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Effect of Nano TiO_2 on performance of Ferrock Concrete Brick

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Abstract. After water, concrete is the most widely consumed material in the world. Cement and aggregates are the primary raw materials used in cement concrete and concrete bricks. However, large-scale cement production places a significant burden on the environment, as approximately 0.9 tonnes of CO_2 are emitted for every tonne of cement produced. As a result, sustainable materials are becoming essential in the rapidly changing construction industry. Ferrock, a material derived from recycled steel dust, has emerged as a promising alternative to cement. Unlike conventional concrete, which has a notable carbon footprint, ferrock is carbon-negative, as it absorbs CO_2 during curing. The present study investigated the compressive strength, water absorption, and thermal properties of ferrock bricks incorporating nanoparticles. Titanium dioxide (TiO_2), added at concentrations of 1%, 2%, and 3%, was used to evaluate its effect on brick performance. The results indicated that a 2% TiO_2 addition was optimal for improving the properties of the ferrock bricks.

1 Introduction

Silica and steel dust waste, both wastes of other processes, are combined to make ferrock. The chemical- reaction among the steel dust waste and the carbon dioxide in the air is a fascinating phenomenon that leads to the solidification of a unique composite material when combined with ferrous rock and water. Ferrock is a cutting-edge, environmentally responsible substitute for conventional concrete in buildings. Ferrock, which is prepared from recycled materials like silica and steel dust, is long-lasting and environmentally friendly. Ferrock is carbon-negative because it absorbs CO_2 while it dries, in contrast to traditional concrete, which releases a lot of carbon dioxide during production. An environmentally friendly substance called Ferrock was created to partially replace cement in concrete, solving issues with carbon emissions and resource depletion brought on by the production of traditional concrete. 60% iron dust, 20% fly ash, 10% metakaolin, 8% lime powder, and (2%) oxalic acid makes up its composition. Ferrock is a sustainable choice because it not only has better mechanical and durability qualities but also absorbs CO_2 during curing.

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1.1 Ferrock's Development

The dilemma that prompted Dr. David Stone to create ferrock was how to handle the enormous volumes of steel dust waste generated by industrial operations. This by-product has degraded the environment by ending up in landfills. However, after conducting a number of experiments, Dr. Stone found that this waste might be converted into a high-strength, eco-friendly substitute for Portland cement. By ingeniously fusing the words "iron" (ferrous) and "rock," the term "Ferrock" alludes to its study strength and iron-rich makeup. The Ferrock composition was taken from literature [1]. Table 1 indicates materials proposed for the present study.

1.2 Benefits of Ferrock

Carbon negative ferrock absorbs CO_2, making it a carbon-negative material. Stronger than concrete ferrock is five times stronger than traditional concrete. More flexible ferrock is more flexible than Portland cement and can withstand seismic activity. Durable ferrock is durable and requires low maintenance. Excels in saltwater: Ferrock performs well in saltwater environments and can even become stronger.

1.3 Benefits of TiO_2 in Concrete

It is typically used in nano form (nano-TiO_2) because of its high surface area and reactivity. An able to modify microstructure and improve the mechanical properties of concrete during hydration. Pore structure: TiO_2 reduces the porosity and capillary pores of concrete and convert harmful pores into less harmful ones and improves the connectivity of capillary pores. Self-cleaning: Concrete with TiO_2 can be self-cleaning, allowing water to wash away pollutants that have absorbed to the surface [2]. Hydration: TiO_2 has the ability to quicken cement's hydration reaction; reducing both the setting times (initial and final) [3].

