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Production and Properties of High Strength Concrete for Heightening Concrete Dam in Sudan

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ABSTRACT: This paper presents a part of an ongoing experimental laboratory investigation being carried out for production and characterization of high strength concrete (HSC) for heightening of an existing concrete dam in the middle of Sudan. Brief description of the main features of the dam and concrete works is presented. Hundreds of trial mixes were performed and tested using local Sudanese aggregates with addition of mineral admixtures (Silica Fume and Fly Ash) and Super plasticizers. Six grades of HSC (50, 60, 70, 80, 90, 100 MPa) had been success fully produced and their mechanical properties were measured and documented. Statistical analysis of tests results was performed and simple correlations were developed relating compressive strength to flexural and Splitting Strengths. The results have offered an important insight for optimizing the rheological characteristics of HSC and permitted to develop guidelines for optimum mix design methods for HSC from locally available aggregates in Sudan. The effect of w/c ratio on strength of HSC was also highlighted. It is concluded that local concrete materials, in combination with mineral admixtures can be utilized in producing High Strength Concrete in Sudan.

Keywords: High Strength Concrete, Silica Fume, Fly Ash, Dams, Sudan.

1. INTRODUCTION

Concrete, a composite material consisting of aggregates enclosed in a matrix of cement paste including possible pozzolans, has two major components, cement paste and aggregates. The strength of concrete depends upon the strength of these components, their deformation properties, and the adhesion between the paste and aggregate surface [1].

In recent years, the construction industry has shown significant interest in the use of high strength concrete (HSC), in applications such as dams, bridges and high rise buildings. This is due to significant structural, economic and architectural advantages that HSC can provide compared to conventional, normal strength concrete (NSC).

Although high strength concrete is often considered a relatively new material, its developed has been gradual over many years. Definition of the minimum strength value for high – strength concrete varies with time and geographical location depending on the availability of raw material and the technical Know-how, and the demand form the industry [2]. Starting form a value of 34 MPa in the 1950s in the United States moving to upper values, the ACI 363, 1999 [4] on high strength concrete defines a value of 51 MPa (cube strength) as a minimum value for high for high strength concrete.

Production of HSC may or may not require special materials, but it definitely requires materials of highest quality and their optimum properties [3]. The production of HSC that consistently meets the requirements for workability and strength development places more stringent requirements on material selection than that for lower strength concrete (ACI 363R, 1999) [4]. However, many trial batches are often required to generate the data that enables the researchers and professionals to identify the optimum mix proportions for HSC [3].

2. GENERAL DESCRIPTION OF ROSEIRES DAM

Roseires Dam is located in Damazin city in the Blue Nile State, about 520Km south-east of Khartoum.The Dam was originally designed to be constructed in two phases, the first phase was completed in 1966 to maximum water level of Alexandria Datum (AD) 483 m with allowance for it to be raised to AD 493 m at a future date.

The Dam is a composite dam with a central 1000 m long concrete buttress dam section that contains the deep level sluices, gated spillways, power intakes for a service power station and head works for future irrigation canals on either side of the river. The maximum height of the existing concrete section is 68 m. It embodies specialized section for deep sluices, spillway, west and east bank irrigation canal head works, main power station (280 MW) and service power station (2 MW). The Embankment Dam is 8500 m long on the left (west) bank and 4000 m long on the right (east) bank. The maximum height of Embankment Dam is 30 m and the maximum width 230 m. Once raised, Roseires Dam will have a combined length of 25 Km (Fig. 1). Table 1 shows the main features and important numbers of the different components of the dam before and after the heightening. As one of the major development projects in Sudan, this project was given a top priority in the strategic planning of the Sudanese government in the last ten years.

