Concrete Mix Design Using Double Coating Method

H. S. Abdelgader[1], A. F. Saud[1], A. M. Othman[1], A. H. Fahema[1] and A. S. El-Baden[1]
[1] Tripoli University, Civil Engineering Department, Tripoli, Libya

Abstract. Considerable study, 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. 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. This paper illustrates the steps used for mix design using the double coating method, which is currently used in some research centres in Poland and was recently applied in the laboratories of the Civil Engineering Department in the University of Tripoli in Libya. Results obtained by this method using the local materials subject to local environmental conditions are presented and discussed.

1 Introduction

The behaviour of concrete, whether fresh or hardened, depends basically on the behaviour of its components and the relationship between them, therefore, obtaining a concrete with certain properties depends fundamentally on the concrete mix design. Concrete mix design generally includes two main steps: 1-Selection of the main components suitable for the concrete (cement, aggregate, water, and additives); 2-Determination of more economical mix ratios to fulfill the workability, strength and efficiency requirements. Currently, there are many international methods locally approved for mix designs. They are all related to each other, they give relatively the same quantities of the mix components and they are all capable of providing a good concrete mix [1]. It is important to consider that these methods give approximate quantities which should be checked by experimental mixes in order to obtain results suitable for the requirements of the local environment and local materials. The ACI and BS methods are the most commonly used. Both of these methods depend on graphs and standard tables derived from previous research experience and actual concrete production as well as studies of the properties of the materials used [2]. Along with the aforementioned methods, there are many other methods used for concrete mix design, such as: 1-The Three Equations Method (Bolomeya Method); 2-Double coating method. The Three Equations Method had been presented and published by the authors [3, 4]. 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 [5].

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.

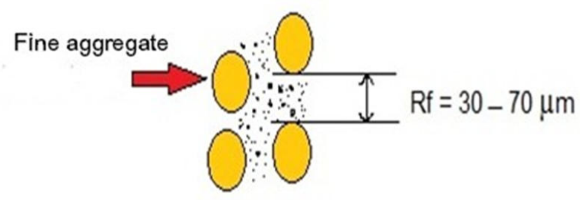

Fig.1 Assumed illustration of the space between sand particles (Rf)

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.

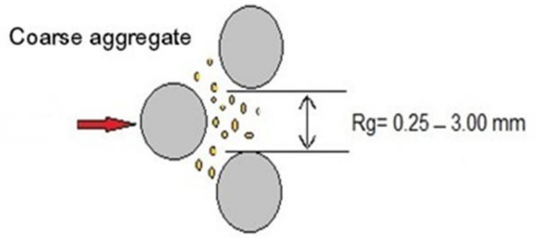

Fig.2 Assumed illustration of the space between coarse aggregate particles (Rg)

Important notes:

1. The diameters (Rf&Rg) which represent the spaces between aggregate particles, will be assumed either using previous experience in the 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 chacteristics 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 micrometer (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 sup-titles.

3.1 Weight of coarse aggregate (G)

$G = [\Upsilon_g / (Mg)]$ (Kg) (1)

Where: Υ_g is the unit weight of Coarse aggregate in terms of either weight per liter (Kg/l) or weight per cubic decimetre (Kg/dm^3).

3.2 Weight of fine aggregate (f)

$Z = [1 - G/(\rho_g)]$ (dm^3) (2)

$f = [\Upsilon f / Mf] * Z$ (Kg) (3)

Where: Z is the volume of mortar, ρ_g is the specific gravity of coarse aggregate and 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). Mortar is a mixture of cement paste and sand.

3.3 Weight of cement (C)

$Z_0 = 1 - [(G/\rho g) - (f/\rho f)]$ (dm^3) (4)

$C = [(Z_0) - (G*Wg) - (f * Wf)] / [Wc + (1/\rho c)]$ (5)

Where: Z_0 is the volume of cement paste, 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.

3.4 Weight of water (W)

$W = C * W_c + G * W_g + f * W_f$ (Kg) (6)

3.5 Check the total volume (V)

$V = (C/\rho_c) + (G/\rho_g) + (f/\rho_f) + W = 1$ (7)

Where: V in cubic decimeter units.

