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CONCRETE MIX DESIGN USING SIMPLE EQUATIONS

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1. INTRODUCTION

Considerable studies, particularly in the last twenty to thirty years, has led to a much better understanding of the structure and behaviour of concrete. This has accompanied by an improved and more sophisticated technology and the product now mad, in its variety of forms, is much more capable of satisfying the huge increasing demands required of it. Because the behaviour of both fresh and hardened concrete is significantly related to their composition it should be possible, at least principle, to choose better ingredients with suitable proportion to gain the required satisfaction. A good mix design for concrete mixtures is considered as a milestone for the construction of any concrete member or structure meets economical, service and durability requirements, as well as safety and efficiency throughout its life cycle. Currently, there are many international methods locally approved for mix designs, such as: the ACI method and the BS method, which are widely used in Libya at research centers, universities, and concrete batch plants as well as pre-cast concrete manufacturing plants (e.g.: pre-stressed concrete beams, concrete columns and slabs, etc.). These methods depend on certain equations and graphs based on mathematical analysis of results obtained from previous field experience (Neville 1981) and (Neville and Brooks 1987). Generally speaking, mix design methods give some indication to the designer to validate and adjust them via experimental mixes in the local laboratories in order to check the variables related to the characteristics and properties of the local materials and the surrounding environment conditions. Along with the aforementioned methods, there are many other methods used for concrete mix design, such as:

1. The Three Equations Method (Bolomey Method);
2. Double coating method. The Three Equations Method had been presented and published by the Hakim S. Abdelgader and others (Abdelgader et al. 2012) and (Abdelgader et al. 2013).

The double coating method will be illustrated in detail in this paper, in addition to the assessment of the results of concrete mixes produced by this method.

2. DOUBLE COATING METHOD PHILOSOPHY

The philosophy of the procedure of concrete mix design using this method based mainly on calculating the weights of the main ingredients of concrete that occupies a volume of one litre of water taking in consideration the following two assumptions:

1- The Spaces between fine aggregate particles assumed as Rf. This distance (Rf) actually represents the diameter between sand particles which will be filled by cement past, as illustrated in figure (1) (Jamrozy1999).

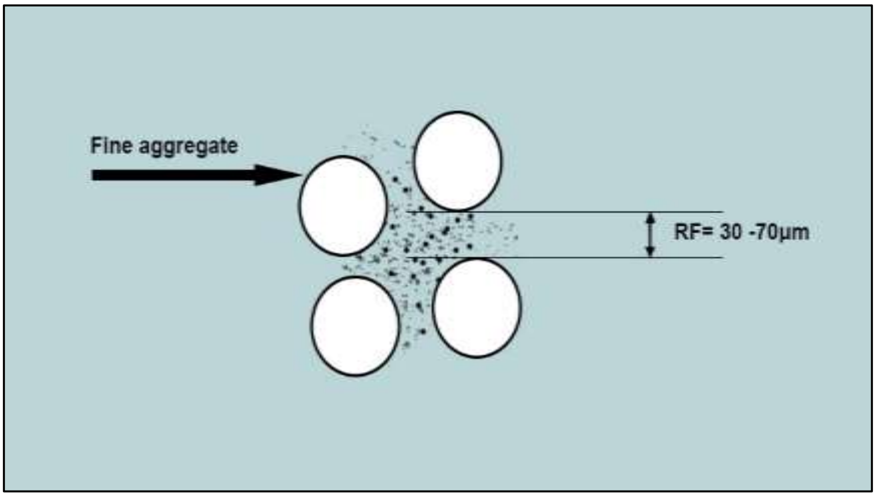

Fig.1: Assumed illustration of the space between sand particles (Rf)

2- The Spaces between coarse aggregate particles assumed as Rg. This distance (Rg) actually represents the diameter between coarse aggregate particles which will be filled by cement mortar (mixture of cement and sand), as illustrated in figure (2) (Jamrozy1999).

