STRENGTH OF REACTIVE SILICA SAND POWDER CONCRETE MADE OF LOCAL POWDERS

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Abstract

The main purpose of this research is to study the strength of the RPC incorporating local powders (reactive silica sand powder) and compare it with RPC incorporating condensed silica fume. Original RPC- in form of superplasticized cement mixture with powder (reactive silica sand or silica fume), steel fiber ,and fine sand (<600 mµ)- was studied in comparison with modified reactive powder concrete (MRPC) where a natural aggregate (max size 8mm)was used to replace the fine sand of the cementitious binder. In the present research work compressive strength, (incorporating local reactive silica sand powder) of reactive powder concrete and modified reactive powder concrete were studied. High 28-day compressive strengths (101-115 MPa) were gained when using local powders.

Keyword: cement, mixture, concrete, powder

مقاومة خرسانات المساحيق الفعالة المصنعة من مساحيق محلية

ميثاق البيرلويس
الجامعة المستنصرية- كلية الهندسة – قسم الهندسة المدنية

الخلاصـــــة

الغرض الرئيسي من هذا البحث هو لدراسة مقاومة الخرسانة ذات المساحيق الفعالة المنتجة من مساحيق محلية (مساحيق الرمال السلكية الفعالة) و مقارنتها مع الخرسانة ذات المساحيق الفعالة المنتجة من أبخرة السليكا المكثفة. الخرسانة ذات المساحيق الفعالة الأصلية – والتي تكون بشكل خليط من السمنت والملدن المتفوق مع مساحيق الرمل السليكي أو الأبخرة السلكية المكثفة ، ألياف الحديد، الرمل الناعم (بمقاس اقل من ٦٠٠ مايكروميتر) قد تم دراستها ومقارنتها مع الخرسانة ذات المساحيق الفعالة المطورة والتي بها يتم استبدال جزء من الرمل الناعم في الخلطة الإسمنتية الرابطة بالركام الطبيعي (بمقاس ٨ ملم كحد أقصى). في هذا البحث فان مقاومة الانضغاط قد تمت دراستها والفحوصات بينت انه الخرسانة ذات المساحيق الفعالة و الخرسانة ذات المساحيق الفعالة المطورة و المصنعة من المسحوق الرمل الزجاجي المحلي أظهرت قيما عالية في مقاومة الانضغاط (١٠١-١١٥ ميكاباسكال).

Introduction

Reactive powder concrete (RPC), is a high-strength, ductile material formulated by combining Portland cement, silica fume, quartz flour, fine silica sand, high-range water reducer, water, and steel or organic fibers **(William Dowd, 1999)**.
Considerable amount of work has been undertaken to investigate the mechanical properties of various types of concrete. However, very limited amount of work has been published to investigate the mechanical properties of RPC and Modified Reactive Powder Concrete (MRPC) containing local reactive silica powder such as reactive silica sand powder and compare it with that fabricated with silica fume.

In this study two types of powder are used (silica fume and reactive silica sand powder) as a mineral admixture with modified polycarboxylic ether and fine sand for reactive powder concrete while adding course aggregate (maximum size 8 mm) to produce a modified reactive powder concrete.
The original concept of RPC was first developed in early 1990's, by researchers at Bouygues laboratory in France. RPC stems from efforts to optimize the microstructure of the matrix by precise gradation of all particles in the mix to yield a matrix with optimum density and extensive use of the pozzolanic properties of highly refined silica fume and optimization of the Portland cement chemistry to produce the highest strength hydrates **(Molyneax and Luk, 2003), (Lee and Chisholm, 2005)**.

Elastic properties of reactive powder concrete were studied by **(Washe et. al., 2004)**. The research reported in this paper examines elastic properties of this new material (reactive powder concrete) and discusses ultrasonic methods for evaluating Young's modulus.
Mechanical properties of reactive powder concrete were also studied by **(Pierre et. al., 1999)** Portland cement, silica fume, ground quartz and sand react chemically during the various processing stages in forming the material. Heating reactive powder concrete for two days in a vapor-saturated atmosphere at 90 ^{o}C, once setting occurred, accelerates the pozzolanic reaction of the silica fume and modifies the structure of the hydrate. Heat treatment increases the strength. Results indicate that the compressive strength is very high (200 MPa) and high ductility provides high flexural strength (25-35 MPa).