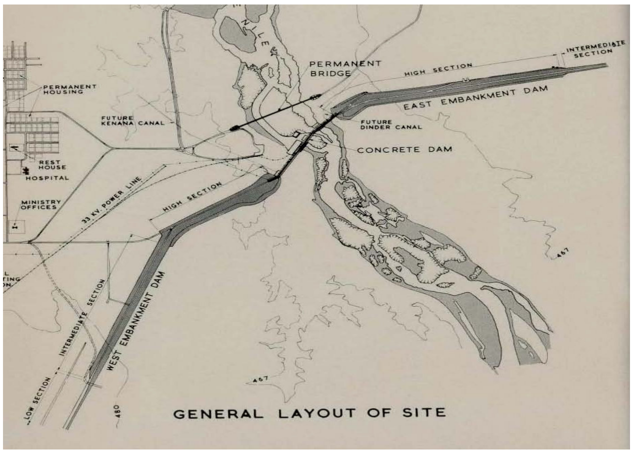


Fig. (1): General Layout of Dam site

Table 1: Main Features of the Dam

Description	**Existing Dam**	**After Heightening**
Reservoir		
Volume (without siltation)	3,000 million m	7,400 million m3
Area	290 Km2	627 Km2
Maximum Water Level (FSL)	AD 483.02m	AD 493.02m
Overtopping Level (Concre Dam)	AD 485.22m	AD 495.22m
Overtopping Level (Embankment)	AD 485.52m	AD 495.52m
Minimum Draw down level	AD 438.52m	AD 438.52m
Tailwater		
Maximum Water Level	AD 459.02m (PMF)	AD 459.02m (PMF
Nominal Wet Season Tailwater level	AD 451.02m	AD 451.02m
Minimum Tailwater level	AD 443.02m	AD 443.02m
Contract Dam		
Roadway level	AD 484.22m	AD 494.22m
Maximum level above Foundation	68.0m	78.0m
Crest Length	1,000m	1,000m
Concrete Volume	850,000 m3	155,000 m3
Embankment Dam		
Crest Length (east)	4,000 m	8,500 m
Crest Length (west)	8,500m	15,500m
Fill Volume	5 million m3	17 million m3

SMEC International in association with Coyne et Bellier of France undertook a review of the tender design and tender documents which were prepared during the early 1990,s and has updated the design as necessary, including preparation of new tender documents.

In January 2009, Lahmeyer International (LI) of Germany substituted Coyne et Bellier as sub-consultant to SMEC. The main contractor of the project was CCMD Joint Venture of SINOHYDRO and CWE (two Chinese companies).

The Accepted Contract Amount for Roseires Dam Heightening was around three hundred and ninety-six million United States Dollars (USD 396,000).

Time required for Completion of the Works is 1308 days, making October 2012 as the completion date for the whole of the works. All concrete works are expected to finish by the end of May 2012, while the rest of other electromechanical and earth embankments works are expected to finish by October 2012.

1.2 Main Concrete Works

The major concrete works in the project included the heightening of the existing concrete dam by ten meters above the existing concrete level (483.02 m AD) which will accordingly increases the crest levels of both eastern and western embankments from 4000 m to 8,500 m and from 8,500 to 15,500 m respectively. The heightening of the concrete dam will increase the volume of the reservoir from 3,000 million m3 to 7,400 million m3 of water per year. A total of 155,000 cubic meters of high strength concrete were properly prepared, mixed, casted and cured using locally Sudanese aggregates, flay ash and locally produced ordinary Portland cement.

Heightening of the existing concrete dam required extension, web thickening and strengthening of buttress and enlargement of the deep sluices (Fig. 2). In order to pour the new high strength concrete on the existing old concrete, anchor bars and high tensile strength epoxy resin was used as a grout after demolishing and roughening the surfaces of existing concrete. Table 2 below shows the details of anchor bars. Fig. 3 shows a general view of the dam when most of concrete works were finished.

