"The Effect Of Particle Size Distribution (Psd) Concept Of Coarse Aggregates On The Water Demand Of The Concrete Mix"

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Abstract

The effect of particles size distribution of the coarse aggregates on the water demand of the concrete mix was studied and analyzed using the concept of particles size distribution in so far as they deviate from the avera size or fineness modulus as indicated by the standard deviation of the sample.

Six concrete mixes 1:2:4 by weight (320 kg/m3 cement content) were designed for a given slump of (30-60) mm. The main variable being the gradation of the coarse aggregates.

The results showed that an increase in the S.D of the coarse aggregate particle distribution resulted in an increase in the water demand of the mix, this was further substantiated by a decrease in the resulting compressive strength. An extra 38 similar concrete mixes were selected randomly from the literature for further supporting evidence.

Keywords: Particle size distribution, Water demand, standard deviation, average size of aggregate

" تأثير توزيع مقاس جزيئات الركام الخشن على بعض خواص الخرسانة باستخدام مفهوم الانحراف المعياري"

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قسم الهندسة المدنية

الخلاصة:

تـم دراسـة وتحليـل تـأثير توزيـع مقاسـات جزيئـات الركـام الخشـن فـي الخلطـة الخرسـانية علـى متطلبات الخلطة للماء بواسطة مفهوم حيود هذا التوزيع عن معدل مقاسـات الجزيئـات أو معامـل النعومة وكما يفسر من خلال الانحراف المعياري لتدرج نموذج الركام الخشن.

تم اعتماد ست خلطات خرسانية (بنسبة 4:2:1 وزناً) ومحتوى أسمنت (320) kg/m³ وبهطول يتراوح بين (60-30 mm)، حيث كان المتغير الرئيسي في هذه الخلطات تدرج الركام الخشن.

أظهرت النتـائج أن زيـادة الانحراف المعيـاري لتوزيـع مقـاس جزيئـات الركـام الخشـن تـؤدي إلـى زيادة في متطلبات الخلطة للماء وبنفس الوقت نقصـان مقاومة الانضغاط.

وأخيراً تم اختيار (38) خلطة خرسانية لا على التعيين من الدراسات السابقة ذات الصلة لإعطـاء إثباتات وأدلة إضافية.

Introduction:

For fully compacted concrete, w/c ratio is the main parameter governing the strength of concrete, according to the law established by Abram [1], and his initial statement, "the strength of concrete is a function of the ratio of cement to the free water in the plastic mixture", agrees with the fact that the strength of concrete continues to increase with the reduction of w/c ratio to a value of 0.2 or even lower.

At equal values of w/c ratios, the strength of workable concrete may be influenced greatly by such factors as the grading, relative amount of aggregates, the shape, surface texture, stiffness, and the maximum size of aggregates.

A suitable gradation [2] of the combined aggregate in a concrete mix is described in order to secure workability and to secure economy in the use of cement. A well-graded mixture produces strong concrete than a harsh or poorly graded one. Singh [3] has proposed that, for constant mix proportions, the increase in specific surface (index of grading) of the aggregate, causes a decrease in the amount of cement relative to the surface of the aggregate, thus causing more voids around the surface of the aggregate particles and decrease in strength.

Specific surface gives in somewhat misleading picture of the workability to be expected and to overcome this difficulty, Murdock [4] has suggested the use of surface index, which is an empirical number, related to the specific surface of the particles with more weightage assigned to the coarser material.

The total surface index (fs) of a mixture of aggregates is calculated by multiplying the percentage weight of material retained on each sieve and the corresponding surface index and to their sum is added a constant of 330 and the result is divided by 1000 [5].

The specific surface varies with different types of aggregate due to variations in the angularity. The angularity index (fa) depends upon the grading of coarse and fine aggregates, angularity number [6] and the relative proportion of coarse and fine aggregates in the mix.

