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ESTIMATION OF COMPRESSIVE STRENGHT OF THE CONCRETE CONTAINING SUPERPLASTICIZERS

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ABSTRACT

The aim of this study is investigating of effect of superplasicizer (SP) type and dosage at different levels of compressive strength on the fresh concrete workability and compressive strength development with age. The experimental program included preparation of 18 concrete mixes; these mixes were divided to three groups depending on compressive strength level, in each group, three different types of superplasticizer with two different dosages (0.5 and 1.0%) for each type of SP. The results showed that the type and dosage of SP have pronounced an effect on the development in early age especially. The early compressive strength development of concrete containing PCP and AP types was almost similar and faster than that of NF type. The estimated compressive strength in the early ages by EC2 and ACI 209 equation was lower than the experimental results.

KEYWORDS: Slump loss; Compressive strength; Superplasticizers

تخمين مقاومة الانضغاط للخرسانة الحاوية على ملدنات فائقة

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الخلاصة

ان الهدف من هذه الدراسة هو التحري عن تأثير نوع وجرعة الملدن الفائق على مستوى مختلف من مقاومة الانضغاط على قابلية التشغيل للخرسانة الطرية وتطور مقاومة الانضغاط للخرسانة مع تقدم العمر. وتضمن البرنامج العملي إعداد 18 خلطة خرسانية، قسمت الخلطات لثلاث مجموعات تبعا لمستوى مقاومة الانضغاط. في كل مجموعة، استخدمت ثلاثة أنواع مختلفة من الملدنان الفائقة,مع جرعتين 0.5 و 1.0٪ من وزن الاسمنت لكل نوع من الملدن الفائق. تم اختبار مقاومة الانضغاط في عمر 3، 7، 14، 28، 56، 90، 120 و 180 يوما. وأظهرت النتائج , أن لنوع وجرعة الملدن تأثير واضحا على تطور مقاومة الانضغاط وخصوصا في الاعمار المبكرة. كانت بداية تطور مقاومة الانضغاط للخرسانة التي تحتوي على النوع المتعدد الكربوكسيل ونوع الاكريليك متماثلة تقريبا، وأسرع من نوع النفثالين الفورمالديهايد. و كانت مقاومة الانضغاط المقدرة في سن مبكرة عن طريق معادلات الكود الاوربي EC2 والمدونة الاميريكية, ACI 209 أقل من النتائج العملية.

1. INTRODUCTION

It is well known that, immediately after mixing cement based materials, the hydration process takes place. CSH is the compound resulting from hydration, and it gives concrete its strength. Cement based materials develops strength with continued hydration. The rate of gain of strength is faster at start, and the rate gets reduced with age [Shetty (2010)]. In spite of considering the 28-day compressive strength for design purposes, actually concrete develops strength beyond 28 days as well. Most codes of practice do not consider the increase of strength beyond 28 days for design purposes [ACI 318(2011), EC2 (2004) and BS8110 (1997)].

British code BS8110 (1997) gives modification factors for permissible compressive strength as 1.0, 1.10, 1.16, 1.2, and 1.24 for 1, 2, 3, 6, and 12 months as minimum age of member when full design load is applied whereas, for high strength concrete, British code allowed to add 0, 4.2, 5.5, 7.7, and 10.2 MPa over the permissible strength at 28 days for 1, 2, 3, 6, and 12 months, respectively. It may be necessary to investigate the strength of concrete at long term ages not only at an early age [Shetty (2010)].

Many research workers have attempted to estimate the strength of concrete at any an age (t) correlate to 28-day strength. Numerous research works have provided certain relationships. For instance;

The compressive strength of concrete at an age t depends on the type of cement, temperature, and curing conditions. For a mean temperature of 20°C and curing in accordance with EC2 (2004), the compressive strength of concrete at various ages fcm (t) may be estimated from the following expressions:

$$fcm(t) = \beta_{cc}(t).fcm \quad (1)$$

With

$$\beta_{cc}(t) = e^{s[1-\left(\frac{28}{t}\right)^{0.5}]} \quad (2)$$

Where:

fcm(*t*) = The mean concrete compressive strength at an age of *t* days

fcm = The mean compressive strength at age of 28 days

β*cc*(*t*) = A coefficient which depends on the age of the concrete *t*

t = The age of the concrete in days

s is a coefficient which depends on the type of cement:

= 0.20 for rapid hardening high strength cements (R) (CEM 42,5R, CEM 52, 5)

