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The effects of water-cement ratio and chemical admixtures on the workability of concrete

Ali M Mansor[1], **Ruben Paul Borg**[2], **Ahmed M M Hamed**[2], **Mohammed M Gadeem**[1], **Mansour M Saeed**[1]

[1] Faculty of Engineering, University of Tripoli, Libya
[2] Faculty for the Built Environment, University of Malta, Malta

E-mail: ruben.p.borg@um.edu.mt

Abstract. Concrete chemical admixtures are used to improve the fresh and hardened properties of mortar or concrete in different applications. Their addition can allow for the reduction of the water to cement ratio (w/c), without affecting the workability of the mixture. By reducing the amount of water, the cement paste will have higher density. However, the reduction of the water content in a concrete mixture should be done in such a way that complete cement hydration take place and sufficient workability is achieved. In order to maintain the workability of the concrete mix, the dosage of the admixture must be carefully calculated and must be taken into account in the calculation of the w/c ratio. In the present study, three types of chemical admixtures; Type A water-reducing, Type D water-reducing and retarding and Type F high range, water-reducing admixtures conforming to ASTM C 494/C 494M – 04 standards, were used to optimize the percentage of the admixture with respect to the w/c ratio. The suitable time for the addition of the admixture is also investigated. Results show that using 1.5 % of Type A admixture with 0.45 w/c gives 45.6 MPa, 28 day compressive strength with an associated slump of 110 mm, compared to zero slump without admixture. 1.0 % Type A admixture with 0.52 w/c gives 33 MPa, 28 day compressive strength with an associated slump of 95 mm, compared to 35 mm slump achieved without admixture. For Type D admixture, using 1.5 % with 0.5 w/c the slump was 190 mm with 47 MPa, 28 day compressive strength, compared to 15 mm slump achieved without admixture. 1.0% of Type F admixture with 0.35 w/c and 0.45 w/c gave slumps of 25 mm, 225 mm and strength of 63.5MPa and 55.3MPa respectively. For all mixes, the best slump results were achieved when the admixtures were added during the initial mixing process, while maximum compressive strengths were achieved for different times of inclusion of the admixtures.

Keywords*:* Admixtures, water reducer, concrete slump

1. Introduction

Many important characteristics of concrete are influenced by the ratio of water to cementitious materials (w/c) used in the mixture. By reducing the amount of water, the cement paste will have higher density, which results in higher paste quality and hence higher compressive strength and lower permeability. Reducing the water content in a concrete mixture should be done in such a way so that complete cement hydration may take place and sufficient workability of concrete is maintained for placement and consolidation during construction.

The w/c ratio needed for cement to complete its hydration ranges from 0.22 to 0.25 [1]. The existence of additional water in the mixture is needed for the workability of the concrete. Reducing the water content in a mixture may result in a stiffer mixture, which reduces the workability and increases potential placement problems.

Water reducing admixtures or, as they are more commonly known, plasticisers are admixtures for concrete, which are used to achieve certain properties in concrete more effectively than by other means, and to maintain the quality of concrete during the stages of mixing, transporting, placing, and curing in adverse weather conditions.

Admixtures vary widely in chemical composition, and many perform more than one function. Two basic types of admixtures are available: chemical and mineral admixtures [2]. All admixtures to be used in concrete construction should meet specifications; tests should be made to evaluate how the admixture will affect the properties of the concrete. The effectiveness of an admixture depends upon factors such as type, brand, and amount of cementing materials; water content; aggregate shape, gradation, and proportions; mixing time; slump; and temperature of the concrete.

The objective of this work was to investigate the effect of w/c ratio on the efficiency of the concrete chemical admixtures used. Three types of chemical admixtures, conforming to ASTM C 494/C 494M standard specification, were used: Type A water-reducing, Type D water-reducing and retarding and Type F high range water-reducing admixtures. Different w/c ratios were considered for each type of admixture to investigate its effect on the workability (slump). Fresh and hardened concrete tests were conducted.

