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Compatibility of superplasticizers with cements different in composition

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Abstract

The contribution of ASTM C 494 Type F superplasticizing admixture, commonly used in the construction market, to the compressive strength of concrete in relation to cement composition was investigated. To accomplish this, three types of cements as blended cement (KC 32.5), pozzolanic cement (TC 32.5), and Portland cement (PC 42.5) were used in preparing concrete mixes with different cement contents of 300, 350, and 400 kg/m^3. To achieve equal workability, a slump ranging from 5–9 cm was targeted for all mixes. Admixture was added to mixing water as 1%, 2%, and 3% by weight of the cement content. Control concrete specimens without admixture were also cast for comparisons. Evaluation was based on the ratios of compressive strengths of concrete containing admixture to the compressive strength of control specimens obtained at the end of 1, 3, 7, and 28 days of curing. Based on the findings obtained from the study, the optimal cement contents were found to be 400 kg/m^3 for KC 32.5, 350 kg/m^3 for TC 32.5, and 300 kg/m^3 for PC 42.5, respectively. The maximum strength gain in concrete was achieved with a 3% admixture addition regardless of cement type. Admixture addition to the concrete mix of more than 3% did not seem to be significant to the strength gain using KC 32.5. The strength gain in concrete using TC 32.5 and PC 42.5 cements especially in early age showed a linear type relationship with the addition of superplasticizer.

Keywords: High-range water reducers; Cement; Workability; Compressive strength

1. Introduction

Chemical admixtures have become one of the essential components of concrete in concrete technology in recent years. Various chemical admixtures different in composition have been offered to the users today in response to the needs of the construction market. The most commonly used for this purpose are those of plasticizers and superplasticizers which have the ability of increasing the workability of concrete considerably.

Currently available superplasticizing admixtures are micromolecular organic agents which often can be divided into four groups according to their chemical contents as sulphonate melamine formaldehyde, sulphonate naphthalene formaldehyde, modified lignosulphonates, and copolymers contain sulphonic and carboxyl groups [1]. These admixtures do not entrain a significant amount of air as they do not markedly lower the surface tension of the pore water of concrete with respect to conventional plasticizers and they can therefore be used rather in higher proportions [2].

Superplasticizing admixtures have affected the fresh concrete in a positive manner by altering its rheology [3]. These polymeric character admixtures can interact with cement particles physically and chemically. Physical interaction emerges from the adsorption of admixture molecules on the cement particle surfaces, together with the stearic effect existing between adsorbed polymeric molecules and the neighbouring deflocculated and dispersed cement particles [4,5]. Admixture adsorbed by the cement particles as a thin layer brings about repulsion forces between cement particles due to its negative electrical charge so that flocculation is prevented as well as cement particles are dispersed homogeneously in the fresh concrete. Internal friction existing between cement particles is decreased due to stearic effect and the resulting workability is improved considerably. Superplasticizers, on the other hand, can also react with hydration products of the cement. It is reported that some of them can lower the initial hydration rate by reacting

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with C_3A preferentially, while others delay the hydration reaction of C_3S component [6].

Superplasticizing admixtures improve concrete properties in early age and they do not have adverse effects later as well, particularly when they are used in high quality concrete. It is pointed out that homogenous distribution of cement particles in concrete would be one of the factors; the other one that contributes to concrete properties could be the increased wetting effect of pore water due to its lowered surface tension [2].

The influence of superplasticizers on concrete properties is directly related to the amount of admixture added to the concrete mix. It has been stated that freeze–thaw durability of concrete, which is one of the profound properties of concrete could improve in case smaller amounts of superplasticizing admixture are used [7]. In another work [8], it has been pointed out that bond strength between reinforcement and concrete is found to be independent of the amount of admixture used.

Superplasticizers, at a given water to cement (W/C) ratio, can increase the workability of concrete considerably, though they, with the exception of very high slumps, have a lowering effect on bleeding [1]. In addition, it is also stated in another work that their effect on shrinkage and creep shows variations depending on the prevailing environmental conditions [9,10]. On the other hand, it is accentuated that the effect of superplasticizer on concrete properties may not be superior so long as soluble alkali content is not sufficient in the pore water of concrete [11].

Concerning all the cases given above, it is considered that a study pointing out the optimal ratios of superplasticizers associated with cement type and the contribution of the compatibility associated with superplasticizer and cement, particularly to compressive strength of concrete, is essential, as well as useful in relation to practical and scientific aspects.