3.6 Calculation of required compressive strength ($fc`_{req}$.)

After the weights of mix ingredients have been calculated per liter then will be magnified for one cubic meter. The design compressive strength (fc`req.) will calculated using the first equation of the three equation method [3, 4] using one of the following equations:

<u>if (C/W) < 2.5 :</u>

$$\frac{C}{W} = \left[\frac{fc'}{A_1} + 0.5 \right] \quad (8-a)$$

if (C/W) ≥ 2.5:

$$\frac{C}{W} = \left[\frac{fc'}{A_2} - 0.5 \right] \qquad (8\text{–b})$$

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

3.7 Calculation of laboratory compressive strength ($fc_{`lab.}$)

f_c` (lab.) = 1.3 * [$f_c$` (req.)] (MPa) (9)

Table 1.expansion indicators of fine aggregate

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

Sieve size (mm)	**Diameter between coarse aggregate particles (R_g)** (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

Table 3. Water absorbed per kilogram of aggregate and cement according to Bolomeya tables

Sieve Size (mm)	Degree of workability				
	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	0.255	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	0.250	0.270	0.290	0.310

Table 4. Values of coefficients A1 and A2

Aggregate Shape	Variables of A	Compressive strength of cement (MPa)		
		32.5	42.5	52.5
Round	A_1	18	20	21
	A_2	12	13	14.5
Angular	A_1	20	22	24
	A_2	13.5	14.5	16

4 Experimental program

This part represents the design and production of a number of concrete mixes following the The Double Coating Method and using the local raw materials. This paper illustrates the results of twenty four concrete mixes with design compressive strengths ranged from 25 to 47 MPa, where the expansion indictors for fine aggregate had values of: 30 and 50 (μm) and the expansion indicators for coarse aggregate had values of 0.5, 1, 1., 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 - Tripoli University.

4.1 Materials used

4.1.1 Cement

The cement used is the Ordinary Portland Cement supplied by zliten factory for cement, its properties shown in Table 5. It was tested according to the BS12 [6].

Table 5. Some physical and mechanical properties of cement

Property name	**The results**	**British Standards limits** (BS 12-1992)
Standard consistency	26.5 %	27-32 %
Initial setting time	132 minutes	≮45 minutes
Final setting time	162 minutes	≯10 hours
Fineness modulus	3178 cm^2/gm	≮2500 cm^2/gm
Soundness	1.4 mm	≯10mm
Compressive strength (3days)	22.2 MPa	≮21 MPa
Compressive strength (28 days)	46.8 MPa	≮39 MPa

4.1.2 Coarse aggregate

The coarse aggregate used was angular aggregate with maximum size of 19 mm, it was imported from a local quarry (nearly 45 km south of Tripoli city). Tests are carried out to check the aggregate specifications according to the BS 882-1992 standards [7]. 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** (BS 12-1992)
Specific gravity	2.64	2.4-2.8
Absorption	1.21	3%
Unit weight	1559	1400-1800 Kg/m^3
Impact value	17.21 %	≯45%
Crushing value	4.82%	≯45 %

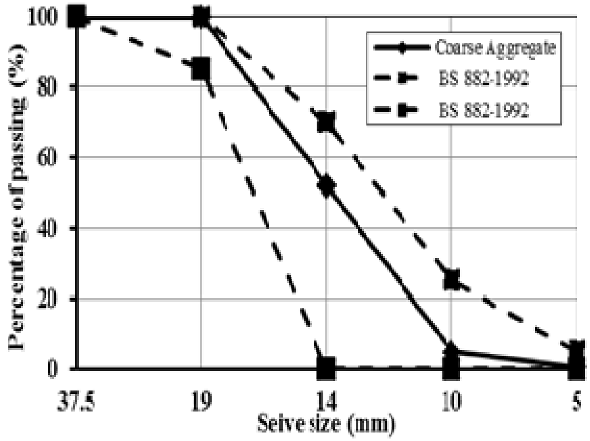

Fig. 3. Sieve analysis of coarse aggregate

4.1.3 Fine aggregate

Natural, fine aggregate that was used in the mixture was natural beach sand from the zliten quarry (nearly 200 km east of Tripoli city). The sand used has grain size not exceeding 2 mm, specific gravity of 2.68 and a unit weight of 1412 Kg/m^3. The grading curve is shown in Figure 4. Tests were carried out according to the BS 882-1992 standards [7].

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 as per Libyan Standards [8].

