MECHANICAL PROPERTIES OF HIGH-PERFORMANCE CONCRETE PRODUCED IN SUDAN

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مُسْـتَخْلَص

الخرسانة عالية الأداء (HPC) تستخدم على نطاق واسع في صناعة تشييد البناء في جميع أنحاء العالم. الهدف الرئيسي من هذه الورقة هو إنتاج HPC في السودان ، باستخدام المواد المتوفرة في الأسواق المحلية. تم إستخدام خلطات تجريبية مختلفة للحصول على مقاومة ضغط تتجاوز 80 ميجا باسكال. تضمنت الدراسة استخدام المضافات المعدنية (غبار السيليكا) و الركام (حجر مكسور و رمل الكوارتز).
تمت دراسة تأثير كميات مختلفة من استبدال غبار السيليكا للأسمنت بنسبة 0 ، 15 ، 20 و 30٪ على الخصائص الرئيسية لـ HPC مثل مقاومة الضغط ،الكثافة والهبوط. اظهرت النتائج أنه يمكن إنتاج HPC في السودان ، مع مقاومة ضغط تزيد عن 80 ميجا باسكال من المواد المتوفرة في الأسواق المحلية ، إذا تم اختيارها بعناية وخلطها بطريقة تعطي توزيعاً أمثل للحبيبات. النسبة المثلي لغبار السيليكا اللازمة لإنتاج HPC هي حوالي 20٪ من وزن الإسمنت.

ABSTRACT

High Performance Concrete (HPC) is widely used in construction industry worldwide. This paper is aim to produce HPC in Sudan, using materials which are available at local markets. Different trial mixes are used to obtain a compressive strength exceeding 80 MPa. Research includes use of mineral admixture (silica fume) and Aggregates (Crushed stone and quartz sand).
Effect of different level of silica fume replacement of cement by 0, 15, 20 and 30% on main properties of HPC, i.e., compressive strength, density and slump were investigated. Test results revealed that it is possible to produce HPC in Sudan, with compressive strength in excess of 80 MPa using materials which are available at local markets, if carefully selected and mixed in such a way as to give optimum distribution of granules. Optimum percentage of silica fume necessary for producing HPC is about 20 % of cement weigh.

Keywords: *Silica fume, High Performance Concrete, Compacting Concrete*

1 Introduction

High performance concrete (HPC) is a construction material that is increasingly used in construction due to its long-term performance and better rheological, mechanical, and durability properties than compacting concrete [1].

HPC permits the use of reduced sizes of structural member, increased building height in congested areas and early removal of formwork. Use of HPC in prestressed concrete construction makes greater span-depth ratio, early transfer of pre-stress and application of service loads. Low permeability of HPC reduces the risk of corrosion of steel and attack of aggressive chemicals. This allows the use of HPC in marine/offshore structures, nuclear power plants, bridges and places of extreme and adverse climatic conditions. Eventually HPC reduces maintenance and repair cost.

1.1 Aims and Objectives

The objectives of the paper are:

- To establish a feasible mix design to produce HPC.
- To obtain consistent concrete.
- To obtain compressive strength of HPC.
- To study the influence of the silica fumes dosage on the compressive and the workability of HPC.
- To enhance the performance of concrete by improving of concrete strength.

2 Constituent Materials and Experimental Program

HPC constituent materials used in this research include Portland ordinary cement, grey silica fume, crushed basalt, quartz sand in addition to super-plasticizer. Experimental investigations have been carried out on the HPC specimens to achieve the workability and strength related properties.

2.1 Cement

Pages ordinary Portland cement CEM I 42.5N was used for the production of HPC. The cement met the requirements of BS 146:2002 specifications [2]. The results of physical and mechanical analyses of the cements are summarized in Table 1.

2.2 Aggregates (Crushed stone, quartz sand)

For producing HPC, selection of very strong aggregate with rough texture is significantly more important. The crushed stone (coarse aggregate) nominal size ranges from 2.36 to 20 mm and quartz sand (fine aggregate) in the range of 0.6 to 0.3 mm which are locally available in Sudan markets as shown in Figure 1. It is important to ensure that the aggregates are clean. Silt and clay will reduce the cement aggregate bond strength and increasing the water demand.

Determination of specific gravity of crushed stone and quartz sand were according to BS 882-1992 [3].

Specific gravity was calculated at different conditions which are: oven-dry (OD), saturated surface dry (SSD) and apparent relative density (APP) shown in table 2, table 3 and table 4.