2. Experimental work

2.1. Objective and scope

The variation of the contribution of ASTM C 494 Type F superplasticizer, commonly used in the construction market, to the compressive strength of concrete in relation to cement composition was investigated in the study. To accomplish this, three types of cements in three different contents were used in preparing concrete mixes. Admixture is added to the mixing water by weight of the cement content and concrete specimens cast were tested at the end of different curing periods to determine the compressive strengths. Control concrete specimens without admixture were also cast for comparisons.

2.2. Materials, program layout, and experimental conditions

Three types of cements, provided by different cement plants, as blended cement (KC 32.5), pozzolanic cement (TC 32.5), and Portland cement (PC 42.5) were used in the program. Cements used with their physical properties and oxide analysis are detailed in Table 1. Aggregate used in the program is crushed with a maximum size of 16 mm. The specific gravity of the superplasticizer used is 1.2 kg/l.

Three different cement contents of 300, 350, and 400 kg/m^3 were determined and admixture was used in three different proportions by weight of each cement as 1%, 2%, and 3%. Control specimens without admixture were prepared for each cement content so as to be able to observe the contribution of the superplasticizer to the compressive strength of concrete. For each cement in this condition, 12 concrete mixes were prepared and thus, a total of 36 mixes were performed. Each mix yielded 12 concrete cube specimens of 15 cm. For equal consistency, a slump ranging from 5 to 9 cm was targeted by adjusting the mixing water.

Table 1
Physical properties and chemical analysis of cements

Cement type (Turkish/EN 197-1)		KC 32.5 (CEM II)	TC 32.5 (CEM IV)	PC 42.5 (CEM I)
Chemical composition (%)	Silica (SiO_2)	31.60	28.42	20.37
	Alumina (Al_2O_3)	4.89	6.46	5.45
	Ferric oxide (Fe_2O_3)	3.48	4.37	3.18
	Lime (CaO), total	51.54	50.98	63.62
	Magnesia (MgO)	1.31	1.53	2.30
	Sulphur trioxide (SO_3)	2.40	2.64	2.24
	Insoluble residue	14.26	16.85	0.86
	Loss on ignition	3.43	3.05	0.60
	Lime (CaO), free	1.28	0.61	0.44
Physical properties	Specific gravity, g/cm^3	3.03	2.87	3.03
	Fineness			
	200 μm (retained), %	0.10	0.28	0.00
	90 μm (retained), %	3.10	8.97	0.30
	Specific surface (Blaine), cm^2/g	3410	3613	3185
Mechanical tests	2-day, MPa	15.4	11.6	26.2
	7-day, MPa	26.6	24.2	39.5
	28-day, MPa	36.5	34.1	47.80

Table 2
Program layout and mix proportions

Cement type	Mix no.	Cement content (kg/m^3)	Admixture ratio (%)	W/C	Slump (cm)	Unit weight (kg/m^3)
KC 32.5 (CEM II)	1	300	0	0.78	7.0	2321
	2		1	0.73	6.5	2302
	3		2	0.69	8.5	2302
	4		3	0.65	8.5	2312
	5	350	0	0.75	8.5	2258
	6		1	0.66	7.5	2296
	7		2	0.59	8.5	2305
	8		3	0.54	9.0	2298
	9	400	0	0.65	8.5	2268
	10		1	0.59	8.0	2277
	11		2	0.54	8.0	2291
	12		3	0.51	7.5	2307
TC 32.5 (CEM IV)	13	300	0	0.79	6.5	2250
	14		1	0.75	5.0	2286
	15		2	0.69	6.5	2295
	16		3	0.64	5.0	2318
	17	350	0	0.77	7.0	2257
	18		1	0.64	8.5	2271
	19		2	0.58	6.5	2302
	20		3	0.55	5.5	2301
	21	400	0	0.62	7.5	2265
	22		1	0.56	7.5	2282
	23		2	0.51	6.5	2303
	24		3	0.48	7.0	2310
PC 42.5 (CEM I)	25	300	0	0.75	7.5	2280
	26		1	0.68	7.5	2298
	27		2	0.62	9.0	2308
	28		3	0.58	9.0	2318
	29	350	0	0.63	7.5	2307
	30		1	0.54	9.0	2315
	31		2	0.50	8.0	2328
	32		3	0.47	9.0	2344
	33	400	0	0.57	8.0	2280
	34		1	0.51	7.5	2312
	35		2	0.47	9.0	2336
	36		3	0.42	8.0	2348

Following the end of the first day of production, the specimens were demolded and stored in water with a temperature of 20±1°C until the testing age. Three specimens of each mix at the end of 1 day, three of them at the end of 3 days, three of them at the end of 7 days, and the rest at the end of 28 days of curing were tested. The program layout is given in Table 2.