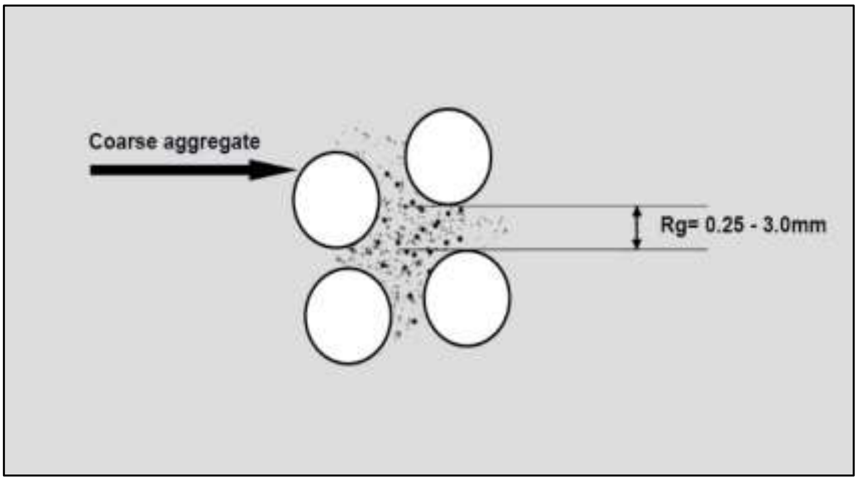

Fig.2: Assumed illustration of the space between coarse aggregate particles (Rg)

There are important notes should be explained as follows:

1- The diameters (Rf & Rg) which represent the spaces between aggregate particles, will be assumed either using previous experience in the subject or using tables given by standards as explain later in this paper.
2- The spaces between aggregate particles play an important role to know and control the weights of cement and sand that fill those spaces.
3- Quality control investigations for concrete ingredients should be carried out to find accurately some of their mechanical and physical characteristics according to the specifications. For example, properties such as: unit-weight, specific gravity and gradations are very important in this method.
4- Assumption or selection of diameters between fine aggregate particles depends mainly on the cement type, strength and fineness. The common range of Rf is considered to be between 20 to 70 micrometre (μm).
5- Assumption or selection of diameters between coarse aggregate particles depends mainly on the sand type, cross section, reinforcement quantity and the reinforcement distribution in the section. The common range of Rg is considered to be between 0.25 to 3 millimetre (mm).

3. DESIGN STEPS SUMMARY

1- Both Rf and Rg should be assumed within the acceptable range as previously indicated.

2- Knowing the aggregated particles-gradation (Sieve analysis), the swelling or expansion indicators for both fine and coarse aggregate (Mf and Mg) will be calculated. Standard tables used for this issue as shown in Tables (1) and (2).

3- Absorbed water by fine aggregate (Wf), coarse aggregate (Wg) and cement (Wc) will be calculated knowing: a)- the aggregated particles-gradation; b)- the degree of concrete workability and ; c)- the expansion indicators of aggregate (Mf and Mg). Table (3) shows values of water absorbed per kilogram of cement and aggregate.

4- Weights of concrete ingredients calculated using equations as explained in the following subtitles.

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3.1 Weight of Coarse Aggregate (*G*)

$$G = [\, \Upsilon g / (Mg)]$$

Eq. (1)

Where: G is weight of the coarse aggregate in saturated and surface-dry condition in (kg) ,Υg is the unit weight of Coarse aggregate in terms of either weight per liter (Kg/l) or weight per cubic decimeter (kg/dm^3) and Mg expansion indicator which determines the increment of the volume of the coarse aggregate of a particular fraction resulting in their wrapping with finer material layers of given thickness (see table 2) (Jamrozy1999)..

3.2 Weight of Fine Aggregate (f)

$$Z = [\, 1 - G / (\rho_g) \,]$$

Eq. (2)

$$f = [\, \Upsilon f / \; Mf \,] \; * Z$$

Eq. (3)

Where: f is weight of the fine aggregate in saturated and surface-dry condition in (kg), Z is the volume of mortar (dm^3) , ρ_g is the specific gravity of coarse aggregate , Υf is the unit weight of fine aggregate in terms of either weight per liter (kg/l) or weight per cubic decimetre (kg/dm^3) and Mf expansion indicator which determines the increment of the volume of the fine aggregate of a particular fraction resulting in their wrapping with finer material layers of given thickness (see table 1). Mortar is a mixture of cement paste and sand (Jamrozy1999)..

