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Effect of environmental conditions on the properties of concretes with different cement types

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Abstract

The paper reports on the changes in properties of concretes with different cement types associated with environmental conditions. Three strength classes with three different cement types (ordinary portland cement PC 42.5 (CEM I 42.5), portland composite cements PKC-A 42.5 (CEM II/A-M 42.5) and PKC-B 32.5R (CEM II/B-M 32.5R)) were used in the study. Also, a mixture was prepared with PC 42.5 and silica fume (SF). The effects of variable ambient conditions on plastic shrinkage of fresh concrete and cement paste, compressive strength, modulus of elasticity, capillary absorption and drying shrinkage of hardened concrete were investigated. In contrast to PC 42.5 cement paste, plastic shrinkage cracks were observed in PKC-B 32.5 and PKC-A 42.5 pastes. Water absorption coefficients of all concretes stored in natural environment were higher at all ages as compared to coefficients of concretes kept in laboratory. Drying shrinkage values of concrete with SF, except the first week, were significantly lower than those of others. Although different behaviors for different cement types were observed, water–cement ratio was one of the dominating factors determining the behavior of concrete. This ratio should be lowered to improve the durability of concrete.

Keywords: Cement types; Environmental conditions; Durability; Plastic shrinkage; Compressive strength; Capillary absorption; Drying shrinkage

1. Introduction

Curing and environmental conditions have significant effects on the physical and mechanical properties of concrete. Weather conditions such as temperature, relative humidity, rainfall and wind velocity can change during construction. Curing conditions can be changed by the engineers on construction as regarding the changes in ambient conditions. Plastic shrinkage cracks, insufficient strength at later ages, durability loss problems can be seen frequently as a result of insufficient curing. Concretes exposed to seasonal fluctuations can be more vulnerable due to these problems. Different cement types are increasingly used in concrete practice to prevent durability loss and obtain desired service life.

The magnitude of early age drying shrinkage is highly dependent on the surrounding environmental conditions. As the evaporation of free water from the fresh concrete increases, the magnitude of early age drying shrinkage also increases. The composition of concrete does affect the expected amount of total early age shrinkage. The materials selected, such as cement type and admixture dosage, have secondary roles controlling other factors within early age drying and autogenous shrinkage [1].

The plastic shrinkage strain increased with increasing dosage of silica fume (5%, 7.5% and 10% by weight of cement). Plastic shrinkage strains in all the silica fume cement concretes were higher than those in the plain cement concrete [2].

When placing concrete in a dry, hot weather climate, precautions are needed to prevent rapid, early drying of the concrete surface. It is indicated that drying begins when the evaporation rate exceeds the bleeding rate, risk of drying

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depends on the environment and on the bleeding rate of the concrete [3].

Alsayed [4] revealed that adding silica fume (10% of cement weight) to concrete mix greatly reduces the 3-year drying shrinkage, the stress due to shrinkage strain, and the rate of first month drying shrinkage of concrete. This is true whether concrete is subjected to controlled laboratory or hot-dry field curing conditions. Adding mineral and/or chemical admixtures to concrete mix has an appreciable influence on the total amount of drying shrinkage. However, Rao [5] reported that the effect of silica fume on drying shrinkage of mortar is very significant at early ages. The mortar bars experienced higher values of drying shrinkage with the incorporation of silica fume. A higher content of silica fume increased the drying shrinkage more. The pozzolanic action of silica fume was completed at the early ages. The effect was insignificant at later ages. Persson [6] found that the total shrinkage was related to age, w/c and type and content of silica fume.

Drying shrinkage of the hydrated cement paste begins at the surface of the concrete and progresses more or less rapidly through the concrete, depending on the relative humidity of the ambient air and the size of capillaries. Drying shrinkage of ordinary concrete is therefore rapid because the capillary network is well connected and contains open capillaries at the surface of the concrete [7].

In order to obtain higher strengths, concrete mixtures have a low water–cementitious ratio and a high cementitious material content which increase heat of hydration and generate higher shrinkage causing the potential for cracking. Therefore, different cement types containing supplementary cementitious materials are generally used to improve properties of concrete and to make concrete more economical. Factors such as insufficient curing and seasonal fluctuations may prevent higher strength from being achieved. Extra care and attention should be paid to the concretes under these conditions.

This research focuses on studying the effect of environmental conditions on the properties of concretes with different cement types. For this reason, an experimental program on plastic shrinkage, compressive strength, modulus of elasticity, water absorption and drying shrinkage was performed with the purpose of evaluating the effect of different cement types and environmental conditions.

2. Experimental study

2.1. Materials and mix proportions

Ordinary portland cement PC 42.5 (CEM I 42.5), portland composite cements PKC-A 42.5 (CEM II/A-M 42.5) and PKC-B 32.5R (CEM II/B-M 32.5R) were used in concrete preparation. Densified silica fume (SF) was used 7.5% of total cementitious materials content in concrete making for strength class C 60. SF was supplied as industrial waste from Antalya Ferro-krom Factory. The chemical composition, physical and mechanical properties of cements and densified silica fume are given in Tables 1–3. Permitted constituents of portland composite cements according to TS EN 197-1 [8] (similar to European Standard EN 197-1 [9]) are shown in Table 4.

Natural river sand (A1), crushed stone sand (A2), natural gravel (A3) and coarse crushed stone (A4) were used in the concrete mixtures. Maximum particle size was 25 mm in diameter. Some physical properties and the grading of the aggregates are presented in Tables 5 and 6, respectively.

Superplasticizer was added to the mixtures when it was necessary. Hyperplasticizer was used in the strength class C 60.