2 Review of Literature

The construction industry has long relied on traditional concrete as a primary building material, but the exploration for more sustainable' and eco-friendly alternatives has led to the development of innovative concrete. The true performance of conventional concrete is determined by parameters like fresh and hardened characteristics. When related to standard SCC, they found that the ferrock-based SCC had a dense matrix, a better degree of compaction, and stronger structure at an ideal replacement level of 10%. These results point to the advantages of ferrock SCC, which may be used in building in the future [4,5]. They investigated the use of FERROCK (Iron dust- 60%, Flyash- 20%, Metakaolin -10%, Lime powder -8%, and Oxalic acid 2%), in specific ratios (10%, 20%, and 30%) by cement weight, as a partial substitute. To cut down on the amount of natural sand used as the chosen concrete, they include replacing all of the river sand with M sand- 85% and Gp-15% [1, 6]. Enhancing strength and durability of concrete made with (RHA) and (TiO2) as pozzolanic ingredients to partially replace Portland cement (PC) have been examined in this work. While PC was partially replaced with TiO2 at different replacement levels (0% to 5%), RHA was used in a single 10% quantity it was concluded that strength and durability characteristics have decreased when TiO_2 nanoparticle concentrations have been raised above 3%. In order to get the best balance of performance, a 3% nano-TiO_2 replacement seems to be the ideal level [7,8].The present study has examined the strength, pore structure, thermal behavior, and microstructure of concrete that contains TiO_2 nanoparticles as a binder and ground granulated blast furnace slag [6,9,10]. They examine how regular Portland cement and ferrock (iron dust- 60%, fly ash -20%, Metakoalin -12%, and limestone -8%) affect the environment, paying particular attention to how they affect energy, water, and carbon pollution [11, 12]. Their research findings show that adding ferrock material can improve a subgrade soil's stability [13]. Ferrock material is more economical and environmentally friendly than expanding soil, however it can be used for foundation work like pavement [14]. According to their findings, nanotechnology fills in gaps and increases the compressive strength after 28 days. When comparing Nano Technology concrete to control concrete, an improvement in early age compressive strength was noted after three days. Flexural and split tensile strength results were determined to be good when compared to control concrete. Their results also demonstrated that utilising nano-TiO_2 to change the cement mortar's fluidity and strength at an early age was advantageous when super plasticizer and slag were used. Their research attempts to evaluate and contrast the effects of several nanoparticles, particularly nano-(Fe_2O_3), nano-(Al_2O_3), and nano-TiO_2 on the mechanical aspects of (SCC) by a number, studies [15]. Existing research on ferrock has largely concentrated on its mechanical properties and environmental benefits as a sustainable substitute to conventional cement. However, this study goes beyond just examining mechanical performance – it also delves into the thermal properties of Ferrock. To better understand the impact of TiO_2 on Ferrock, detailed microstructural analysis was conducted using SEM (Scanning Electron Microscopy) and EDS (Energy Dispersive Spectroscopy). Although ferrock bricks have traditionally been used for wall construction, the findings of this study indicate that they could also be suitable for use in load-bearing structures. This opens up new possibilities for utilizing ferrock in more demanding construction projects, highlighting its versatility and strength. The use of nanomaterials in concrete impacts the overall cost of the structure.

3 Methodology

3.1 Materials

The materials used in the present study are presented in Table 1 and Figures 1 and 2.

Table 1. Materials proposed for the present study

Composition of Ferrock	The ferrock mix proportions were as follows: iron dust 60%, fly ash 20%, metakaolin 10%, oxalic acid 2%, and limestone 8%.
Coarse Aggregates	The coarse aggregate used passed through a 10 mm sieve and was retained on a 5.6 mm sieve. sieve.
Fine Aggregate (FA)	The aggregate used passed through a 4.75 mm sieve and was retained on a 1.18 mm sieve.

Fig. 1. Nano material (TiO2)

Fig. 2. Ferrock

3.1.1 Cement

OPC 53 grade was used. The properties of the cement are presented in Table 2.

Table 2. Physical properties of cement

Test	Value
Specific gravity	2.9
Consistency	32%
Fineness	2%
Initial & final setting time	92 and 241 min

3.1.2 Fine aggregate

River sand (zone III)-IS (383): Specific gravity -2.68 and fineness modulus-2.9

3.1.3 Coarse aggregate: IS383

Specific gravity of aggregate is 2.98

3.1.4 Ferrock: (Specific gravity 4.75)

TiO2: specific gravity-4 & viscosity-11mpa-s.

3.1.5 Proposed proportion for ferrock concrete Bricks:

The quantity of concrete mix used for concrete brick and the suggested experimental trails are displayed in Table 3 & 4. Figure.3 illustrations the casting of concrete bricks and Figure.4 shows the specimens subjected at a high temperature.