3.3 Weight of Cement (*C*)

$$Z0 = 1 - [\, (G / \rho_g) - (\, f / \rho_f) \,]$$

Eq. (4)

$$C = [\, (Z0) – (\, G * Wg \,) – (\, f * Wf \,)] \,/\, [Wc + (\, 1/ \rho_c)]$$

Eq. (5)

Where: $Z0$ is the volume of cement paste in (dm^3), ρc is the specific gravity of cement, cement paste is a mixture of cement and water and the weight of cement is in Kilograms units (Jamrozy1999).

3.4 Weight of Water (W)

$$W = C * Wc + \; G * Wg \; + \; f * Wf$$

Eq. (6)

3.5 Check the Total Volume (V)

$$V = (C/\rho_c) + (\, G/\rho_g) + (\, f/\rho_f) + W = 1$$

Eq. (7)

Where: V in cubic decimetre units.

3.6 Calculation of Predicted Compressive Strength

After the weights of mix ingredients have been calculated per liter then will be magnified for one cubic meter. The predicted compressive strength ($Fc_{(pr)}$) will calculated using the first equation of the three equation method (Abdelgader et al. 2012) and (Abdelgader et al. 2013). Using one of the following equations:

If (C/W) < 2.5:

$$\frac{C}{W} = \left[\frac{\mathrm{Fc(pr)}}{A_1} + 0.5\right]$$

Eq.(8-a)

If (C/W) ≥ 2.5:

$$\frac{C}{W} = \left[\frac{\mathrm{Fc(pr)}}{A_2} - 0.5\right]$$

Eq.(8-b)

Values for A1 and A2 are given in Table (4) in terms of aggregate shape and cement compressive strength.

Table 1: Expansion Indicators of Fine Aggregate (Jamrozy1999).

Sieve size (mm)	Diameter between fine aggregate particles (R_f) (μm)					
	20	**30**	**40**	**50**	**60**	**70**
2/1	1.03	1.06	1.08	1.10	1.12	1.15
1/0.5	1.09	1.12	1.17	1.21	1.26	1.31
0.5/0.25	1.16	1.26	1.36	1.45	1.56	1.67
0.25/0.125	1.37	1.56	1.79	2.03	2.30	2.59

Table 2: Expansion Indicators of Coarse Aggregate (Jamrozy1999).

Sieve size (mm)	Diameter between coarse aggregate particles (Rg) (mm)							
	0.25	**0.5**	**0.75**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**
63/32	1.02	1.03	1.04	1.05	1.09	1.12	1.17	1.27
32/16	1.03	1.06	1.09	1.13	1.20	1.27	1.35	1.44
16/8	1.06	1.13	1.19	1.27	1.42	1.59	1.76	1.95
8/4	1.13	1.27	1.37	1.60	1.95	2.37	2.85	3.36

4. EXPERIMENTAL PROGRAM

This part represents the design and production of a number of concrete mixes following the Double Coating Method and using the local raw materials. This paper illustrates the results of twenty-four concrete mixes with predicted compressive strengths (Bolomey's equation (Abdelgader et al. 2012)) ranged from 25 to 46 MPa, where the expansion indictors for fine aggregate had values of: 30 and 70 (μm) and the expansion indicators for coarse aggregate had values of 0.5, 1, 1.5, 3 (mm). Each mix was tested for medium, high and very high degree of workability. These mixes were prepared and produced in the concrete laboratory at the Faculty of Engineering - Benghazi University.

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4.1 Materials Used

4.1.1 Cement

The cement used is the Ordinary Portland Cement supplied by Alfatayh factory for cement, its properties shown in Table (5). It was tested according to the British Standard (BS 12 1991).

