-eight days in a water bath as shown in Figure 3.

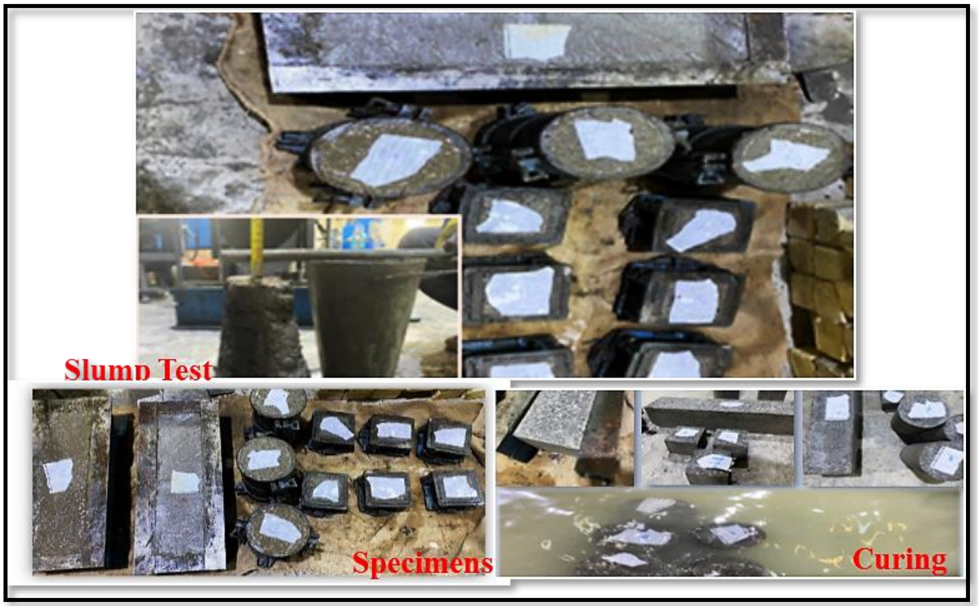

Figure 3.
(a) Concrete casting and slump (b) Specimens curing.

Special concrete mixes with natural zeolite (SCZ) were designed, and specimens prepared with the same concrete composition amounts but 10% and 15% natural zeolite of cement quantity were added as newly developed trials. Natural zeolite was grinded and sieved pass #200 grain size, then the special mixtures of the two SCZ proportions were cast in molds for curing and tested after mixtures slump checking for the design period and analysis. Figure 4 shows the SCZ specimens trial preparation stages.

Figure 4.
Special concrete mix with natural zeolite process.

The supplementary materials in cement manufacturing have received attention in recent years. This is inspired by the need for durable, sustainable, and high-performance construction alternatives. In this work, the next design trial was a silica fume and natural zeolite combination in a concrete mixture with various proportions as another choice of SCMs among sustainable concrete construction developing. The urgent need to minimize the environmental effects of cement production and uses in concrete makes these experiments mandatory to be tested.

Special concrete mixtures with natural zeolite and silica fume (SCZSF) were designed with various proportions as shown in Table 2. The samples were prepared to investigate the zeolite and silica fume combination effect on concrete properties as pozzolanic materials after casting and curing. Figure 5 shows the experimental steps of SCZSF sample formation.

Figure 5.
An Overview of special concrete specimens with zeolite and silica fume.

3.2.2. Samples Testing Techniques

The examination of concrete mixtures has primarily focused on investigating their mechanical properties, specifically their compressive, tensile, and flexural strengths, and has taken into account the most critical properties across all concrete specimen types. The designed specimens were examined at 7 and 28 days directly after the casting process. The test results for each mixture were calculated by the average ultimate stress with a specific contact area of the three concrete specimens.

Concrete samples for each mixture type were cast into standard cube molds of (150 mm x 150 mm x 150 mm) for compressive strength. Testing was performed using a universal testing machine by applying compression load after removing concrete molds from the curing at each study period according to ASTM C39 as shown in Figure 6. Concrete mixtures and sample preparation procedures are described in this section of the work. Four different types of mixtures were designed in various proportions of natural zeolite and silica fume materials and employed with a reference concrete mixture of Portland cement.

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Figure 6.
Compression Strength Test: (a) Compression Apparatus (b) Tested Specimen.

Moreover, concrete samples for tensile splitting strength were tested after they were cast in standard cylindrical molds typically with 150 mm diameter x 300 mm height and cured in water for the design mixtures based on ASTM C496 as shown in Figure 7.