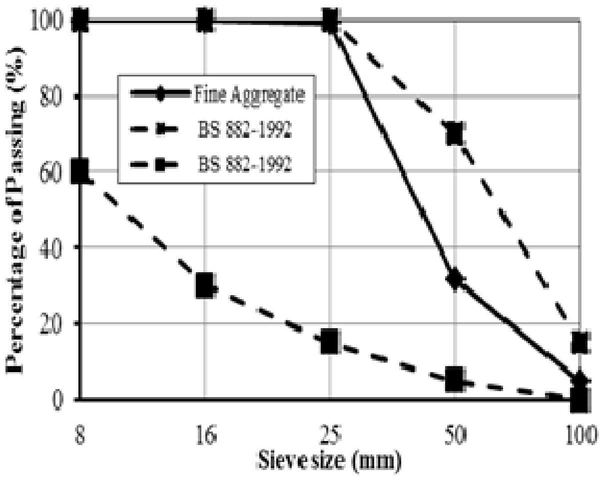

Fig. 4. Sieve analysis of fine aggregate

4.2 Samples

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). Table 7 represents sample of calculation of water absorbed by fine aggregate (W_f) for medium workability using the diameter between fine aggregate grains (R_f) as 30 µm. Knowing that the specific gravity and the unit weight were 2.68 and 1560 Kg/m^3 respectively. Table 8 represents sample of calculation of water absorbed by coarse aggregate (W_g) for medium workability using the diameter between fine aggregate grains (R_g) as 0.5 mm. Knowing that the specific gravity and the unit weight were 2.64 and 1410 Kg/m^3 respectively. Table 9 shows the weights of the mixes components targeted in this research.

Table 7. Sample of calculation of water absorbed by fine aggregate

Seive size (mm)	Aggregate passing %	Aggregate retained %	Absorption indicator (L/Kg)	water quantity l	Expansion Indicator (L/Kg)	Expansion Quantity l
2.36	100	0				
1.18	100	0.64	0.043	0.02752	1.06	0.6784
0.6	99.36	67.56	0.058	3.91848	1.12	75.6672
0.3	31.8	26.76	0.084	2.24784	1.26	33.7176
0.15	5.04	5.04	0.122	0.61488	1.56	7.8624
		100		6.80872		117.9256
			Mf=	0.0680872	**Wf=**	1.179256

Table 8. Sample of calculation of water absorbed by coarse aggregate

Sieve size (mm)	Aggregate passing %	Aggregate retained %	Absorption indicator (L/Kg)	water quantity l	Expansion Indicator (L/Kg)	Expansion Quantity l
37.5	100	0				
19	100	47.86	0.016	0.76576	1.06	50.7316
14	52.14	47.24	0.02	0.9448	1.13	53.3812
10	4.9	4.9	0.026	0.1274	1.27	6.223
						0
		100		1.83796		110.3358
			Mg=	0.0183796	**Wg=**	1.103358

Table 9.Mix proportions

Required strength R(req) (MPa)	**Design strength** (MPa)	Rg	Rf	W/C	**Degree of workability**	**Components weight (Kg/m^3)**			
						cement C	water W	fine Agg. G	coarse Agg. f
28	37	0.5	30	0.47	**Medium**	335	158	1462	482
30	39	1		0.46		371	170	1362	523
31	40	1.5		0.45		401	179	1275	558
32	42	3		0.43		483	206	1041	654
33	43	0.5	50	0.42		394	167	1462	408
34	44	1		0.41		433	179	1362	443
35	45	1.5		0.4		468	190	1275	473
36	47	3		0.39		560	218	1041	555
24	31	0.5	30	0.54	**High**	310	166	1462	482
25	33	1		0.52		344	178	1362	523
26	34	1.5		0.5		373	188	1275	558
28	36	3		0.48		451	216	1041	654
28	37	0.5	50	0.48		368	175	1462	408
29	38	1		0.46		406	188	1362	443
30	39	1.5		0.45		440	199	1275	473
32	41	3		0.43		528	229	1041	555
19	25	0.5	30	0.63	**Very high**	278	176	1462	482
20	26	1		0.61		311	189	1362	523
21	27	1.5		0.59		339	200	1275	558
23	29	3		0.56		413	229	1041	654
23	30	0.5	50	0.55		336	185	1462	408
24	32	1		0.53		373	199	1362	443
25	33	1.5		0.52		405	210	1275	473
27	35	3		0.49		490	241	1041	555

4.4 Mixing procedure

All Concrete batches were prepared in a rotating drum mixer having a capacity of 0.05 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.

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 [8]. Table 10 shows sample of results obtained through this research.

4.6.2 Density and voids Percentage

The fresh concrete density (ρ_{lab}) calculated after the concrete mixing process completed and before casting the moulds as described by the British Standards BS 1881-Part 107 [9]. 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 [9]. Sample of results obtained through this research is presented in Table 10.