(Perry and Zakariasen, 2004) found that the ductile behavior of this material is a first of concrete, with the capacity to deform and support flexural and tensile loads, even after initial cracking. The use of this material for construction is simplified by the elimination of reinforcing steel and ability of the material to be virtually self placing or dry cast.
An experimental investigation on RPC made by adding Portland cement, silica fume, superfine fly ash, and super plasticizers was reported by **(Wen-Yu et. al., 2001).** They showed that the RPC has high strength (157 MPa at 6 days, 147.3 MPa at 28 days), high durability, including excellent impermeability of chloride and frost-resistance, high split tensile strength (15 MPa at 6 days 21.1 MPa at 28 days), and elastic modulus of 48.5 GPa at 28 days.
RPC also has ultra-high durability characteristics resulting from extremely low porosity. Penetrations of liquid and/or gas become nearly non-existent in comparison to high performance concrete HPC **(Dauriac, 1997)**.

(Jianxin, 1996) reported that the original UHPC was modified through partial replacement of cement or silica fume by fine quartz powder and also showed that the compressive strength higher than 200 N/mm^2 can be reached under normal curing condition.
From the previous review, it can be noticed that there are very few studies concerning MRPC and available data were not found about the properties of RPC and MRPC incorporating Iraqi reactive silica sand powder. In the present work, the compressive strengths of reactive powder concrete (RPC) and modified reactive powder concrete (MRPC) containing condensed silica fume and local reactive silica sand powder are studied.

Experimental Work

Materials

Cement

Tasluga ordinary Portland cement manufactured in Iraq was used throughout this research. The used cement conforms to **(Iraqi Specification No. 5/1984)**.

Fine Aggregates

Two types of fine aggregate are used in this study. The first one is Al-Ekhaider sand and the second is silica sand known as glass sand.

Al-Ekhaider natural sand was used as fine aggregate. It was tested to determine the grading and other physical and chemical properties. Results indicated that the fine aggregate grading and the sulfate content were within the requirements of the **(B.S. 882/1992 specification)**. For reactive powder concrete, very fine sand with maximum size 600µm is used. This sand is separated by sieving; its grading satisfies the fine grading in accordance with the **B.S. specification No.882/1992**. The sieve analysis of the original and the separated fine sand is shown in **(Tables 1**and **2)**

In order to compare with natural fine sand, fine silica sand known as glass sand is used **(Table 3)**. This type of sand is by produced in Al- Ramadi Glass factory. The sieve analysis of this sand is shown in **(Table 4)**.

Coarse Aggregates

Crushed gravel obtained from Al-Nebai quarry was used. The maximum coarse aggregate size was chosen to be 10mm. Table (5) show the grading of coarse aggregate which conforms to the **(B.S. 882/1992 specification)**.

High Range Water Reducing Admixture Glenium 51

High range water reducing admixture used in this study is modified polycarboxylic ether, which is known commercially as Glenium 51.

Glenium 51 is free from chlorides and complies with **(ASTM C494 Types A and F, 1988)**. **(Table 6)** shows the main properties of Glenium 51.

Water

Ordinary tap water was used in this research for mixing and curing for all concrete specimens.

Reactive Powder

In this study two types of reactive powders are used: silica fume and reactive silica sand powder.

Silica Sand powders

Silica sand used throughout this investigation was crushed Iraqi silica rock brought from Al-Ramadi Glass Factory. To avoid any differences between different batches, the whole quantity of silica sand was brought from the factory from a single batch and stored in a suitable place (nylon container) to avoid exposure to atmosphere or water.

The chemical composition and physical properties of silica sand used in this research are shown in **(Table 7)** and **(Table 8)**. The amorphous silica sand can be converted to very fine particles by grinding resulting in a highly active pozzolana. The grinding of silica sand was carried out in a grinding mill for a period of 24 hours for each 0.5 kg of the silica sand. The fineness was determined by Blaine air permeability method in accordance with **(ASTM C 204-84, 1989)**.

The silica sand, which is used throughout this work, conformed to the chemical and physical requirements of **(ASTM C 618 Class N Pozzolan, 1989)**, **(Table 9 and 10)** respectively.

Condensed Silica Fume

This type of pozzolan is with SiO2 content of 98.9%.

Preparation of Local Reactive Powder

Grinding of cement and reactive powder produce the samples of high performance cement. The grinding process was done with a laboratory ball mill; grinding time was set at 24 hours for each 500 gm of the local reactive powder (silica sand powder) and finally grinding time was set at 120 minutes for each 500 gm of the reactive powder and cement.