Table 3: Water Demands per kilogram of Aggregate and Cement According to Bolomey's Tables (Jamrozy1999).

Sieve Size	Degree of workability				
(mm)	Very Low	low	Medium	high	Very High
63/32	0.0085	0.011	0.013	0.015	0.016
32/16	0.011	0.014	0.016	0.018	0.022
16/8	0.013	0.017	0.020	0.023	0.027
8/4	0.017	0.022	0.026	0.029	0.034
4/2	0.022	0.028	0.032	0.037	0.044
2/1	0.029	0.037	0.043	0.048	0.058
1/0.5	0.039	0.050	0.058	0.065	0.077
0.5/0.25	0.056	0.072	0.084	0.095	0.112
0.25/0.125	0.082	0.104	0.122	0.137	0.151
0.125/0	0.160	0.205	0.239	0.225	0.296
0.5/0	0.098	0.127	0.148	0.168	0.198
0.25/0	0.124	0.160	0.186	0.211	0.248
W(cement)	0.230	0.25	0.270	0.290	0.310

Table 4: Values of Coefficients A1 and A2 (Jamrozy1999).

Aggregate Shape	Variable of A	Compressive strength of cement (MPa)		
		32.5	42.5	52.5
Round	A1	18	20	21
	A2	12	13	14.5
Angular	A1	20	22	24
	A2	13.5	14.5	16

Table 5: Some Physical and Mechanical Properties of Cement

Property name	The results	British Standards limits (BS 12-1992)
Standard consistency	29.5 %	27-32 %
Initial setting time	145 minutes	≮45 minutes
Final setting time	170 minutes	≯10 hours
Fineness	3210 cm^2/gm	≮2500 cm^2/gm
Soundness	1.8 mm	≯10mm
Compressive strength (7 days)	30.5 MPa	-
Compressive strength (28 days)	47.9 MPa	≮39 MPa

4.1.2 Coarse aggregate

A blend of two types of single size was used in the mixes in order to improve coarse aggregate gradation. The first type was crushed rock with a particular size range from 5 to 10 mm. Second one was the same of the first one but with particular size range from 10 to 20 mm. 1:2.33 for combination of 10 and 20 mm coarse aggregate was adopted. They were imported from a local quarry. Tests are carried out to check the aggregate specifications according to the British Standard (BS 882 1992). Figure (3) shows the sieve analysis results and Table (6) demonstrates some of its mechanical and physical characteristics.

Table 6: Some Physical and Mechanical Properties of Coarse Aggregate

Property name	The results	British Standards limits (882-1992)
Specific gravity	2.57	2.4-2.8
Absorption	1.61	3%
Unit weight	1440	1400-1800 Kg/m3
Impact value	24.45 %	≯45 %
Crushing value	30.39%	-
10% fine value	124.3 kn	min 50 kn

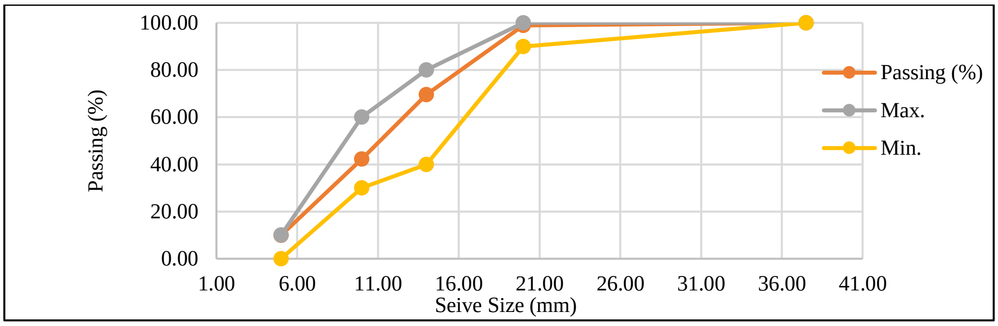

Fig.3: Sieve analysis of combined coarse aggregate

4.1.3 Fine aggregate

Natural, fine aggregate that was used in the mixture was natural beach sand from the Shat Elbideen quarry (nearly 100 km west of Benghazi city). The sand used has grain size not exceeding 2 mm, specific gravity of 2.77 and a unit weight of 1710 Kg/m3. The grading curve is shown in Figure (4). Tests were carried out according to the British Standard (BS 882 1992)