= 0.25 for normal and rapid hardening cements (N) (CEM 32,5R, CEM 42, 5)

= 0.38 for slow hardening cements (S) (CEM 32, 5)

According ACI 209 (2008), a study of concrete strength versus time indicated an appropriate general equation as in the formula (3) for predicting compressive strength at any time.

$$(fc)_t = \frac{t}{a+b.t}.(fc)_{28} \quad (3)$$

Where *a* in days and *b* are constants, $(fc)_{28}$ is 28-day compressive strength and t in days is the age of concrete. The evaluation of compressive strength with time is a great concern to structural engineers. ACI Committee 209 recommends the following relationship for moist-cured concrete made with normal Portland cement (ASTM Type I):

$$(fc)_t = \frac{t}{4+0.85\,t} \cdot (fc)_{28} \tag{4}$$

And for moist-cured concrete made with normal Portland cement (ASTM Type III):

$$(fc)_t = \frac{t}{2.3+0.92\,t} \cdot (fc)_{28} \tag{5}$$

It is well recognized that the prediction of concrete strength is important in the modernized concrete construction and engineering judgment. This is because it provides the time for concrete form removal, re-shoring to slab, project scheduling, and quality control. Also, it is useful information for designers and engineers including the structural engineer, especially in the application of post-tensioning [Lee (2003)].

The superplasticizers due to the water content decrease, at a given consistency, can enhance both the early and the ultimate strength of concrete. At a given water-cement ratio, the presence of superplasticizers generally has a positive influence on the rates of cement hydration and early strength development. Admixtures characterized with ability to accelerate or decrease cement hydration obviously would have a great influence on the rate of strength gain; however, the ultimate strengths may not be significantly affected. It is noticed that there is a tendency toward a higher ultimate strength of concrete while having the rate of strength gain at early ages retarded [Janković et al.(2011)]. Therefore, relationships should be provided to estimate the compressive strength of concrete mix containing superplasticizers with different types and dosages.

This paper introduces experimental results that can help predicting the compressive strength for a concrete mix containing superplasticizers at any age with different studied parameters. Those parameters included compressive strength value, type of superplasticizer, and dosage of superplasticizer.

2. EXPERIMENTAL PROGRAM

The experimental work in this study includes preparation and test of 18 superplasticizered concrete mixes. The study parameters were the type and dosage of superplasticizer as well as concrete compressive strength. The main characteristics of materials and procedures used for the purpose of this research are as explained below:

2.1. Materials

Ordinary Portland cement with specific gravity of 3.15 and Blaine fineness 3133 cm2/g was used. The physical properties and chemical composition of cement are shown in Table (1). The cement properties comply with the requirements of Iraqi Standard No.5-1984. A local crushed coarse aggregate and natural fine aggregates from Zubair region in Basrah city were used, which meet the requirements of ASTM C33-03. Table (2) presents the grading of coarse and fine aggregates. Both coarse and fine aggregate have a specific gravity of 2.63, water absorption of coarse and fine aggregate was 0.75 and 1.5%, respectively. Three different types of superplasticizer were used in this study, the first type was polycarboxylate polymer (PCP), the second type was acrylic polymer (AP), and the third type was naphthalene formaldehyde (NF) with Cellulose sulfate (for control slump loss). All used superplasticizers complied with the requirements of ASTM C494-04 specification [10]. Table (3) presents the types and properties of the used superplasticizers.

Table 1. Physical properties and chemical composition of cement

Physical properties		**Limits of I.O.S No.45-1984**
Setting time (min)		
Initial	120.0	> 45
Final	245.0	< 600
Compressive strength (MPa)		
7 days	18.90	> 15
28 days	26.40	> 23
Specific surface,blaine,cm^2/g	3133	> 2300
Chemical analysis,%		
Lime (CaO)	61.89	
Silica (SiO_2)	21.23	
Alumina (Al_2O_3)	5.500	
Iron Oxide (Fe_2O_3)	2.990	
Magnesia (MgO)	2.640	< 5
Sulfate (SO_3)	2.010	2.8
Loss on Ignition (LOI)	0.750	< 4
Insoluble residue (I.R.)	0.600	< 1.5
Lime saturation factor (L.S.F)	0.840	0.66-1.02

