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Effect of Sudanese Aggregate on Production of High Strength Concrete

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Abstract: *The purpose of this paper was to study the effect of use of Sudanese aggregate with supplementary cementitious materials silica fume and fly ash in high strength concrete mixes, and study the effect of water-cementitious materials ratio and concrete ingredients in compressive strength, workability and cost of high strength concrete. The concrete specimens were tested at different age levels, 7-days and 28-days for mechanical properties of concrete, namely, cube compressive strength, fresh properties, slump test.*
This paper presents a part of an ongoing experimental laboratory investigations being carried out for production and characterization of high strength concrete for heightening of an existing concrete dam in the south of Sudan. Brief description of the main features of the dam and concrete works are presented. Hundreds of specimens were performed and tested using local Sudanese aggregates with addition of supplementary cementitious materials (Silica Fume and Fly Ash) and Super plasticizers. Various percentages of silica fume and fly ash were added at different water/cementitious (w/cm) ratios. Thirty three trial mix designs of grade 80 MPa according to ACI 211.4, high strength concrete had been success fully produced and their mechanical properties were measured and documented. The results have offered an important insight for relationship and influence of components mixture in properties of high strength concrete and in cost. The effect of w/cm ratio on strength of high strength concrete was also highlighted. Optimum replacement percentage is not a constant one but depends on the w/cm ratio of the mix. It is concluded that local concrete materials, in combination with supplementary cementitious materials can be utilized in producing high strength concrete in Sudan, water/cementitious ratio (w/cm)is in inverse relationship with compressive strength and its effect is very strong in strength, silica fume had a positive effect in producing high strength concrete and contributed to both short and long-term properties of concrete, fly ash had inverse relationship with28 days compressive strength, fine aggregate had an inverse relationship with compressive strength and local Sudanese coarse aggregate had a strong positive effect in producing high strength concrete. Also the effect of concrete ingredients in slump and cost were studied.
Keywords– *Compressive strength, Fly ash, High strength concrete, Silica fume, Super- plasticizers*

I. Introduction

In conventional concrete technology, the strength of the paste is a function of its water/ cement ratio. This is true also for high strength concrete, but it is also the effect of the porosity within the paste, the particle size distribution of the crystalline phases and the presence of inhomogeneities within the hydrated paste that must be considered in detail. (1)A reduction in water/cement ratio will produce a paste in which the cementitious particles are initially closer together in the freshly mixed concrete. This results, in less capillary porosity in the hardened paste and hence a greater strength. (1) When the transition zone between the paste and the aggregate is improved the transfer of stresses from the paste to the aggregate particles becomes more effective. Consequently the mechanical properties of the aggregate particles themselves may be the 'weakest link' leading to limitation of achievable concrete strength. Fracture surfaces in HSC often pass through aggregate particles rather than around them. (1) Crushed rock aggregates are generally preferred to smooth gravels as there is some evidence that the strength of the transition zone is weakened by smooth aggregates. The aggregate should have a high intrinsic strength and granites, basalts and limestones have been used successfully, as have crushed glacial gravels. (1)

Super-plasticizers / high range water reducers should be used to achieve maximum water reduction.

Supplementary cementatious materials are materials that, when blended with Portland cement, contribute to the properties of concrete through hydraulic activity, pozzolanic activity, or both. Hydraulic activity occurs when phases in the supplementary cementatious materials chemically react with water, forming cementitious hydration products similar to those formed through hydration of Portland cement. This is in contrast to pozzolanic activity, which is characterized by the reaction between siliceous or aluminosiliceous material in the supplementary cementatious materials with calcium hydroxide (a reaction product from the hydration of Portland cement), forming calcium silicate hydrate and other cementitious compounds. Calcium silicate hydrate is a more desirable hydration product and thus the pozzolanic reaction is considered to have a positive impact on the long-term properties of the hardened concrete.

This paper presents a part of an ongoing experimental laboratory investigation being carried out for production and characterization of high strength concrete for heightening of Roseires Dam, which, located on Blue Nile River in Sudan, was constructed in 1960s for power generation and irrigation purposes. It has been decided to heighten this composite concrete buttress and earth fill dam by 10m to increase its storage capacity.

The raising works of Roseires concrete dam comprise the addition of mass concrete, reinforced concrete, and post-tensioning requirements into both crest and the downstream portions of the dam. The concrete dam section is divided into (11) typical structures along its 1km length. The total numbers were 69 buttresses. Because each structure has its specific geometry and function different design methodologies are needed for each.