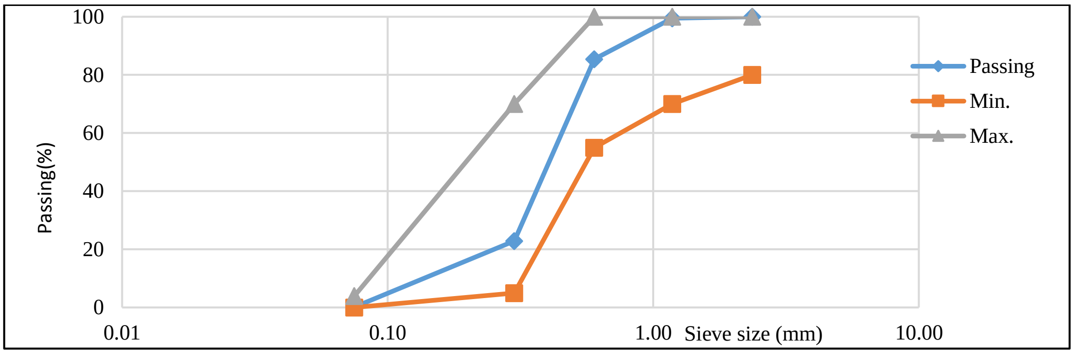

Fig.4: Sieve analysis of fine aggregate

4.1.4 Mixing water

Fresh, dirt-free water is used, with a percentage of total dissolved salts not exceeding 2,000 particles per million.

4.2 Sample

Standard cubes of size 150x150x150 mm were used as samples to test the compressive strength of concrete. A total of 72 cube samples were casted in an average of 3 samples per mix and per each degree of workability (medium, high and very high).

4.3 Mix Proportions

The calculations of mix proportions of the materials used in this research were performed in accordance to the steps explained earlier in this paper (See section 3). Table (7)and table (8) represent calculations of expansion indicators of coarse and fine aggregate respectively using Rg = 0.5, 1, 1.5 and 3mm for coarse aggregate and Rf = 30 and 70μm for fine aggregate. Table (9) shows calculation of water absorbed by fine aggregate Wf and coarse aggregate Wg for low, medium and high workability. Knowing that specific gravity and unit weight for coarse aggregate were 2.57 and 1440kg/km3 and for fine aggregate were 2.77 and 1710kg/m3 respectively. Table (10) shows the weight of mixes components targeted in this research.

Table 7: Expansion Indicators of Combined Coarse Aggregate (Mg)

Sieve Size mm	Returned Percentage %	Diameter Between Coarse Aggregate Particles (Rg) (mm)			
		0.5	1	1.5	3
63/32	1.12	1.1536	1.1760	1.2208	1.4224
32/16	29.3	31.058	33.109	35.16	42.192
16/008	27.39	30.9507	34.7853	38.8938	53.4105
08/004	32.26	40.9702	51.616	62.907	108.3936
∑Mg		1.0413	1.2069	1.3818	2.0542

Table 8: Expansion Indicators of Fine Aggregate (Mf)

Sieve Size mm	Returned Percentage %	Diameter Between Fine Aggregate Particles (Rf) (um)	
		30	70
2/1	0.5	0.5300	0.5750
1/0.5	14.1	15.7920	18.4710
0.5/0.25	62.6	78.8760	104.542
0.25/0.125	22.5	35.1000	58.2750
0.125/0.00	0.2	0.4600	1.0660
∑Mf		1.3076	1.8293

4.4 Mixing Procedure

All Concrete batches were prepared in a rotating drum mixer having a capacity of 0.027 m^3. First, the aggregates and cement are introduced and mixed on dry condition for not less than 2 minutes to ensure the homogeneity of the blend. Mixing water in a clean container introduced to the mixer slowly. Mixing continues for three minutes and then stopped for one minute for absorption then the mixing resumed and continues for other 2 minutes.