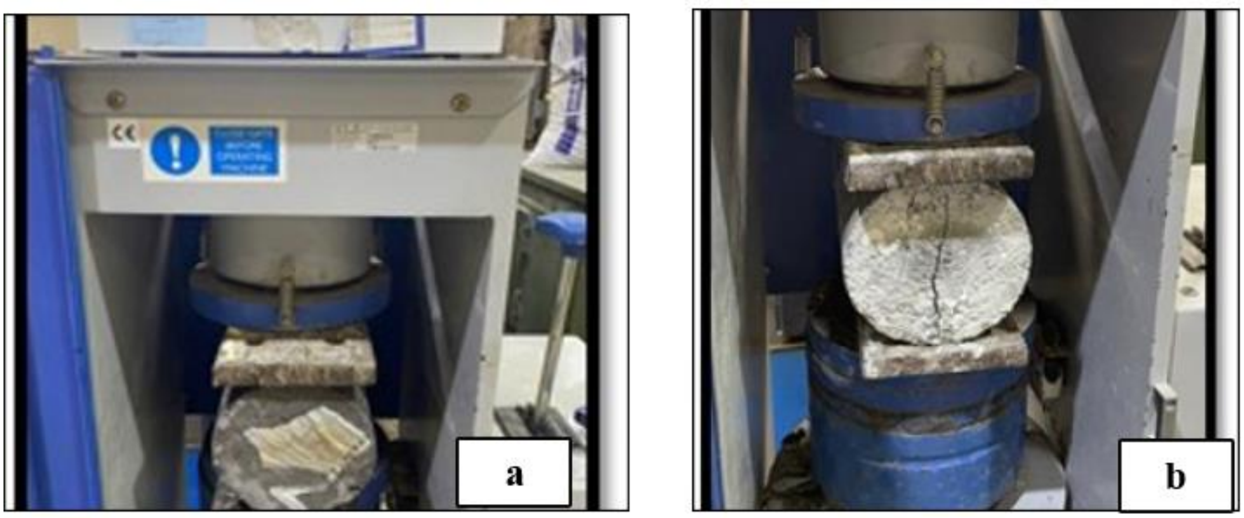

Figure 7.
Tensile Splitting Test: (a) Tensile Apparatus (b) Tested Specimen.

Flexural Strength measured concrete bending using a third-point loading method as per ASTM C78. The specimens were 100 mm x 100 mm x 500 mm prisms; the loading was applied until failure, and then the maximum load was recorded after the curing process as described in Figure 8. However, microstructural analysis, including scanning electron microscopy (SEM) was utilized to analyze the microstructure changes and crystalline phase composition of design concrete samples in detailed images.

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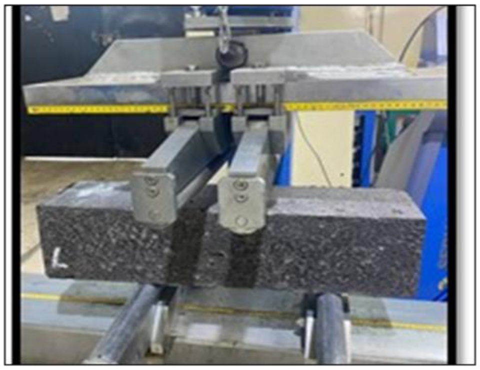


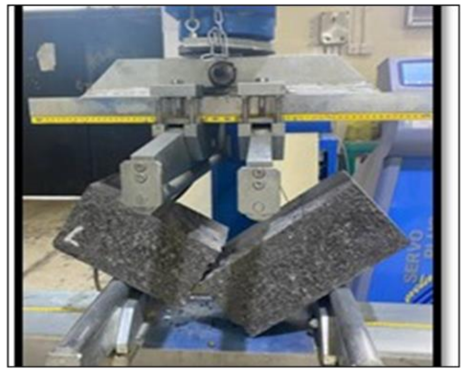


Figure 8.
Flexural strength test: (a) Flexural apparatus (b) Tested specimen.

4. Results and Discussion

4.1. Concrete Mixture Properties with Natural Zeolite

The impact of natural zeolite on concrete properties was investigated while implementing various replacement trials proportions of cement amount in concrete mixtures compared with the ordinary mixes. The main goal was to study the effect of Jordanian natural zeolite on concrete characteristics and behaviors with different percentage trials.

The addition of 10% and 15% of natural zeolite to concrete mixtures led to a significant impact on their fresh properties, like slump test and water absorption after 28 days from molds curing, as represented in Table 3, and mechanical characteristics in hardened ones compared with `the normal concrete mixture's properties after casting and curing molds for several tests, mainly compressive, tensile splitting, and flexural strengths. The following table 4 shows the results of concrete mixtures with and without natural zeolite for hardened characteristics at 7 and 28 days.