Three strength classes with three different cement types were used in the study: C 20 (PC 42.5-20, PKC 42.5A-20, PKC 32.5B-20), C 40 (PC 42.5-40, PKC 42.5A-40, PKC 32.5B-40), C 60 (PC 42.5-60, PKC 42.5A-60, PKC 32.5B-60). Also, a mixture was prepared with PC 42.5 and SF in C 60 (PC 42.5S-60). The amount of slump was nearly same (11 ± 1 cm) for all mixtures. The temperature of fresh concrete was kept constant 20–25 °C after mixing in the

Table 1
Some physical properties of aggregates

	A1	A2	A3	A4
Specific gravity	2.63	2.63	2.67	2.70
Water absorption (%)	1.8	1.8	0.8	0.6

Table 2
The aggregate gradation

Aggregate type	Sieve size (mm)							
	0.25	0.5	1	2	4	8	16	31.5
	Percentage passing							
A1	37	56	81	100	100	100	100	100
A2	11	25	44	62	83	100	100	100
A3	0	0	0	0	4	44	97	100
A4	0	0	0	0	0	0	7	100

Table 3
Chemical analysis of cements and silica fume

	PC 42.5	PKC-A 42.5	PKC-B 32.5R	SF
SiO_2 (%)	20.0	–	–	93.0
Al_2O_3 (%)	4.90	–	–	1.0
Fe_2O_3 (%)	3.12	–	–	2.0
CaO (%)	62.65	–	–	–
MgO (%)	2.33	–	–	0.7
SO_3 (%)	3.06	3.64	2.11	–
Loss of ignition (%)	1.42	–	–	–
Insoluble residue (%)	0.37	–	–	–

Table 4
Some physical properties of cements

	PC 42.5	PKC-A 42.5	PKC-B 32.5R
Specific surface, blaine (cm^2/g)	3385	3584	–
Specific gravity	3.10	2.94	2.93
Initial time of setting (min)	170	160	150
Final time of setting (min)	200	240	200

Table 5
Mechanical properties of cements

Compressive strength (MPa)	PC 42.5	PKC-A 42.5	PKC-B 32.5R
2 Days	26.3	23.5	17.6
7 Days	38.4	38.2	–
28 Days	50.6	48.4	39.8

concrete pan mixer. The mix proportions and some properties of concretes for the 10 mixtures used in the study are given in Table 7.

2.2. Test procedure

Plastic shrinkage test on fresh concretes and cement pastes, compressive strength, drying shrinkage, capillary absorption tests on hardened concretes were performed. Deformations of specimens were measured to determine modulus of elasticity in compression.

2.2.1. Plastic shrinkage

Concrete slabs (600 × 600 × 60 mm) were utilized for evaluating plastic shrinkage cracking. C 20 concretes with three cement types and C 60 concretes with PKC-B 32.5 and PC 42.5+SF were used for the plastic shrinkage test. The fresh concretes were cast into the moulds in different sunny days and kept in the natural environment outside the laboratory in which the temperature and relative humidity were 32 ± 2 °C and 65 ± 5%, respectively. The concrete slabs were visually monitored and the initial cracks were recorded. In addition, cement paste specimens were made with constant w–c ratio of 0.30 (90 mm in diameter and 20 mm in height). Like concrete slabs, cement paste specimens were visually inspected for initial crack occurrence, too.

2.2.2. Compressive strength and modulus of elasticity

Cylinders (150 × 300 mm) were used to determine the compressive strength and modulus of elasticity. The compressive strength tests were conducted on three specimens and determined by using a 2000 kN capacity compression testing machine. After testing the first specimen, a deformation frame and compressometer were installed on other two specimens parallel to the direction of the applied load so as to measure modulus of elasticity (TS 3502 [10]). The compressive strength tests were performed at 7, 28, 56 and 90 days and modulus of elasticity of specimens at 28, 56, 90 days. The concrete cylinders were demoulded after 24 h and put into a water curing tank at 20 ± 2 °C. The cylinder specimens tested at 56 and 90 days were cured in water at 20 ± 2 °C until the age of 28 days. At the end of 28 days, they were taken from the tank and stored under constant environmental condition, in the laboratory at 23 ± 2 °C and 55 ± 5% RH. For the determination of effect of various environmental conditions on strength, drying shrinkage test prisms were used after measuring their final lengths at the age of 194 days. First, they were divided into two in flexure and then compressive strength tests were performed on each piece.

2.2.3. Capillary water absorption

For determining absorption of water by capillary, the 100-mm cube specimens were cast. The specimens were kept in water curing tank for 7 days. After 7 days, they were taken out from the water tank, half of them were stored outside the laboratory (D) and the other half were kept in the controlled laboratory conditions (L). Before the test, the specimens were put in a well-ventilated oven and dried at 50 °C. After that, their four sides except bottom and top faces were sealed with paraffin to prevent

Table 6
Permitted constituents of portland composite cements (%)

Cement	Clinker	Gran. blast. slag (S)	Silica fume[a] (D)	Natural pozzolana (P)	Industrial pozzolana (Q)	Siliceous fly ash (V)	Calcareous fly ash (W)	Burnt shale (T)	Lime stone (L)
PKC-A	80–94				6–20				
PKC-B	65–79				21–35				

[a] In the case of using silica fume, it is limited to 10% on cement.

Table 7
Mix proportions of concretes

Mixture	Adm. type	Adm. prop. (%)	Water/binder	Slump (cm)	Content of constituents (kg/m^3)						
					C	SF	A1	A2	A3	A4	W
PC 42.5-20	–	–	0.71	13	260	–	248	743	519	405	185
PC 42.5-40	SP	1.2	0.45	11	340	–	134	823	541	426	153
PC 42.5-60	HP	1.0	0.28	12	450	–	19	904	427	555	126
PC 42.5S-60	HP	1.0	0.29	11	370	30	19	937	441	575	115
PKC 42.5A-20	–	–	0.63	12	310	–	128	971	519	223	195
PKC 42.5A-40	SP	1.0	0.46	11	340	–	133	817	538	424	156
PKC 42.5A-60	HP	0.7	0.29	10.5	450	–	19	899	425	554	131
PKC 32.5B-20	SP	0.6	0.59	12	280	–	134	861	522	407	165
PKC 32.5B-40	SP	1.6	0.41	10	340	–	96	900	523	407	139
PKC 32.5B-60	HP	1.0	0.27	11	450	–	19	905	427	555	122

water penetration from the sides during the test. The specimens were immersed in the water up to 3–4 mm for 24 h. The weight increases were recorded at intervals of 1, 4, 9, 16, 25, 36, 49, 64 min and 24 h.