4.5 Test Specimens and Curing

Standard cubes of size 150×150×150 mm are used to investigate the compressive strength, density and voids percentage. A total of 72 samples were casted out of all mixes. After conducting the slump test as a workability characteristics experiment, the concrete mix was poured in the moulds required for assessment. After 24 hours of casting the specimens were demoulded and were transferred to the curing water tanks. After the curing period 28 days specimen removed from curing tank and screed off the all face of specimen and taken for testing.

Table 9: Water Demands in Kilogram per 1 kg of Aggregate Fraction and Cement

Sieve Size mm	Degree Of Workability		
	Low	Medium	High
63/32	0.01232	0.01456	0.0168
32/16	0.4102	0.4688	0.5274
16/008	0.4656	0.5478	0.6300
08/004	0.7097	0.8388	0.9355
04/002	0	0	0
2/1	0.0185	0.0216	0.0240
1/.5	0.7050	0.8178	0.9165
0.5/0.25	4.5072	5.2584	5.9470
0.25/0.125	2.3400	2.7450	3.0825
0.125/0.00	0.041	0.0478	0.0510
0.5/0.00	0	0	0
0.25/0.00	0	0	0
Cement	0.25	0.27	0.29
∑Wg	0.015979	0.018699	0.021097
∑Wf	0.076117	0.088905	0.10021

4.6 Laboratory Investigations

4.6.1 Slump test

This test is used to determine the degree of workability of the concrete mix in order to watch the consistency of the concrete and check the design workability according to the British Standards (BS 1881-Part 102 1992). Table (11) shows sample of results obtained through this research.

4.6.2 Density and voids percentage

The fresh concrete density (ρlab) calculated after the concrete mixing process completed and before casting the moulds as described by the British Standards (BS 1881-Part 107 1992). Theoretically the concrete density calculated by summing the ingredients of each mix per cubic meter. By knowing the density, the voids percentage could be found as previous described by the specifications. Sample of results obtained through this research is presented in Table (11).

4.6.3 Compressive strength test

The objective of this test is to determine the maximum compressive strength of the hardened concrete subject to compressive stresses. It is carried out by putting the samples under a compression on the centreline of the concrete samples used. The load is increased gradually up to failure. The compressive strength is calculated as the mean of three samples per each mix as shown in table (11). The test is conducted according to the requirements of the British Standards (BS 1881-Part 116 1992). A graphical presentation of compressive strength results after 28 days of curing are demonstrated in figures (5) and (6).

Table 10: Mix Proportions

Predicted Strength $Fc_{(pr)}$ (MPa)	Rf (μm)	Rg (mm)	W/C	Degree of Workability	Components weight (Kg/m^3)				
					Cement C	Water W	Coarse Agg. 5-10 Fraction	Coarse Agg. 10-20 Fraction	Fine Agg. f
37.62	30	0.5	0.47	Low	310	146	415	968	1383
40.33		1	0.45		371	165	358	835	1193
42.07		1.5	0.43		419	181	313	729	1042
45.07		3	0.41		529	216	210	491	701
30.10		0.5	0.55	Medium	280	155	415	968	1383
32.80		1	0.52		337	176	358	835	1193
34.54		1.5	0.50		383	192	313	729	1042
37.55		3	0.47		487	229	210	491	701
24.34		0.5	0.64	High	254	163	415	968	1383
27.00		1	0.60		309	185	358	835	1193
28.71		1.5	0.57		352	202	313	729	1042
31.68		3	0.53		451	241	210	491	701
48.56	70	0.5	0.37	Low	442	166	415	968	1383
50.30		1	0.36		525	188	358	835	1193
51.41		1.5	0.35		590	207	313	729	1042
53.31		3	0.34		738	247	210	491	701
42.66		0.5	0.43	Medium	412	175	415	968	1383
45.30		1	0.41		490	199	358	835	1193
46.45		1.5	0.39		553	218	313	729	1042
48.39		3	0.38		695	261	210	491	701
36.73		0.5	0.48	High	385	184	415	968	1383
39.36		1	0.45		460	209	358	835	1193
41.04		1.5	0.44		521	229	313	729	1042
43.94		3	0.42		567	273	210	491	701