High Strength Concrete is a relatively recent development in concrete technology made possible by the introduction of efficient water-reducing admixtures and high strength cementitious materials. This paper will discuss the materials technology underlying the development of high strength concrete, influence of mixture ingredients in the properties of both fresh and hardened high strength concrete; finally, the effect of components in the cost will be studied. It is intended that this will lead to an understanding of the potential benefits and limitations of high strength concrete, together with the expertise required to produce and use the material in a practical and effective manner.

There is no "scientific" method for proportioning. This means that there is no chart that can be used to derive the mixture ingredients to meet a specified level of performance. There are simply too many variables for such a chart to be developed. Here are some general rules for proportioning: [(2)] In the laboratory test and production scale during mixture development, the process is too complex to predict what the outcome will be without appropriate testing. Allow plenty of time for the necessary testing. [(3)] The procedure described in the ACI 211.4 was used. This procedure has evolved over many years and is the best recommendation currently available. [(4)] Mixture proportions for high-strength concrete typically contain 350 to 500 kg/m^{3}of cementitious materials that may include 5 to 10% silica fume by mass. This concrete may have a w/cm as low as 0.20. Fly ash may also be included in this concrete for either high-strength or high durability applications. [(5)] Hence the purpose of this paper was to study the effect of use of Sudanese aggregate with supplementary cementitious materials, silica fume and fly ash in high strength concrete mixes, and study the effect of water- cementitious materials ratio and concrete ingredients in compressive strength, workability and cost of high strength concrete.

Figure (1) Roseires Dam Concrete Section downstream view

II. Materials Used

2.1 Cement: In this research, a locally produced ordinary Portland cement type I, conforming to ASTM C150 (OPC 42.5N) [(6)]which is extensively used in Sudan, was used in the trial batches production. The specific gravity of cement used was 3.15, initial and final setting times were 2.2 and 3.6, other physical and mechanical properties for cement are shown in Table (1).

Table (1) Physical and Mechanical Properties of Cement

Test according to BSEN196		Result
Normal Consistency		27.4%
Setting Time	Initial Setting Time	2.2 hour
	Final Setting Time	3.6 hour
Loss on ignition		1.95%
Compressive Strength	2 days	32.1 MPa
	28 days	60.7 MPa

2.2 Aggregates

The coarse and fine aggregates used in this study were crushed marble processed from the local quarries around Damazin City, the quarry for Roseires Dam Heightening Project. The maximum aggregate size was 20 mm, The specific gravity and absorption of the coarse aggregates, determined in according with ASTM C127 [7] were 2.84 and 0.25respectively, whereas those of fine aggregates, determined in accordance with ASTM C128 [8]were 2.839 and 0.45 respectively. All the sand samples were tested for their absorption percentage in saturated surface dry (SSD) condition. Organic impurities in sand were tested in accordance with ASTM C-40. The water-cement ratio of all trial mixes were based on saturated surface dry condition (SSD) of the aggregates, different type of aggregates from another quarry was used. To compare with marble, granite aggregates from Merwei Dam (another recently constructed concrete dam in the north of Sudan) location were used.

2.3 Chemical Admixtures (Superplasticizer)

The superplasticizer used in this study has the trade name of "PCA-(I)" from Jiangsu Bote new Materials Company-China. PCA-(I) is a polycarboxylate polymer-basedcomposite admixture. It is a liquid which has the performance of high range water reduction, excellent slump retention and strengthening. The specific gravity of the superplasticizer was 1.085 and the PH was 8.11 with nil chloride content percentage by weight. It is specially adapted for the production of high durability concrete, self-compacting concrete, high compressive strength concrete, and high workability concrete. PCA-(I) superplasticizer is formulated to comply with the ASTM specifications for concrete admixture: ASTM494, Type G [9].

