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Properties of High Strength Concrete Containing Stone Powder as Natural Pozzolanic Materials

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Abstract: Currently high-strength concrete is increasingly used in modern concrete technology and particularly in the construction of high rise buildings. This study has been conducted to investigate the properties of high-strength concrete that was produced by using stone powder (SP) as an alternative of proportion on cement after being processed , since its main oxides are similar to those of cement.
The aim of the research is to study the effect of (10,15,20,25)% stone powder as replacement of cement, used in concrete mix which it has a mixing proportion of (1:2:1.8;w/c =0.26), and it is shown their effect on some of mechanical properties (compressive strength, splitting tensile strength, and flexural strength). The test results showed clear improvement in some mechanical properties of concrete by using 20% (SP). The increment where its ratio (34, 41, 34.4)% for each compressive strength, splitting tensile strength, and flexural strength compared with reference mixture for the same duration respectively.

Keywords: High strength concrete(HSC) ; Stone powder (SP); Chemical reaction; Mechanical properties.

Introduction

Considering the volume, concrete is the first mostly used building material in the world. Every year more than 1 m³ is produced per person (more than 10 billion tons) worldwide[1].
The definition of high strength changes over the years as concrete strength used in the field increases. This publication considers high-strength concrete (HSC) to have a strength significantly beyond what is used in normal practice[2].
High strength concrete is a type of high performance concrete generally with a specified compressive strength of 40 MPa or greater.
In the last few decades, considerable research effort has been spent on the utilization of industrial by product (fly ash, blast furnace slag, silica fume, etc.) and natural resources (lime stone, pozzolans, etc.) as replacement of Portland cement. The benefits of addition of supplementary materials to Portland cement are well documented[3,4].
Supplementary cementitious materials can be used for improved concrete performance in its fresh and hardened state. they are primarily used for improved workability, durability and strength. These materials allow the concrete producer to design and modify the concrete mixture to suit the desired application[5].
Many researches examine the possibility of using stone powder, limestone powder as partial replacement of sand and partial replacement of cement. The test results indicate that granite powder of marginal quantity as partial sand replacement has beneficial effect on the mechanical properties such as compressive strength, split tensile strength, modulus of elasticity[6].
*The aim of this research is to study the influence of stone powder (which has approximately the same chemical composition of cement, silica fume and fly ash) used as partially replacement of cement on important mechanical properties of hardened concrete.

Supplementary cementing materials

The mineral admixture of today were among the chief cementitious components of concretes produced many centuries ago. Commonly termed "pozzolans," these materials are capable of forming a durable binder. A pozzolan is defined in ASTM C 618 as " a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties." These characteristics make

pozzolans ideal additions to Portland cement concrete mixtures.
They are composed of similar materials and react with the products of hydrating cement to create additional cementitious binder. Pozzolanic material can be used to modify and improve plastic and hardened properties of concrete[7].

Types of supplementary cementing materials :

Silica fume :
Is a highly reactive pozzolanic material and is a byproduct from the manufacture of silicon or Ferro-silicon metal. It is collected from the flue gases from electrical arc furnaces. Silica fume is an extremely fine powder, with particles about 100 times smaller than an average cement grain. Silica fume is available as a densified powder or in a water-slurry form. The standard specification for silica fume is ASTM C 1240[8].

Fly ash :
Is a byproduct of coal-fired furnaces at power generation facilities and is the non-combustible particulates removed from the flue gases. Fly ash used in concrete should conform to the standard specification, ASTM C 618[9].

Ground blast furnace slag :
Is a non-metallic manufactured byproduct from a blast furnace when iron ore is reduced to pig iron. The liquid slag is rapidly cooled to form granules, which are then ground to a fineness similar to Portland cement. Ground granulated blast furnace slag (GGBFS) used as a cementitious material should conform to the standard specification, ASTM C 989[10].

Rice husk ash, and :
Rise husk ash (RHA) is a natural byproduct from the processing of paddy rise. The husks, which are approximately 50 percent cellulose, 30 percent lignin and 20 percent silica, are incinerated by controlled combustion leaving behind an ash that predominantly consists of amorphous silica. This material are also covered under the standard specification, ASTM C 618[11].

Chemical composition of supplementary cementing materials:

Table (1) shows chemical analysis of silica fume, fly ash, (GGBFS), rise husk ash and white sandstone powder[12].