Table 3.
Fresh properties and permeability of SCZ mixtures.

Tests at 28 days	Normal concrete mix.	SCZ 10%	SCZ 15%
Slump (mm)	25	23	17
Water absorption (%)	4	1.04	0.94

Table 4.
Normal concrete and SCZ mixtures mechanical properties results.

Mix property	Normal concrete	SCZ 10%	SCZ 15%
at 7 days			
Compressive strength (MPa)	29.01	32.2	21.4
Tensile strength (MPa)	2.6	3.2	1.8
Flexural strength (MPa)	3.7	4.3	2.2
at 28 days			
Compressive strength (MPa)	40.3	51	30.9
Tensile strength (MPa)	3.2	4	2.6
Flexural strength (MPa)	5.5	6.1	3

The results indicate that 10% natural zeolite has a noticeable effect on the fresh concrete properties of the concrete mixture. The water demand of the SCZ mix varies with the zeolite quantity variation. This reveals a significant assumption: as the proportion of zeolite replacement in SCZ production increased, the water demand for the resulting mix decreased. In addition, concrete mechanical properties with natural zeolite were improved with a clear enhancement of strengths during study period. After 14 days of (10% SCZ) specimen curing, the compressive strength had a little drop compared to 15% SCZ, which was explained by the uncompleted material behavior effect with concrete composition. This is shown by the strength results of the special concrete mixes with natural zeolite after 28 days.

4.2. Concrete Properties with Both Zeolite and Silica Fume

The impacts of varying percentages of natural zeolite in concrete mixtures production were determined and evaluated while maintaining consistent proportions of concrete compositions. Then, special concrete mixtures were done by applying two supplementary cementitious materials as partial replacement of cement quantity in mixes.

Table 5.
Fresh Properties and Permeability of SCZSF Mixtures with Proportions Design.

Tests at 28 days	Normal mix	SCZSF (10%, 5%)	SCZSF (10%, 10%)	SCZSF (15%, 10%)
Slump (mm)	25	22	24	21.5
Water absorption (%)	4	1.12	1.01	0.92

Table 6.
Mechanical properties of normal concrete and SCZSF mixtures.

Mix Property	Normal mix	SCZSF (10%, 5%)	SCZSF (10%, 10%)	SCZSF (15%, 10%)
at 7 days				
Compressive strength (MPa)	29.01	27.7	24.2	26.3
Tensile strength (MPa)	2.6	1.9	1.6	1.75
Flexural strength (MPa)	3.7	2.9	2.6	2.7
at 28 days				
Compressive strength (MPa)	40.3	35	29.5	30.3
Tensile strength (MPa)	3.2	2.0	1.8	1.91
Flexural strength (MPa)	5.5	3	2.7	2.81

According to the above results, the combined mixture of natural zeolite and silica fume exhibits less strength compared to previous mixes containing only natural zeolite and normal concrete. The increase in silica fume amount has an adverse effect on concrete behavior when used at 5%, then 10% of the cement amount, while the increase in natural zeolite percentage in each trial resists this impact by 10% and 15% replacement. That means the increase in silica fume amount with the presence of natural zeolite too in the concrete mix will reduce strengths and control by zeolite mass.