Table 10.Experimental results

Required strength R(req) (MPa)	Design strength $\bar{R}$ (MPa)	Rg	Rf	W/C	Degree of workability	Experimental results: fresh density $\rho_{(lab)}$ (Kg/m^3)	Dry density ρ. (Kg/m^3)	Compressive strength fc` (MPa)	Voids %	Slump (mm)
28	37	0.5	30	0.47	**medium**	2434.8	2434.1	60.61	0.09	0
30	39	1		0.46		2420.6	2418.1	58.07	0.22	10
31	40	1.5		0.45		2417.4	2414.9	57.92	0.18	15
32	42	3		0.43		2414.8	2412.3	55.13	1.29	40
33	43	0.5	50	0.42		2444	2411.5	64.29	0.53	0
34	44	1		0.41		2434.5	2430.4	63.1	0.7	10
35	45	1.5		0.4		2430.1	2426.2	61.56	1	15
36	47	3		0.39		2370.4	2349.6	57.77	0.15	50
24	31	0.5	30	0.54	**high**	2453.3	2449.4	57.77	1.37	0
25	33	1		0.52		2436.5	2433.5	55.4	1.22	15
26	34	1.5		0.5		2414.3	2413.3	54.96	0.85	30
28	36	3		0.48		2374.3	2366.4	39.09	0.52	140
28	37	0.5	50	0.48		2464.7	2460.2	60.37	2.14	0
29	38	1		0.46		2420.3	2417.2	59.66	0.89	15
30	39	1.5		0.45		2410.4	2405	55.24	0.69	40
32	41	3		0.43		2372.3	2371.4	48.14	0.81	140
19	25	0.5	30	0.63	**very high**	2430.6	2428.1	45.3	1.36	0
20	26	1		0.61		2412.3	2406.4	43.2	1.14	20
21	27	1.5		0.59		2405.9	2404.4	42.4	1.43	60
23	29	3		0.56		2350.1	2396.6	41.8	0.5	230
23	30	0.5	50	0.55		2433.6	2429.6	49.9	1.78	0
24	32	1		0.53		2410	2408.4	48.4	1.39	20
25	33	1.5		0.52		2403.5	2400	44	1.69	65
27	35	3		0.49		2363	2356	43.7	1.54	210

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 centerline 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 10. The test is conducted according to the requirements of the British Standards BS 1881-Part 116 [10]. A graphical presentation of compressive strength results after 28 days of curing are demonstrated in figures 5 and 6.

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 (R_g) reduced to a value less than 1.5 mm.

3. This method efficiently meets the compressive strength requirements.

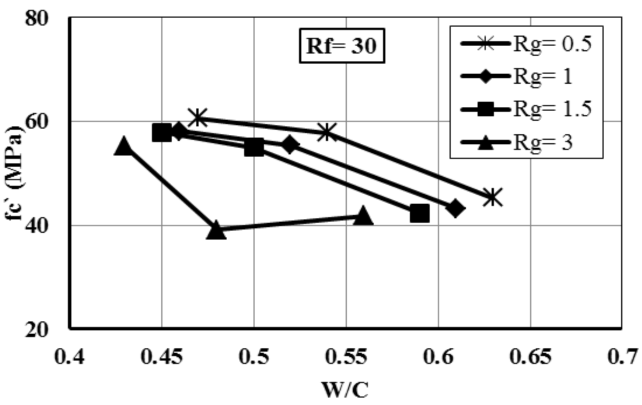

Fig. 5. Compressive strength results at (Rf=30μm) and (Rg ranged from 0.5 to 3 mm).

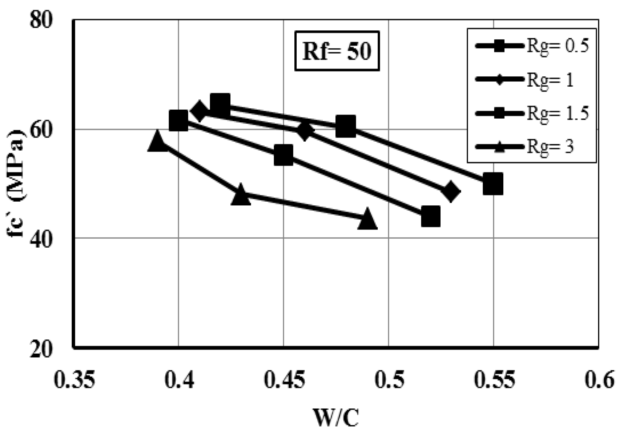

Fig. 6. Compressive strength results at (Rf=50μm) and (Rg ranged from 0.5 to 3 mm).

6 Conclusions and recommendations

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

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