Chemical reactions : [13].

Hydraulic vs. pozzolanic reaction.

Pozzolanic reactions:
Chemical reaction with calcium hydroxide (lime) and water that leads to the formation of cementitious products, like C-S-H.

Latent hydraulic reactions:
Chemical reaction with water that leads to setting and hardening of the material.

Hydration of calcium silicates in cement.

2C3S + 6H $\rightarrow$ C3S2H3 + 3CH

2C2S + 4H $\rightarrow$ C3S2H3 + CH

C-S-H; molar reaction can vary; strength-giving phase CH; no cementitious properties (does not contribute to strength); easily leached; prone to chemical attack.
Reminder on cement chemistry notation:
C = CaO; S = SiO_2; H = H_2O .

Pozzolanic reaction:
C3S + H fast $\rightarrow$ C-S-H + CH
C2S + H fast $\rightarrow$ C-S-H + CH
Pozzolan + CH+H slow $\rightarrow$ C-S-H SLOW

Experimental work

6.1 Materials

6.1.1 Cement:
Ordinary Portland cement (sinjar) was used in this work. Tables (2) and(3) show the chemical and physical properties of the cement used. The test result indicated that the selected cement conformed to the Iraqi specification [14].

Water:
Ordinary tap water was used for all the mixtures.

Fine aggregate:
Medium natural sand in accordance with British standard (B.S.)882:1992 [15] was used. Its particle size shown in table (4).

Coarse aggregate:
River gravel round shape was used ,has maximum aggregate size of 12.5mm, sieve analysis was performed and table (5) shows the results of the sieve analysis, it is found compatible to the American standard(ASTM C33-93) [16].

stone powder:
White sand stone powder can be used as a mineral admixture similar to above materials. A primary goal is a reduction in the use of Portland cement, which is easily achieved by partially replacement it with various cementitious materials. White sand stone was washed and dried with a maximum size (45 mm), then grinding machine shown in figure (1) was manufactured and used to get very fine powder of stone. Figure (2) shows the morphology of the stone powder, after grinding and from the figure, fineness of the stone powder found about 2μm, and more than 50% of the particle was classified as Nano particles.

superplasticizer:
(FFN) High range water reduces was used as superplasticizer, its color was brown and has a density of (1.21-0.02) Kg/L.

Activity index:
To evaluate the activity of the stone powder used, activity index test ASTM C311 [17] was used. The

result of strength activity index at 28 day equal to (136) %.

Mixture proportions and testing:

Concrete mixtures included one control mixture with a cementitious materials content of 450 kg/m³ was prepared. Others concrete mixtures were made with a stone powder content 10%, 15%, 20% and 25% as replacement of cement. The proportions of the five mix proportions are summarized in table (6). The water/cementitious material of the five mixtures is 0.26. The batching followed ASTM C192 [18].

The concrete Steel Molds include:

Cube (100*100*100)mm used for compressive strength test,

Prism (400*100*100)mm for flexural test and

Cylinder (200*100)mm for splitting test, (21) samples were casted for each mix.

*After one day the samples were removed from molds and soaked in (23 c°) water, and kept to the time of test.

Testing program :

8.1 Compressive strength for 3,7,28,56 and 90 days, according to (BS. 1881:part 116) [19].

8.2 Splitting tensile strength, at 28 days of age, according to ASTM C496 [20].

8.3 Flexural strength, at 28 days of age
, according to ASTM C78 [21].

results of testing

Tables (6,7,8,9) show mixture properties and the results of testing specimens.

Compressive strength:

The compressive strengths of the concrete made with and without admixture are given in table (7) and represented in figure (3). A comparison between the compressive strength of mix1 and other mixes showed that the using of stone powder gave the highest percentage increase.

Tensile & flexural strength

The splitting tensile strength of the concrete specimens made with the different percentages of stone powder and the control mix are given in table (8) and shown in figure (4). The flexural strength results for the different concrete mixes are shown in table (9) and figure (5). From the test results it can be seen that for both groups the concrete with partially replacement with stone powder showed higher strength than those without replacement.