The experimental evidence presented and mathematical analysis clearly shows that the importance of fineness modulus is greatly underrated nowadays. The limit of validity of this method is much wider and its applicability is much better than is generally believed [7].
The grading is characterized numerically by the fineness modulus. This makes possible the development of formula to express the effect of grading on the concrete properties [1]. The fineness modulus represents an average particle size of the aggregate and, as such, it is a fundamental parameter of the particle size distribution.

Both the fineness modulus and the specific surface are measures of average particle size. Experimental results, however, show better correlation with fineness modulus [7].

All normal concretes containing the optimum coarse aggregate content (for workability) have fine aggregate to cement ratios well in excess of (0.8). The more frequent cause for losses in strength is at the other extreme: because the critical maximum value is exceeded, incomplete compaction occurs. However, for all practical purposes, when the optimum coarse aggregate is being used, these extreme conditions of either too little or too much fine aggregate are readily avoided [8].

Increasing the proportion of the rounded particles decreases the

percentage of voids. Since the cement paste required for concrete is proportional to the void content of the combined aggregates, it is desirable to keep the void content to a minimum [9,15].

Researchers [10, 11] have suggested that, an increase in the maximum aggregate size results in lower compressive strength in rich mixes and higher compressive strength in leaner mixes. At a given w/c ratio and mix proportions, concrete with smaller maximum aggregate size develops greater strength than concrete with larger size [12]. The particle size distribution (as they deviate from the fineness modulus is indicated by the standard deviation of the aggregate particle) [13].

Statistical analysis indicates that the lower the value of the standard deviation, the higher will be the percentage of particles close to the average size, conversely a higher standard deviation indicates a larger portion of particles in the coarse and fine fractions.

If the coarse aggregate is regarded as standard, i.e., kept unchanged throughout a series of tests, it will be found that the use of different sands in the mix results in different water demands. Consequently, it may be referred to the "water demand of the sand". On the other hand, if the sand is regarded as standard the use of different coarse aggregate in the mix also results in different water demand and it may then be referred to the "water demand of coarse aggregate", [12].

Objective of the Research:

The object of the current work is to show that the particles size distribution of the coarse aggregate using the concept of standard deviation has a definite effect on the mix water demand and ultimately on the concrete compressive strength.

Experimental Program:

Materials used: -

Locally available materials were used. Their main properties are as indicated below:

Cement: the cement used was in accordance with Iraqi specification (IQS) No. 5 (1984) [16].

Fine aggregates: Fine aggregates used consisted of medium normal river sand in accordance B.S. 882-(1992) [17].

Coarse aggregates: Coarse aggregates used were normal river gravel (irregular, almost rounded) in accordance with B.S. 882-(1992) [17].

Table (1) shows some relative properties with the sieve analysis of the used coarse aggregate.

Table (1) Relative properties & grading of coarse aggregates –according to

B. S. 882-1992

Sieve Index	Sieve Size (mm)	(1) Graded 20mm	(2) ungraded	(3) Graded 20mm	(4) Graded 20mm	(5) ungraded	(6) UNESCO
4	40	100	100	100	100	100	100
8	20	95	90	98	100	95	90
7	10	30	20	45	60	70	50
6	5	0	0	5	10	65	10

5	2.36	0	0	0	0	0	0
4	1.18	0	0	0	0	0	0
3	$600\mu_m$	0	0	0	0	0	0
2	$300\mu_m$	0	0	0	0	0	0
1	$150\mu_m$	0	0	0	0	0	0
	F.M	6.75	6.9	6.52	6.3	5.7	6.5
	S.D	0.536	0.538	0.545	0.64	1.004	0.82

Procedure

The above mentioned materials were used in preparing six concrete mixes 1:2:4 by weight, cement content (320) kg/m^3, maximum aggregate size (20) mm and having a slump of (30-60) mm. The main variable was the gradation of the coarse aggregates used as shown in Table (1).