Table 2. Grading of coarse and fine aggregate

Coarse aggregate			**Fine aggregate**		
Sieve size mm	Passing (%)	ASTM C33-03 limits	Sieve size mm	Passing (%)	ASTM C33-03 limits
25.0	100	100	9.50	100	100
19.0	97	90-100	4.75	97	95-100
9.50	37	20-55	2.36	88	80-100
4.75	2	0-10	1.18	71	50-85
2.36	1	0-5	0.60	45	25-60
			0.30	11	5-30
			0.15	2	0-10

Table 3. Properties of the used superplasticizers

Property	Superplasticizer type		
	PCP	**AP**	**NF**
Chemical base	Polycarboxylic polymers	Acrylic polymers	Naphaline Formaldehyde
Standard complied	ASTM494-type F*	ASTM494-Type G**	ASTM494- Type D***
Liquid colour	Light brownish	Light Yellow	Brown
Relative density	1.10	1.11	1.14
pH value	5.50	7.40	7.60

*type F: Water-reducing, high range admixtures.
**type G: Water-reducing, high range, and retarding admixtures.
***typ D: Water-reducing and retarding admixtures.

2.2. Mix proportions

British Research Establishment Method (1997) has been used to design all mixes. The details of the mixes are shown in Table (4). The compressive strength classes were C25, C35, and C45 to cover wide range of compressive strength. The W/C ratios were 0.54, 0.46, and 0.40 for class C25, C35 and C45 respectively. For each class of compressive strength, three types of superplasticizers were used with two dosages for each type. The superplasticizer dosage was selected to give slump greater than 100 mm flow for all mixes.

2.3. Preparation of specimens and test methods

The slump test was carried out in accordance with BS EN 12350 (2009); this test method was used for the assessment of fresh properties of mixes and activity of the used superplasticizer as shown in Table (5). The slump-loss with time was examined for concrete mix with W/C ratio of 0.46 and with superplasticizer dosage of all SP types of 1.0% of cement weight. Standard 150 mm cubes were used to determine compressive strength at age 3 to 180 days according to BS EN 12390 (2002). The specimens for compressive strength test were cast in molds. All samples were demolded after 24 hours, marked and cured in water until testing age.

3. TEST RESULTS AND DISCUSSION

The results for compressive strength test are given in Table (5). The ratio of compressive strength at any age relative to the compressive strength at the age of 28 days is tabulated in Table (6). Determination or estimation of the strength could by attained by EC2 (2004) and ACI 209 (2008) model capable of predicting strength of concrete at different ages, the discussion of the effect of the studied different parameters on the compressive strength is presented in the following sections:

Table 4. Mix proportions and slump value all mixtures

Mix symbol	Strength class	SP type	SP dosage % of cement weight	W/C	Cement Kg/m^3	Gravel Kg/m^3	Sand Kg/m^3	Water Kg/m^3	Slump mm
1	C25	PC	0.5	0.54	350	1080	785	189	115
2			1.0		330	1115	775	178	121
3		AP	0.5		350	1080	785	189	110
4			1.0		330	1115	775	178	115
5		NF	0.5		350	1080	785	189	100
6			1.0		330	1115	775	178	104
7	C35	PC	0.5	0.46	400	1090	725	184	117
8			1.0		380	1100	740	175	125
9		AP	0.5		400	1090	725	184	114
10			1.0		380	1100	740	175	117
11		NF	0.5		400	1090	725	184	110
12			1.0		380	1100	740	175	114
13	C45	PC	0.5	0.40	455	1075	690	182	143
14			1.0		430	1100	700	172	150
15		AP	0.5		455	1075	690	182	140
16			1.0		430	1100	700	172	145
17		NF	0.5		455	1075	690	182	120
18			1.0		430	1100	700	172	130