2.2.4. Drying shrinkage

The concrete prismatic specimens cast for drying shrinkage tests were $100 \times 100 \times 500$ mm. Two studs were inserted in the longitudinal direction of concrete for each specimen. The specimens were covered with wet burlap to prevent moisture loss from their surfaces. After being demoulded at the age of one day, they were kept in the laboratory, covered with wet burlap until the age of 7 days. The measurement of length change was performed using a mechanical Demec gauge of 200 mm gauge length. Likewise absorption test specimens, half of them were put outside the laboratory (D) and the remaining half were left in the laboratory (L) after initial length readings were recorded. The temperature and relative humidity were kept constant at 23 ± 2 °C and 55 ± 5% RH, respectively in the controlled laboratory conditions. All concretes for outdoor shrinkage test were produced in 15 days regarding initial variations of surrounding temperature and relative humidity. Outdoor specimens were put in a proper place to provide direct solar radiation exposure in sunny days and also, rain in rainy days. The temperature and relative humidity of natural environment were recorded by using a thermo-hydrograph, continuously. For internal temperature measurement of specimens, a digital thermometer was used. For this purpose, a special hole was formed by a stick with the same height of probe on fresh concrete and the hole was sealed in order to avoid ingress of water. Figs. 1 and 2 present the variations of temperature and relative humidity of natural environment. The measurement of drying shrinkage tests was continued for 187 days.

3. Results and discussion

3.1. Plastic shrinkage results

The tests on cement pastes were performed in same weather conditions. In contrast to PC 42.5 pastes, cracks were observed in PKC-B 32.5 and PKC-A 42.5 pastes in 56th and 47th minutes, respectively after being exposed to the outdoor conditions. It can be stated that ordinary portland cement paste may show rapid strength develop-

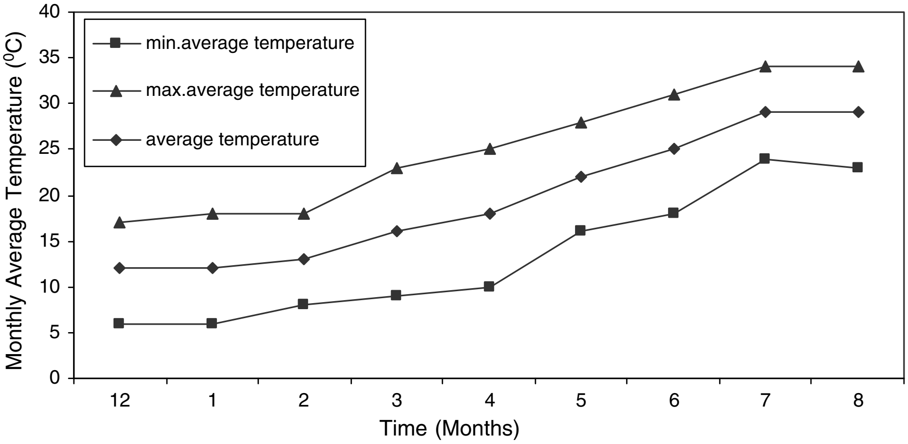

Fig. 1. Variation of outdoor temperature.

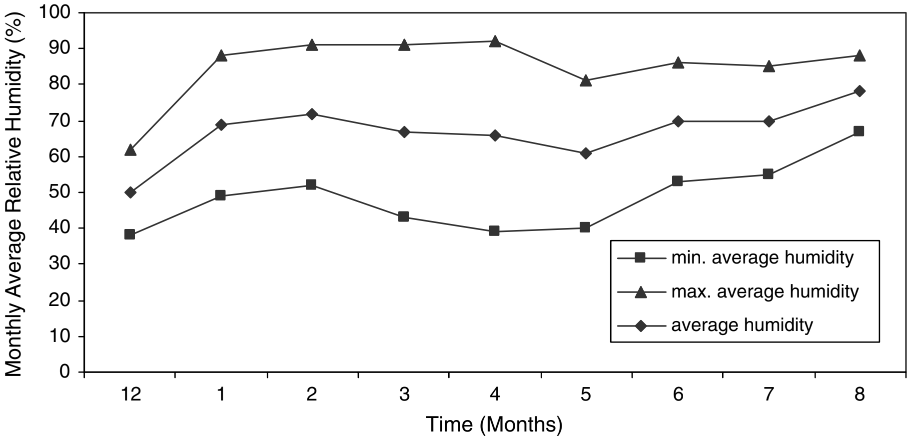

Fig. 2. Variation of outdoor relative humidity.

ment to prevent negative pressure in the capillary pores. The plastic shrinkage test results of cement pastes are shown in Table 8.

Plastic shrinkage cracks were seen in all C 20 concrete specimens. An earlier cracking occurred in the case of PC 42.5 concrete. Although this specimen was subjected to slightly lower relative humidity, this is to be expected considering that portland cement concrete had a higher w–c ratio in contrast to cement paste. The water–cement ratios were 0.71, 0.63 and 0.59 for PC 42.5, PKC-A 42.5 and PKC-B 32.5, respectively. It is evident that PC 42.5 concrete had a higher amount of capillary pores. Almussalam et al. [11] reported a similar observation stating that earlier initial cracks were noted in PC concretes compared to blended cement concretes.