For further evidence, number of mixes totaling 38 were chosen randomly from the literature [12, 14] designated No. 7 to No. 44 Table (3).

Investigated Parameters

The main investigated parameters of the present research work are as follows:

1. The standard deviation of the coarse aggregate particle size distribution was calculated, this is shown in col.3 of Table (3), and typical calculation is listed in Appendix (A).

2. The slump range for all the mixes considered with the w/c ratios (water demand of the mix) are given in col. 4 and 5 of Table (3) respectively. See also Figs (1, 2, and 3.)

3. The 28-day experimental cube compressive strength of 100x100x100 mm cubes prepared, cured, and tested according to B.S 1881, 1983 parts 108, 111, and 116 respectively is listed in col. 6 of Table (3).

4. The calculated compressive strength using the following equation which is predicted using the regression analysis on 44 test result from the present study and the published data as shown in Table (1) is given in col. 7 of Table (3); this equation has a correlation coefficient of (0.92).

$$\sigma = 96.69 - 112.1 \ W/C - 0.045 \ S - 9.81 \ S.D \qquad \ldots \ldots \ldots (1)$$

σ = Calculated Compressive strength of concrete (MPa).

W/C = Water cement ratio.

S = Slump (mm)

S.D = Standard Deviation of aggregates.

5. Col. (8) shows the Cal./Exp. values of the compressive strength, see also Fig. (4).

6. Finally the A/C ratios, which are the richness of the mixes considered, are shown in col.2 of Table (3).
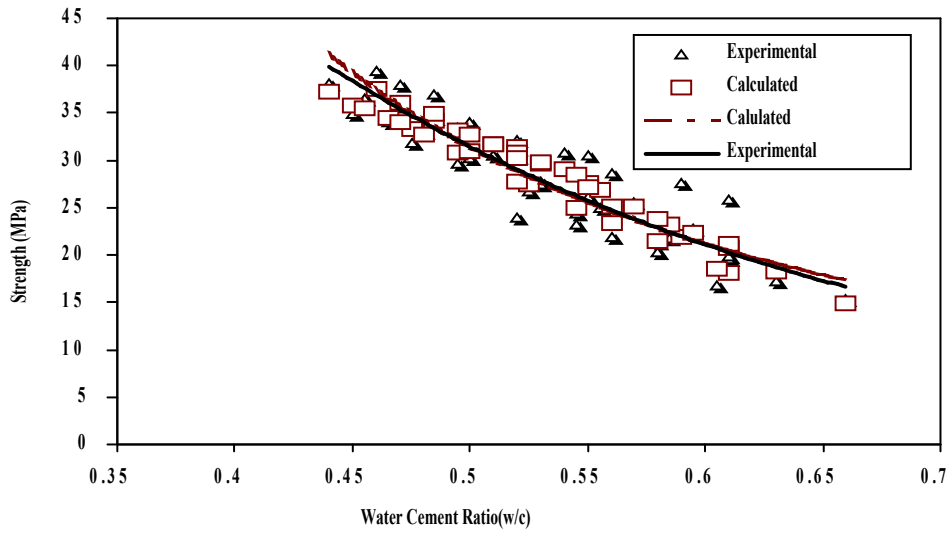
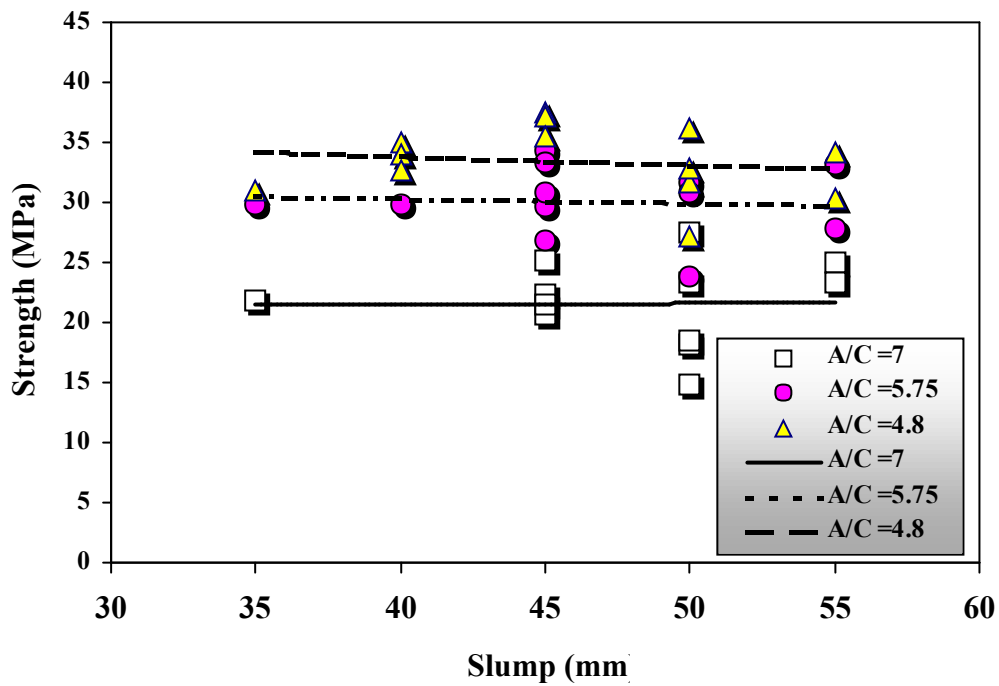**Fig. (1) Relationship between Water Cement Ratio and Cube Compressive Strength.**

