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Research Article

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Pyrite effect: correlation between compressive strength and durability properties for concrete samples

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Highlights

- In this study, water absorption values of pyrite were obtained.
- Also, the effects of pyrite on compressive strength were investigated.
- With this study, the negative effect of pyrite on mechanical values was determined.

Abstract

Despite the two centuries that have passed, concrete still maintains its place at the top as a building material. Although it has different strength and performance characteristics than when it was first discovered with the developing technology, it can be said that it is still the most studied building material today. For this reason, researchers are investigating various materials that can improve the performance of concrete and at the same time can be recycled as waste. In this study, the effect of substitution of pyrite mineral rocks obtained from copper mines into concrete as fine aggregate on the compressive strength and water absorption values of concrete specimens was investigated. For this purpose; 2.5% and 7.5% by weight of pyrite aggregate was substituted for sand and crushed sand aggregate in the concrete design mix. A total of 9 concrete cube specimens of 100x100x100 mm were produced for 3 series together with the reference specimens and the averages of 3 specimens were used as data after 28 days of curing. The data obtained show that as the pyrite aggregate substitution rate increases, the water absorption rate increases by 0.41%, and the compressive strength decreases by 21.32%.

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1. Introduction

Concrete is widely used in roads used for the transportation of pedestrians and vehicles, in the production facilities of enterprises such as food, chemistry, pharmaceuticals that work on industry, in recreation areas where people spend their leisure time, in recreation areas around the buildings used for education and training. Since concrete is a low-cost and durable building material compared to other building materials, its use is constantly increasing [1].

However, concrete is not without its drawbacks. Researchers have sought to address these issues, exploring innovative solutions to enhance the material's performance and sustainability. One of the key challenges is the low tensile strength of concrete, which can lead to cracking and deterioration, particularly in structures subjected to bending or pulling forces. Additionally, the production of Portland cement, a primary ingredient in concrete, contributes to significant greenhouse gas emissions, underscoring the need for more environmentally friendly alternatives [2].

Conventional concrete has disadvantages such as low tensile strength, poor surface strength and rapid crack development during cracking. The performance of concrete depends on its material composition, internal structure and degradation mechanisms in the service environment. Pavement concretes used for any purpose are subjected to compressive, bending stresses as well as abrasion forces in the environment in which they serve. While the flexural strength of the concrete pavement plays an important role when designing such materials, the design of pavements used on airport runways focuses more on impact strength [3].

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Concrete pavements on concrete roads with heavy traffic load, shopping malls, vehicle fuel stations, storage and industrial sites deteriorate in short periods of time due to the abrasion and impact forces to which they are exposed. In order to prolong the surface deterioration of concrete pavements exposed to continuous abrasion, concrete surface improvement processes are used in addition to the use of high-strength concrete and fiber concrete applications.

Pyrite, a naturally occurring mineral with a distinct golden-yellow hue, has gained attention as a potential substitute for traditional concrete in construction applications. Composed of iron and sulfur, pyrite exhibits unique properties that make it a promising alternative, particularly in terms of its mechanical and water absorption characteristics [4, 5].

Substituting pyrite for concrete could yield significant gains in terms of circular economy and sustainability. Pyrite is a mineral obtained from mineral deposits and can contribute to concrete in terms of strength and durability by using it in concrete. In addition, since pyrite is a heavy aggregate source, it can be used in the construction of imaging units of hospitals for radiation attenuation effect [6-8].

Research has shown that the integration of pyrite into concrete can significantly enhance its performance. Replacing natural sand with iron tailings, a byproduct of pyrite mining, has been shown to improve the compressive strength, splitting tensile strength, and elastic modulus of the resulting concrete mixture, making it a more durable and reliable building material [9]. Moreover, the use of pyrite-based concrete has been found to have a lower corrosion rate and decreased susceptibility to acid erosion, further enhancing its durability and longevity [9].

The utilization of industrial waste materials like pyrite in concrete production aligns with the growing emphasis on sustainable and eco-friendly construction practices. By incorporating these alternative materials, the construction industry can reduce its reliance on natural resources, minimize waste, and contribute to a more environmentally conscious built environment [10].