Table 3. Mix proportion for Brick

Materials	**Quantity**
Cement	1:2:4 Proportion And W/C ratio-0.5
FA	
CA	
Water	
Mix with Ferrock ratios 50%, Fly ash 20%, Tio_2 1%,2%	
Ferrock	250gms
Tio_2-1%	2.5ml
Tio_2 -2%	5ml
Tio_2 -3%	7.5ml

Table 4. Types of mixes

Type-1	Cement 100%+ FA+ CA + Water
Type-2	Cement 50%+ Ferrock 50%+ FA+ CA + Water
Type-3	Cement 50%+ Ferrock 50%+FA+ CA + Water+ Nano Titanium Tio2-1%
Typel-4	Cement 50%+ Ferrock 50%+FA+CA + Water+ Nano Titanium Tio2-2%
Type-5	Cement 50%+ Ferrock 50%+ FA+ CA + Water+ Nano Titanium Tio2-3%

Fig.3. Casting of specimens

Fig.4. Bricks subjected at a high temperature

4 Experimental Program

The following tests were conducted on ferrock concrete after 7 and 28 days of water curing, and the results were compared with those of the control concrete.

4.1 Compressive Strength

Compressive strengths are displayed in Table 5 at 'seven and twenty-eight days' after curing, respectively.

Table 5. Ferrock brick Compressive Strength

Mix Designation	7-days (N/mm^2)	28-days (N/mm^2)
F0%	10.50	13.90
F50%	9.50	12.00
F50%-TiO_2 1%	10.80	15.02
F50%-TiO_2 2%	11.50	17.00
F50%-TiO_2 3%	10.50	14.82

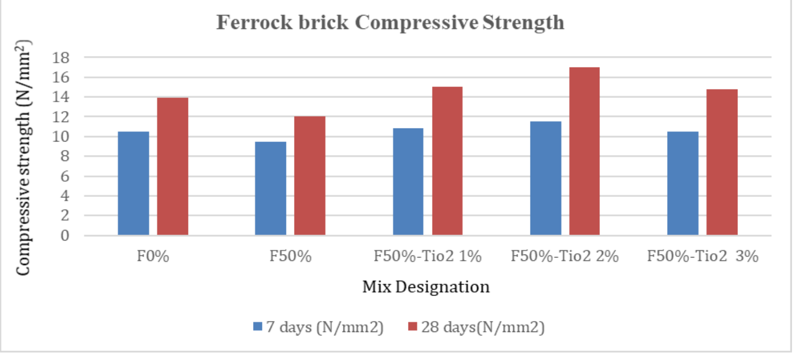

Fig.5. Ferrock brick -Compressive Strength

Figure 5 shows that compressive strength of ferrock concrete bricks, the control mix (F0%) and (F50%) have lower strengths compared to TiO_2-enhanced mixes. Strength increases up to 2%, by TiO_2 content, slightly decreases at 3%. At 28 days with the addition of 1%, 2%, and 3% TiO_2, percentage variations are 28%, 32%, and 29%, respectively.

4.2 Water Absorption

Water absorption for bricks is to know the quality and durability of bricks by measuring their ability to absorb water. This test ensures that the bricks are suitable for construction purposes and provides insights into their porosity and density. Excessive water absorption can weaken bricks and lead to structural issues over time. Figure.6 shows results of water absorption.