Fig. 2: Thickening and Strengthening of buttresses

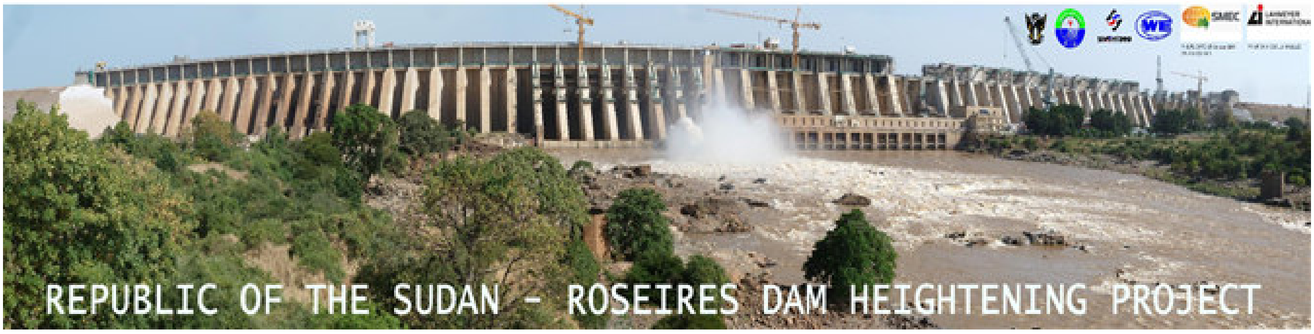


Fig. 3: General View of Concrete Dam Almost Finished

Table 2: Details of anchor bars

Anchor Bars Diameter (mm)	Anchor Bars Length (mm)	Diameter of Drilled hole (mm)	Length of Drilled hole (mm)	Spacing at site staggered (mm)
16	1400	25	700	1000
32	2800	45	1400	1500

3. EXPERIMANTAL PROGRAM

The following subsections present the details of the materials used in the production of HSC and the related testing and specifications.

3.1Concrete Ingredients

Cement

In this research, a locally produced ordinary Portland cement type I, conforming to ASTM C150 (OPC 42.5N) [5] 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 time were 3:17 and 4:38, other physical and mechanical properties test for cement are shown in Table 3.

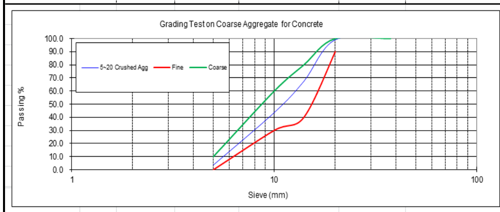
Table 3: Physical and Mechanical Properties of Cement

Test		Result
Normal Consistency		29%
Setting Time		
	Initial Setting Time	3:17 hrs
	Final Setting Time	4:38 hrs
Loss on ignition		2.29%
Compressive Strength		
	2 Days	20.8 Mpa
	28 Days	56.4 Mpa

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 grading of the coarse and fine aggregates is shown in Figure 4. The specific gravity and absorption of the coarse aggregates, determined in according with ASTM C127 [8] were 2.84 and 0.25respectively, whereas those of fine aggregates, determined in accordance with ASTM C128 [9] 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 [10]. The water-cement ration of all trial mixes were based on saturated surface dry condition (SSD) of the aggregates. For the mix HSC6, different type of aggregates from another quarry was used. To compare with marble, granite aggregates from Merwei Dam (recently constructed another concrete dam in the north of Sudan) location were used.

Sieve Size (mm)		37.5	20	14	10	5	
Envelope-BS882	Fine		90	40	30	0	
	Coarse	100	100	80	60	10	
Sieve Adopted (mm)		37.5	20	14	10	5	Pan
Mass of retain (kg)		0.000	0.096	3.259	2.451	4.128	0.355
% of retain		0.0	0.9	31.6	23.8	40.1	3.4
% of passing		100.0	99.1	67.4	43.6	3.5	0.087



Remarks:
Envelope according to BS882:1992
Coarse aggregate 5~20mm

Fig. 4: Gradation of Fine & Coarse Aggregates

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-based composite 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 [11].

Mineral Admixtures (Silica Fume and Fly ash)

Silica Fume

Silica fume (SF) is a by-product of the manufacture of silicon metal and ferro-silicon alloys. The process involves the reduction of high purity quartz (SiO2) in electric arc furnaces at temperatures in excess of 2000□□C. SF is a very fine powder consisting mainly of spherical particles or microspheres of mean diameter about 0.15 microns, with a very high specific surface area (15,000-25,000 m²/Kg). Each microsphere is on average 100 times smaller than an average cement grain. At a typical dosage of 10% by mass of cement, there will be 50,000-100,000 SF particles per cement grain. In bulk, SF is generally dark grey to black or off-white in colour and can be supplied as a densified powder or slurry depending on the application and the available handling facilities. SF is available globally. There is no health hazard associated with the use of SF as non-crystalline silica is non-hazardous. The dense microstructure of concrete containing SF leads to major improvements in mechanical performance and resistance to chemicals (such as acids, fuel oil, chlorides and sulfates). SF is ideally suited to the most demanding applications, such as concrete slipways, dam spillways and hard standings, where chloride, chemical or abrasion resistance are required. SF concretes have performed well under these circumstances, as they are chemically stable and have very low permeability. The 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. The specific gravity of the silica fume silica fume used in this study was 2.373. SF the pozzolanic high activity, which can be filled the gap between cement, increase the density of the system, so as enhance strength, impermeability, wear proof, anti-corrosion, anti-scour, antifreeze, and strong early performance.

