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EXPERIMENTAL STUDY OF THE EFFECT OF POLYCARBOXYLATE SUPERPLASTICIZER ON CONCRETE STRENGTH PROPERTIES

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ABSTRACT: Nowadays, concrete is used more often than before due to its strength, durability and other desirable properties. Plasticizers and super-plasticizers are used to increase performance by decreasing the amount of water in concrete. In the present study, the effect of polycarboxylate superplasticizer (PCEs) on the properties of concrete was investigated. The specimens were made with a constant mix design and the desired superplasticizer was added to it with 0.3, 0.5 and 0.7% of the cement weight. Compressive and flexural strength due to flexural of concrete specimens were measured at the ages of 7, 14, 28, and 90 days. The results showed that, increasing the amount of PCEs to a certain degree, increases the flexural and compressive strength of the specimens, especially at low ages, and then, the strength will be decreased at high amounts of PCEs. Also, the specimens' fracture angle will be changed by increasing the PCEs.

KEYWORDS: Polycarboxylate superplasticizer, Concrete, Flexural strength, Compressive strength.

1 INTRODUCTION

At present, compounds of cement in general and concrete in particular are among the most used materials in the world, and this issue is so important that concrete is known as a building material of the twenty-first century. Given the growing research and use of concrete and cement compounds, it seems that the future of these materials is even clearer. The major reason for this is that the construction of concrete with cheap and affordable materials on one hand and its flexibility, strength and durability properties on the other hand, as well as the benefits related to energy saving and environmental considerations, have resulted in the prominence of this material.

Today, most of the concrete produced in different countries of the world have one or more additives. Polycarboxylate superplasticizer (PCE) is a new type of plasticizer that came into use in 1980 [11]. The effect of PCEs on the properties of a cementitious system depends on various structural parameters. Apart from adsorbent groups, bond density and molecular composition, the molecular weight of PCEs have a significant effect on the properties of concrete. There are numerous studies on the effect of molecular weight on the performance of PCEs [2, 15, 19, 23 & 24].

The mechanism of action of the superplasticizers in the concrete is dispersing the massive grains of cement and releasing the trapped waters by releasing a repulsive force between them [22]. It has been widely accepted that the performance of dispersion by superplasticizers in cement paste is achieved via adsorption of cement grains. By the heterogeneous level of load distribution derived from different inorganic phases, cement grains can significantly adsorb superplasticizer molecules due to electrostatic interactions between cement and superplasticizers surfaces [16, 20].

In recent years, various studies have been conducted on superplasticizers. Hui et al. [14] carried out a study on the synthesis and mechanism of action of PCEs. In this research, the structural unit of the main and secondary chains, the position and effects of functional groups of PCEs were discussed. Based on the results obtained, the PCEs, which were synthesized in two steps with polyethylene glycol, acrylic acid, and sodium methyl sulfonate propylene as raw materials, when the 0.16 to 0.2% super-plasticizer was added to the cement paste, the steady fall of the initial slump reached about 200 mm, and the initial strength of the cement paste was greatly improved. Examining 12 polycarboxylate specimens, Lange et al. [18] investigated the effect of hydrophilic–lipophilic balance value of polycarboxylate on the behavior of mortar flow. Ran et al. [21] studied the effect of the molecular weight of PCEs on the dispersion, adsorption and hydration of cement systems, and concluded that the molecular weight of these PCEs has a tremendous effect on the properties of cement systems and particles of polycarboxylates with different molecular weights have different advantages and disadvantages. Concretes with PCEs have better performance and durability than concretes with polynaphthalene superplasticizers as a result of less porosity and smaller pore diameter [13]. PCEs with high molecular weight require a longer hydration time to attain the highest temperature. The hydration reaction between cement and water can be controlled by adsorbing PCEs on the surface of cement particles. With the increase of carboxylate groups, the adsorption of PCEs in the cement particle surface is enhanced and the effect of superplasticizer delay is highlighted [17].

In this paper, the effect of PCEs on the compressive and flexural strength of concrete was investigated. Firstly, the experimental operations such as materials used, the mix design and the procedure of the experiments were explained and then, the results were analyzed.