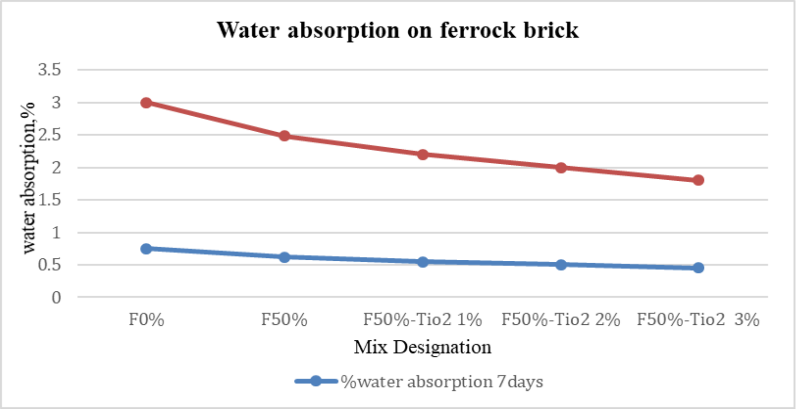

Fig.6. Water absorption on ferrock brick

Two distinct trends are visible: for both curing ages, water absorption decreases progressively with the addition of TiO_2. At 7 days, water absorption values are consistently low across all mixes, starting at approximately 0.75% for the control and dropping to around 0.45% for the 3% TiO_2 mix. At 28 days, the sorption is more than at 7 days but still follow a similar downward trend, beginning at roughly 3% for the control and reducing to about 1.8% for the 3% TiO_2 mix. The results figure.6 show that incorporating TiO_2 into the Ferrock mix reduces water absorption, with the lowest absorption achieved at the highest TiO_2 content tested (3%). Additionally, water absorption decreases slightly with longer curing time, which reflects the continued densification and reduced porosity of the material as it matures. This suggests that TiO_2 not only strengthens Ferrock bricks but also enhances their resistance to moisture ingress.

4.3 Concrete Exposed to Elevated Temperature

Elevated Temperature test evaluates the thermal stability and durability of bricks when subjected to high temperatures. This test is essential for determining the suitability of bricks for structures exposed to fire or high-temperature environments, such as kilns, furnaces, or industrial facilities. Table 6 indicates test results and figure7 shows bricks subjected to elevated temperatures. The outcomes of bricks with different ferrock ratios were subjected to a specific temperature at 200°C intervals.

Table. 6. Results of tests conducted on bricks with different ferrock concentrations subjected to a specific temperature at regular intervals.

Designation of mix	Ferrock bricks compressive strength after subjected to temperature (N/mm^2).		
	0°c (2hrs)	200°c (2hrs)	400°c (2hrs)
F0%	13.90	17.62	15.91
F50%	12.00	17.15	15.52
F50%-Tio_2 1%	15.02	19.21	16.81
F50%-Tio_2 2%	17.00	21.52	19.15
F50%-Tio_2 3%	14.82	18.34	15.87

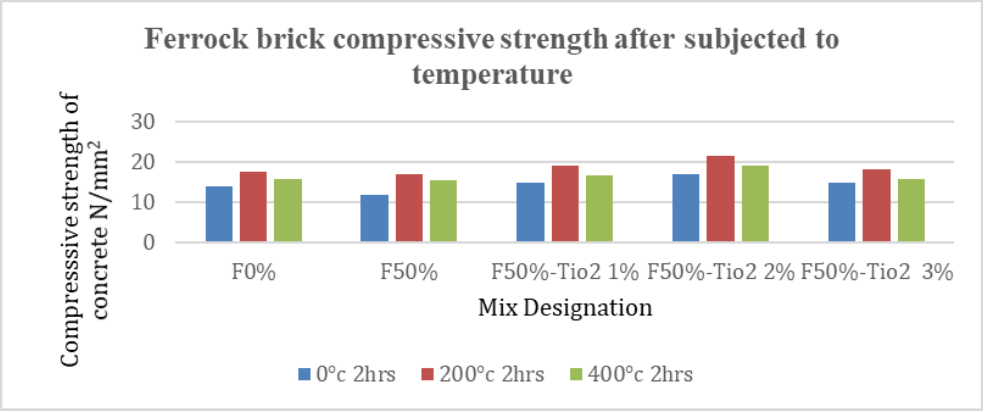

Fig. 7. Ferrock brick compressive strength after exposed to temperature

Figure 7, observed that strength of ferrock brick after exposed to 200°C and 400°C temperature is increased from 25-30% and 10-15% respectively, when compared with the compressive strength of brick which is not exposed to temperature.

4.4 The strength of ferrock brick in contrast to other bricks

The table below illustrates the average compressive strength and weight of different types of bricks. It was concluded that, because of their exceptional compressive strength, ferrock bricks are perfect for load-bearing structures

Table 7. Comparison of results with various bricks

Type of Brick	Avg. Compressive strength (N/mm^2)	Avg. weight (gms)
Clay Brick	3.5	2900
Fly ash	10	3150
Cement brick without ferrock	13	3660
Cement+ Ferrock	12	3570
Cement+ Ferrock with Tio_2	17	3610