Plastic shrinkage cracks were not visually observed in both PKC-B 32.5 and PC 42.5+SF concretes in strength class C 60. This result indicates that concretes with lower water–cement ratios and higher cement content may gain sufficient strength in a short time period, therefore negative pressure in the capillary pores could not cause remarkable plastic shrinkage cracks in surrounding environmental conditions. Table 9 provides the observations of the plastic shrinkage test results.

3.2. Compressive strength and modulus of elasticity results

The relative compressive strength values are presented in Figs. 3–5. Also, Figs. 6–8 illustrate relative modulus of elasticity as compared to the 28-day values. As compared to the concrete with portland cement, concretes with portland composite cements had higher cement content and considerably low water–cement ratio in order to obtain same strength at the age of 28 days in C 20. However, PC 42.5 concrete gained higher strength at later ages. Also, 28-day modulus of elasticity values of PKC concretes were lower than those of PC 42.5 concrete in the same strength class. Although modulus of elasticity values of PKC concretes increased rapidly in long term, they could not reach the values of PC concrete.

Differences in w/c and cement content values decreased continuously for 28-day strengths in the higher strength classes such as C 40 and C 60, the effect of cement type became insignificant. In addition, modulus of elasticity values were closer for different cement concretes in the higher strength classes. On the other hand, differences were observed in strength gain. PKC concretes showed lower strength development than PC concretes at early ages. However, PKC concretes exhibited higher strength development between 7 and 28 days. This result indicates that pozzolan based components in composite cements are significantly effective after 7 days. Similar behavior was also observed in the case of mixture containing silica fume. Generally, a reduction in strength gain was observed among PKC concretes with high cement content and concrete with SF after 28 days. This is consistent with the observation made by Bilodeau et al. [12]. Strength gain of PKC concretes after 28 days was not significantly high as compared to the PC concrete. Haque [13] found that all laboratory made specimens irrespective of their composition (with or without cement replacement materials) give lower strength when inadequately cured and exposed to drying regimes for a long period of time and inadequate moisture led to a higher reduction in strength when fly ash was used as compared with PC concrete. The indicated result can be attributed to the low relative humidity in laboratory condition. PKC concretes with high cement content and concrete with SF exhibited less strength gain at later ages of 28 days. Changes in elastic modulus after 28 days were extremely small. Whereas, composite cement concretes experienced relatively high rise. This could be due to denser microstructure occurrence in PKC concretes depending on continuous pozzolanic reactions as compared to PC concretes.

Table 10 presents the compressive strength test results of prisms. The compressive strengths of outdoor specimens, except three mixtures, were higher than those of indoor specimens according to the compressive strength tests performed on the prisms which were used for drying shrinkage measurements. The values of temperature and relative humidity were changeable in the natural environment, also these specimens were sometimes subjected to the rain. When internal temperatures of concrete were considered, the values of outdoor concretes, especially in the case of coinciding to winter months, were lower than

Table 9
Plastic shrinkage results of cement pastes

Cement type	Air temp. (°C)	Air RH (%)	The time of specimen placed	The time of first crack observed
PC 42.5	36	40 ± 5	10:25	Not observed
PKC 42.5A	36	40 ± 5	10:20	11:07
PKC 32.5B	36	40 ± 5	10:09	11:05

Table 8
Plastic shrinkage results of concrete specimens

Mixture	Air temp. (°C)	Air RH (%)	The time of specimen placed	The time of first crack observed	The time of second crack observed
PC 42.5-20	33	55–60	10:45	11:10	11:12
PKC 42.5A-20	32	70 ± 5	10:05	11:15	11:45
PKC 32.5B-20	34	60 ± 5	10:34	11:25	11:30
PC 42.5S-60	32	60 ± 5	10:25	Not observed	Not observed
PKC 32.5B-60	33	65	10:12	Not observed	Not observed

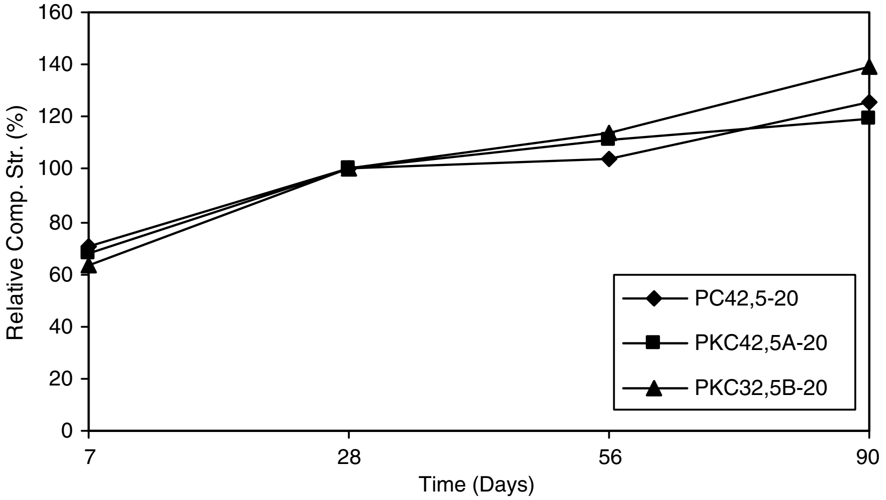

Fig. 3. Relative compressive strength versus age for C 20.