2 EXPERIMENTAL

The aim of the tests is to investigate the effect of PCEs on concrete strength properties. Experiments were conducted at the Islamic Azad University, Ferdows branch. The superplasticizer effect was measured on the compressive strength of the cube specimens, the flexural strength of the beam specimens, the specific weight of the dry concrete and the concrete slump.

2.1 Test materials

The PCE used in this study is of type F according to ASTM C494 [3] and a specific weight of 1.08 g/cm3. Its physical state is bright liquid without chlorine ion. In order to obtain the effect of this product on concrete strength properties, three mix designs with superplasticizer amounts of 0.3, 0.5, and 0.7% of cement weight were compared to the nonsuperplasticizer mix design.

In this study, ordinary Portland cement was used. Using ASTM C188 [5], the cement density was determined to be125.3 g/cm3. Grain materials with a maximum nominal diameter of 25 mm were used. The SSD relative density of the coarse-grained materials was 2.5 and their water adsorption was 2%, according to ASTM C127 [8]. In addition, according to ASTM C128 [9], the SSD relative density of fine-grained materials was 2.4 and their water adsorption was 4%. The dense coarse-grained mixed density was obtained as 1610 kg/m3 according to ASTM C29 [4]. The mix designs of cube and beam specimens for concrete compressive and flexural strength tests were determined according to ACI 211.1 [1]. The target strength was considered to be 25 MPa. Accordingly, a constant mix design was considered with the values of Table 1. The mix designs of C0, C3, C5 and C7 were named for four mix designs with the values of 0, 0.3, 0.5 and 0.7% of superplasticizer, respectively.

Table 1. Values of material for mix design

Cement (Kg/m^3)	Gravel (Kg/m^3)	Sand (Kg/m^3)	Water (Kg/m^3)
386	1077	587	189

2.2 Testing methodology

Experiments of compressive strength were conducted at 7, 28, 90 days of age while the experiments of flexural strength were conducted at the age of 14, 28 and 90 days. For each age, three specimens were tested. The compressive strength of cube specimens was measured according to BS EN 12390-3 [10]. The cube specimens of the compressive strength experiments were 150 × 150 × 150 mm in size. The loading speed of specimens was considered to be 0.5 MPa/s. The rupture modulus of the beam specimens was conducted according to ASTM C293 [6] (flexural strength of concrete specimens using three-point loading). The beam specimens were 150 × 150 × 510 mm in size. When loading, the distance from the center to the center of the supports was 450 mm (height was one third of the distance from the center to the center of the support). Loading rate was also set at about 1 MPa/min. For all mix designs, the slump test was carried out in accordance with ASTM C143 [7].

3 RESULTS AND DISCUSSION

In Figure 1, the manner of rupture of some flexural strength beam specimens are shown with different percentages of superplasticizers. As shown in Figure 1, the super-plasticizer affects the fracture angle of the specimens. The fracture line of beam specimens without superplasticizer is almost vertical, and it can be said that the fracture is flexural. Higher percentage of superplasticizer leads to smaller angles, and the shear-flexural failure occurs. According to Figure 1, it can be concluded that higher percentage of the superplasticizer in the concrete leads to more oblique fracture line and makes the rupture closer to the shear state. Of course, in specimens with 0.7% superplasticizer, flexural fracture has occurred due to the high amount of plasticizers. In flexural beams, flexural fracture is expected in the middle of the beam. Nevertheless, with increased superplasticizer, it seems that the adhesion force between the particles has increased, causing the diagonal paths to be weaker than the vertical pathway where the fracture has occurred.