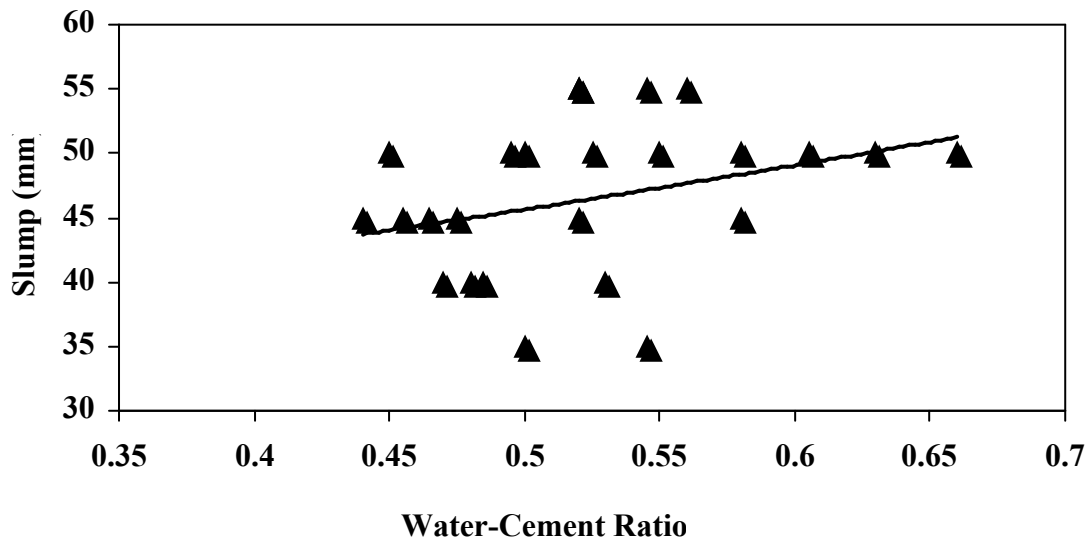**Fig. (2) Relationship between Slump and Compressive Strength.**
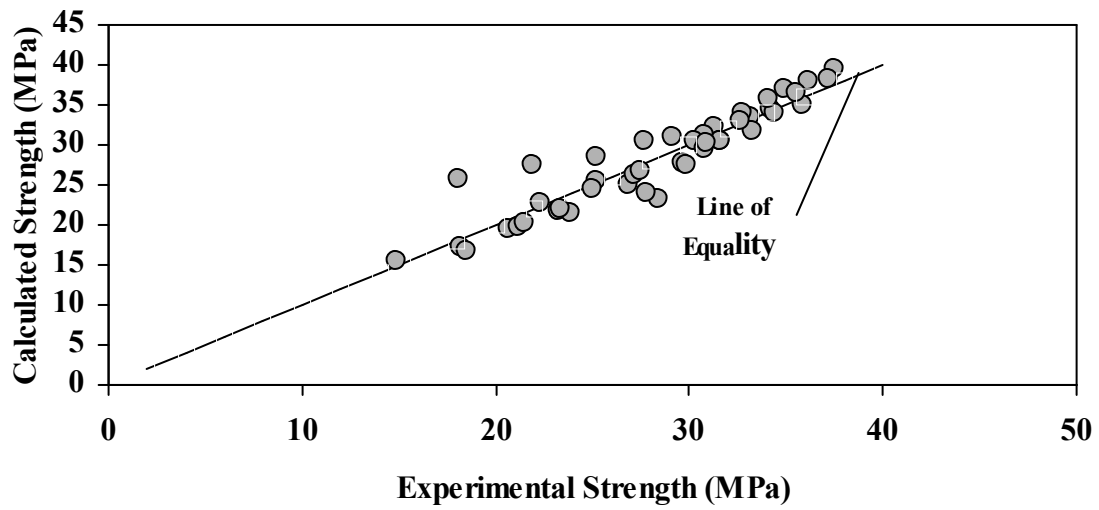
Fig. (3) Slump- Water Cement Ratio Relationship.