5. DISCUSSION

The results obtained from the concrete mix components and quality control tests show that:

1. The concrete mix components obtained using this method is in compliance with those obtained by the common design methods such as ACI and BS methods
2. The results of the slump test are relatively reduced in each degree of workability specifically when the diameter between coarse aggregate particles (Rg) reduced to a value less than 1.5 mm.
3. As shown in fig (7) experimental compressive strengths meet the predicted compressive strengths with $R^2 \approx 0.8$

6. CONCLUSIONS AND RECOMMENDATIONS

A. This method is considered as an added value to the concrete mix design methods due to the following advantages:

- Introducing of the effect of spaces between aggregate particles in the design process;
- Introducing of the effect of water demand by cement.
- Introducing of the effect of water demand by fine and coarse aggregate as well as the grading in the design.

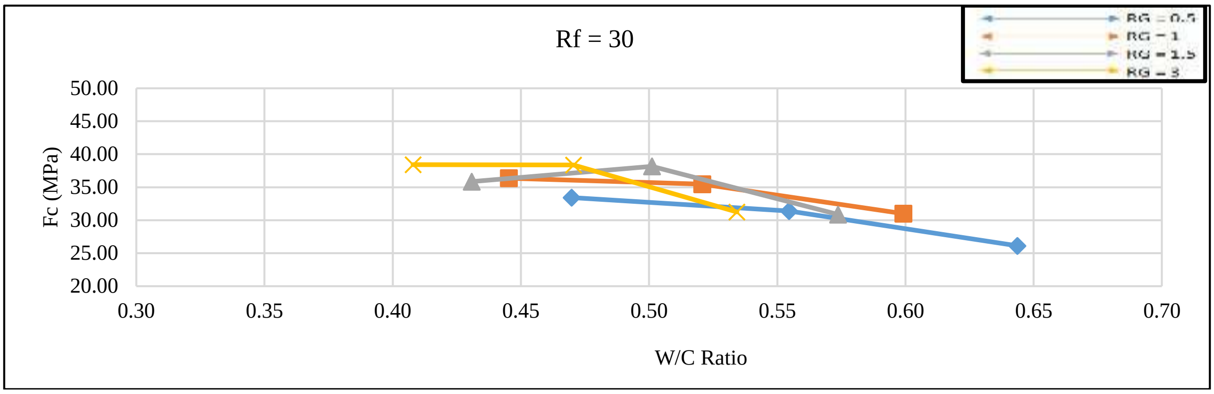

Fig.5: Compressive Strength Versus W/C Ratio results at (Rf=30μm) and (Rg ranged from 0.5 to 3 mm).

Table 11: Experimental Results

Predicted Strength $Fc_{(pr)}$ (MPa)	Rg (mm)	Rf (μm)	W/C	Degree of Workability	Experimental Results			
					Fresh Density ρ(lab) g/cm^3	Compressive Strength Fc (MPa)	Voids %	Slump (mm)
37.62	0.5	30.0	0.47	Low	2.32	33.43	5.832	0
40.33	1		0.45		2.35	36.37	3.751	0
42.07	1.5		0.43		2.37	35.87	2.568	0
45.07	3		0.41		2.33	38.42	3.335	0
30.10	0.5		0.55	Medium	2.34	31.42	4.261	0
32.80	1		0.52		2.36	35.45	2.632	0
34.54	1.5		0.50		2.35	38.17	2.625	0
37.55	3		0.47		2.34	38.36	1.909	50
24.34	0.5		0.64	High	2.40	26.13	0.914	0
27.00	1		0.60		2.35	31.00	2.244	50
28.71	1.5		0.57		2.32	30.88	2.687	110
31.68	3		0.53		2.30	31.25	2.450	140
48.56	0.5	70.0	0.37	Low	2.34	36.66	3.997	0
50.30	1		0.36		2.37	44.49	2.193	0
51.41	1.5		0.35		2.37	47.69	1.544	0
53.31	3		0.34		2.31	46.67	2.724	0
42.66	0.5		0.43	Medium	2.37	36.07	1.916	0
45.30	1		0.41		2.41	42.34	-0.612	30
46.45	1.5		0.39		2.35	43.52	1.492	120
48.39	3		0.38		2.33	43.86	0.907	130
36.73	0.5		0.48	High	2.40	33.22	-0.035	70
39.36	1		0.45		2.36	42.20	0.894	100
41.04	1.5		0.44		2.39	41.20	-1.085	130
43.94	3		0.42		2.31	38.82	0.379	160