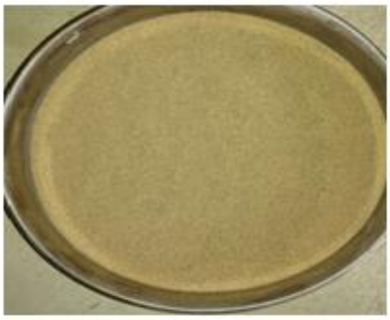
Unit weight or the bulk density of the aggregate is the weight of the aggregate per unit volume.

Table 1: Cement characteristics

Test NO	Test Conducted	Results	Requirements Of BS 146:2002
1	Consistency	30.0%	………………..
2	Soundness	-	Not more than 10mm (+1mm)
3	Setting times (min) a-Initial b-Final	177 min 247 min	Not less than 60 min. Not more than 390 min
4	Compressive Strength (N/mm^2) a- 2-days 1. 2. 3. b- 28-days 1. 2. 3.	23.2 N/mm^2 23.2 N/mm^2 23.4 N/mm^2 44.3 N/mm^2 44.9 N/mm^2 46.8 N/mm^2	Equal or Greater than 10 N/mm^2 Equal or Greater than 42.5 N/mm^2

(a)

(b)



(c)

Figure 1: Aggregates used in mixture preparations: (a) crushed stone aggregate 3/8"(b) crushed stone aggregate 3/4". (c) Quartz sand with maximum size of 0.6 mm.

The unit weight is necessary to select concrete mixtures proportions in HPC .The determination of unit weight was according BS 882-1992 table 4 for grading.

Table 2: Physical property of quartz sand

Dust. Silt and clay cent	2.0 **%**
Absorption	0.4 **%**
Specific gravity	A-SSD=2.59 B-OD=2.55 C-APP=2.61

Table 3: Physical property of aggregate (Crushed stone 3/8")

Crushing value	12%
Absorption	1.4%
Specific Gravity	SSD=2.52 OD= 2.48 APP=2.57

Table 4: Physical property of aggregate (Crushed stone 3/4")

Crushing value	16%
Impact value	8%
Absorption	1.1%
Specific Gravity	A. SSD=2.66 B. OD= 2.63 C. APP=2.71

2.3 Water

Tap water was used in all concrete mixtures and in the curing of specimens.

2.4 Silica Fume

Silica fume is a byproduct of the production of ferrosilicon metal in arc kiln furnaces, obtained from fume rising through furnace stoves by the condensation process.

silica fume which condenses from the gases escaping from the furnaces has a very high content of amorphous silicon dioxide and consists of very fine spherical particles [4].The silica fume was supplied by Dams Implementation Unit Figure 2 shows the appearance of used silica fume, as supplied by the producer. Table 5 and Table 6 show the silica fume chemical in Industrial Research & Consultancy Centre and silica fume analysis (data sheet).

Figure 2: silica fume

Table 5: Typical chemical composition of silica fume (source: from supplier)

constituent	Sio_2	AL_2O_3	Fe_2O_3	Cao	MgO	Na_2O	K_2O
percent **%**	93.58	0.86	0.32	0.62	0.02	0.71	0.35

Table 6: Silica fume analysis (source: from supplier)

Parameters	**data sheet**	**ASTM C 1240-93 specifications [5]**
SiO_2	93.58	Min 85
Na_2O	0.71	max1.5
Fineness retained on 45 Micron sieve	4.8%	Max 10%
Specific surface area m^2/g	20-30	15-30
Specific weight g/cm^3	2.3	No limit
Moisture Content	0.8%	3% max

2.5 Admixture

The chemical admixture used is super-plasticizer admixture which is manufactured to conform to ASTM C494 Type F specification [6]. This plasticizing effect can be used to increase the workability of fresh concrete, reduce the w/c ratio and delay the initial and final setting of the concrete, thus resulting in better slump retention. This type is known as "Sera PLAST SP 901" delivered from Betra Company, shown in Figure 3. Some technical data for the "Sera PLAST SP 901" are shown in Table 7.