Steel Fibers

The steel fibers used in this work have the properties described in **(Table 11)**.

Mixing of Concrete

The mixing was performed in a rotary mixer with a capacity of 0.1 m^3. For the small specimens (50×50×50mm) mixing by hand was performed for reactive powder concrete and modified reactive powder concrete. The aggregate was used in a saturated surface dry condition.
The reactive powder was mixed with cement before the addition to the mixer for 30 minutes to ensure uniform dispersion of this admixture by means of a ball mill to disperse the reactive powder particles throughout the cement particles. After that the dry materials (cement, reactive powder, aggregate) were well mixed for about 5 minutes to attain uniform mix. The required amount of tap water and superplasticizers previously mixed together was then added to the rotary mixer and the whole mix ingredients were mixed for a sufficient time. When fibers were used, they were introduced, dispersed uniformly.

Concrete Mixes and Strength Results

The mixes used in this work are presented in Tables (12) to (16).

Conclusions

Depending on the results of this investigation on RPC and MRPC the following conclusions can be drawn:

1. It is possible to produce reactive powder concrete (RPC) and modified reactive powder concrete (MRPC) from silica sand powder or silica fume as a pozzolanic admixture, and Glenium 51 as a high range water reducing admixture (HRWRA).
2. The RPC or MRC containing local reactive powder (silica sand powder) were tried and investigated in order to be compared to the RPC or MRPC with classic powder (silica fume). The results were lower by approximately 18% in compressive strength. However looking at the use of local materials this may be considered a gain.
3. Reactive powder concrete (RPC) with a compressive strength of 115 MPa , can be attained at age of 28 days and at 20 ^{o}C by adding local powder (silica sand powder) as a pozzolanic admixture, fine normal sand ,ultra fine steel fiber and Glenium 51 to ordinary portland cement .
4. Reactive powder concrete (RPC) with a compressive strength of 141 MPa can be attained at age of 28 days and at 20 ^{o}C by adding silica fume as a pozzolanic admixture, fine normal sand ,ultra fine steel fiber and Glenium 51 to ordinary portland cement.
5. When fine normal sand is replaced by fine glass sand the compressive strength becomes 101 MPa and 129 MPa compared with RPCs described in points 3 and 4 mentioned above, respectively.
6. When gravel is introduced as 50% replacement to fine normal sand, the compressive strengths

becomes 90 MPa and 149 MPa compared with RPCs described in points 3 and 4 mentioned above, respectively.

7. When using silica sand powder and fine glass sand with silica fume the 28-day compressive strength reached 130 to 139 MPa for RPC and MRPC, respectively.

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(Table 1) Grading of Al-Ekhaider natural sand compared with the requirements of B.S.882:1992

Sieve size (mm)	Cumulative passing %	Limits of B.S. 882/1992 overall grading
4.75	100	89-100
2.36	91.4	60-100
1.18	81.7	30-100
0.60	65.3	15-100
0.30	23.0	5-70
0.15	8.15	0-15

(Table 2) Grading of separated natural sand compared with the requirements of B.S.882:1992

Sieve size (mm)	Cumulative passing %	Limits of B.S. 882/1992 fine grading
4.75	100	100
2.36	100	80-100
1.18	100	70-100
0.60	100	55-100
0.30	65	5-70
0.15	11	0-15

(Table 3) Physical properties of the fine sand

Physical properties	Test result	Limit of Iraqi specification No 45/1984
Specific gravity	2.60	-
Sulfate content%	0.09	0.5(max)
Absorption%	0.71	-
Materials finer than 75µm	0.093 %	5(max)

(Table 4) Grading of separated silica sand compared with the requirements of B.S.882:1992

Sieve size (mm)	Cumulative passing %	Limits of B.S. 882/1992 fine grading

4.75	100	100
2.36	100	80-100
1.18	100	70-100
0.60	100	55-100
0.30	52	5-70
0.15	10	0-15

(Table 5) Grading of coarse aggregate

Sieve analysis (mm)	Cumulative passing %	Limits of B.S.882/1992 specification
14	100	100
10	91	85-100
5	16	0-25
2.36	2.5	0-5

(Table 6) Typical properties of Glenium 51

Form	Viscous liquid
Colour	Light brown
Relative density	1.1 gm/cm^3 at 20 ^oC
pH	6.6
Viscosity	128 cps at 20 ^oC
Transport	Not classified as dangerous
Labeling	No hazard label required
Chloride content	None