4.5 Microstructure study of bricks

The microstructural analysis of TiO_2-enhanced Ferrock bricks, as observed by Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) Figure.8, reveals significant improvements in the material's internal structure. SEM images indicate that the fusion of TiO_2 nanoparticles promotes the formation of a denser matrix, primarily through the increased generation of calcium silicate hydrate (C-S-H) gel. This is attributed to the nano-sized TiO_2 particles effectively filling micro-pores within the Ferrock' matrix, leading to reduced porosity' and a more compact microstructure. Such pore-filling not only improves the physical integrity of the brick but also enhances its durability by limiting water ingress and other forms of deterioration. Furthermore, EDS analysis confirms a notable increase in silica content for TiO_2-modified Ferrock bricks' compared to control samples. The pronounced silica peaks detected in the EDS spectra indicate a richer presence of silicate compounds, directly related to the formation of additional C-S-H gel. This enhanced silica composition contributes to the improved mechanical properties, as observed in compressive strength tests, and supports the reduced water absorption results, highlighting the dual role of TiO_2 in both strengthening and densifying' the Ferrock brick structure.

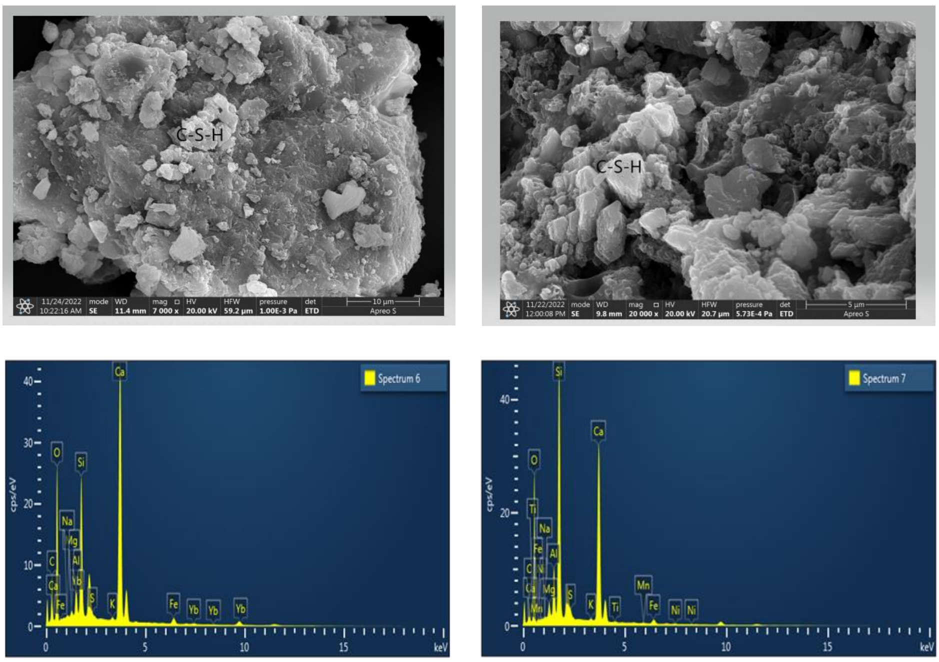

Fig.8. SEM and EDS analysis for bricks

5 Conclusions

Based on the test results, it can be concluded that adding TiO_2 to ferrock bricks increases their compressive strength.
1. The addition of TiO_2 at 1%, 2%, and 3% increased the compressive strength of ferrock concrete bricks by 28%, 32%, and 29%, respectively, over a curing period of 7 to 28 days.
2. The present study concluded that adding 3% TiO_2 results decreases in compressive strength compared to the 2% addition. Therefore, the optimal percentage of TiO_2 in Ferrock is determined to be 2%.
3. The cement setting time accelerated with an increase in TiO2 concentration. TiO_2 nanoparticles may thereby accelerate processes. Rapidly eliminating free water increases viscosity and accelerates solidification by making it easier for gaps to fill more quickly. The addition of TiO_2 to the mixture led to increased generation of C-S-H gel, as the nanomaterials effectively filled all the pores.4. The percentage of water absorption of ferrock concrete bricks decreased with the addition of TiO_2. After two hours of exposure to 200°C and 400°C, the ferrock brick will increase in strength by roughly 20% and 15%. Ferrock bricks have a high compressive strength, which makes them perfect for load-bearing structures.

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