Pyrite, a naturally occurring mineral composed of iron and sulfur, has garnered the attention of researchers and engineers in the field of concrete construction due to its potential to influence the mechanical and physical properties of this widely-used building material. There are some studies in the literature for this purpose. The researchers found that the addition of pyrite led to a significant increase in the compressive strength of the concrete, with the optimal replacement rate being around 10% [11]. The other study investigated the use of pyrite as a fine aggregate in concrete, reporting that the inclusion of pyrite improved the density and reduced the porosity of the concrete, contributing to enhanced durability [12]. Demirci [13] studied heavy concrete with pyrite aggregates with s/w 0.4, 0.5 and 0.6, and concluded that as the s/w ratio increases; modulus of elasticity, compressive strength and absorption coefficients decrease. Salguero et al. [14] produced concretes by substituting some of the fine aggregate with pyrite in order to create a new design by replacing fine aggregate in concrete design and conducted research on concretes. They obtained a compressive strength value of 56.44 MPa in concrete specimens using pyrite and 41.03 MPa in reference specimens without pyrite and stated that pyrite is suitable for use in concrete [14].

The use of pyrite in concrete instead of fine aggregate will add financial value to the pyrite mine by reducing waste costs and contributing to the aggregate sector. In the light of the literature research, there are studies on pyrite substitution in concrete, but it is understood that the scope of these studies is not sufficient to fully elucidate the changes caused by the substitution of pyrite in concrete. For this purpose, this paper presents the results of compressive strength and water absorption values obtained as a result of experimental studies.

2. Material and Methods

CEM I 42.5 R type cement was used for concrete design. The pyrite used was obtained from the copper mine. Waste pyrite rock was crushed to coarse aggregate sizes in a jaw crusher. It was then sieved through a 4 mm sieve and converted into fine aggregate. Table 1 shows the percentages of pyrite passing through the sieve after granulometry analysis. Figure 1 shows the granulometry curves of the aggregates used in the mixture and the mixture.

Table 1. Pyrite aggregate sieved (%) values

Sieved size (mm)	Sieved material (%)
4	100
2	76.2
1	47.1
0.5	18.7
0.25	3.2
0.125	0.8
0.063	0.0
Pan	0.0

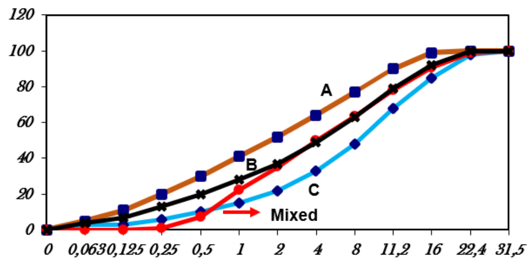

Figure 1. Granulometry curves of aggregates and mixed

The physical properties of aggregates used in concrete design are given in Table 2 [15]. Also, data on the physical properties and density values of the pyrite mineral are given in Table 3.

Table 2. Physical features of aggregates

	Natural Sand (0/4)	Crashed Sand (0/4)	Coarse Aggregate1 (4/16)	Coarse Aggregate2 (16/32)	Pyrite Aggregate (0/4)
Specific Weight	2.31	2.48	2.62	2.69	4.74
Water Absorption (%)	10.62	4.48	1.48	1.13	0.60
Moisture Content (%)	9.46	2.53	0.44	0.45	0.00

Concrete design calculations were made to meet the strength criteria of C40/50 class [17]. The water/cement ratio was 0.45 and the slump was 4 cm. Concrete mixtures were prepared with a pan type mixer. The specimens were filled into 100x100x100 mm molds (Figure 2.) The concrete specimens were subjected to curing in lime-saturated water at room temperature of 20 °C until the 28th day.

Table 3. Pyrite aggregate sieved (%) values

Explanation	Properties
Chemical Composition	FeS_2
Crystal arrangement	Cubic
Crystal Shape	Usually cubic, octahedral, pyritohedral crystalline
Hardness	6-6.5
Specific Gravity	5-5.028
Color and Transparency	Metallic brass yellow, opaque
Line Color	Greenish black
Brightness	Metallic

After the sample cured for 28 days in accordance with TS EN 1097-6 standard, the water absorption amount was removed from the curing pool, the water film around it was wiped with a cloth and the saturated dry surface mass was weighed (W1), these samples were weighed again (W2) after they were kept in a 40 °C oven until they reached constant mass (Figure 3) and the water absorption values of the samples were measured according to Equation 1.

$$Wa=(W1-W2)/W1\times100 \quad (1)$$

In Eq. 1, Wa is the sample water absorption percentage, W1 is the saturated dry surface mass and W2 is the oven dry mass.

Figure 2. Prepared cube samples

The compressive strengths of the 100x100x100 mm cube specimens with 0%, 2.5% and 7.5% pyrite fine aggregate ratios were calculated according to Eq. 2 in accordance with TS EN 12390-2 standard [18] (Figure 4).

$$Fc= P \text{ x } a^2 \quad (2)$$

Figure 3. Air-dry weighing and dry-tube weighing

In Eq. 2, Fc is the compressive strength (N/mm²), a is the specimen edge length (100 mm), P is the maximum force at fracture (N).