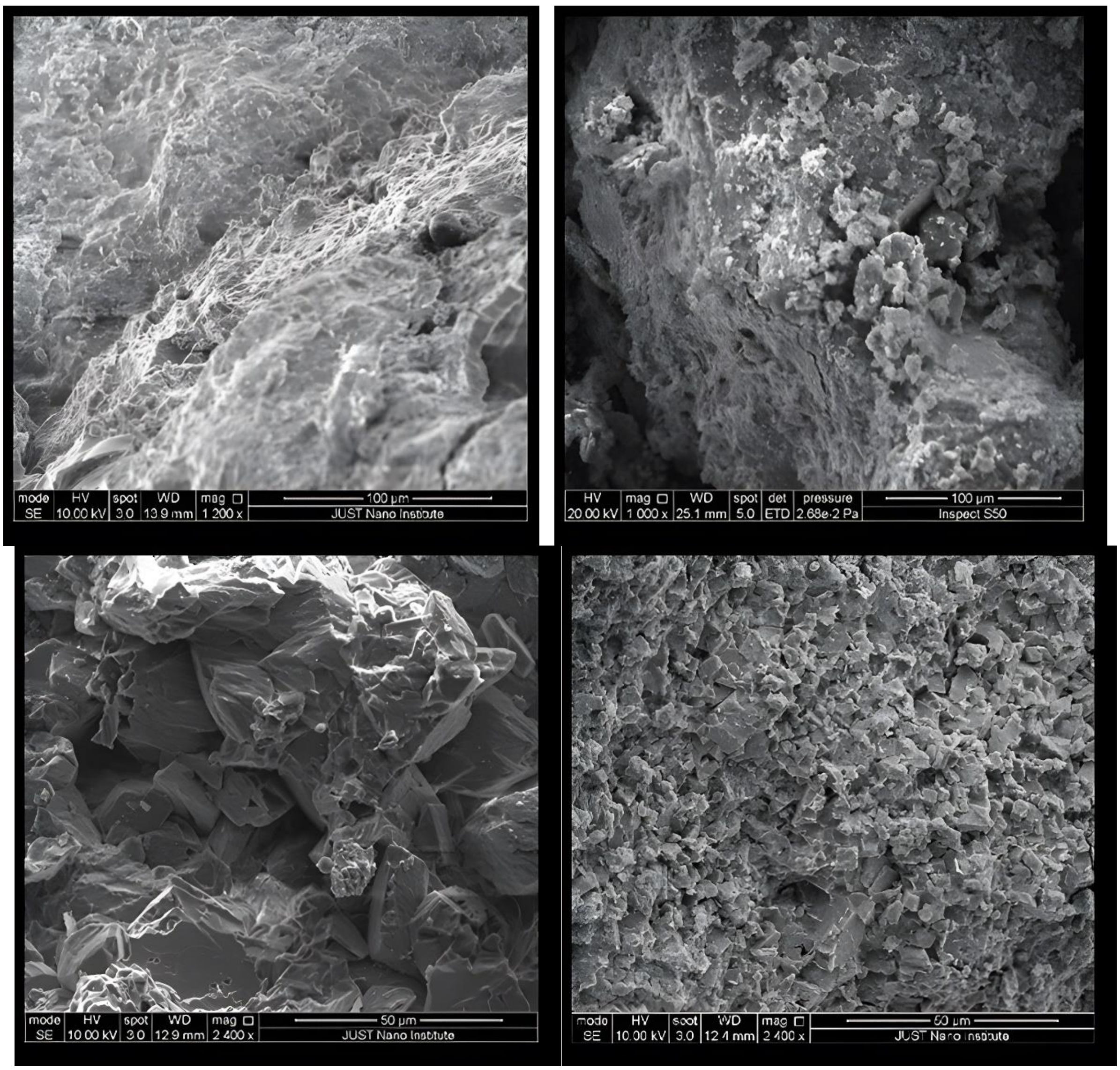
On the other hand, the study demonstrates that SCZSF mixes with 10% Jordanian zeolite and 5% silica fume significantly enhances the performance of concrete with low water absorption and high chemical resistance with 0.5% weight loss compared to 2.5% for the conventional concrete mix.

4.3. Effect of Using Natural Zeolite and Silica Fume in Concrete Blends with Microstructure Analysis Development

Concrete microstructural analysis is a unique approach to determining the morphological characteristics of concrete. Scanning electron microscopy (SEM) is the common technique used to visualize the microstructural behavior of concrete throughout the hydration process.

With the use of these modern techniques, the particular qualities contained inside the concrete can be observed. The unique behavior of concrete and the presence of minor compounds within the hardened cement paste of concrete can be better understood with the use of the mineral data derived from the microstructural analysis.

In this research, SEM test investigates the changes in the microstructure, creation, and decomposition of types in special concrete mixture specimens, adding the SCMs changes the hardened concrete microstructure. Figure 9 shows the microstructure connection of special concrete components with natural zeolite (SCZ 10%) after 28 days at 100 μm and 50 μm compared to the conventional mix. Hydrated materials improve pores, contributing to enhanced flexural strength and concrete structure durability. A critical decrease in microcracks is shown in SEM photographs of SCZ 10% mix compared with the ordinary concrete mix with the effective connection between aggregates and cement ingredient cohesion at 28 days of age. This significant impact leads to dense microstructure mixes with high-strength properties and sustainable concrete behavior.



(a) (b)

Figure 9.
Nano-SEM Images: (a) Reference Mix (b) SCZ 10% Mix at (100 and 50 μm) Magnification.