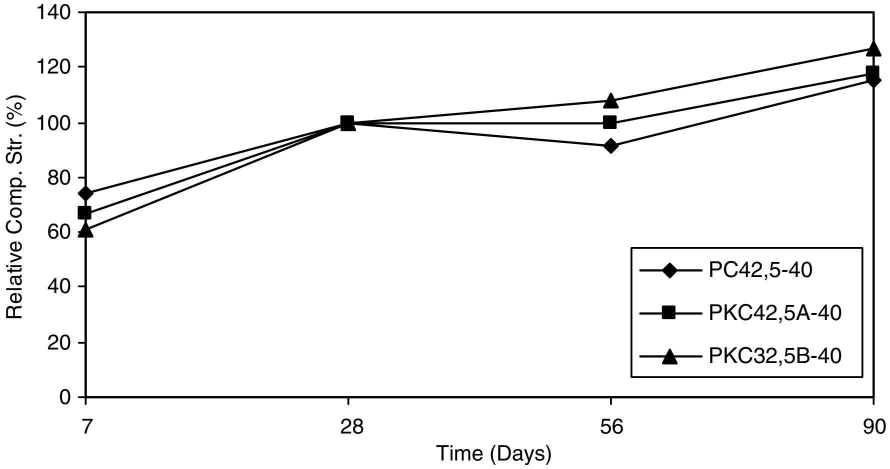

Fig. 4. Relative compressive strength versus age for C 40.

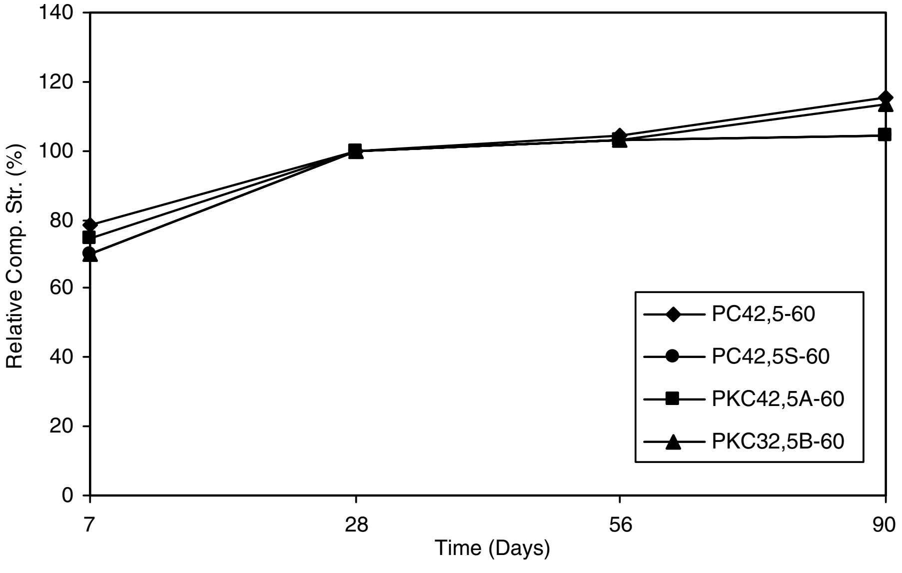

Fig. 5. Relative compressive strength versus age for C 60.

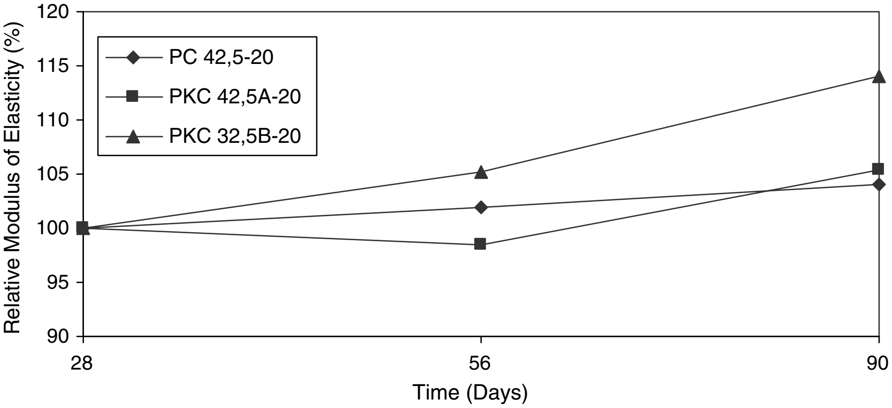

Fig. 6. Relative modulus of elasticity versus age for C 20.

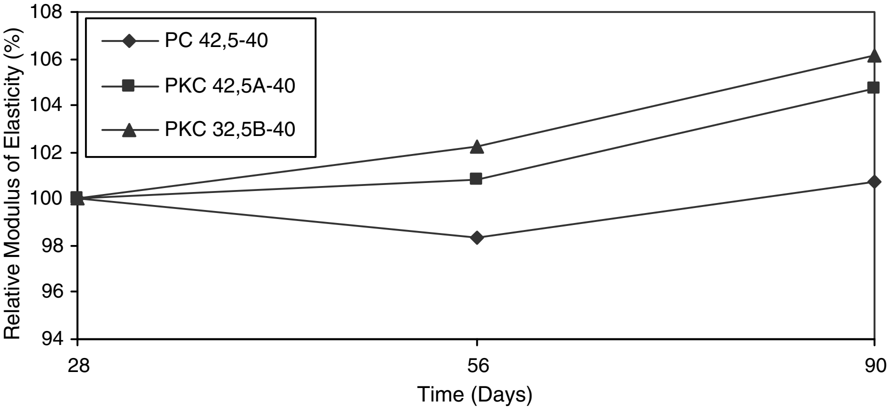

Fig. 7. Relative modulus of elasticity versus age for C 40.