2.4 Silica Fume

The Silica fume(SF) used in this study was in accordance with the most international standards such the European BS EN 13263 Silica fume for concrete, Part 1:2005 Definitions, requirements and conformity criteria Part 2:2005 Conformity evaluation, and the American ASTM C1240-97b, Standard specification for silica fume for use as a mineral admixture in hydraulic- cement concrete, mortar and grout.[10]

Table (2) Physical Properties of KD-12 Silica Fume

Test items	Specified limits according to ASTM C12405, BS EN13263	Test Results
Absolute density (kg/m^3)	≥2200	2249
Loss on ignition (%)	≤3.5	1.88
Coarse particle	≤1.5	1.1
SiO_2 (%)	≥86	92
Carbon content (%)	≤2.5	2.3
Moisture (%)	≤1	0.85
Specific area (m^2/g)	≥15	20

2.5 Fly ash

Fly ash used in this study was manufacture by Zouxian power plant-China. The properties of fly ash are presented in Tables 3,4. ASTM C618; the requirement for Class F and Class C fly ashes, and the raw or calcined natural pozzolans, Class N, for use in concrete. Fly ash properties may vary considerably in different areas and from different sources within the same area. The preferred fly ashes for use in high strength concrete have a loss on ignition not greater than 3 percent, have a high fineness, and come from a source with a uniformity meeting ASTM C 618 requirements [11].

Table(3) Chemical Properties of Fly Ash

Test items	Specified limits according to BS 3892	Test Results
SO_3 (%)	Max.2.0%	1.68%
Chloride (%)	Max.0.1%	0.03%
Calcium Oxide (%)	Max.10%	8.4%

Table(4) Physical Properties of Fly Ash

Test items	Specified limits according to BS 3892	Test Results
Loss on ignition (%)	Max.7.0%	1.39%
Moisture Content	Max.0.5%	0.29%
Fineness	Max.12%	8.24%
Particle Density	Min.2000kg/m^3	2039kg/m^3
Water Requirement	Max.95% (30%Fly Ash+70%Cement)	92%
Soundness	Max.10mm	9.02mm
Strength Factor	Min.0.8	0.83

III. Experimental Programme

4.1 Slump Test:

After mixing, a portion of the fresh concrete was placed aside for plastic properties determination. Slump of fresh concrete was measured according to ASTM C143. Precautions were taken to keep the slump between 150-200 mm to obtain pumpable concrete for dam construction. [12]

4.2 Compressive Strength test:

Lime saturated-water curing method was used in this study. Concrete casting was performed according to BS EN 12390-1:2000. [13] Molds were covered to prevent loss of water from evaporation. Specimens were kept for 24 hours in molds at a temperature of about 23 C in casting room, and then cured for the specified time at approximately 23 C ± 2 C. [14]The specimens were tested in dry state for compressive strengths tests, in accordance with BS EN 12390-3:2002. [15]

IV. Results

Table (5) presents the mix proportions for grade 80 (MPa), Concrete compressive strength, slump and cost estimation for one meter cube. It can divided concrete strength to three different grades of high strength concrete (80, 90, 100MPa), these are successfully produced using local Sudanese aggregates , silica fume and silica fume with fly ash. w/cm ratios ranges between 0.19~0.3 utilized to produce the maximum values of strength in the different grades of concrete. Silica fume and fly ash replacements in the range of 6.7 to 15% and zero to 15% of cementunise materials respectively. Cement content between 390 and 560 Kg/m^3 for the three grades. In figure (2) by default, a 95% bivariate normal density ellipse is shown in each scatter-plot. The narrowness of the ellipse shows the correlation of the variables. If the ellipse is fairly round and is not diagonally oriented, the variables are uncorrelated. If the ellipse is narrow and diagonally oriented, the variables are correlated.

Table (5) Concrete compressive strength, slump, concrete ingredients and cost estimation