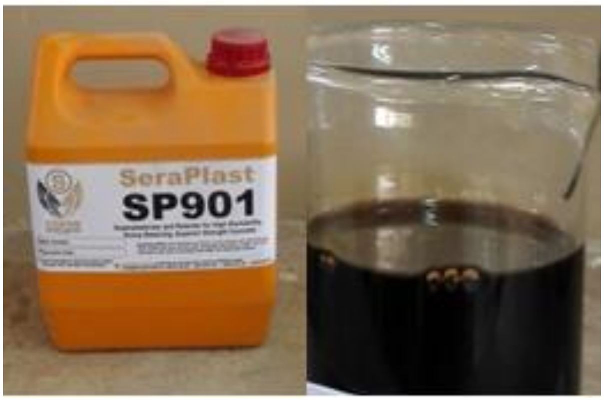


Figure 3: The chemical admixture

Table 7: Typical chemical composition of admixture (source: from supplier)

Specific gravity	1.19 +_0.03@ 25C
Appearance	Dark Brown Liquid
Air entrainment	Does not entrain air voids
Chloride Content	Nil-Tested to B.S 5075
Freezing	0 C., Mix prior to use

3 Mix Proportions of HPC

For HPC there is no specific method of design mix. In the present investigation ACI method and the available literatures on HPC are used. Three different doses of silica fume directly replacing by mass (15 %, 20 %, and 30 %) for Portland cement, has been used to explore the influence on compressive strength of HPC. The water/cement ratio = 0.33 and Super-plasticizer weight versus cement was kept constant (0.02) for all mixtures. The design mix shown in Table 8.

4 Fresh properties results

ACI 211.1[7] states that the slump test will give a reasonable indication of how easy a mix can be placed although it does not directly measure the work effort needed to compact the concrete.

The slump value for the HPC mixes was 4 cm. This was achieved by adding a 2%dosage of the super plasticizer. This slump was considered, stiff plastic consistency.

The workability was good and can be satisfactorily handled when the concrete is to be consolidated by appropriate vibration, which indicates that HPC can be used in various type of construction according to its workability as suggested by ACI 211.

Table 8: Mixes design for different silica fume percentage

Material	Unit	Mixture A	Mixture B	Mixture C	Mixture D
Cement CEM I 42.5N	kg/m³	650	565.21	541.61	500
Silica fume	kg/m³	0	84.78	108.3	150
Silica fume replacement level	%	0	15	20	30
Sand	kg/m³	700.3	700.3	700.3	700.3
Crushed aggregate 3/4"	kg/m³	758.55	758.55	758.55	758.55
Crushed aggregate 3/8"	kg/m³	408.45	408.45	408.45	408.45
Super-plasticizer	kg/m³	11.5	10	9.6	8.85
Water	kg/m³	214.5	186.5	178.73	165

4.1 Effect of silica fume on slump flow results

Unit weight of hardened concrete and slump was measured (according to ASTMC642, ASTM C143) [8, 9] to determine the workability of fresh concrete for each samples to study the influence of different silica fume percentages on workability and density change of HPC. Table 9 below shows the slump value for different dosage of silica fume. Figure 4 shows a graphical representation of slump values.

Slump tests indicate that as the percentage of silica-fume content is increased, the concrete may appear to become plastic; this is primarily due to the low surface area of the silica fume with low absorption ability of the water. Slumps from 0 % silica-fume content to 20 % silica-fume content were considered Stiff plastic. The slumps of 30 % silica-fume content is considered plastic due to the drop in the range of 4 cm to 8 cm the workability can be satisfactorily handled by vibration.

Table 9: slump value for different dosage of silica fume

Silica Fume percentage	Slump (cm)
0%	4
15%	5
20%	6
30%	8

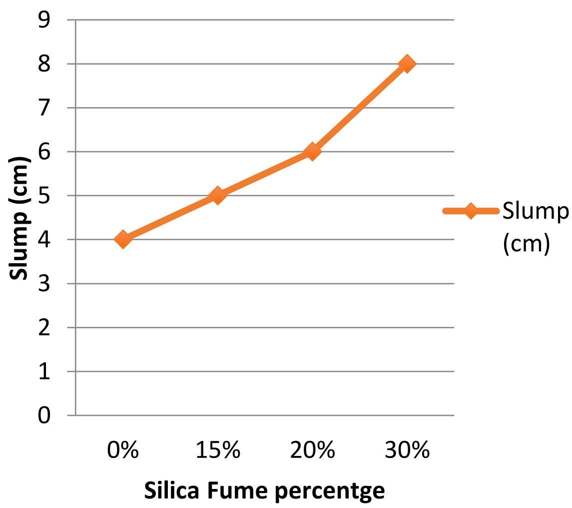


Figure 4: Effect of silica fume dosage on slump

4.2 Segregation in the trial mixes

In all trial mixtures, where the W/C was constant and equal to 0.33, no segregation was observed all mixtures were homogenous.

5 Hardened properties results

The cubic testing specimens were used 150x150x150 mm. All cubes were demoulded after 24 hours following casting and then curing in water at 25°C. Three of these cubes were tested for compressive strength (according to BS 12390-3:2009) [10] at 28days age.