Table 5. The compressive strength value (MPa) of all mixes

Strength class	**C25**						**C35**						**C45**					
SP type	PCP		AP		NF		PCP		AP		NF		PCP		AP		NF	
SP dosage %	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0
Age (days)																		
3	15.5	16.5	15.0	15.7	13.6	12.0	22.5	22.5	20.7	21.2	20.2	18.1	30.5	30.7	28.8	28.2	25.9	23.1
7	19.0	20.5	18.3	19.3	17.6	17.1	27.2	28.0	25.0	26.3	25.4	25.0	36.2	37.3	34.5	35.5	31.3	31.5
14	21.5	22.7	21.0	22.2	19.3	19.1	31.1	31.2	28.7	30.3	28.1	28.5	42.0	42.3	40.0	40.3	35.0	36.8
28	25.3	26.0	24.8	25.7	24.8	23.9	36.0	35.4	33.7	34.7	35.4	34.7	47.6	46.8	46.3	45.7	43.2	43.1
56	26.6	27.3	26.2	27.3	27.0	26.1	37.8	37.2	35.6	36.8	38.6	37.8	50.0	49.1	48.8	48.5	47.2	47.1
90	27.7	28.2	27.5	28.3	27.6	26.7	39.6	38.4	37.1	37.9	39.2	38.2	51.6	50.4	51.0	50.2	47.6	47.9
120	28.1	28.6	27.7	28.6	27.8	27.0	39.9	39.1	37.4	38.4	39.4	38.7	52.4	51.5	51.3	50.5	47.8	47.9
180	28.2	28.9	27.8	28.7	28.0	27.1	40.1	39.3	37.6	38.7	39.5	38.8	52.8	51.8	51.5	50.9	48.1	48.1

Table 6. The compressive strength at any time to 28-day compressive strength ratio of all mixes

Strength class	**C25**						**C35**						**C45**					
SP type	**PCP**		**AP**		**NF**		**PCP**		**AP**		**NF**		**PCP**		**AP**		**NF**	
SP dosage %	0.500	1.000	0.500	1.000	0.500	1.000	0.500	1.000	0.500	1.000	0.500	1.000	0.500	1.000	0.500	1.000	0.500	1.000
Age (days)																		
3	0.613	0.633	0.605	0.610	0.550	0.500	0.625	0.636	0.615	0.611	0.570	0.521	0.641	0.655	0.621	0.618	0.60	0.535
7	0.752	0.787	0.738	0.752	0.710	0.714	0.755	0.790	0.741	0.759	0.718	0.720	0.760	0.797	0.745	0.777	0.725	0.731
14	0.850	0.872	0.847	0.864	0.780	0.800	0.865	0.881	0.851	0.873	0.795	0.821	0.883	0.904	0.864	0.882	0.811	0.854
28	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
56	1.051	1.050	1.055	1.061	1.087	1.090	1.051	1.050	1.055	1.061	1.089	1.089	1.051	1.050	1.055	1.061	1.092	1.093
90	1.095	1.086	1.108	1.100	1.113	1.116	1.100	1.085	1.102	1.093	1.107	1.100	1.085	1.077	1.101	1.099	1.101	1.111
120	1.110	1.100	1.117	1.111	1.121	1.128	1.107	1.105	1.110	1.108	1.112	1.115	1.101	1.100	1.107	1.104	1.106	1.112
180	1.115	1.112	1.121	1.118	1.130	1.134	1.113	1.110	1.117	1.115	1.115	1.119	1.109	1.107	1.112	1.114	1.114	1.116

3.1. Workability

The PCP based superplasticizer, as shown in Table (4), was more effective than that based on AP and NF superplasticizer for the water reducing capability, but the types AP and NF showed more efficiency for the maintenance of the initial slump level than PCP type as illustrated in Fig. 1. This means that the retarding effect of the AP and NF types of superplasticizers was beneficial to reduce slump loss with respect to the concrete containing the less retarding PCP superplasticizer.

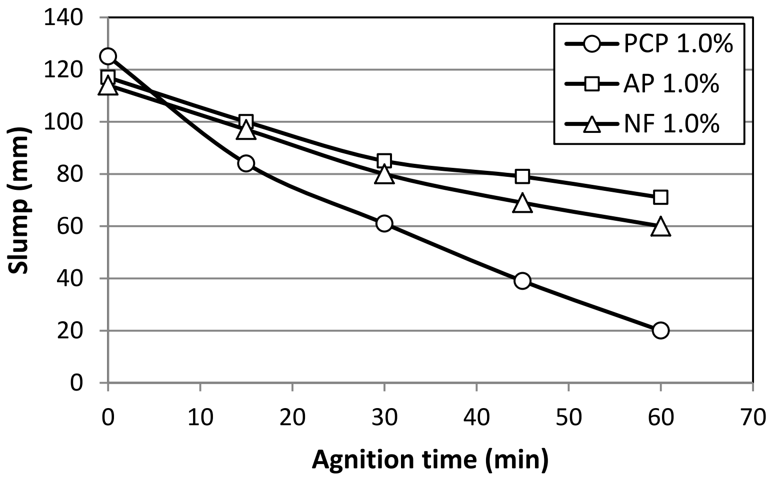

Fig. 1. Slump-loss of superplasticizered concrete with W/C ratio of 0.46 and superplasticizer dosage of 1.0% of cement weight.