Test No	Date	Ave Compressive Strength (Mpa) for 7days	Ave Compressive Strength (Mpa) for 28days	Slump mm	Aggregate Types	W/Cm Ratio	Cement (kg/m^3)	Silica Fumetype KD-12 (kg/m3)	Fly Ash (kg/m3)	Super Plasticizer type PCA(1) (kg/m3)	Water (kg/m3)	Sand (kg/m3)	Coarse Aggregate (kg/m3)	Cost of m3 $
1	30-Oct-09	75.0	81.2	190.0	marble	0.28	500	56	0	8.88	155	689	1023	166.4
2	31-Oct-09	62.7	80.0	182.0	marble	0.27	416	56	83	7.77	150	704	1003	165.3
3	6-Nov-09	69.8	80.9	190.0	marble	0.24	545	55	0	9.6	145	648	1042	174.4
4	11-Nov-09	79.3	91.1	205.0	marble	0.2	587	115	77	10.75	154	443	1057	253.5
5	14-Nov-09	79.0	87.6	195.0	marble	0.23	587	65	0	10.432	147	601	1045	192.2
6	5-Dec-09	88.1	96.4	188.0	marble	0.22	708	62	0	12.32	169	385	1191	213.2
7	6-Dec-09	77.3	97.7	216.0	marble	0.21	670	62	0	12.32	162	268	1231	205.4
8	7-Dec-09	92.3	86.3	207.0	marble	0.2	647	126	67	13.44	168	399	1050	275.1
9	7-Dec-09	92.2	91.7	215.0	marble	0.2	672	118	0	12.64	158	440	1025	259.1
10	13-Jan-10	65.6	80.3	220.0	granite	0.27	550	50	0	9.6	162	586	1022	170.0
11	14-Jan-10	68.5	83.7	230.0	granite	0.25	550	50	50	9.6	163	586	1022	179.5
12	15-Jan-10	80.4	91.5	165.0	granite	0.22	650	50	50	12	165	466	991	199.3
13	15-Jan-10	85.9	87.0	170.0	granite	0.23	600	50	50	11.2	161	499	1013	189.5
14	20-Jan-10	68.8	84.2	180	granite	0.3	495	55	0	9.6	165	615	1027	164.5
15	26-Jan-10	72.9	83.5	200.0	granite	0.23	595	70	35	11.9	161	498	1011	205.2
16	28-Jan-10	86.6	96.9	220.0	granite	0.22	660	90	0	12.75	165	467	992	230.2
17	29-Jan-10	91.5	105.2	170.0	granite	0.19	655	77	39	9.6	146	296	1184	222.0
18	29-Jan-10	80.2	88.2	200.0	granite	0.21	655	77	39	13.09	162	346	1095	224.4
19	8-Feb-10	81.7	88.5	143.0	granite	0.21	630	70	0	11.2	147	357	1195	204.9
20	11-Feb-10	81.8	95.3	155.0	granite	0.23	572	78	0	10.4	150	469	1149	201.4
21	15-Feb-10	91.9	100.6	162.0	granite	0.2	660	90	0	12	150	382	1145	230.1
22	17-Feb-10	98.2	104.7	161.0	granite	0.23	528	72	0	9.6	138	491	1202	187.2
23	19-Feb-10	98.7	109.2	121.0	granite	0.2	500	75	50	10	125	457	1235	194.5
24	19-Feb-10	94.7	100.4	134.0	granite	0.2	572	78	0	9.6	130	451	1218	201.1
25	21-Feb-10	88.6	96.9	159.0	granite	0.21	528	72	0	9.6	126	500	1225	187.4
26	24-Feb-10	92.9	106.1	116.0	granite	0.19	616	84	0	11.2	133	436	1180	216.0
27	25-Feb-10	88.4	104.3	215.0	granite	0.22	540	78	32	10.4	143	521	1106	201.5
28	28-Feb-10	101.0	110.6	77.0	granite	0.2	480	72	48	9.6	117	503	1233	187.5
29	1-Mar-10	81.3	94.5	205.0	granite	0.24	528	72	0	9.6	144	587	1091	187.2
30	21-Mar-10	87.1	97.9	185.0	granite	0.23	528	72	0	9.6	138	593	1101	187.3
31	31-Mar-10	90.7	103.6	115.0	marble	0.23	484	66	0	8.8	124	551	1225	173.1
32	14-Apr-10	93.4	102.4	125.0	marble	0.22	585	65	0	10.4	140	641	1190	193.0
33	25-Apr-10	94.1	102.8	145.0	marble	0.22	575	50	0	10	138	662	1177	176.6