Discussion of results:

The higher compressive strengths obtained when use 20% stone powder as replacement of cement. The strengths of the interface zone and hardened cement paste are increased in stone powder which causes the particles of these materials to wrap up tightly on the surface of the aggregate and fill the gaps between the cement particles. From the results of splitting strength, it can be observed that for each group the splitting tensile strength of the modified concrete is higher than that of concrete without admixtures. This behavior of the admixture enriched concrete is similar to that observed when investigating the compressive strength of concrete mixes containing stone powder. And From the test results of flexural strength, it can be seen that for both groups the concrete with partially replacement with stone powder showed higher strength than those without replacement.

Conclusion:

10.1 High performance concrete can be produced by using stone powder as partial replacement of cement.

10.2 White sand stone powder and each mineral such as silica fume, fly ash, rice husk ash, metakaolin, blast furnace slag, palm oil fuel ash, etc. can play a part to improve the performance of concrete. Since each mineral has one or two useful characteristics in binder blends, incorporations of two or three supplementary cementitous materials have been explored by different experts, and different properties such as early age or late hardening, compressive strength, tensile strength, dry shrinkage, creep, etc. have been studied.

10.3 At 28 days, the compressive strength of samples containing stone powder still more than the results for samples without stone powder but both are of acceptable range.

10.4 The most suitable percentage of stone powder as partial replacement of cement was 20%, which gave highest activity index.

10.5 Splitting and flexural tensile strength were found to increase as the compressive strength increased, therefore the use of admixture (stone powder) has significant improvement to the tensile strength.

10.6 Replacement of cement by 20% stone powder will be economist.

10.7 Still, more tests should be run in order to prove the quality of concrete containing high volume supplementary cementitous material. Brittle behavior, crack formation, shrinkage, corrosion time initiation, passivity, carbon dioxide absorption, etc. are still question marks in the multi blended cement concrete field.

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Table (1) chemical analysis of silica fume, fly ash, (GGBFS), rise husk ash and white sandstone powder [12].

Oxides	Silica fume	Fly ash	(GGBFS)	Rise husk ash	White sandstone
SiO_2	90,48	40.47	38	87.2	44.89
Al_2O_3	0.99	4.57	12	0.15	0.3
Fe_2O_3	2.60	8.75	1.25	0.16	0.68
CaO	2.12	34.94	39	0.55	18.6
MgO	0.86	7.18	10	0.35	2.34
SO_3	0.87	0.25	-	5.91	0.39
K_2O	0.15	0.75	-	-	0.26
Na_2O	0.2	0.3	-	3.54	1.06

***Except stone powder was tested in (Hamam Al- Aleel) factory.**

Table (2) physical properties of cement used.

Physical properties	Test results	Limit of Iraqi specification
Specific surface blain method	290	230 minimum
Initial setting (minutes)	149	45 min
Final setting (hours)	3.25	10 hrs.
Compressive strength 3 days 7 days	 22 30	 15 minimum 23minimum

Table (3) chemical properties of cement used.

Basic components %	Cement
SiO_2	21.2
Al_2O_3	6.5
Fe_2O_3	2.5
CaO	63
MgO	2.75
SO_3	3.1
K_2O	0.45
Na_2O	0.24
C_3A	13.6

***The test was conducted in Sinjar Cement Factory Laboratories.**

Table (4) Grading of fine aggregate.

Sieve size (mm)	Percentage passing				
	Total limit	Percentage passing of the sand used	Grading zone limit		
			Course	Medium	Fine
4.75	89-100	100	-	-	-
2.36	60-100	88	60-100	65-100	80-100
1.18	30-100	69.2	30-90	45-100	70-100
0.6	15-100	46.7	15-54	25-80	55-100
0.3	5-70	14.1	5-40	5-48	5-70
0.15	0-15	3.9	-	-	-

Table (5) Grading of course aggregate.

Sieve size (mm)	Total limit %	Percentage passing %
19	100	100
12.5	90-100	93.8
9.5	40-70	59.3
4.75	0-15	0.94
2.36	0-5	0

Table (6) composition of mixes.

Materials	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
Cement kg/m³	450	405	382.5	360	337.5
Stone powder kg/m³	-	45	67.5	90	112.5
Sand kg/m³	900	900	900	900	900
Gravel kg/m³	810	810	810	810	810
Super plasticizer kg/m	6	6	6	6	6
w/c	0.26	0.26	0.26	0.26	0.26

Table (7) compressive strength.