3.2. Compressive strength development

Table (4) presents compressive strength of all mixtures in the ages 3, 7, 14, 28, 56, 90, 120, and 180 days. Table (5) shows the ratio of compressive strength at any age relative to the compressive strength at the age of 28 days. The effect of type and dose of the superplasticizer and values of compressive strength on the development of compressive strength with time are discussed in the following sections.

3.2.1. Effect of superplasticizer type

Fig. 2 shows the effect of the type of superplasticizer at different doses and different strength on fc(t)/fc(28) ratio. Generally, the PCP type gave fc(t)/fc(28) ratio slightly more than of the AP type and is relatively larger than the NF type until the age of 28 days. This fc(t)/fc(28) ratio difference between these types decreases as age increases up to the age of 28 days. That means that the effect of the type of superplasticizer has the effect of compressive strength values in the early ages more than the latter. Where the Type NF shows delays in access compressive strength in the age of 3 days clearly; this is attributed to that, the NF type contained Cellulose sulfate (for control slump loss) which retarded the development of hydration process. The PCP type was cement accelerator interact with water because the polymeric composition of the superplasticizer which not contain material encapsulates the cement particles and reduce their interaction with water. The AP type is one of the polymers of acrylic acid. It was found that this polymer has an effect on the delay time of setting, but has no effect on reducing the development of compressive strength in the early ages clearly [Gupta and Gupta (2012)].

After the age of 28 days, it is observed that the effect of the different types of plasticized decays until the age of 180 days and especially between type I and II. For the NF type, it is worth noting that, especially at the age of 56 days it showed a development in a higher strength than the PCP and AP types as illustrated in Fig. 2.