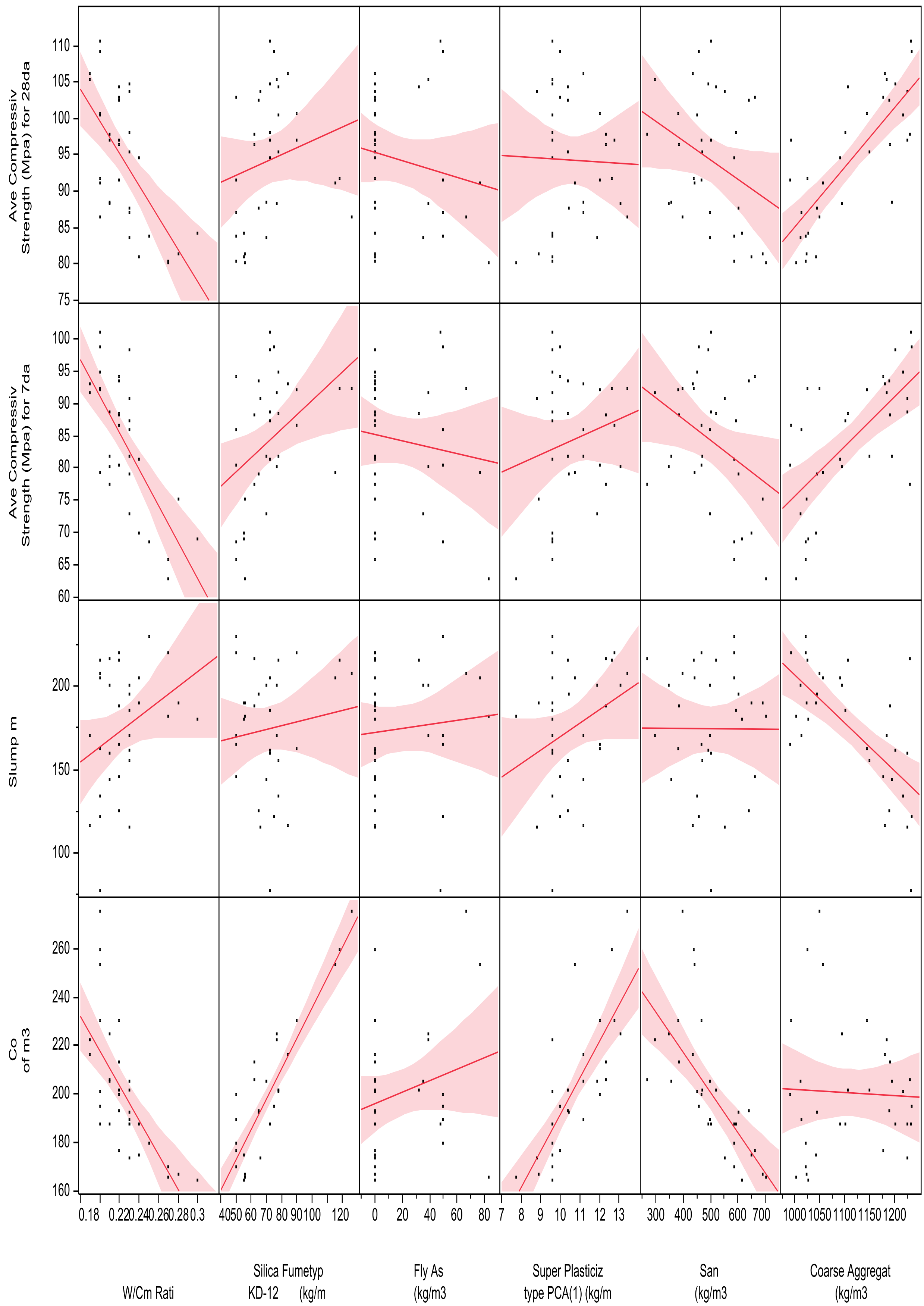

Figure (2) Multivariate relationship between compressive strength 28 days (MPa), compressive strength 7 days (MPa) and Cost with all mixture compounds.

V. Conclusions

On the basis of test results the following major conclusions can be drawn:

1. The present study shows that the maximum values of compressive strength for different grades were obtained at water-cementitious materials ratios between 0.19 and 0.3.
2. The relationship between 28 days compressive strength and w/cm ratio is strong inverse relationship, when one quantity increases the other decreases. For example, when w/cm ratio is increased, the compressive strength decreases.
3. The relationship between 28 days compressive strength and Silica fume type KD-12 is direct relationship both physical quantities may increase or decrease simultaneously.
4. The relationship between 28 days compressive strength and fly ash type (F) is inverse relationship.
5. There is no effect in the relationship between 28 days compressive strength and Super-plasticizer type PCA (1).
6. The relationship between 28 days compressive strength and fine aggregate is inverse relationship.
7. The relationship between28 days compressive strength and Coarse aggregate is strong direct relationship. That means the local coarse aggregate is main factor in producing high strength concrete.
8. The relationship between 28 days compressive strength and 7 days compressive strength is strong direct relationship.
9. The results of the present investigation indicated that the maximum compressive strength occurred at about 6.7 to 15% Silica fume content.
10. The relationship between28 days compressive strength and cost is direct relationship.
11. Silica fume and Super-plasticizer type PCA (1) had strong influence in cost.
12. Water- cementitious materials ratio had positive effect in slump.
13. Coarse aggregate had strong negative effect in slump.

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