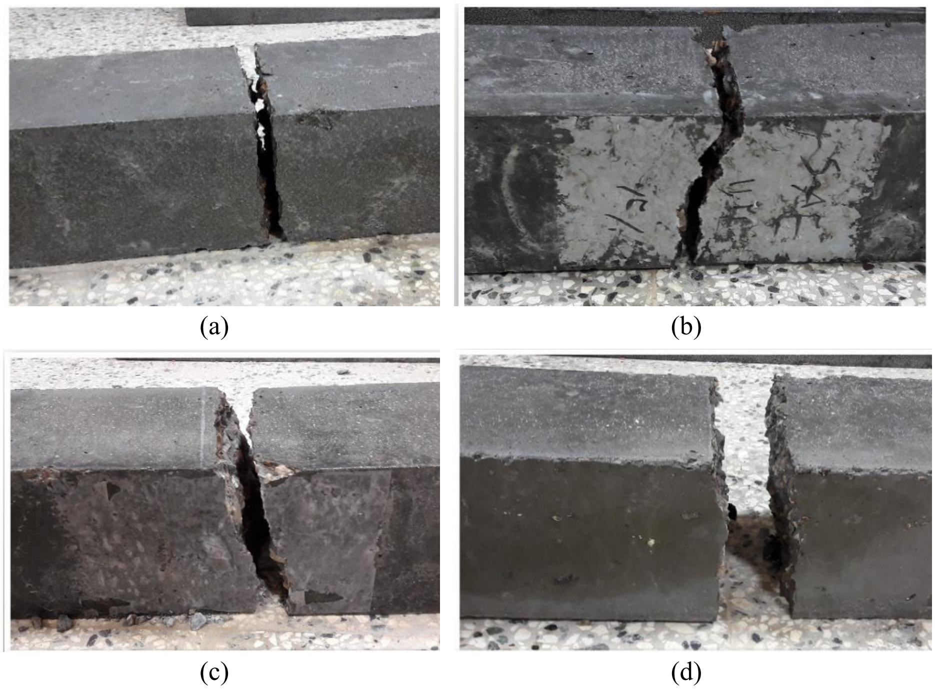

Figure 1. Effect of superplasticizer on fracture line of beam specimens: a) 0%, b) 0.3%, c) 0.5%, d) 0.7%

Figure 2 shows the results of the slump tests conducted on the mixtures made for specimens of flexural and compressive strengths. As shown in Figure 2, the highest drop in concrete is related to the C7 mix design with 0.7% of the PCEs relative to the cement weight. In this mix design, due to the falling slump, 250 mm is considered. As shown in Figure 2, with the increase in the percentage of PCEs in the mix design, the amount of slump has also increased. Growth of the C3 mix design slump compared to C0 is 17%, while growth of the C5 mix design slump compared to C3 is 48%. Due to the increase of slump and consequently the increase of concrete workability with the use of PCEs, we can make a more plasticizer concrete without adding water which decreases the strength of the concrete, and also, reduces the energy required for vibration.

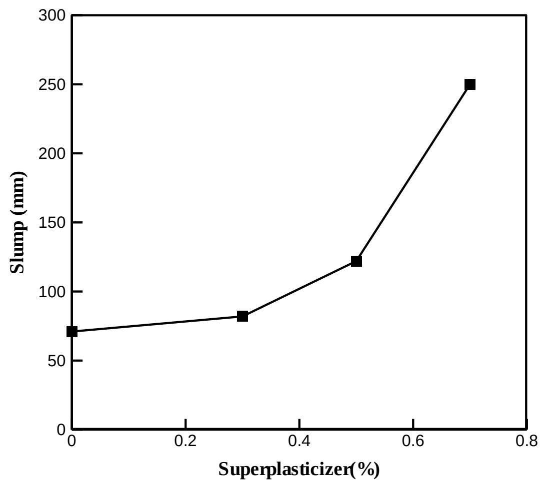

Figure 2. Effect of superplasticizer on slump of mix design

Figure 3 shows the effect of the PCEs on the specific weight of the dry concrete. As shown in Figure 3, the highest specific weight of the dry concrete is observed in the specimens of C7 mix design with a value of 2.39 g/cm3. The smallest amount is related to the specific weight of C0 mix design without PCEs, which is equal to 2.33 g/cm3. Increasing the amount of PCEs in the mix design increased the amount of dry concrete specific weight. Increasing the specific weight of dry concrete during application of the superplasticizer, reduces the porosity and permeability, thereby decreasing a number of cracks due to the contraction and possible creep of concrete.