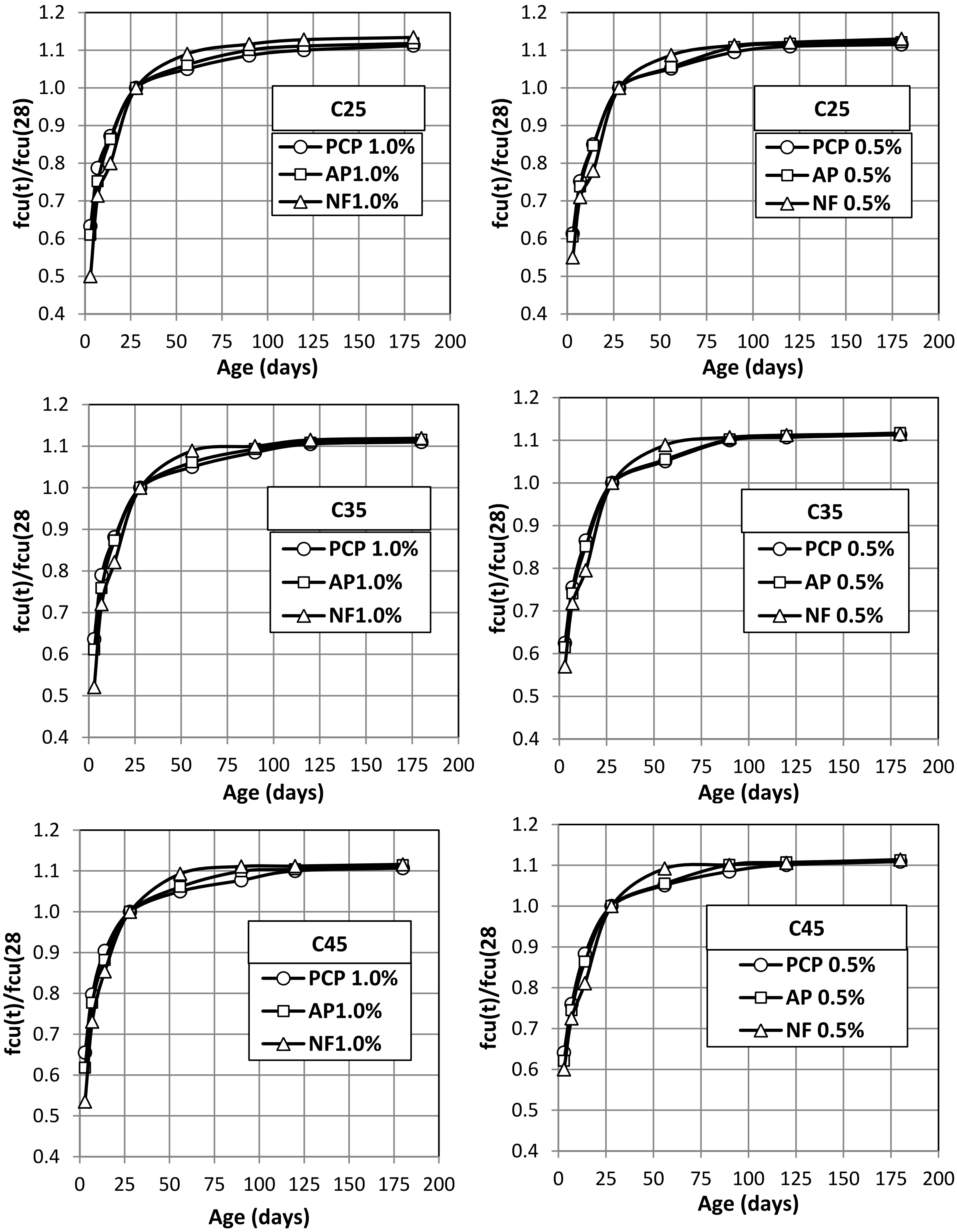

Fig. 2. Effect of SP type with different dosages on fcu(t)/fcu(28) ratio at different compressive strengths.

3.2.2. Effect of compressive strength value

From Fig. 4 it can be noted that, with constancy of type and dosage of superplasticizer, and with increasing the compressive strength from 25 to 45 MPa, there is no a clear effect on fcu(t)/fcu(28) ratio.