Mix no.	3 days (MPa)	7 days (MPa)	28 days (MPa)	56 days (MPa)	90 days (MPa)
Mix 1	18	32	47	55	58
Mix 2	21	35	55	63	65
Mix 3	23	40	61	70	72
Mix 4	25	42	63	73	76
Mix 5	20	33	50	56	60

Table (8) Splitting results.

Mix no	Splitting strength (MPa)
Mix 1	3.9
Mix 2	4.6
Mix 3	5.2
Mix 4	5.5
Mix 5	4.2

Table (9) flexural results.

Mix no	Flexural strength (MPa)
Mix 1	5.8
Mix 2	6.6
Mix 3	7.1
Mix 4	7.8
Mix 5	6.0

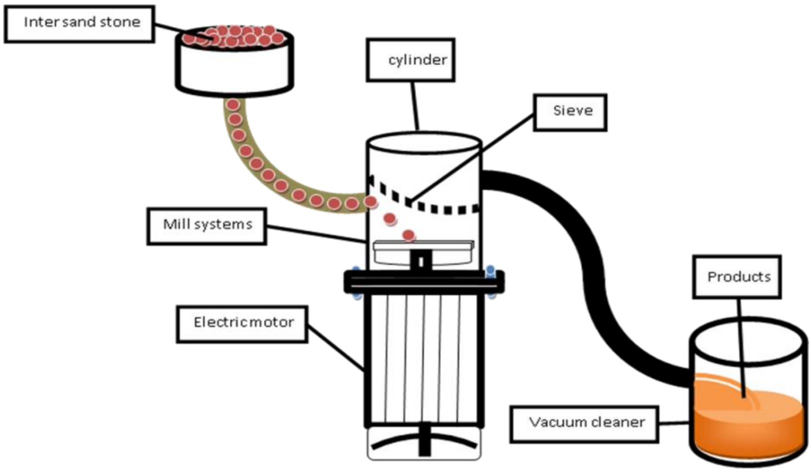

Figure (1) Schematic diagram of the grinding machine.

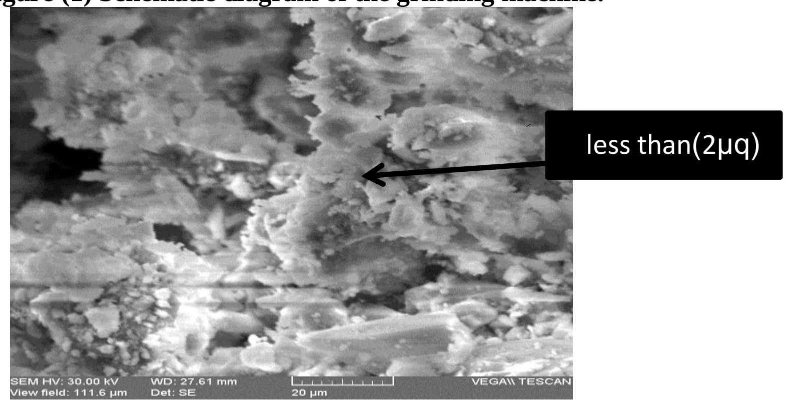

Figure (2) The morphology of the stone powder.

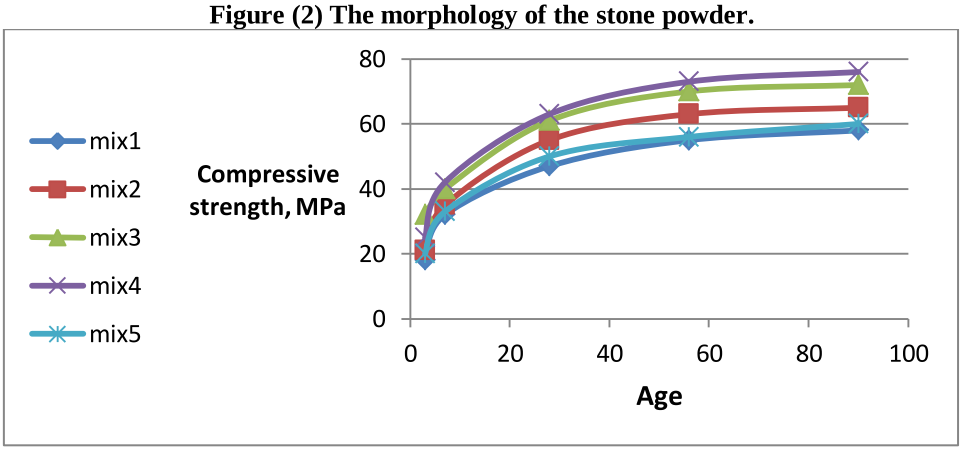

Figure (3) Compressive strength of different mixes.