2. Materials

Ordinary Portland cement (OPC) type 42.5N conforming to the Libyan standards 340-2009 was used as the main binder. The fine aggregate used is a local Libyan natural sand referred to as Zliten sand, with a specific gravity 2.66, moisture absorption 0.18%, fine materials 2.2% and unit weight 1660 kg/m^3 conforming to the Libyan standards 49-2002. Two different sizes of coarse aggregate were used, 20 mm and 14 mm conforming to the Libyan standards 256 and ASTM C29/129M: 2007. A clean water free from contaminants was used as mixing water for the production of concrete specimens. Three types of the chemical admixtures, conforming to ASTM C 494/C 494M – 04 standards, were used; Type A water-reducing admixtures (Plasticizer), Type D water-reducing and retarding admixtures (Plasticizer) and Type F water-reducing, high range admixtures (Super-plasticizer),

3. Experimental work

Table 1 shows the quantities of materials used for one cubic meter of concrete. The water cement ratio was adjusted for the required initial slump.

Table 1, Concrete mixes.

Cement (kg)	Coarse Agg. (kg)		Fine Agg. (kg)	Water (kg)	w/c %	Admixtures (kg)
	20 mm	14 mm				
360	466.2	299.3	684.5	122.6 – 230.6	0.34 – 0.64	3.6 – 5.4

A sufficient number of mixes were batched and prepared, for each type of admixture and for each w/c ratio selected. Six cubes 150x150x150 mm were prepared for each mix. Ingredients were introduced to the mixer and mixed in a dry form for homogeneity. The mixing water was added first and the batch was mixed for two minutes. Then the assigned portion of the admixture was added and the batch was remixed for another three minutes. The cubes were filled in three layers and demoulded after 24 h. The concrete specimens were water cured in a controlled environment until the time of testing.

4. Results and observations

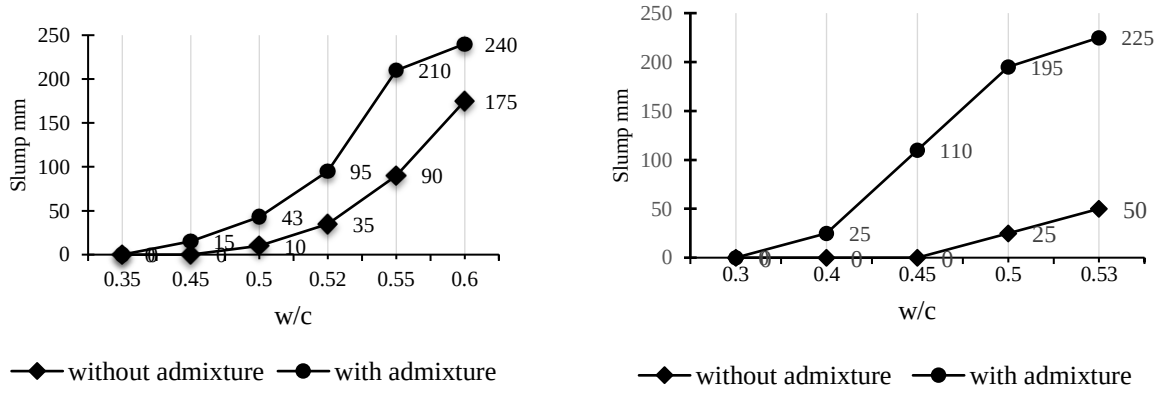
4.1 Type A admixture

The results and observations of the effect of the w/c ratio with the use of type A admixture on the slump and compressive strength of the concrete mixes are shown in table 2.

Table 2, Results and observations of using Type A chemical admixture with various w/c ratios.