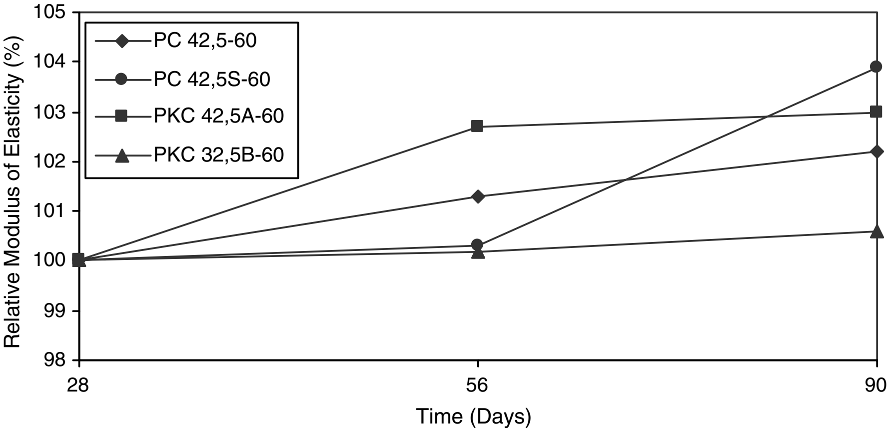

Fig. 8. Relative modulus of elasticity versus age for C 60.

those of indoor concretes in the first 28 days. Therefore, it is clear that maturity degrees of outdoor prisms were lower at the time period of the important part of hydration reactions that has taken place. Moreover, average relative humidity for outdoor specimens (regarding wetting due to the rainfall) was higher as compared with indoor specimens. However, it is observed that internal temperatures of outdoor concretes produced at the end of the winter and in the beginning of the spring were not low. Concrete internal temperatures were markedly high at later ages. For that reason, mechanical properties of outdoor concretes besides other long-term properties were also affected by the variable weather conditions. El-Sakhawy et al. [14] reported that wetting–drying cycles

Table 10
Compressive strength test results of concrete prisms

Mixture	Compressive strength (MPa)	
	Laboratory	Outdoor
PC 42.5-20	27.0	33.6
PC 42.5-40	50.9	44.5
PC 42.5-60	62.8	64.6
PC 42.5S-60	63.5	69.1
PKC 42.5A-20	26.4	32.9
PKC 42.5A-40	42.6	47.4
PKC 42.5A-60	58.9	61.6
PKC 32.5B-20	30.1	30.4
PKC 32.5B-40	45.2	43.4
PKC 32.5B-60	56.7	61.5

had negative effects on strength. However, this finding was obtained by comparing water curing conditions. In the present investigation, the wetting–drying cycles depending on rainfall were moderate and the comparison was made with lower relative humidity conditions in the laboratory. In the mild climate regions such as Antalya, in the case of prevention of outdoor condition effects in the first days after production in winter, no serious problem can be observed in strength gain.

3.3. Capillary water absorption test results

The results are exhibited in Figs. 9–11. In strength class C 20 the highest capillarity coefficients were obtained by PKC-A 42.5 concretes (Fig. 9). On the other hand, PKC-B 32.5 concretes had the lowest values. Capillary water absorption is affected by water–cement ratio. PC concrete had the highest water–cement ratio among C 20 concrete class mixtures. PKC-B 32.5 concrete was prepared with the lowest water–cement ratio. However, the total water contents in PC 42.5, PKC-A 42.5 and PKC-B 32.5 were 184.6, 195.3 and 165.2 l, respectively. As a result, PKC-A 42.5 concrete should have the highest amount of capillary pores. The test results indicated that the total water content used in mixtures had also an effect on water absorption. In addition, the pore volume and pore size distribution of cement based materials change with time and the incorporation of pozzolanic materials affects this change.

The results which were mentioned for C 20 could not be pronounced for other concrete classes (Figs. 10 and 11). Disregarding the mixture containing SF, water absorption coefficients of most composite cement concretes were higher than those of PC concretes.

Water absorption coefficients of all concretes stored in natural environment were higher at all ages as compared to coefficients of concretes kept in laboratory. These results are contrary to general trend of the results obtained for compressive strength. The differences between the capillarity coefficients of laboratory and outdoor concretes became smaller within time in C 20, whereas this was not valid for some mixtures in higher strength classes.

3.4. Shrinkage/swelling test results

Test results are exhibited in Figs. 12–17. PC 42.5 and PKC-A 42.5 concretes exhibited similar behavior in the laboratory conditions for C 20 strength class (Fig. 12). The drying shrinkage strain of PKC-B 32.5 concrete was significantly lower than those of others after the first two weeks. The acceleration of shrinkage increased more rapidly at the earlier stages. High shrinkage strain at earlier stages can be attributed to the shrinkage of capillary pore. Shrinkage strain increased more slowly later and remained nearly constant after 7–8 weeks. Massaza [15] reported that shrinkage depends on cement content and water–cement ratio. Drying shrinkage strain decreases with a lower water–cement ratio [16]. The magnitude of shrinkage in cementitious materials is directly proportional to the paste volume content for different w–c ratios, shrinkage increases as paste volume content in concrete or mortar increases [17,18]. In C 20, PKC-B 32.5 concrete with lower shrinkage strain had the lowest w–c ratio and capillary absorption coefficient. This could be due to less moisture movement for these specimens.

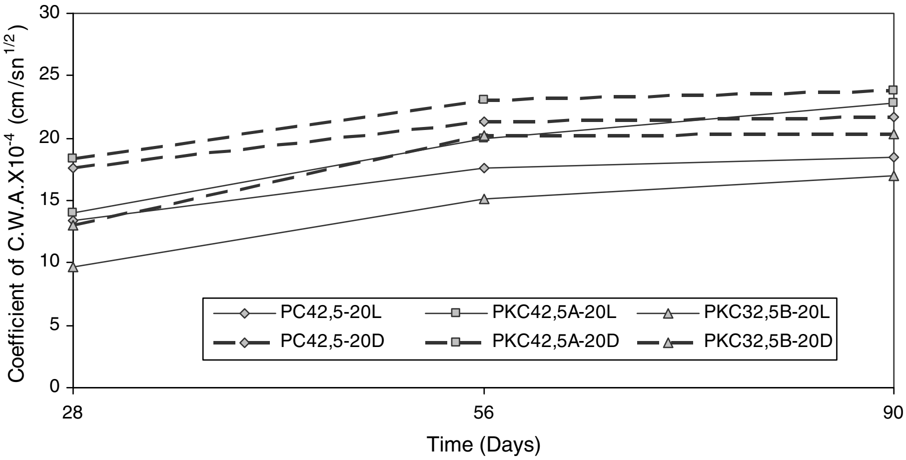

Fig. 9. Coefficient of capillary water absorption versus age for C 20.