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4.4. EIA Study of Natural Zeolite Concrete Mixture

After examining the effect of natural zeolite material on the features of the modified concrete through different tests. The environmental impacts of introducing zeolite to concrete mixes should be explained to improve construction sustainability. The environmental benefits, like resource conservation and global warming, outweigh the difficulties related to material properties and processing. Environmental Impact Assessment (EIA) is a systematic method used to evaluate the predicted environmental effects of proposed work before its implementation. It aims to ensure decision-makers and the public are aware of the environmental issues, ensuring that environmental aspects are incorporated into the planning and decision processes.

The significant environmental effects of using natural zeolite in concrete are assessed using a variety of detailed EIA methods, which compare it to conventional concrete based on specific considerations of sourcing, processing, and potential contaminants to maximize its benefits and minimize any negative effects through careful monitoring and assessments.

To assess the overall environmental performance impacts of zeolite in concrete before it reaches an endpoint manner that systematically impacts human health or ecosystems in an efficient eco-design practice, the RECIPE 2016, Cumulative Energy Demand (CED), and Environmental Design of Industrial Products (EDIP 2003) methods were studied and developed for Life Cycle Assessment (LCA) using Open LCA Software. Table 7 shows the results of an EIA study comparing the special 10% natural zeolite concrete mixes with regular concrete based on inputs used during the design mixes stage. According to the comparison with the three selected evaluation techniques, there are major environmental advantages of 10% zeolite in concrete mixtures, especially in terms of resource conservation.

Table 7.
EIA Study Comparison between the Conventional and Natural Zeolite Concrete Mixes.

Impact Categories	Conventional	10% NZ
Recipe 2016		
Fossil resource scarcity (kg oil eq)	1462	500
Global warming (kg CO_2 eq/m^3)	750	400
Human carcinogenic toxicity (kg 1.4-DCB/m^3)	1.03	0.6
Mineral resource scarcity (kg Cu eq/m^3)	15	7
Ozone formation, Human health (kg NOx eq/m^3)	1.05	0.7
Ozone formation, Terrestrial ecosystems (kg NOx eq/m^3)	1.35	0.5
Stratospheric ozone depletion (kg CFC^{-11} eq/m^3)	0.02	0.001
Terrestrial acidification (kg SO_2 eq/m^3)	2.5	1.5
Terrestrial ecotoxicity (kg 1.4-DCB)	0.74	0.44
Cumulative Energy Demand (CED)		
Non-Renewable, fossil (MJ/m^3)	1560	1100
Non-Renewable, minerals (MJ/m^3)	329	110
Renewable, potential (MJ/m^3)	12	5.5
Renewable, solar (MJ/m^3)	1.73	5
EDIP		
Ecotoxicity soil chronic (m^3)	0.413	0.2

5. Conclusion

This study concerned on investigating the effect of natural zeolite and silica fume on the mechanical properties and microstructure characteristics of concrete under environmental conditions. The following outcomes based on the study's results are drawn:

1. Using SCZ in concrete mixtures improves strength properties and durability performance with a significant sustainable behavior as a developed solution along concrete service life and environmental impacts.

2. Special concrete mixtures with various natural zeolite percentages improve compressive, tensile

and flexural strengths after 28 days of curing as a partial replacement material of cement paste over conventional concrete and special concrete with silica fume.

3. After 28 days of curing, the mixture's compressive, tensile, and flexural strengths are higher compared to the reference concrete mix and SCZ 15%.

4. Natural zeolite and silica fume special concrete mixes have an adverse result in the mechanical properties of concrete with various design trials and proportions compared with mixes with zeolite only and that of reference mix.

5. Water absorption in concrete mixtures with zeolite decreases for SCZ 10% mix showing the potential of zeolite in reducing water permeability.

6. The combination of Jordanian natural zeolite and silica fume significantly improves concrete performance with low water absorption and permeability and high chemical resistance while decreasing the strengths. This recommends the use of them for better performance in severe sulfate environments for more durable and sustainable concrete.

7. Jordanian natural zeolite has a significant notable impact in minimizing the environmental impact of cement use and mixing, presenting a sustainable behavior of concrete production and use in various applications such as pavement.

8. The microstructural analysis study with XRD and SEM techniques performs a crucial role that supports the results of decreasing microcracks and increasing the cohesion in SCZ mixes at the interface of aggregate cement paste.

The recommendation for future work is to assist the long-term performance of sustainable concrete in various practices, such as rigid pavement construction, to assess pavement resistance to fatigue cracking and other types of distress and deterioration over service life with the use of natural zeolite under different situations.

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Regarding the publication of this manuscript, there are no conflicts of interest.

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Upon reasonable request, the corresponding author will make the datasets supporting the study's conclusions available. This publication contains the majority of the data generated and processed.

Transparency:
The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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