Admixture, % of cement	w/c %	Workability		Slump (mm)		Compressive strength (MPa)	
		Without admixture	With admixture	Without admixture	With admixture	7 days	28 days
1.5	0.3	Very low	Very low	0.0	0.0	7.5	11
	0.4	Very low	Low	0.0	25	31.4	47.6
	0.45	Very low	Medium	0.0	110	41.2	45.6
	0.5	Low	High (with little segregation)	25	195	37	45.7
	0.53	Low	High (with segregation)	50	225	31.2	43
1.0	0.45	Very low	Low	0.0	15	25.6	31.7
	0.5	Very low	Low	10	45	26.8	30.7
	0.52	Low	Medium	35	95	24	33
	0.55	Medium	High (with segregation)	90	210	29.7	39
	0.6	High	High (with segregation)	175	240	27	38.5

Results showed that for 1.5% Type A admixture a slump of 110 mm could be achieved with 0.45 w/c ratio compared to zero slump without admixture. At the same percentages, the 28 days compressive strength was recorded as 45.6 MPa. A higher compressive strength of 47.6 MPa was reported for 1.5% admixture and 0.4% w/c ratio with a low workability. For 1.0% admixture and 0.45 w/c ratio, neither a good workability nor a good compressive strength were achieved, comparing to the 1.5% admixture mix. A slump of 95 mm was reported at 0.52 w/c ratio associated with a compressive strength of 33 MPa for the 1.0% admixture mix. Figure 1, a and b show the relations between w/c ratio and concrete slump for 1.0% and 1.5% Type A admixtures, respectively.

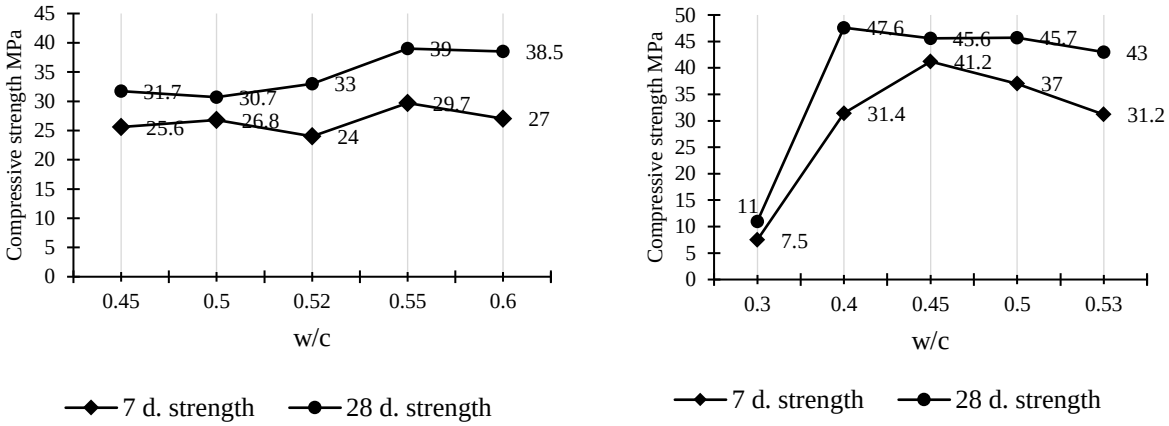


(a): 1.0% admixture

(b): 1.5% admixture

Figure 1. Slump with and without type A admixture

Figure 2, a and b show the relations between w/c ratio and concrete compressive strength for 1.0% and 1.5% Type A admixture, respectively



(a): 1.0% admixture **(b):** 1.5% admixture

Figure 2. Compressive strength for concrete with and without Type A admixture

4.2 Type D admixture

Table 3 illustrates the results and observations of the effect of the w/c and Type D admixture on the slump and compressive strength of the concrete mixes.

Table 3, Results and observations of using type D chemical admixture with various w/c ratios.

Admixture, % of cement	w/c %	Workability		Slump (mm)		Compressive strength (MPa)	
		Without admixture	With admixture	Without admixture	With admixture	7 days	28 days
1.5	0.35	Very low	Very low	0.0	0.0	24.6	48
	0.45	Very low	Low	0.0	25	39.8	52
	0. 5	low	High	15	190	33.6	47
	0.55	High	High (with segregation)	145	210	28	40. 6

Similar to type A chemical admixture, results showed that for 1.5% type D admixture a slump of 190 mm could be achieved with 0.5 w/c ratio comparing with only 15 mm achieved without admixture. At the same percentages, the 28 days compressive strength was recorded as 47 MPa. A higher compressive strength of 52 MPa was reported at 0.45% w/c ratio with a poor workability. At 0.55 w/c ratio, a slump of 145 mm was reported for the mix without admixture, associated with ingredients segregation and a lower compressive strength of 40.6 MPa when the admixture was introduced. Figures 3 and 4 show the relations between w/c ratio and concrete slump and concrete compressive strength for 1.5% type D admixture, respectively.