5.1 Effects of silica fume on HPC density

Figure 5 summarizes the effect of silica fume on the HPC density, the results show that the density of concrete decreases when increasing the silica fume content. This can be due the space occupied by cement is partly replaced by a relatively lighter powder of silica fume.

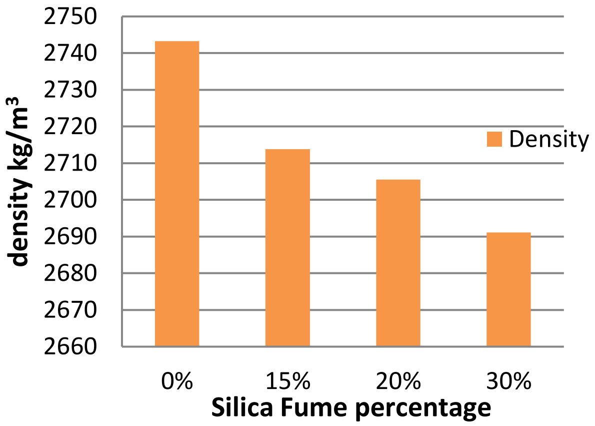


Figure 5: Effect of silica fume on HPC density

5.2 Effects of silica fume on compressive strength

Table 10 and Figure 6 show the average values calculated for compressive strengths at 3, 7, 14, and 28 days of the prepared mix shown in Table 8.

Table 10: Summary of mean compressive strength test results at different ages for HPC

Mix	No. of specimens	Compressive strength MPa			
		3 days	7 days	14 days	28 days
A	3	33	51	67	75
B	3	45	56	65.3	80
C	3	46	56.2	78	87.5
D	3	40	48	62	72

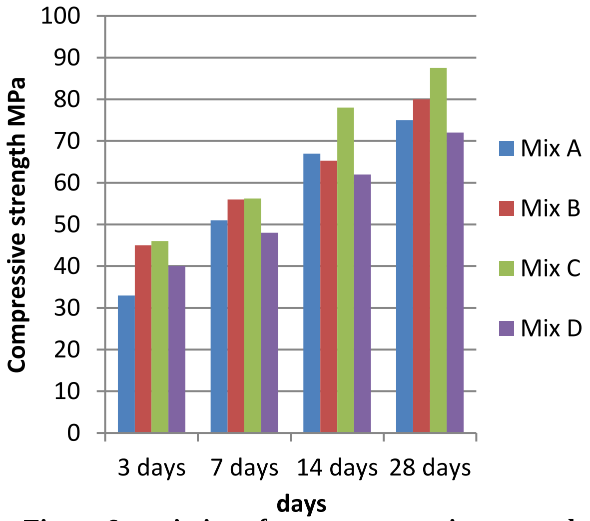


Figure 6: variation of mean compressive strength with age for HPC

The use of 20 % of silica fume as replacement of cement exhibits comparable result with the mixture containing 0 % silica fume. The compressive strength of the concrete specimens for 20 % silica fume replacement was up to 80 MPa, which met the target compressive strength for this research.

The explanation is that the silica fume works in two levels, the Pozzolanic reaction and the physical function. More ever the silica fume particle can fill the voids creates by free water in the matrix, thus creating a much denser pore structure the benefit of this reacts is twofold; increasing compressive strength and decreasing total pores volume.

6 Conclusions

Based on the results of this investigation, the following conclusions can be drawn:

1) The compressive strength:

- It is possible to produce HPC in Sudan using materials which are available at the local markets if they are carefully selected and achieving mix composition in grain size distribution that will achieve a minimum compressive strength of 80 MPa at 28days. Such concretes can be produced with crushed stone, quartz sand and silica fume as the mineral admixture.
- Because of a larger amount of Type I cement plus silica fume used in the HPC concrete mixtures along with a relatively low W/C ratio, the strength development of the concretes is much more rapid in the first 7 days than predicted by the current recommendation of ACI Committee 209 (1993a) for conventional concrete. The subsequent rate of strength growth is greatly decreased and is comparable to that predicted by the ACI method.
- The slump value for the HPC mixes has an average about 6cm. This was achieved by adding the 2% dosage of the super plasticizer.

2) The silica fume dosage:

- The use of silica fume is necessary for the production of HPC. The cube compressive strength studies indicate that the optimum percentage of silica fume is about 20%.
- An increase in silica fume content leads to a decrease in the slump of fresh concrete.
- The density of HPC decreases as of silica fume content increases.

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