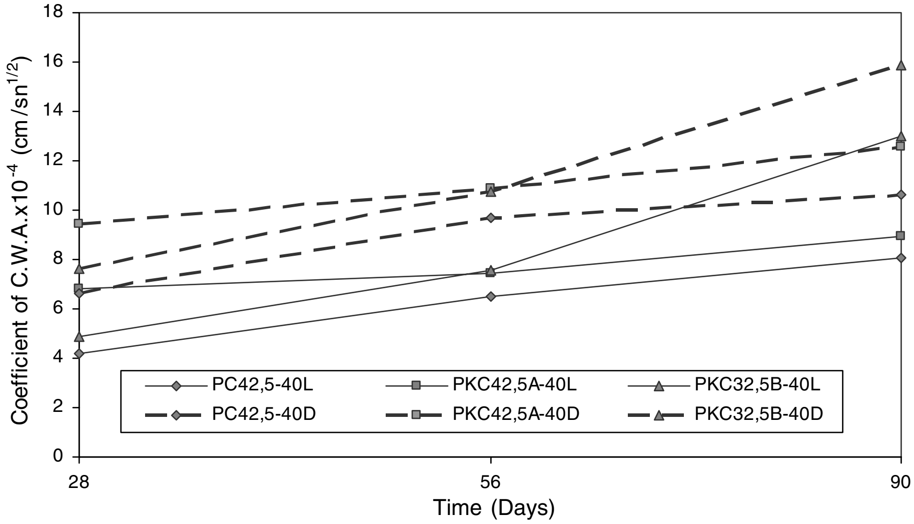

Fig. 10. Coefficient of capillary water absorption versus age for C 40.

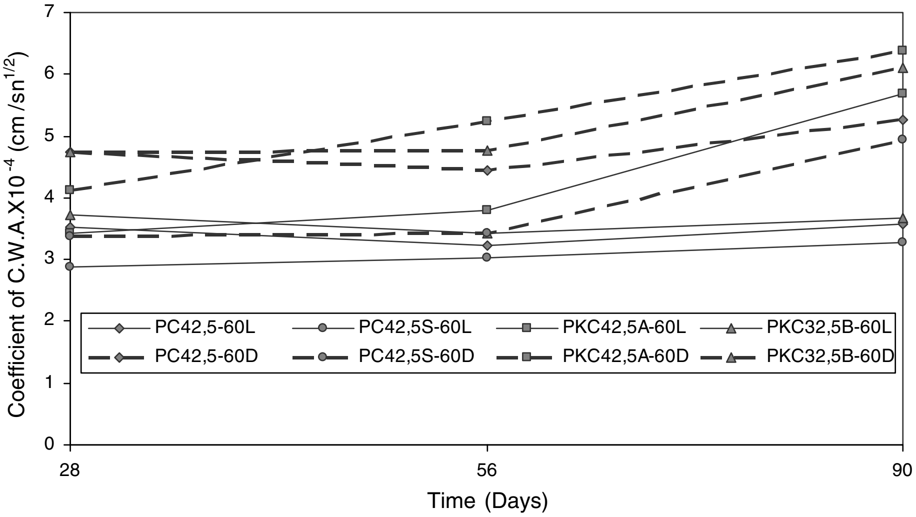

Fig. 11. Coefficient of capillary water absorption versus age for C 60.

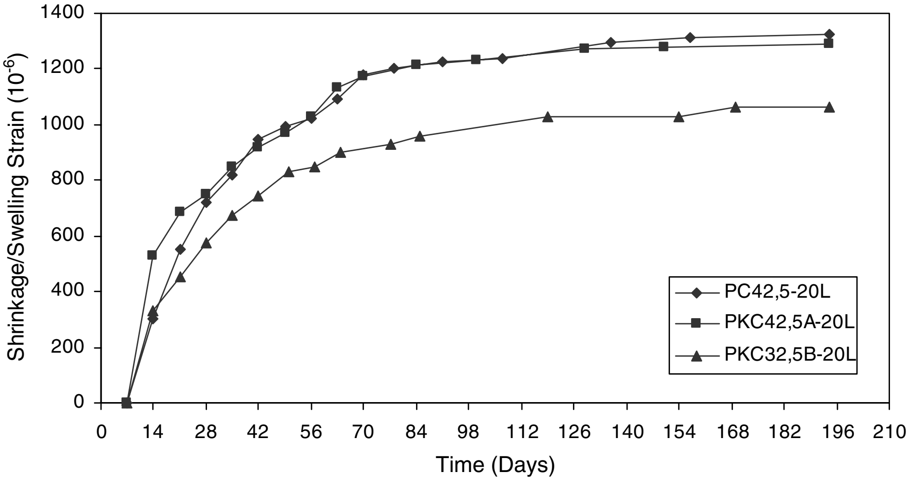

Fig. 12. Shrinkage/swelling strain versus age for C 20 concretes in laboratory.