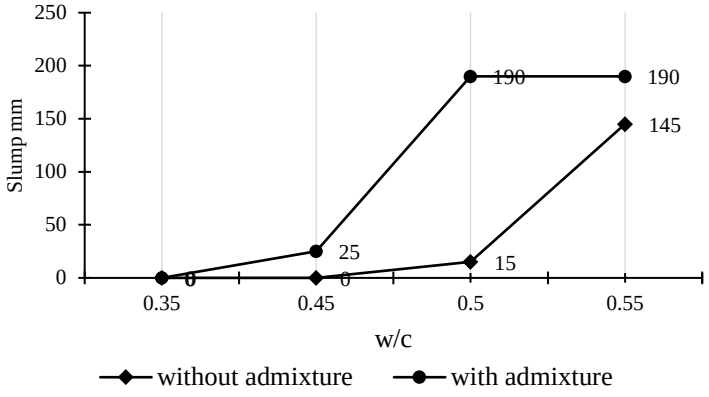


Figure 3. Slump with and without type D admixture

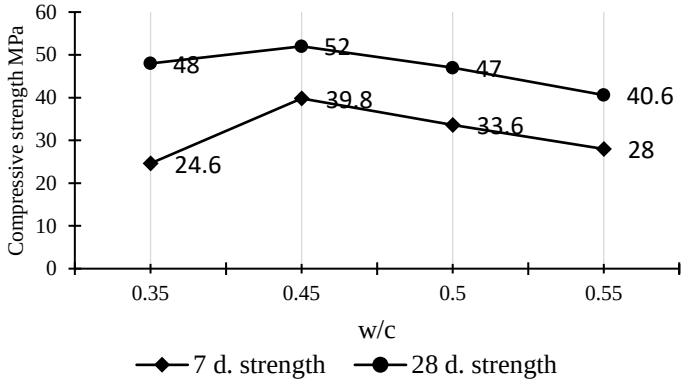


Figure 4. Compressive strength with and without type D admixture

4.3 Type F admixture

Table 4 illustrates the results and observations of the effect of the w/c and type F admixture on the slump and compressive strength of the concrete mixes.

Table 4, Results and observations of using type F chemical admixture with various w/c ratios.

Admixture, % of cement	w/c %	Workability		Slump (mm)		Compressive strength (MPa)	
		Without admixture	With admixture	Without admixture	With admixture	7 days	28 days
1.0	0.3	Very low	Very low	0.0	0.0	53	58.5
	0.35	Very low	Low	0.0	25	50. 6	63.5
	0. 45	Very low	High (with segregation)	0.0	225	39.7	56
	0.5	Very low	High (with segregation)	15	225	31.7	42.7

For type F chemical admixture, as a high range water reducing admixture, results showed that for 1.0% addition, a high workability was reported with a slump of 225 mm at 0.45 w/c ratio, associated with ingredients segregation, comparing with 0.0 mm achieved without admixture. A higher compressive strength of 63.5 MPa was reported at 0.35% w/c ratio with a very low workability.

Figures 5 and 6 show the relations between w/c ratio and concrete slump and concrete compressive strength for 1.5% type F admixture, respectively.