Figure 4. Compressive strength measurement device

3. Result and Discussion

Water absorption and compressive strength values obtained from 100x100x100 mm concrete specimens with PC0, PC2.5 and PC7.5 pyrite fine aggregate content are shown in Figure 5. PC abbreviates concrete cube samples with pyrite mineral. The compressive strength values given in Figure 5 are the average strength values of 3 specimens measured on the 28th day. The use of 7.5% pyrite aggregate resulted in a 21.33% decrease in the compressive strength and a 21% increase in the water absorption value of the PC7.5 specimens compared to the PC0 specimen.

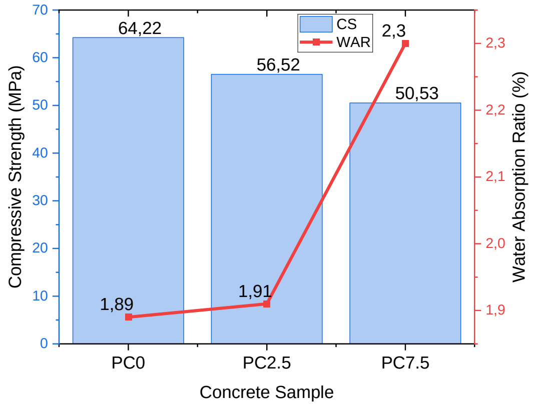

Figure 5. Compressive strength and water absorption values for reference and concrete samples with pyrite

Guo et al. [19] substituted pyrite wastes into concrete and investigated their effect on compressive strength. They showed that the compressive strength increased when the substitution rate was between 0-20%, while the compressive strength decreased between 20-40%.

In their study, Ustabas et al. [6] determined that as the pyrite fineness increased, the specific gravity decreased and the amount of water absorption increased. They observed that pyrite concrete had higher compressive strength than normal concrete at varying water/cement ratios. When the values in this study are compared with the values in the study of Ustabas et al. [6]; it is seen that the use of pyrite contributes positively to the compressive strength, while it has a negative effect on the compressive strength of conventional concrete.

Although direct concrete substitution studies with pyrite are limited, a study by Wang et al. [20] on the use of copper wastes with high sulfur content in cementitious filler pastes showed that compressive strengths generally increased with going up sulfur content, depending on the curing time. However, while the sulfur content of the wastes used was maximum 30.7%, the general sulfur content of pyrite mineral was above 40%. Due to this difference, there may be a difference between the present study and the compressive strengths.

4. Conclusion

In this study, pyrite rock from copper mines was processed into fine aggregate and substituted into concrete cube specimens at 2.5% and 7.5% by weight. In this study, which was carried out to determine the effect of pyrite mineral on the mechanical and physical properties of concrete specimens, the following conclusions can be drawn in the light of the data obtained from the compressive strength and water absorption tests.

i. When pyrite fine aggregate was used in concrete mix, water absorption increased by 0.02% in PB2.5 sample compared to PB0 reference sample.

ii. When pyrite fine aggregate was used in concrete mix, compressive strength decreased by 12.00% compared to PB0 reference specimen.

iii. While the water absorption value of the PB7.5 sample increased by 0.41%, the compressive strength value decreased by 21.32%.

iv. The use of pyrite decreased the compressive strength of conventional concrete with increasing substitution rate, while increasing the water absorption values of the specimens.

Although there are many parameters for the usability of a mineral in concrete, the results of the tests give us clues that pyrite can be used in concrete. However, the limits of this study include compressive strength and water absorption tests as mechanical and physical tests. In future studies, the study team plans to investigate the physical properties of pyrite specimens such as mass loss and wear length; SEM-EDS analysis for micro mechanical properties; and algae and mossing for durability properties. For upcoming studies, the durability properties of pyrite concrete (fire and acid resistance, etc.) may be interesting topics to investigate.

The sustainability and durability of the building material used against external influences is important in terms of extending the economic life of industrial buildings in terms of both housing for life and the continuation of production. Fires, which are an indirect effect of today's global warming, can have devastating effects both economically and socially. In this context, it is essential to discover innovative materials and minerals that improve the strength and durability properties of building materials against external influences such as acid and fire effects, or to emphasize the importance of those already available, in order to prepare the ground for future studies.

Declaration of Interest Statement

The authors declare that the work described has not been published before; that it is not under consideration for publication anywhere else; that its publication has been approved by all co-authors; that there is no conflict of interest regarding the publication of this article.

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