Figure 4 shows the average results of the compressive strength ($f_c^{'}$) of different mix designs at the age of 7, 28, and 90 days. According to Figure 4, by increasing the percentage of PCEs in the mix design, the average compressive strength of the cube specimens increases. The average compressive strengths of C3, C5, and C7 at 7 days were29, 45 and 66%, respectively. At 28 days of age, this increase in compressive strength was about14, 22 and 8%, respectively. Also, at 90 days of age, the increase in average compressive strength of C3, C5, and C7 were 16, 28 and 18%, respectively. Therefore, the highest growth rate of the specimens was at 7 days of age and the highest growth rate is associated with the

C7 with 66% increase, indicating that the PCEs have a significant effect on compressive strength in the early ages of concrete.

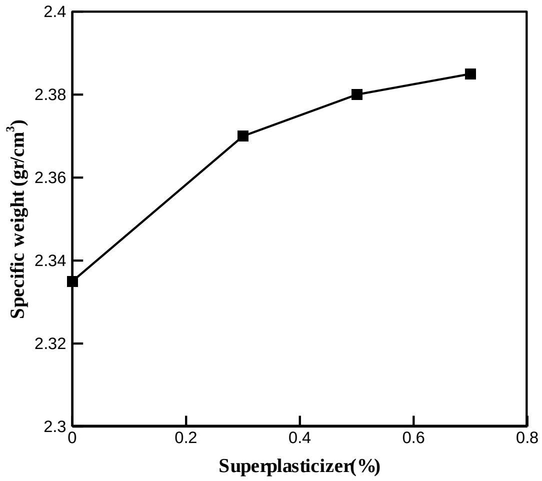

Figure 3. Effect of superplasticizer on specific weight of the dry concrete

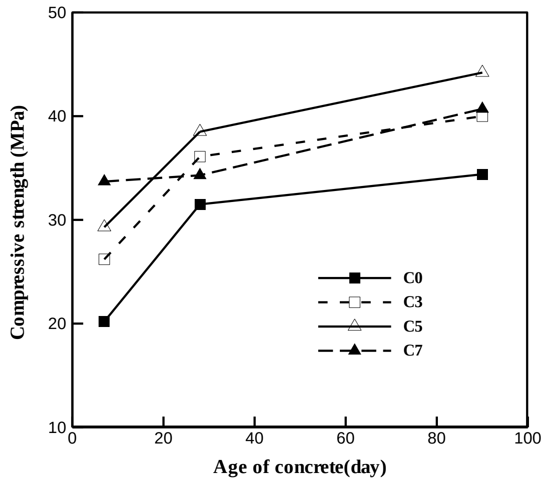

Figure 4. Effect of superplasticizer on compressive strength of specimens at different ages

As shown in Figure 4, the average compressive strength of specimens of C7 mix design at the ages of 28 and 90 days is lower than that of the C5 mix design, which can be attributed to the high lubrication of concrete and also the lack of water reduction in the plans with more amount of PCEs. Therefore, it can be concluded that by increasing the amount of superplasticizer up to 0.5% of cement weight, the compressive strength of cube specimens increases and then decreases.

The compressive strength is expected to be increased by reducing the W/C (water-to-cement ratio) if using percentages higher than 0.5% of superplasticizer. Due to the decrease in the compressive strength for C7 mix designs at the age of 28 and 90 days, it can be said that if the W/C is reduced, higher strength can be achieved.

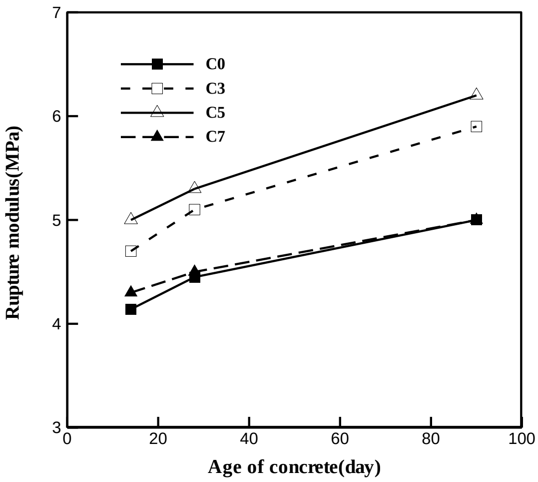

Figure 5. Effect of superplasticizer on rupture modulus of specimens at different ages

