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The Effect Wadi Alshati Iron Oxide Fine-Particles on the compressive Strength of the Concrete

Mohammed Al Kilani Almadani & *Ibrahim Bakari Al-Arabi
Department of Materials Engineering, Faculty of Energy and Mining Engineering,
Sebha University, Libya
*Corresponding author: Ibr.bakari@sebhau.edu.ly

Abstract Concrete is a heterogeneous material obtained by mixing cement paste (binder) with aggregates (filler), the later constituting more than 80% of the concrete. Concrete is a macro-material strongly influenced by addition of fine-properties such as iron oxide. One of the most important properties of hardened concrete is its compressive strength, which can be quantitatively measured. The objective of the present work is to study the effect of partial replacement of one of (*Wadi Alshati*) iron oxide fine-particles. Its proposed to replace fine aggregates with iron oxide and find its effects on the compression strength of the concrete. Six percentage levels of replacement i.e. 5, 10. 15, 20, 25 and 30 percent are considered for partially replacing sand with iron oxide. Plain concrete (PC) grade is initially designed without replacement and subsequently sand is partially replaced with iron oxide. The compressive strength was measured after 14 days of completion of curing. Results showed that the compressive strength of the concrete using iron oxide nanoparticles were not equivalent to that of the conventional concrete. Maximum decreasing in compressive strength was about 40%. According to the results of compression strength for conventional and incorporated specimen, the addition of iron oxide to concrete will decreases the compressive strength of concrete due to formation of porosity.

Keywords: Portland cement concrete, Iron oxide, Nano-particles, Compression test.

تأثير جسيمات أكسيد حديد وادي الشاطئ علي قوة الضغط للخرسانة

محمد الكيلاني المدني و *ابراهيم بكاري العربي
قسم هندسة المواد والتآكل، كلية الهندسة الطاقة والتعدين، جامعة سبها
*للمراسلة: Ibr.bakari@sebhau.edu.ly

الخلاص الهدف من هذا المشروع هو دراسة تأثير اضافة اكسيد حديد (وادي الشاطئ) على مقاومة الضغط للخرسانة الإسمنتية. في هذه الدراسة تم اجراء اختبار لـــ18 عينة، واحدة خالية من أكسيد الحديد و 6 عينات أخرى تحتوي على نسب مختلفة من أكسيد الحديد (5، 10، 15، 20، 25، 30)%. نتائج اختبارات الضغط لعينات الخرسانة الإسمنتية بينت أن وجود أكسيد الحديد له تأثير سلبي علة مقاومة الضغط للخرسانة، حيث أن أقصى فقدان لمقاومة الضغط بلغ حوالي 40%. يعزى سبب ذلك الى أكسيد الحديد يؤدي ال تكون فجوات داخل الخرسانة، وبالتالي فإن مقاومتها للضغط تقل.

الكلمات المفتاحية: الخرسانة الأسمنتية البورتلاندية، أكسيد الحديد ، جسيمات النانو، اختبار الضغط.

1. Introduction

1.1. Iron Oxide Nano-particles

Iron oxides are not only engineered materials, but are also present in various forms in natural systems, both in bulk as well as in fine-form [1]. Naturally occurring fine-scaled iron oxides are widely distributed throughout the atmosphere, ocean, water and most living organisms [2].

Iron oxide fine-particles have many other applications in construction industry, but of particular interest is as coloring and as anti-corrosion agent in construction materials and coatings. Iron oxide fine-particles have very good Ultra-Violet (UV) blocking capabilities making nanoparticles ideal for glass [3].

1.2. Concrete Strength

The most two important properties of hardened concrete are its compressive strength and durability. The former can be quantitatively measured while the latter cannot. In concrete design and quality control, strength is the property generally specified. This is because, compared to most other properties, testing strength is relatively easy. Furthermore, other properties of concrete, such as elastic modulus, water tightness or impermeability, and resistance to weathering agents including aggressive waters, are directly related to strength and can therefore be deduced from the strength data [4].

1.3. Concrete Compressive Strength:

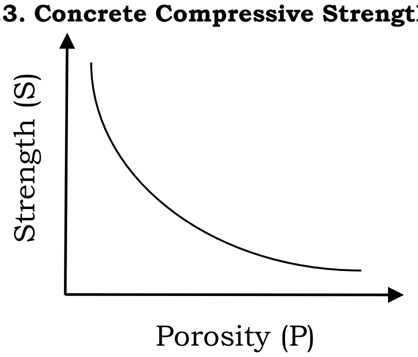

Figure1.1. Relation between Compressive Strength and Porosity [5]

There exists a fundamental inverse relationship between porosity and strength: $S = S_0 e^{-KP}$ where, S

compressive strength at porosity, S_0 intrinsic strength at zero porosity, K is constant and P is porosity as shown on the previous figure [3].

Many empirical relations between compressive strength and one or more of these variables have been proposed. Thus, Feret's law (1892) states that the strength is

Proportional to: $[c/(c+w+a)]^2$ [6] where c, w and a are the volumes of cement, water and air respectively [6]. The porosity of the hardened paste, is strongly correlated with strength.