Fig. (4) Experimental –Calculated Compressive Strength.

Table (2) Final main properties of the considered mixes in the present study.

Mix	F.M of gravel	Average sieve size (mm)	% passing average sieve size	S.D of agg. Particles	w/c based on S.S.D for a given slump	Water Demand as related to S.D and average Sieve size	σ 7 days MPa	σ 28 days MPa	Type of agg.
(1)	6.75	10	30	0.536	0.52	S.D (Small) =higher % of particles close to average sieve size.	21.0	32.2	Graded
(2)	6.9	10	20	0.538	0.54	S.D (Small) = higher % of particles closes to average sieve size.	21.2	30.9	Ungraded
(3)	6.52	10	45	0.545	0.55	S.D (small) but increases in water demand	19.4	30.5	Graded

						due to increase in % passing average sieve size.			
(4)	6.3	4.75 10	10 60	0.64	0.56	S.D (large) indicating large proportion of particles in the fine fraction (60 % passing sieve 10 mm) further increase in water demand.	17.9	28.6	Graded
(5)	5.7	5 10	65 70	1.004	0.59	S.D (large) further increase in water demand.	16.5	27.6	Ungraded
(6)	6.5	10	50	0.82	0.61	S.D (large) large proporti	16.0	25.8	Graded (roun

						ons of particles in the fine fraction (50% passing average sieve size).			ded)

Table (3) Main Investigated Parameters.

No.	A/C Ratio	S.D	Slump (mm)	W/c Ratio	Strength (exp.)	Strength (cal.)	Cal/Exp.
1*	6	0.536	40	0.52	32.2	31.35	0.9736
2*	6	0.538	40	0.54	30.9	29.09	0.94142
3*	6	0.545	45	0.55	30.5	27.67	0.90721
4*	6	0.64	55	0.56	28.6	25.16	0.87972
5*	6	1.004	40	0.59	27.6	21.9	0.79348