(Table 7) Chemical properties of silica sand powder*

Oxide Composition	Oxide Content (%)
SiO_2	98.45
Al_2O_3	0.98
Fe_2O_3	0.05
CaO	0.6
MgO	0.8
SO_3	0.06
L.O.I.	2.14

* *Tests for chemical properties of silica sand powder were conducted by AL-Ramadi Glass Factory*

(Table 8) Physical properties of silica sand powder

physical properties	cement	silica sand powder

Setting time hr:min Initial setting time final setting time	 1:31 3:31	 1:20 3:10
Surface area (Blaine method) m^2/kg	240	280
Specific gravity	-	2.58

(Table 9) Chemical requirement of silica sand and pozzolan ASTM C_{618}

Oxide composition	Pozzolan class N	Silica sand
$SiO_2+Al_2O_3+Fe_2O_3$ Min. percent	70	98.48
SO_3, max. percent	4	0.06
Loss in ignition %	Max. 10	-

(Table 10) Physical requirements of silica sand and pozzolan ASTM C_{618}

Physical properties	Pozzolan class N	silica sand
Flow table, max percent	115	110
Surface area (Blaine method) m^2/kg	-	280
Specific gravity	-	2.58
Strength activity index with portland cement at 28 days, min. percent of control	75	150.5

(Table 11) Properties of the steel fibers

Description	straight
Length	13 mm
Diameter	0.18 mm
Density	7800 kg/m^3
Tensile strength	1800 MPa
Aspect ratio	72

(Table 12) Mix proportion of original RPC mixtures with reactive silica sand powder

Mix No.	01
Portland Cement C (kg/m^3)	940
Silica Sand Powder SSP(kg/m^3)	190
Normal Fine Sand (kg/m^3)	980
SP* % by Weight of Cement	8%
Steel Fiber S_f % by Volume	2%
Water (kg/m^3)	240
W/C (%)	0.25
W/(c+cm)* (%)	0.21
Compressive Strength at 28 days(MPa)	114.9

(Table 13) Mix proportion of original RPC mixtures with Condensed silica fume powder

Mix No.	02
Portland Cement C (kg/m^3)	940
Silica Fume SF(kg/m^3)	210
Normal Fine Sand (kg/m^3)	990
SP* %by Weight of Cement	8%
Steel Fiber S_f% by Volume	2%
Water (kg/m^3)	216
W/C (%)	0.23
W/(c + cm)* (%)	0.188
Compressive Strength at 28 days(MPa)	141.0

(Table 14) Composition of reactive powder concrete with glass sand

Powder Type	Silica Sand Powder	Silica Fume Powder
Mix No.	**03**	**04**
Portland Cement C (g_m)	940	940
Silica Sand Powder SSP (gm)	180	/
Silica Fume SF (gm)	/	200
Fine Glass Sand (gm)	1020	970
SP* % by Weight of Cement	8%	8%
Steel Fiber S_f % by Volume	2%	2%
Water (kg/m^3)	240	240
W/c (%)	0.25	0.23
Compressive Strength at 28 days (MPa)	100.8	128.5

(Table 15) Composition of modified reactive powder concrete with normal fine sand

Mix no.	05	06
Portland Cement (kg/m^3)	960	960
Silica Sand Powder (kg/m^3)	194	/
Silica Fume (kg/m^3)	/	200
Normal Fine Sand (kg/m^3)	530	530
Gravel (kg/m^3)	430	426
SP* (Glenium51)	8%	8%
Steel Fiber	2%	2%
Water (kg/m^3)	218	210
W/c (%)	0.227	0.218

Flow Table (%)	73	77
Compressive Strength (MPa)	89.6	149.1

(Table 16) Composition of modified reactive powder concrete with two types of powder and two types of sand

Mix No.	07	08
Portland Cement (kg/m^3)	960	960
Silica Sand Powder (kg/m^3)	40	50
Silica Fume SF (kg/m^3)	170	190
Fine Glass Sand (kg/m^3)	30	30
Normal Fine Sand (kg/m^3)	1000	550
Gravel G (kg/m^3)	/	230
SP* (%) by Weight	8%	8%
Steel Fiber S_f(%) by Volume	2%	2%
Water (kg/m^3)	224	236
W/c (%)	0.23	0.245
Compressive Strength at 28 days (MPa)	130.5	139.4

***Notes**

SP = Super plasticizer

W/(c+cm) = ratio of Water to cement and cementitious materials