The cement pastes of various degrees of hydration and w/c ratio conformed to the

relation: $\sigma = \sigma_o X^A$ [6]

where X is a quantity called the gel/space ratio, and equal to the volume of hydration product divided by that of hydration product plus capillary porosity. [6] The value of A was about 30 if non-evaporable water was used as a measure of the degree of hydration, and typical values were 90 - 130 MPa. This equation breaks down for mature pastes of low w/c ratio, because it implies that the strength does not then depend on the w/c ratio. In reality, strength increases with decreasing w/c ratio, even though some of the cement does not hydrate [6].

1.4. Mechanism of Compression Failure

Strength cannot be explained by relating it empirically to porosity or pore size distribution; it is necessary to know what holds the material together and what happens when it fails. Cohesion has often been attributed to the interlocking of fibrous or acicular particles. This could be important in the more porous parts of the material, but in the material as a whole, attractive forces between those parts of adjacent layers or other phases that are in contact are probably more important, both within particles and, in so far as the material is particulate, between them. As in other brittle materials, failure occurs through the initiation and spread of cracks, which originate in places where the local stress is high. Hardened cement pastes are about ten times as strong in uniaxial compression as in tension. It is probable that the ultimate mechanisms of failure are essentially similar, but that the cracks propagate more readily under tension. The relations between microstructure and strength must thus be sought in the features that give rise to high local stresses and in those that favour or, conversely, that arrest the spread of cracks. This is consistent with the conclusion that porosity is a major factor but not the only one [7].

2. Materials and Design Methodology

2.1.Materials:

2.1.1. Portland Cement:

Portland cement is the most important type of cement and is a fine powder produced by grinding Portland cement clinker. Cement materials used in the present work experiments were produced in *Ziliten* cement factory (Libya), it's a Portland cement grade (42.5 N), in accordance to Libyan specifications No. (340/2009).

2.1.2. Local Sand:

The composition of sand varies, depending on the local sources and conditions. The most common is a silica (silicon dioxide) usually in the form of quartz.

2.1.3. Water:

Generally, water that suitable for drinking is satisfactory for use in concrete. The pH was 6.07 and the chemical content of water are showed on table 2.1 .

Table 2.1. The chemical content of water used in the present work

K	SO_4	Cl	Ca	CO_3	NO_3	NO_2
9.41	3.70	28.40	3.20	39.04	6.16	4.60

2.1.4. Iron Oxide:

The used iron oxide namely (Hematite Fe_2O_3) was collected from *Wadi Al-Shati* iron ore quarry (about 100 km north west *Sebha* city-Libya) , has a reddish brown color. Iron oxide sample is show the in figure 2.1:

Figure 2.1. Wadi Al-Shati Iron Oxide Collected Sample

2.5. Experimental Specimen Preparation:

The experimental program including preparation of a six specimens, the first specimen is free of iron oxide (Reference specimen), and the other five specimens are contain gradually increasing of sand with iron oxide (5g, 10g, 15g, 20g, and 25g). The percentage of sand replacement with iron oxide are shown in the table 2.2 . For each specimen (PC, H10, H20, H30, H40, and H50), The two types were prepared in order to take the average of the obtained results for each specimen.

All specimen were prepared as cylinder shape with dimensions 30 mm length and 35 mm diameter as shown on figure 2.2 .

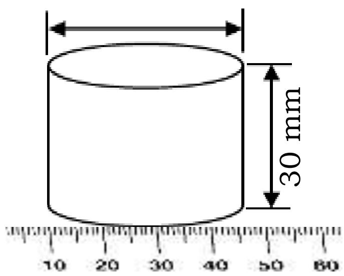

Figure2.2. Dimensions of Experimental Specimen

Table 2.2. Date of Experimental Work [8]

Specimen	Cement (g)	Water (mL)	Local Sand (g)	Local Sand (%)	Iron Oxide (g)	Iron Oxide (%)
Control (PC)	100	50-55	300	100	0	0.0
H10	100	50-55	295	98.3	5	1.7
H20	100	50-55	290	96.7	10	3.3
H30	100	50-55	285	85.0	15	5.0
H40	100	50-55	280	93.3	20	6.7
H50	100	50-55	275	91.7	25	8.3

3. Results and Discussion

3.1. Research objective

The main objective of the research program was to understand the compressive strength aspect of concrete obtained using iron oxide as partial replacement of sand. In order to achieve the objectives of the present study, an experimental program was planned to investigate the effect of iron oxide on compressive strength of concrete. The experimental program consists of casting, curing and testing of reference and iron oxide specimens at different concentrations.

3.2. Compression Test Procedure and Results

The cylinder specimens of dimension of (30 and 35 mm as length and diameter respectively) were prepared for testing compressive strength concrete as shown schematically on figure 3.1. The concrete mixes with varying concentrations (0% , 1.7%, 3.3%, 5.0%, 6.7%, and 8.3%) of iron oxide as partial replacement of sand were cast into cylinders for subsequent testing. In this study to make a concrete, cement, sand and iron oxide were mixed, water then was added and the whole mass was mixed together. After 24 hours the specimens were removed from the moulds and placed in clean and fresh water at temperature (27^{o}C ± 3). The specimens so cast were tested after 14 days of curing (after water was added to the dry mix). Each specimen was divided into two sub-specimen and three of the four sub-specimens were tested. Before testing, each specimen was ground in order to obtain a balanced surface to get accurate results. The load was applied axially without shock till specimen was crushed. Results of compressive strength test with varying proportion of iron oxide replacement are given in table 3.1.