6*	6	0.82	50	0.61	25.8	18.12	0.70233
7	7	0.5722	45	0.57	25.5	25.16	0.98667
8	7	0.5722	50	0.585	21.8	23.26	1.06697
9	7	0.5722	45	0.61	19.6	20.68	1.0551
10	5.75	0.5722	55	0.495	33.4	33.11	0.99132
11	5.75	0.5722	50	0.51	30.6	31.66	1.03464
12	5.75	0.5722	45	0.53	27.8	29.65	1.06655
13	5.75	0.5722	45	0.555	25	26.84	1.0736
14	4.8	0.5722	45	0.46	39.5	37.49	0.94911
15	4.8	0.5722	50	0.47	38	36.14	0.95105
16	4.8	0.5722	55	0.485	34.5	34.23	0.99217
17	4.8	0.5722	50	0.51	30.6	31.66	1.03464
18	7	0.5722	45	0.595	22.8	22.36	0.9807
19	7	0.5722	35	0.61	19.8	21.14	1.06768
20	7	0.5722	50	0.63	17.2	18.21	1.05872
21	7	0.5722	50	0.66	15.4	14.85	0.96429
22	5.75	0.5722	45	0.52	31.3	30.77	0.98307
23	5.75	0.5722	40	0.53	27.4	29.87	1.09015
24	5.75	0.5722	35	0.545	23.2	28.42	1.225
25	5.75	0.5722	50	0.58	21.4	23.82	1.11308
26	4.8	0.5722	40	0.485	37	34.92	0.94378
27	4.8	0.5722	50	0.5	34	32.78	0.96412
28	4.8	0.5722	55	0.52	30.4	30.31	0.99704
29	4.8	0.5722	50	0.55	26.2	27.18	1.0374
30	7	0.829	50	0.525	26.7	27.46	1.02846
31	7	0.829	55	0.545	24.4	24.99	1.02418
32	7	0.829	55	0.56	21.9	23.31	1.06438
33	7	0.829	45	0.58	20.3	21.52	1.0601

34	7	0.829	50	0.605	16.8	18.49	1.1006
35	5.75	0.829	50	0.45	34.9	35.86	1.02751
36	5.75	0.829	45	0.465	34	34.41	1.01206
37	5.75	0.829	45	0.475	31.8	33.29	1.04686
38	5.75	0.829	50	0.495	29.6	30.82	1.04122
39	5.75	0.829	55	0.52	24	27.79	1.15792
40	4.8	0.829	45	0.44	38.2	37.21	0.97408
41	4.8	0.829	45	0.455	36.5	35.53	0.97342
42	4.8	0.829	40	0.47	35.8	34.08	0.95196
43	4.8	0.829	40	0.48	33	32.68	0.9903
44	4.8	0.829	35	0.5	30.3	30.94	1.02112
Cube Compressive Strength MPa						Average	1.00679

* Present Study

Discussion of Results

Table (2) shows the main investigated parameters of the six mixes considered for the present work. It is clear from the Table that the water/cement ratios (i.e. water demand of the mix) is dependent on the standard deviation of the coarse aggregate particles, this is based on the fact that a small standard deviation means a higher percentage of the particles close to the average size, that is a low water demand, hence higher compressive strength both at 7& 28 days, this is true whether graded or ungraded aggregates are used as the results of mixes 1,2 &3 indicate.

A noticeable increase in the standard deviation (from 0.536 to 0.64) indicates a decrease in the strength (as shown in Fig. (5)). This is clear for mixes 4,5, and 6 of Table (2), the reason for this

behavior being that an increase in the standard deviation indicates that a large proportion of the aggregates is in the fine fraction this is further substantiated by the higher percentages passing the average sieve size (60, 70, and 50%) for mixes 4, 5, and 6 respectively. This means an increase in the surface area hence an increase in the water demand of the mix (w/c = 0.56, 0.59, and 0.61) for mixes 4, 5, and 6 respectively.