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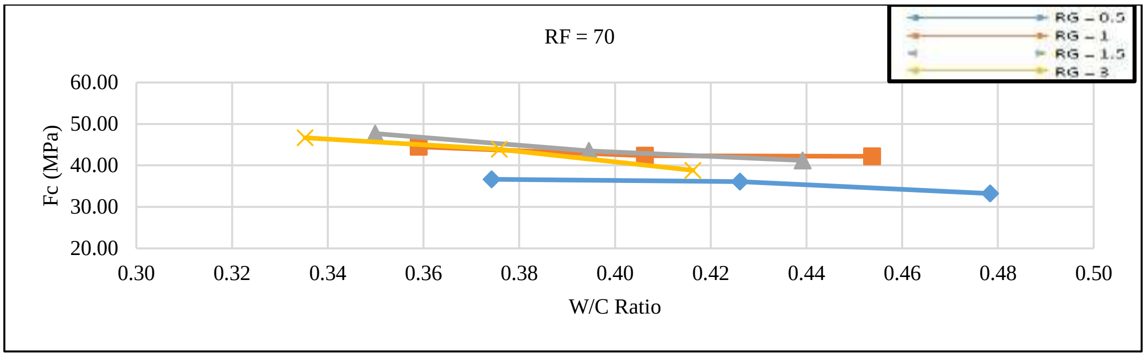

Fig.6: Compressive Strength Versus W/C Ratio Results at (Rf=70µm) and (Rg ranged from 0.5 to 3 mm).

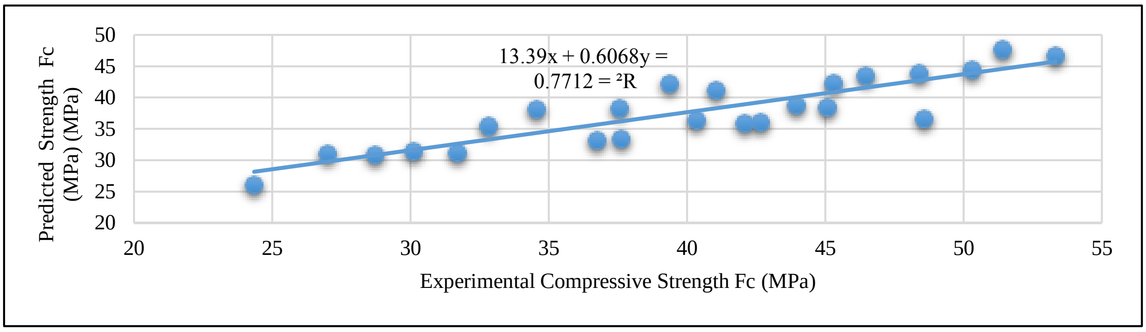

Fig.7: Correlation between Experimental and Predicted Compressive Strength Values for 24 Concrete Mixes

B. In order to make this method more efficient, it is recommended to carry out more researches to know the quantities of water demand by the cement and aggregate for the local raw materials similar to those used in this method.

C. It is recommended to carry out more researches to investigate other concrete properties such as: shrinkage, creep……etc.

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