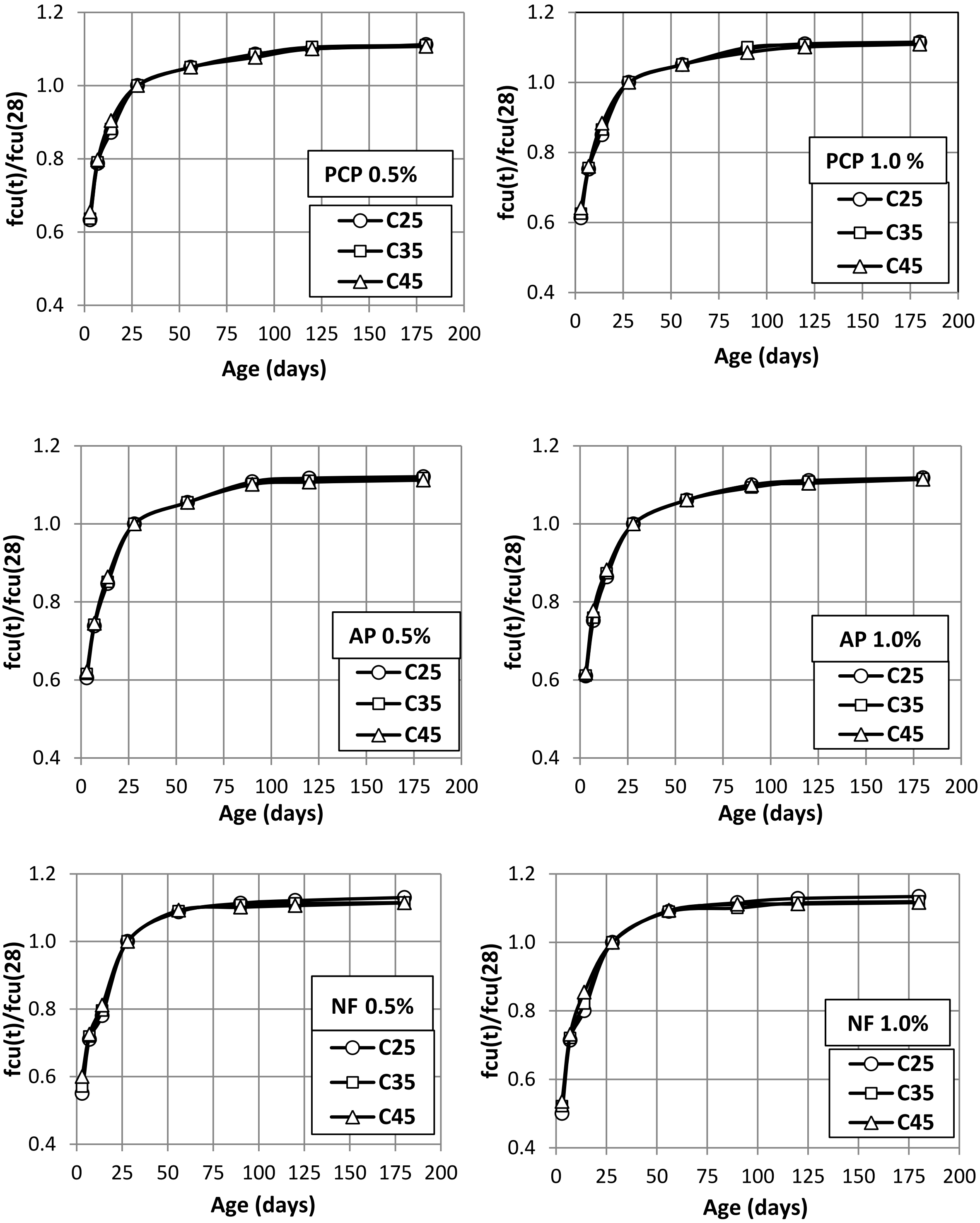

Fig. 3. Effect of SP type with different dosages on fcu(t)/fcu(28) ratio at different compressive strengths.

3.2.3. Effect of superplasticizer dosage

From the results presented in Table (5) and from Fig. 3, it can be observed that, at the same compression strength and for the same type of superplasticizer in the early ages, especially until the age of 28 days, in case of PCP and AP types, fcu(t)/fcu(28) ratio increases slightly with increasing superplasticizer dose. For the NF type, the situation was the opposite, where with increasing superplasticizer dose the fcu(t)/fcu(28) ratio decreases. This is due to that the NF type has a retarder materials for the interaction of cement with water; the greater the proportion of these materials is increasing, delaying interaction where these materials encapsulate cement granules and make slow reaction either. In the case of type PCP and AP, the increased dosage leads to decreasing the amount of water in the mixture clearly as it can be seen in Table (4), increasing convergence cement particles together which increases the speed of access to the early strength.

As for the ages after the age of 28 days, there is no influence of the plasticizer dose on fcu(t)/fcu(28) ratio for all types of superplasticizers used in this study as it is evident in Fig. 3. From These results, it can be concluded that, the effect of superplasticizer only in the early ages does not continue.

3.2.4. Estimated fcu(t)/fcu(28) ratio from EC2andACI 209 formulations

Eqs. (1) and (3) are mathematical formulations designed to approximately describe the compressive strength of the Portland cement concrete over a certain restricted range of variables involved. This equation provides a clear indication of the range of compressive strength obtainable by simply varying the type of cement. However, the formulation variables such as water to cement ratio and admixture types employed and the environmental variables such temperature and relative humidity as well as cure conditions will generally result in a change standard deviation.

Table (7) shows the estimated fc(t)/fc(28) ratio at different ages by using Eqs. (1) and (3) . It is observed that, at age of 3 days, for PCP and AP types, this ratio was greater than that estimated by EC2 and ACI 209 unlike NF type which was greater than that of ACI 209 and smaller than that of EC2. At age of 7 days, all types showed fc(t)/fc(28) ratio greater than ACI 209 equation, but only AP type exhibited fc(t)/fc(28) ratio more than estimated from EC2 equation. At age of 14 days, overall, all types gave fc(t)/fc(28) ratio smaller than that of EC2 and ACI 209 except PC type was equal to ACI 209 at this time. At age of 56 days, fc(t)/fc(28) ratio of NF type was greater than the estimated ratio of EC2 and ACI 209 Conversely in the other two types. From 90 to 180 days age, fc(t)/fc(28) ratio estimated by EC2 and ACI 209 was more than of experimental results of all types of used superplasticizers.