This of course is followed by a decrease in the resulting compressive strength both at 7 and 28 day.
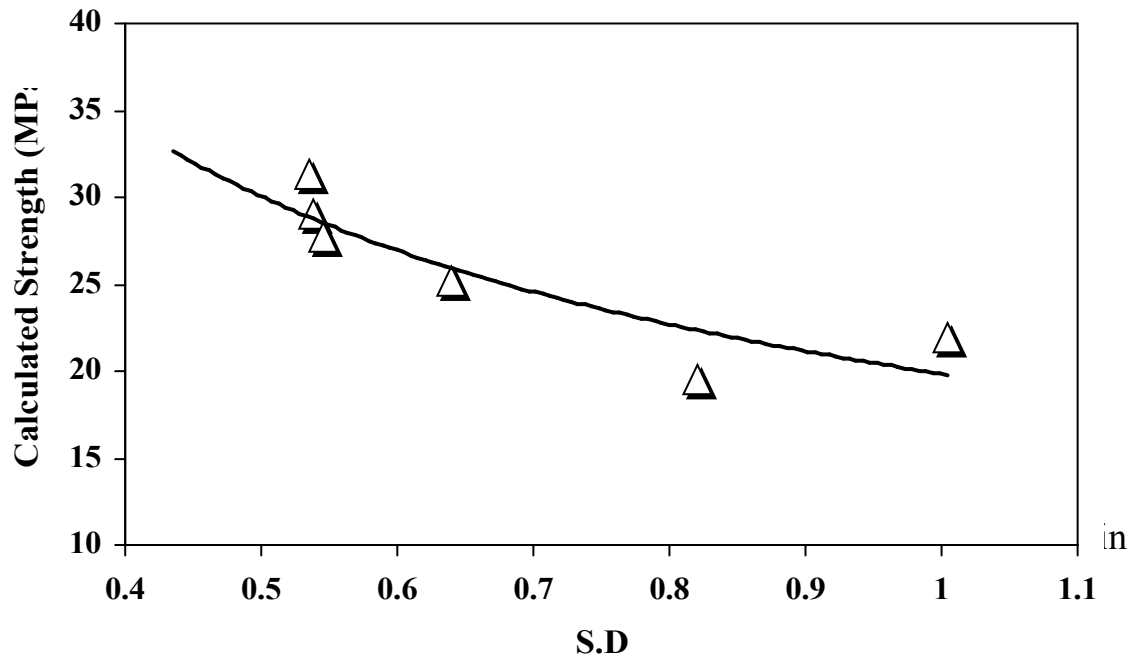

Fig.(5) Relationship between Calculated Compressive Strength and Standard Deviation.

sample may be used in checking the water demand of the mix.

2. Generally speaking an increase in the standard deviation indicates a higher water demand and a strength reduction for concrete mixes.

3. An empirical estimation based on the issue of standard deviation was obtained to predict the compressive strength of concrete (σ) with a good degree of accuracy, as given by:

$$\sigma = 96.69 - 112.1 \ W/C - 0.045 \ S - 9.81 \ S.D$$

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Appendix (A)

Typical Calculations:

1.   Average sieve size: grading 20mm aggregates

Col. (1) Table (1) $= \dfrac{0 + 5 + 70 + 100 + 100 + 100 + 100 + 100 + 100}{100} = 6.75$

Fineness modulus = 6.75 $\longrightarrow$ 7.0

$\therefore$ Sieve index (7) is the average sieve size = sieve 10 (col. (3) Table (٢))

2.   Standard deviation

(Col. 7) ungraded 20mm max. Agg. Size (F.M =5.7)

$$S.D = \frac{1}{10}\sqrt{\%rtd\ on\ 1st\ sieve(sieve\ index - F.M)^2 + \%rtd\ on\ 2nd\ sieve(sieve\ index - F.M)^2 + ...}$$

$$S.D = \frac{1}{10}\sqrt{0(9 - 5.7)^2 + 5(8 - 5.7)^2 + 5(6 - 5.7)^2 + 65(5 - 5.7)^2}$$

$= 1.004$