3. Results and discussion

The results obtained from the study are graphically illustrated in Figs. 1–3. Fig. 1 represents the variation of the proportions of the compressive strengths with admixture to those without admixture with regard to admixture addition for blended cement; Fig. 2 stands for pozzolanic cement; and Fig. 3 stands for Portland cement, respectively.

As can be seen from Fig. 1, regardless of the testing age, the highest compressive strength gain was achieved with a cement content of 400 kg/m^3. This strength gain achieved with a 3% admixture addition is levelled at about 100% at the end of 1 and 28 days of curing, and is 125% at the end of 3 and 7 days of curing. Strength gains at all testing ages indicate almost the same propensity for all cement contents. They all increase in a slow manner, and decrease as proceeding with regard to the admixture addition. It can be seen that the increase would get slower further for admixture additions over 3%. In this regard, it can be said that admixture addition over 3% can be beneficial to the strength gain. Moreover, a 2% admixture addition may be preferred to 3% in terms of economical aspects due to negligible differences occurring between strength gains. Considering strength gains in concrete obtained using 3% admixture based on the cement content, the difference, which existed at the end of 1 day of curing is not discernable. However, it is getting quite significant at the end of 3, 7, and 28 days of curing particularly for a cement content of 300 kg/m^3.

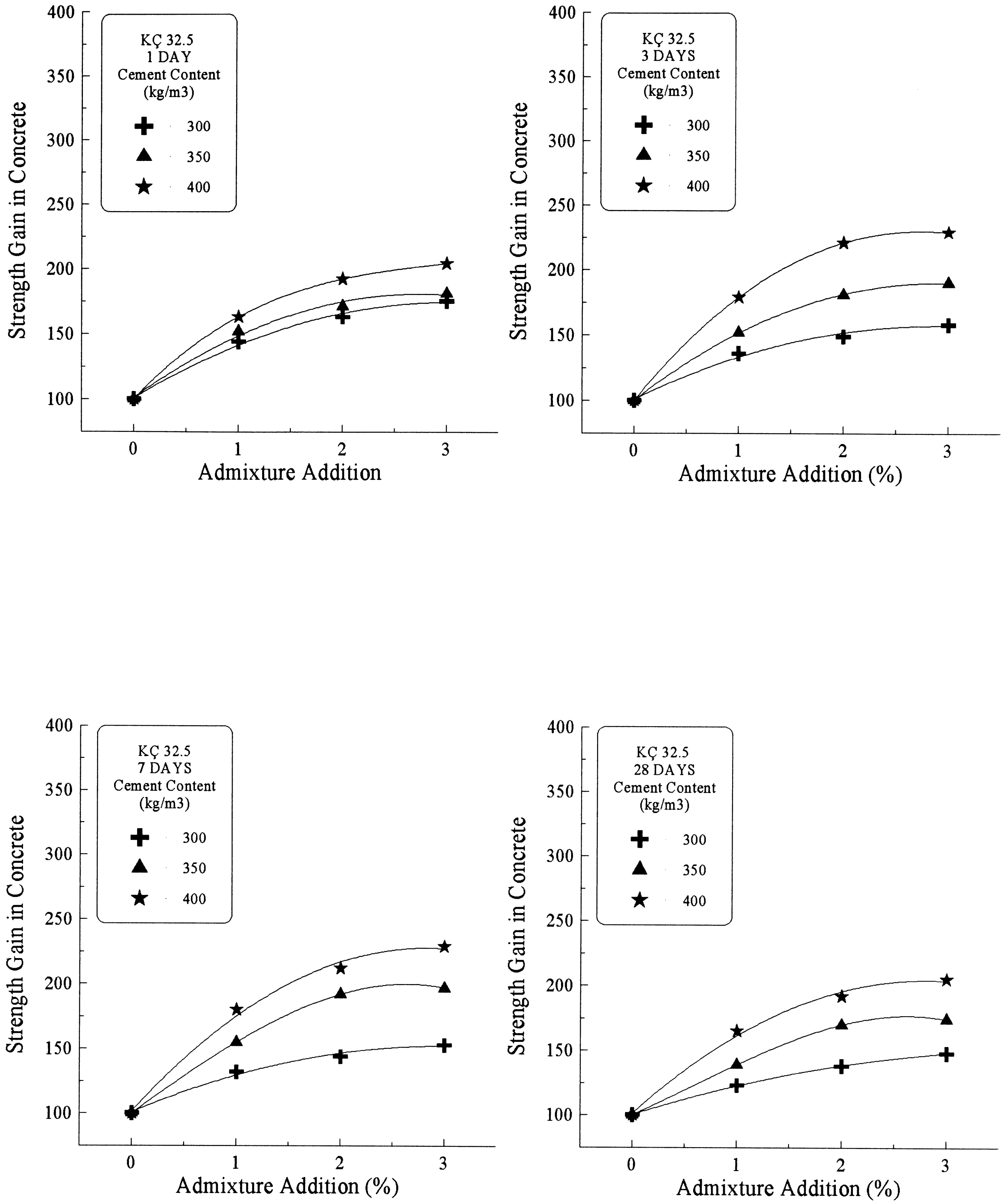

Fig. 1. Strength gain in concrete using KC 32.5 cement in relation to admixture addition.

When Fig. 2 is closely examined, it can be seen that the highest strength gain is achieved for a cement content of 350 kg/m^3 for all testing ages. Strength gain achieved for 3% admixture addition reached 200% at the end of l, 3, and 7 days of curing while it is levelled at about 125% at the end of 28 days of curing. Admixture addition higher than 3% would obviously contribute to the strength gain significantly.

Regardless of the testing age and admixture addition, Fig. 3 indicates that the highest strength gain is achieved for a cement content of 300 kg/m^3. Strength gains for 3% admixture addition reached 250% at the end of 1 day of curing, 175% at the end of 3 days of curing, 125% at the end of 7 days of curing, and 100% at the end of 28 days of curing, respectively. Strength gains observed, regardless of the cement content and the testing age, indicate a propensity that they would increase in case of an admixture addition higher than 3%. When an evaluation based on the cement content is performed for 3% admixture addition, it can