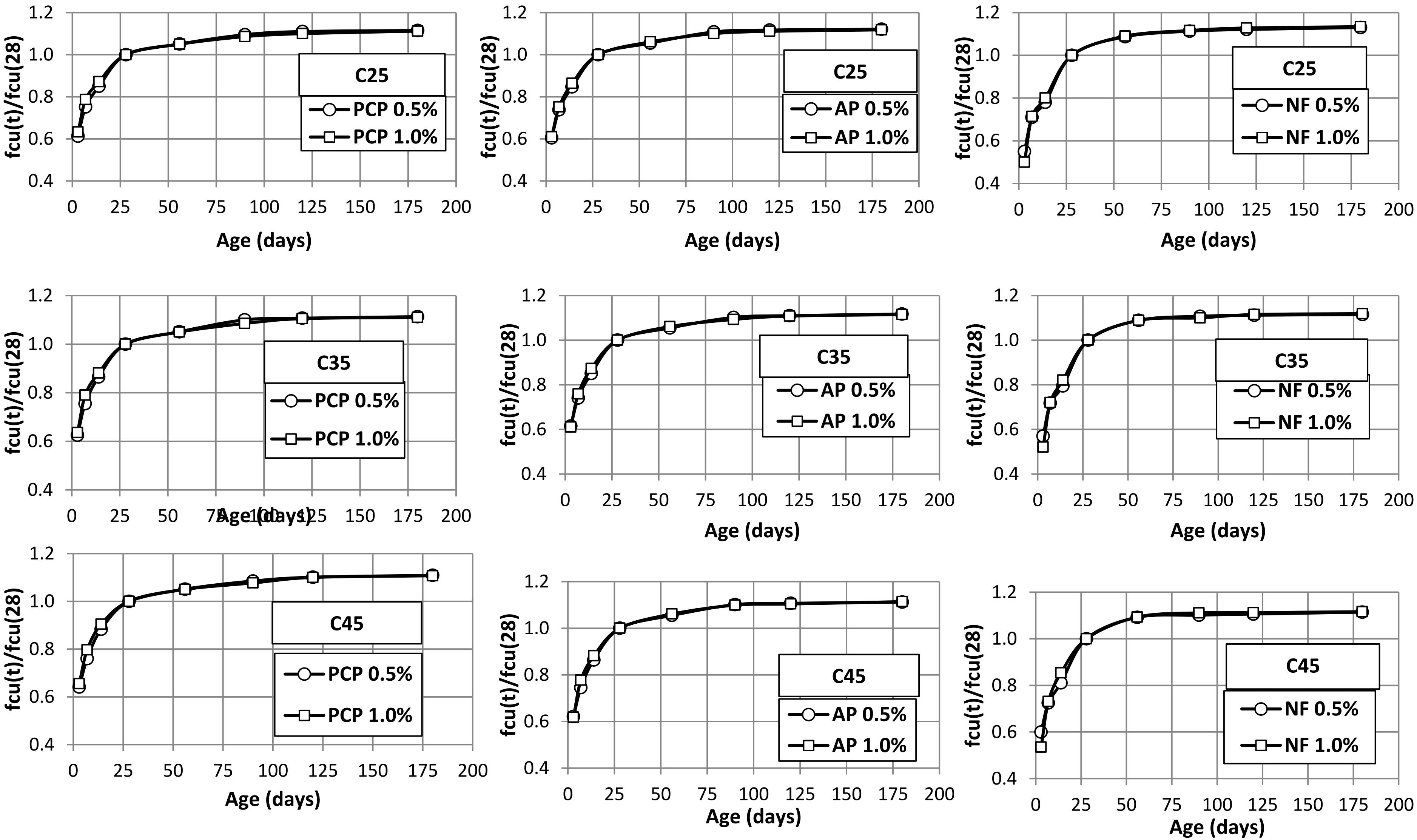

Fig. 4. Effect of dosage of different types of SP on fcu(t)/fcu(28) ratio at different compressive strengths.

Table 7. fcu(t)/fcu(28) ratios estimated from EC2 and ACI 209 formulations

Age (days)	3.000	7.000	14.00	28	56.00	90.00	120.0	180.0
EC2	0.598	0.779	0.902	1.0	1.076	1.118	1.138	1.163
ACI 209	0.458	0.704	0.881	1.0	1.085	1.119	1.132	1.146

4. CONCLUSIONS

In this study, the following conclusions can be drawn:

1. The results indicate that, the type and dosage of superplasticizer affect the workability and strength development at the early ages evidently.

2. For the same dosage and type of superplasticizer, there is a little effect for compressive strength value on the compressive strength development.

3. The concrete with superplasicizer PCP type gives better workability and strength than AP and NF types without any retarding.

4. The concrete contained AP superplasicizer exhibites workability and strength development near than that of contained PCP type with excellent slump retention (retarding).

5. With the same super plasticizer dosage, The NF gives lower slump and lower early strength compared to the other two superplasticizer types. The slump retension of the concrete contained NF superplasticizer is similar to that of AP type.

6. At the early ages, the actual compressive strengths of concrete containing PCP and AP super plasticizers is higher than those estimated by EC and ACI 209 equations.

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