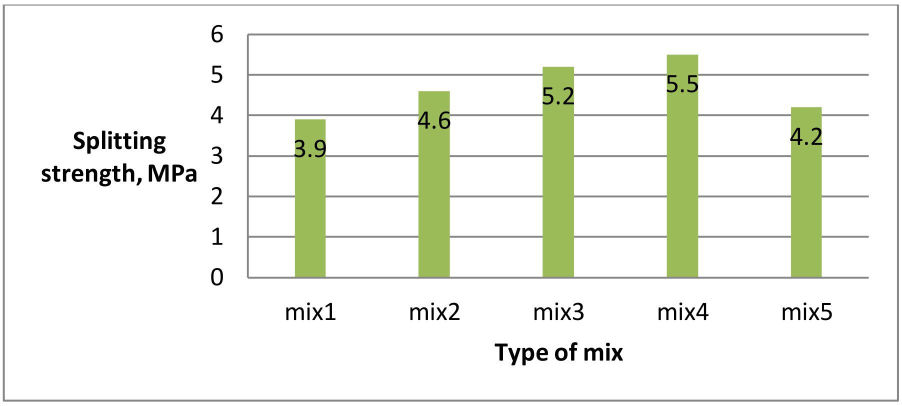

Figure (4) Splitting strength at 28 days.

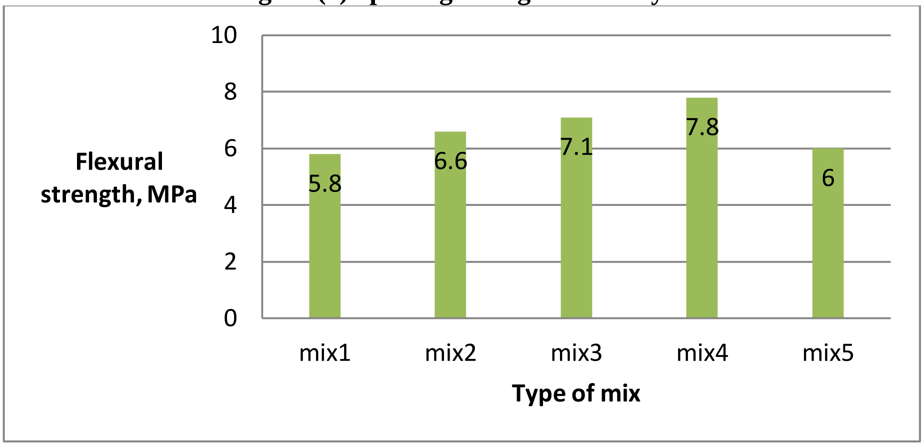

Figure (5) Flexural strength MPa at 28 days.

خصائص الخرسانة عالية المقاومة المحتوية على مسحوق الحجارة كمادة بوزولانية طبيعية

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الخلاصة:

تستخدم خرسانة عالية المقاومة في تقنية الخرسانة الحديثة وخصوصا في انشاء ابنية عالية الارتفاع. خصصت هذه الدراسة للبحث في خواص الخرسانة عالية المقاومة المنتجة باستخدام مسحوق الحجارة كنسبة استبدال عن السمنت لكون أكاسيده الرئيسية مشابهة الى اكاسيد السمنت.ان الهدف الرئيسي للبحث هو دراسة تأثير استبدال مسحوق الحجارة (الحصى الابيض) وبنسب وزنية (10،15،20،25)% من وزن السمنت المستعمل في الخلطة الخرسانية ذات النسب الوزنية (1:2:1,8) ونسبة الماء الى السمنت(0,26) وبيان مدى تأثيره على بعض الخواص الميكانيكية ,مقاومة الانضغاط, مقاومة شد الانفلاق, ومقاومة الانثناء.اظهرت نتائج الفحص تحسنا واضحا في بعض الخواص الميكانيكية للخرسانة باستعمال 20% من مسحوق الحجارة نسبته (34،41،34,4)% لكل من مقاومة الانضغاط ,مقاومة شد الانفلاق, ومقاومة الانثناء على التوالي مقارنة بالمرجعية ولنفس الفترة الزمنية.