Table 4: Physical Properties of Silica Fume

Moisture Content %	Loss on ignition %	Fineness Retain 0.045 mm	Expansion (mm)	Water Requirement %
0.22	0.48	6.67	1	88.9

Fly ash:

Fly ash used in this study was manufacture by Shandong Zouxian-China.the specific gravity of the fly ash is 2.4, loss on ignition 0.48, the other properties of fly ash are presented in Table 5. 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 [12].

Table 5: Physical Properties of Fly Ash

Moisture Content %	Loss on ignition %	Fineness Retain 0.045 mm %	Density Kg/m³
0.67	2.7	0.23	2373

3.2 Proportioning, Mixing and Casting of Specimens

There is no empirical method available for proportioning high strength concrete. The procedure to get the proportions in this study is the approach that recommended the in ACI 211.4R-08[13], by starting with mixture proportion that has been used successfully on other projects with similar requirements. Given this starting point, trial mixtures were made in the laboratory and under field conditions to verify performance with actual project materials. Hundreds of trial batches were performed in the laboratory and several adjustments were carried out in order to identify the optimum proportions. The final optimum and best trials used in the construction of the concrete dam are shown presented in Table 6. A concrete fixed mixer with capacity of 0.125 m3was used, the mixes from Table 6 were scaled down depending on number of molds for different tests, and the mixer was buttered by mixing amount of cement, sand with water because it is difficult to recover all the mortar from the mixer. The mortar adhering to the mixer after discharging is intended to compensate for loss of mortar from the test batch. The following steps were to mix each batch; all the mixing ingredients, including the mixtures, were scaled down and weight out. The coarse and fine aggregates, cement and other cementitous materials were added to the mixer. The mixer rotated for 2 minutes (dry mixing). Superplasticizer was dispersed in about 2/3 of water before added to the mixer and started rotated the mixer again for 2 minutes. The mixer was shut off about 1 minute to let the aggregate absorb some of the paste, the aggregates were approximately in saturated surface dry condition (SSD) at the time the batch was prepared. The aggregates were sprayed with water and covered by burlaps for at least 24 hours.

3.3 Curing and Testing of Specimens

Two different curing methods were used in this study; lime saturated-water curing and the curing compound methods.

The effect of different curing method was studied and commented on. 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. Concrete casting was performed according to ASTM C192. 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. The specimens were tested in dry state for compressive, flexural, and splitting strengths tests in accordance with BS EN 12390-2:2000[12], ASTM C78 or ASTM C29, and ASTM C496 respectively.

4. RESULTS AND DESCUSSION

4.1 Optimum Proportions

Table 6 presents the optimum mix proportions for the different grades used in the dam construction project. From the table it is clear that five different grades of high strength concrete (60, 70, 80, 90, 100MPa) were successfully produced using local Sudanese aggregates and fly ash. Three w/c ratios 0.22, 0.32, and 0.35 were found to produce the maximum values of strength in the different grades of concrete. SF and FA replacements in the range of 10 to 15% for each one were found in the optimum combinations of ingredients to produce high strength concrete. Cement content between 390 and 560 Kg/m3 for the five grades.

Table 6: Optimum Mix Proportion for Different Grades of HSC

Mix Design	Concrete Class	W/C	Sand %	Cement (Kg/m^3)	Water (Kg/m^3)	Fly ash (Kg/m^3)	Silica Fume (Kg/m^3)	Admixture (Kg/m^3)	Crushed Sand (Kg/m^3)	Aggregate (5-20) (Kg/m^3)	Unit Weight (Kg/m^3)
HSC1	50 MPa	0.46	42	390	179	0	0	3.21	798	1102	2473
HSC2	60 MPa	0.35	40	419	163	47	0	3.72	746	1119	2496
HSC3	70 MPa	0.32	38	486	173	0	54	6.48	667	1089	2475
HSC4	80 MPa	0.3	38	500	167	0	56	8.896	665	1086	2483
HSC5	90 MPa	0.22	36	585	143	0	65	10.4	621	1104	2528
HSC6	100 MPa	0.22	34	560	154	70	70	12.6	522	1014	2403