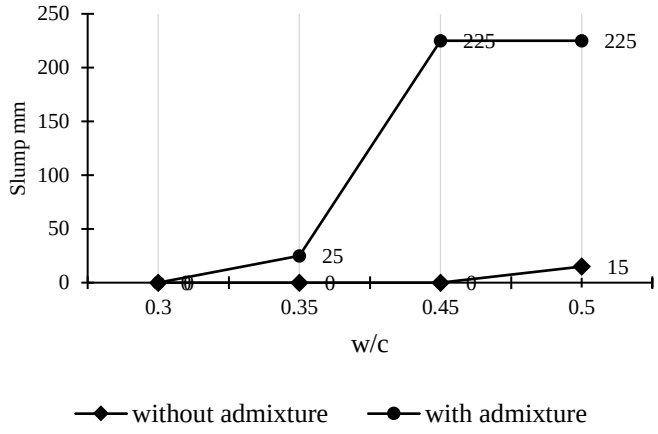


Figure 5. Slump with and without type F admixture

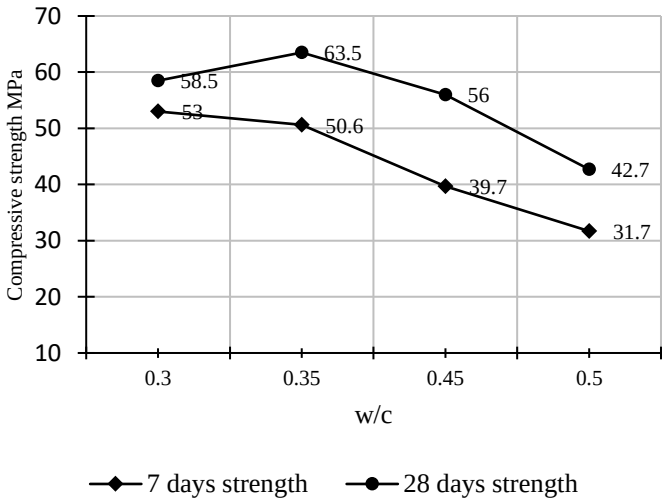


Figure 6. Compressive strength with and without type F

4.4 Effect of time of inclusion of admixture

Different groups of concrete mixes were prepared to investigate the effect of the time of introducing the admixture on the concrete slump and compressive strength.

Table 5 illustrates the results and observations of the effect of the time of inclusion of 1.5% of type A, D and 1.0% of type F chemical admixtures on the slump and compressive strength, respectively. Slump variation with the time of inclusion of the admixture indicates that up to 15 minutes, the admixtures were acting, almost through the same mechanism of dispersing the flocculated cement grains. At the mentioned percentages of type A, D and F admixtures and w/c ratios, the highest compressive strength values were reported at 10 min for type A., at 5 min for type D and at 10 min for type F.

Table 5, Effect of the admixtures inclusion time on the slump and compressive strength.

Type of admixture	Adding time (min.)	w/c	Slump (mm)	7 d. strength	28 d. strength
A	0	0.5	160	28.5	40.4
	5		210	32	45.4
	10		200	34.5	48.5
	15		185	33.5	44.4
D	0	0.49	165	35.4	46.57
	5		200	38.5	55.8
	10		210	38.8	51
	15		220	38.3	48.6
F	0	0.43	220	31.3	39.7
	5		210	39.4	48
	10		210	41.6	50
	15		210	36.6	45.5

5. Conclusions

On the basis of the materials and mixes used, the following conclusions can be drawn from the research presented in this paper:

1. A certain w/c ratio is required for the concrete chemical admixtures to be effective.
2. The efficiency of type A and type D chemical admixtures (plasticizers) starts at about 0.4 w/c ratio.
3. The efficiency of type F chemical admixtures (super-plasticizers) starts at about 0.35 w/c ratio and has no effect on the concrete workability after 0.45 w/c ratio.
4. The time of inclusion of the admixture affects both the workability and the compressive strength.
5. The plasticizing action of water reducers is related to their adsorption and dispersing effects in the cement-water system.
6. For greatest significance and to improve the corresponding performance, the right variety of the concrete chemical admixture should be selected and the dosage and time of inclusion should be determined before.
7. Trial mixtures should be made with the admixture and the materials used for the concrete mix, at temperature and relative humidity anticipated on the job.
8. It is recommended that the dosage of admixture as recommended in the manufacturer's data sheet should be verified through trial mixes.

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