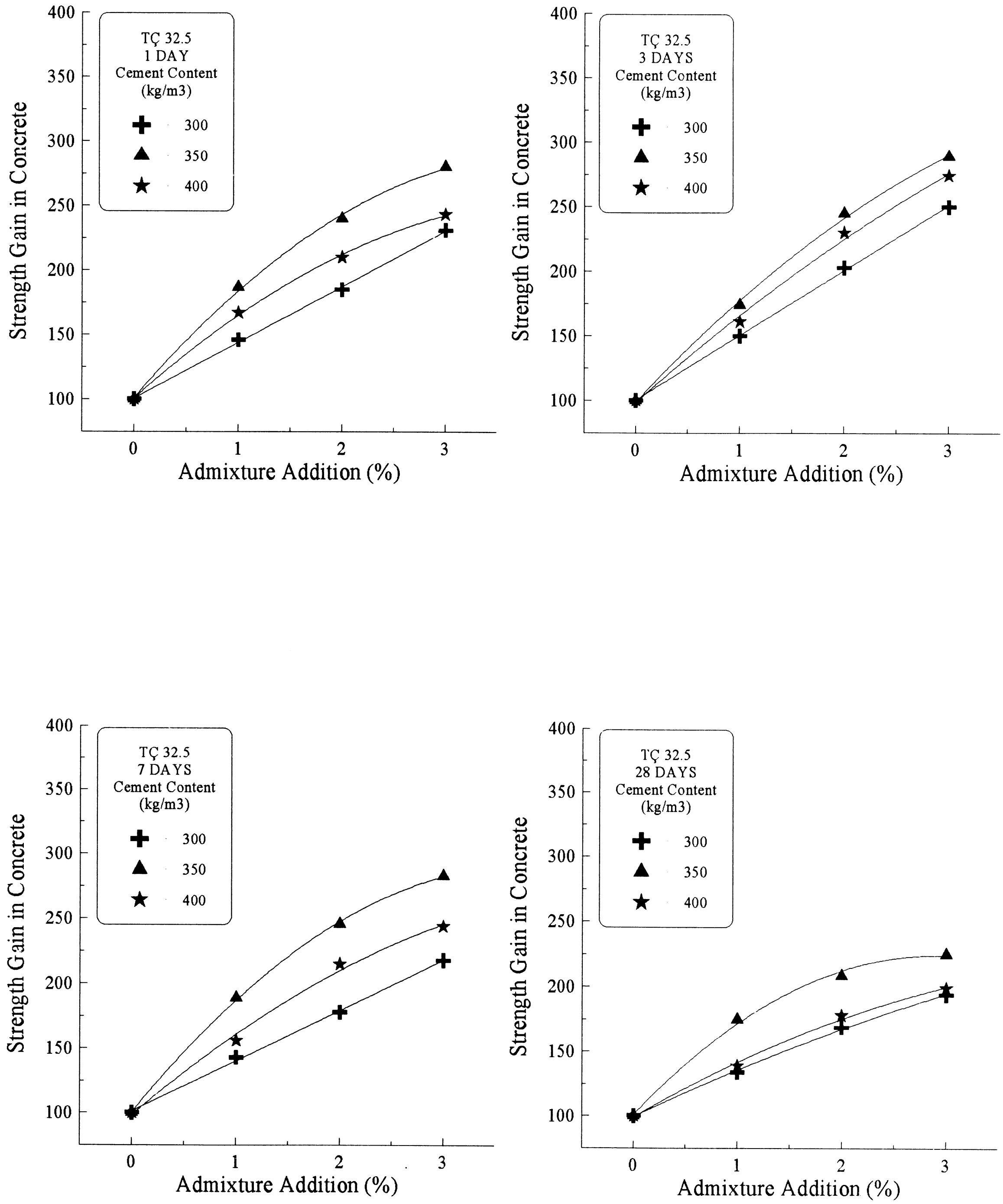

Fig. 2. Strength gain in concrete using TC 32.5 cement in relation to admixture addition.

easily be seen that the difference which existed between strength gains is not quite noticeable, moreover, it has been losing its significance particularly at the end of 3 and 7 days of curing.

Two main points can be extracted from the graphs depicted above. The first one is that the effect of superplasticizer has been varying with the kind of cement used and similarly, regardless of the admixture addition and the testing age, the amount of cement that provides the highest strength gain has been changing depending on cement type as well. In other words, the chief factor that controls the behaviour of the superplasticizer is the composition of cement rather than the amount of cement used. This is because the positive effect of superplasticizers can only take place if they improve concrete properties by reacting with the hydration products of cement. This can occur by the deflocculation and dispersion effects of superplasticizer on the cement particles, on the one hand, and by effecting the