4.2 Compressive Strength

Fig. 6 shows the variation of strength concrete for the different grades with time. Starting form three days up to 28 days, it is clear that it was possible to produce high strength concrete (up to 110 MPa) with stable and acceptable rate of strength gain. Considering the type of cement used in this study (ordinary Portland cement) and the relatively small ration of SF, it is also clear that it was possible to produce high strength concrete with very high rates of early strength using the same local materials. Different relations were obtained from data accumulated from the tests results. High strength concrete shows a higher rate of strength gain with age than normal strength. Parrott reported typical ration of 7 days to 28 days strength of 0.8 ~ 0.9 for high strength and 0.7 ~ 0.75for normal strength (ACI). The high strength gain with age in this study of 3 to 28 and 7 to 28 days are 0.5~ 0.64 and 0.75 ~ 0.86 respectively.

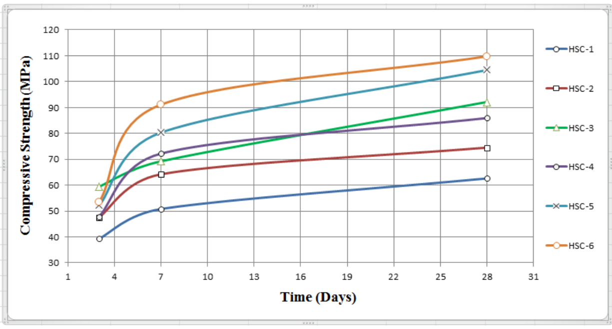


Fig. 6: Variation of Compressive Strength with Time for Different Grads

Fig. 7 shows the variation of the compressive with the water-cementitious materials ratio. Non-linear regression analysis performed for the tow parameters concluded that an exponential formula strongly related the compressive strength and the water-cementitious materials ratio. The exponential formula is shown in the figure. Fig. 8 shows the effect of san content on the compressive strength of HSC. Non-linear regression analyses performed have shown that a quadratic formula strongly relates these two parameters.

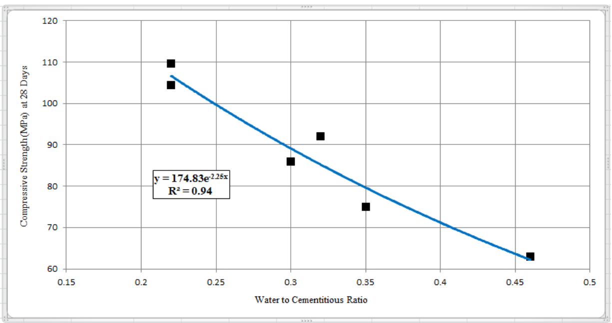


Fig. 7: Effect of Water-Cementitious Ratio on Comperssive Strengh

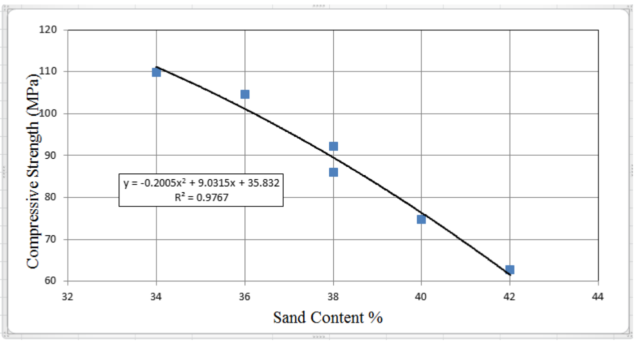


Fig. 8: Effect of Sand Content on Compersive Strength

4.3 Flexural Strength

Fig. 9 shows an exponential correlation between flexural strength and compressive strength of HSC. This correlation obtained from the non-linear regression analysis performed for data collected during the experimental program. A simple linear relationship was found between the flexural strength and the water-cementitious materials ratio and shown presented in Fig. 10.