The rupture modulus (fr) was calculated by measuring the maximum force applied during the rupture of the beam specimens. Figure 5 shows the average results of the specimens' rupture modulus at different ages. As shown in Figure 5, by increasing the percentage of PCEs in the mix design, the magnitude of the rupture modulus of the beam specimens also increased. The average rupture modulus of C7 mix design specimens at different ages, shows higher growth only compared to the C0 mix design, which can be due to the high slump of concrete and also lack of reduction of water mixture in designs with more superplasticizers. Therefore, by increasing the amount of PCEs up to 0.5% of cement weight, the flexural strength of beam specimens also increases.

The rupture modulus at the age of 14 days in C3, C5, and C7 increased at about 13, 24 and 5%, respectively, in comparison to C0. At the age of 28 days, the growth rates of the rupture modulus were14, 19 and 96%, respectively. At the age of 90 days, the growth rates of rupture modulus in the C3 and C5 designs were 16 and 23%, respectively, in comparison to C0. Of course, the C7 plan had a 1.1% rupture modulus reduction at 90 days of age, compare to C0, probably due to lack of reduction in concrete water. The highest growth of specimens' rupture was observed at 7 days of age and the highest growth rate was related to the C5 with a 24% increase, indicating that the PCEs have a significant effect on flexural strength in the early ages of concrete.

Table 2 compares rupture modulus obtained from experimental results with results obtained from CSA A23.3-14[12]. According to CSA A23.3-14[12], the rupture modulus (fr) of concrete sample is calculated by:

$$f_r = 0.6\lambda\sqrt{f_c^{'}} \quad (1)$$

Where λ is a factor for the effect of low-density aggregates. For normal density concrete, λ=1.0. According to Table 2, Eq.(1) underestimates rupture modulus of samples. The experimental results of the rupture modulus at 28 and 90 days of age, respectively, are 38 and 49% higher than the rupture modulus results obtained in Eq.(1). Moreover, in all cases, an almost identical trend was observed between results of experimental and Eq.(1). However, it can be said that Eq.(1) has high factor of safety in design of structures and factor λ can be considered to be more than 1.0 for normal concrete.

Table 2. Comparison of the results of the rupture modulus obtained from CSA A23.3-14[12] with experimental results

PCEs(%)	*28 days*			*90 days*		
	f_c(MPa)	*fr(MPa) Experimental*	*fr(MPa) CSA[12]*	*f_c(MPa)*	*fr(MPa) Experimental*	*f_r(MPa) CSA[12]*
0	32.11	4.54	3.40	35.07	5.19	3.55
0.3	36.80	5.21	3.64	40.77	6.02	3.83
0.5	39.25	5.42	3.76	45.06	6.38	4.03
0.7	34.96	4.59	3.55	41.49	5.13	3.86

4 CONCLUSIONS

In this paper, the effect of PCEs on concrete workability and strength properties was investigated. Four different mix designs with 0, 0.3, 0.5, and 0.7% of superplasticizers were prepared. In all mix designs, the amounts of gravel, sand, water, and cement were considered constant. Specific weight, slump, compressive and flexural strength tests were conducted on specimens. The results showed that increasing the percentage of PCEs in the mix design increases the amount of slump and dry concrete specific weight. By increasing the amount of PCEs up to 0.5% of cement weight, the flexural strength and compressive strength of the specimens will increase. In addition, the angle of the fracture line of the flexural strength specimens became higher than the vertical state with increase in superplasticizer percentage up to 0.5% of the cement weight and their fracture become closer to the shear fracture. Using a high amount of PCEs and holding the water constant in the mix design reduce the specimens' compressive and flexural strengths. Moreover, the results showed that the effect of PCEs on the concrete strength in the early age of concrete is more than the higher ages.

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