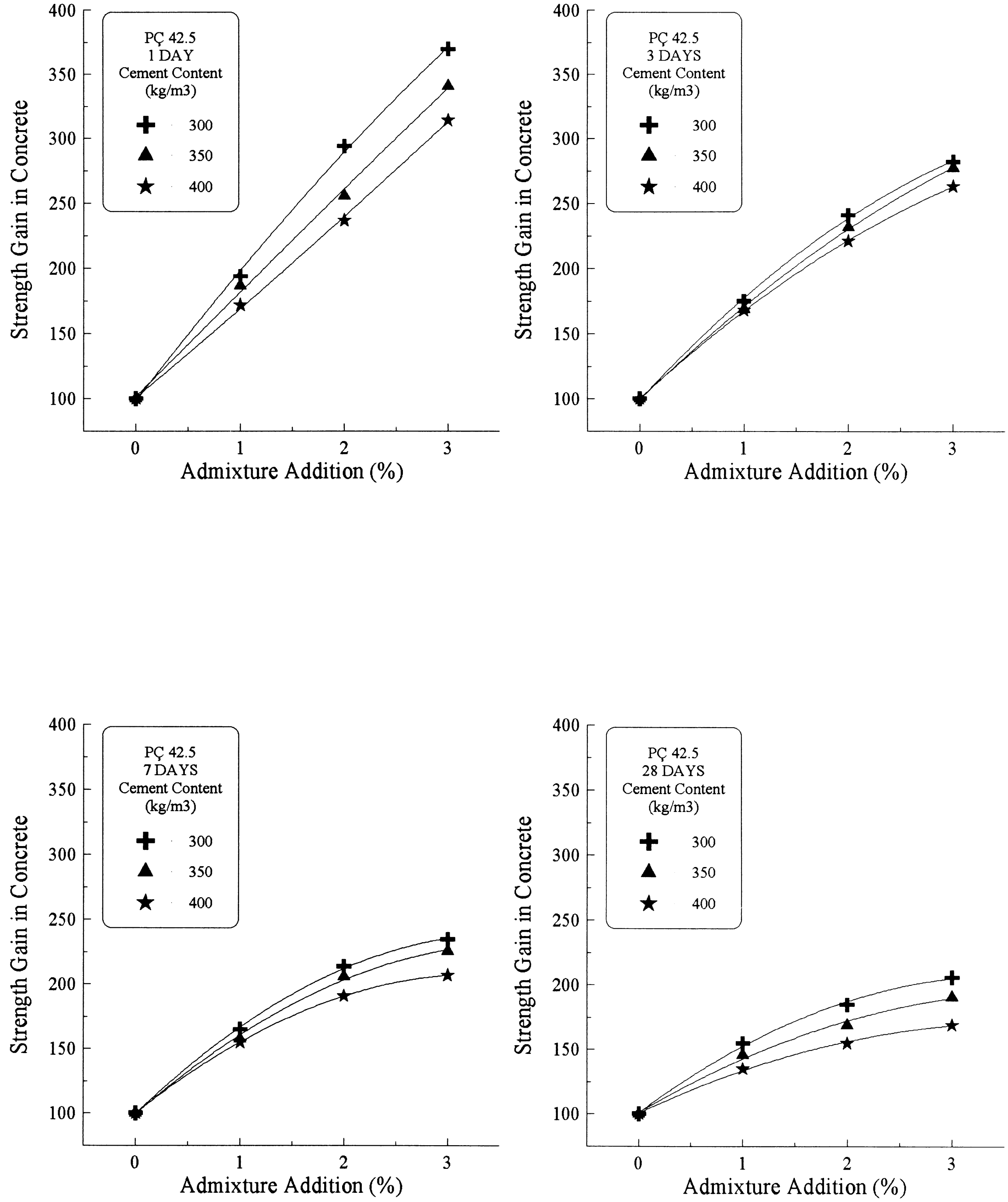

Fig. 3. Strength gain in concrete using PC 42.5 cement in relation to admixture addition.

reaction rates of C_3A and C_3S components on the other hand [6]. This is why the effect of superplasticizing admixture is basically varying depending on the cement type. The difference in strength gains in concrete obtained using KC 32.5 and TC 32.5 cements could be attributed to their fineness rather than their types, as they are quite similar in composition. The standard compressive strengths are higher for pozzolanic cement (TC 32.5) with a content of 400 kg/m^3 owing to its higher Blaine fineness. This obviously resulted in lower strength gains with respect to those obtained using blended cement with the same amount of cement content.

Strength development of Portland cement is considerably rapid with regard to those of blended and pozzolanic ones and the standard compressive strengths are quite high particularly when higher amounts of cement are used. The strength gain for a cement content of 400 kg/m^3 is therefore lower. As a result, the strength gain in concrete using

PC 42.5 cement is the highest with a cement content of 300 kg/m^3.

4. Conclusions

The findings obtained from the study on the compatibility of a superplasticizing admixture with cements different in composition are briefly outlined below.

(i) Cement content providing the highest strength gain in concrete changes with the kind of cement used. This indicates that the effect of a superplasticizing admixture depends on the composition of cement rather than the amount used.

(ii) The highest compressive strength gain obtained using KC 32.5 cement is achieved with a cement content of 400 kg/m^3 regardless of the admixture addition and the testing age. The gain for 3% admixture addition reached 125% at the end of 3 and 7 days of curing.

(iii) Regardless of the admixture addition, the highest strength gain for TC 32.5 cement is achieved for a cement content of 350 kg/m^3 for all testing ages. The strength gain obtained using 3% admixture reached 200% at the end of 1, 3, and 7 days of curing.

(iv) Regardless of the admixture addition and testing age, the highest strength gain in concrete using PC 42.5 cement is achieved with a cement content of 300 kg/m^3. Strength gain for 3% admixture addition reached 250% at the end of 1 day of curing.

(v) Considering the strength gains, admixture addition higher than 3% does not seem to be beneficial to KC 32.5 cement. It is obvious that higher admixture additions would result in higher strength gains for TC 32.5 and PC 42.5 cements particularly in early age.

(vi) When an evaluation concerning the early strength gains (1- and 3-day) is performed, it can be concluded that superplasticizing has proved to be quite compatible with PC 42.5 cement. Considering the 28-day strength gains, it can be seen that the strength gain reached is about the same for all cements investigated.

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