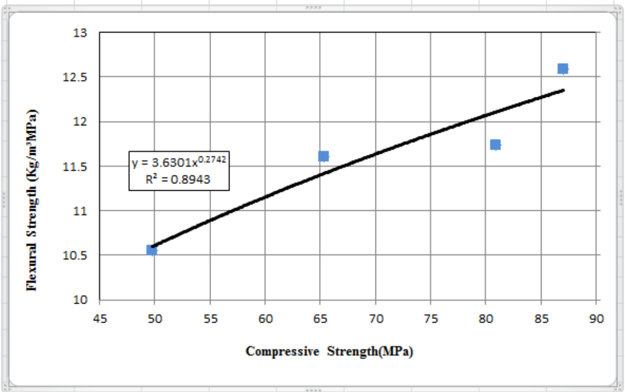


Fig. 9: Variation of Flexural strength with Compressive Strength

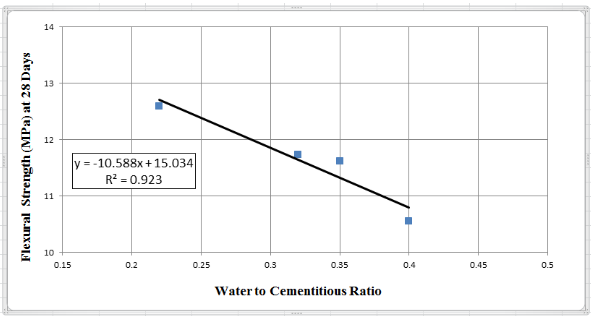


Fig. 10: Variation of Flexural strength with Water-Cementitious Ratio

4.4 Tensile Splitting Strength

Fig.11 shows the non-linear exponential relation between the splitting tensile strength and the compressive strength of HSC. A non-linear quadratic relation was found to describe the effect of water-cementitious materials ratio on the splitting tensile strength. This relation is shown presented in Fig. 12.

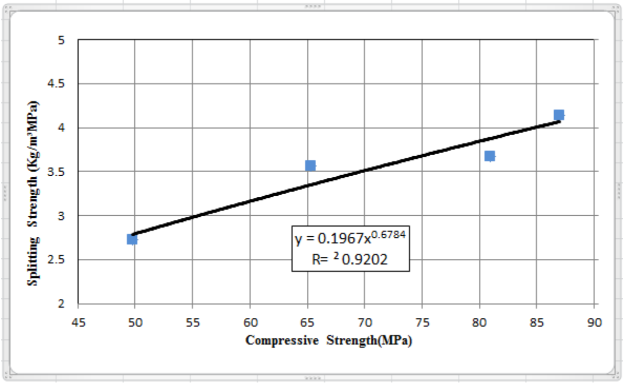


Fig. 11: Variation of Spliting strength with Compressive Strength

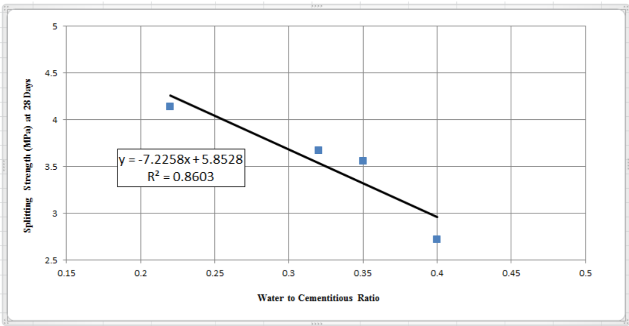


Fig. 12: Variation of Spliting strength with Water-Cementitious Ratio

5. CONCLUSIONS

Based on the findings of this study the following conclusions were made:

i. When carefully mixed and cured, locally produced concrete materials (aggregates, fly ash and ordinary Portland cement) of good quality and with their optimum proportioning can be successfully used with other chemical and mineral admixtures to produce high strength concrete of excellent properties.

ii. It is essential to optimize the doses of mineral and chemical at admixtures (silica fume, fly ash, and supper plasticizer) when producing mass high strength concrete in order to control the cost of materials.

iii. With other mix proportioning parameters held constant, the results of the present investigation indicated that the maximum compressive and flexural strength occurred at about 10 to 15% Silica fume content and 20% fly ash content.

iv. The present study shows that the maximum values of compressive strength for different grades were obtained at water-cementitious materials ratios between 0.22 and 0.35.

v. Both compressive and flexural strengths of concrete continue to increase as the percentage of silica fume increases.

vi. Non-linear regression analysis was used to correlate different parameters involved in the characterization of high strength concrete produced from local Sudanese aggregates, such as compressive, tensile, and flexural strengths, water-cementitious ratio, sand content, and cementitious content.

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