Figure 3.1. Experimental Specimen before Compression Test

Table 3.1. Compression Test Results

Specimen	Iron Oxide %	Failure Load (F_L) (kN)		Failure Load Average (kN)
Control (PC)	0.0	PC (A)	30	26.00
		PC (B)	28	
		PC (C)	20	
H10	1.7	H10 (A)	16	20.33
		H10 (B)	25	
		H10 (C)	20	
H20	3.3	H20 (A)	16	15.66
		H20 (B)	14	
		H20 (C)	17	
H30	5.0	H30 (A)	12	16.00
		H30 (B)	18	
		H30 (C)	18	
H40	6.7	H40 (A)	25	20.33
		H40 (B)	16	
		H40 (C)	20	
H50	8.3	H50 (A)	18	18.00
		H50 (B)	18	
		H50 (C)	20	

The compressive strength can be calculated using the formula:
$\sigma_c = \frac{F_L}{A}$ [8] where, F_L is the failure load registered on the machine after the concrete specimen had failure, and a specimen area, can be calculated as following: Area of cylinder specimen is equal to: $[\pi r^2]$ = $[\pi(0.00175\ m)^2] = 9.621x10^{-6}$ m^2.
The compressive strength for each specimen was calculated according to the last equation, the table 3.2 showing the results.

Figure 3.2. Compression Test Machine Used in the Present Work.

Table 3.2. Compression Strength Results

Specimen	Compressive Strength (MPa)	Decreases in Compressive Strength (%)
Control (PC)	27.02	00.00
H10	21.13	21.18
H20	16.28	39.75
H30	16.63	38.45
H40	21.13	21.18
H50	18.71	30.75

It is well known that the compressive strength is the most important property of concrete. It was expected that addition of iron oxide – a material with higher hardness than cement – will increase the compressive strength. The results are presented in figure (3.3). It can see from the figure that the addition of iron oxide to the Portland cement has a negative effect. The decrease in compression strength was not linear as the percentage of iron oxide is gradually increased. In the first specimen H10 (5g – 1.7% iron oxide), the compression strength decreases with percentage about (21%). For the specimens H20 and H30 (10g –3.3% and 15g – 5.0% respectively), the compression strength decreases with average about (39%). For specimen H40 (20g –6.7%), the compression strength decreases with about (21%). In the last specimen H50 (25g – 8.3%), the compression strength decreases with about (31%).

The reason behind decreasing in compressive strength (In general about 30%) comparing with the plain concrete may be attributed to the formation of porosity of iron oxide. [10] As shown on figure 3.4 .

It should be considered that because hematite includes high iron ore volume, it tends to undergo undesirable oxidation [9].

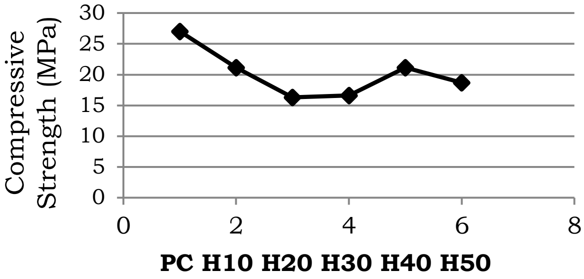

Figure 3.3. Compressive Strength of Hardened Concrete Specimens.

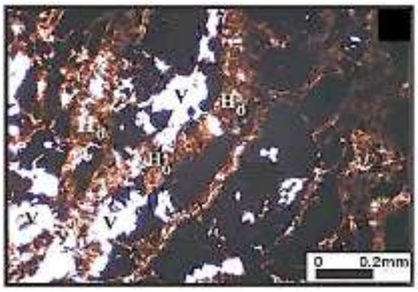

Figure 3.4. Iron Oxide Aggregates have high porosity (A consequence of voids (V) which have appeared during formation of iron oxide H_0) [8].

4. Conclusion:

This research work is concerned with studying the effect of replacing a mix sand of concrete with different weight of iron oxide namely (hematite) (5g, 10g, 15g, 20g and 25g). It was expected that addition of iron oxide material with higher density and higher hardness than Portland cement will increase the compressive strength. Unfortunately, the resulted data of those concrete specimens consisting of partially replaced with iron oxide showed that there is a decreasing in compression strength for all tested specimen comparing with the plain concrete (with no iron oxide addition). The reduction in compression strength of concrete ranges from 21.18% to 39.75% with no linearity. The reason for decline in compression strength for all specimens may be attributed to the porosity of iron oxide formation in hardened concrete. The overall conclusion is that the incorporating of iron oxide nanoparticles is not recommended in where case of high compression strength is required.

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