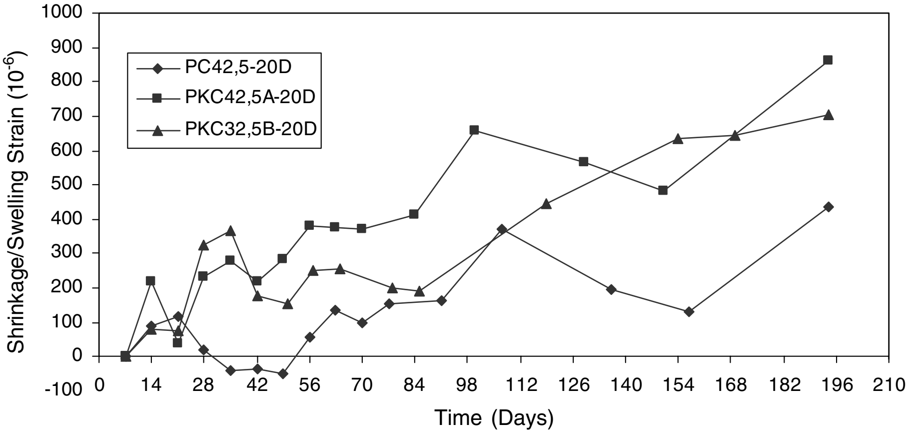

Fig. 13. Shrinkage/swelling strain versus age for C 20 concretes in natural environment.

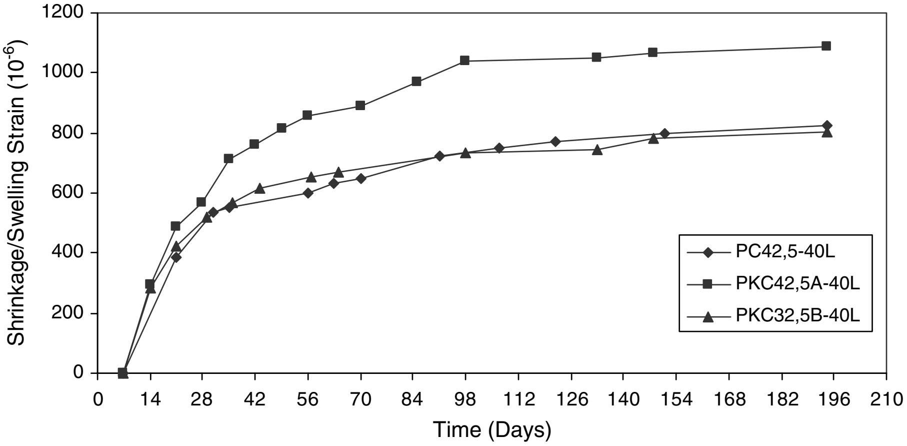

Fig. 14. Shrinkage/swelling strain versus age for C 40 concretes in laboratory.

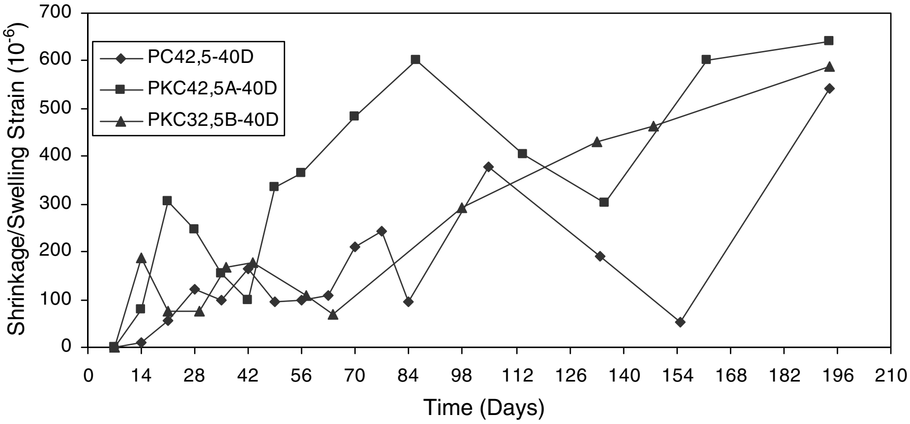

Fig. 15. Shrinkage/swelling strain versus age for C 40 concretes in natural environment.

The shrinkage strains of PC 42.5 and PKC-B 32.5 concretes were markedly closer to each other and significantly lower than those of PKC-A 42.5 concretes in C 40 (Fig. 14).

The difference of shrinkage strains of three cement types was considerably smaller, except mixture with SF, in C 60 (Fig. 16). It should be noted that concretes in this class had similar w–c ratios and also little difference in capillarity coefficients up to 90 days. Drying shrinkage of concrete with SF, except the first week, was significantly smaller than those of others. Although water–cement ratio was not lower, capillarity coefficient of concrete with SF was

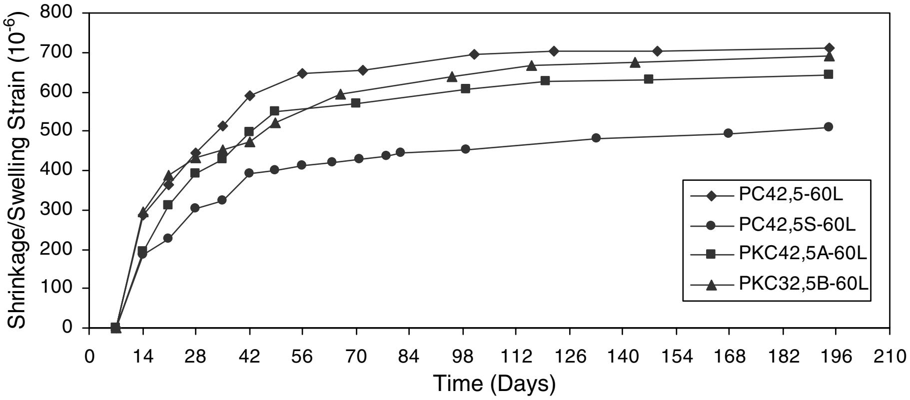

Fig. 16. Shrinkage/swelling strain versus age for C 60 concretes in laboratory.

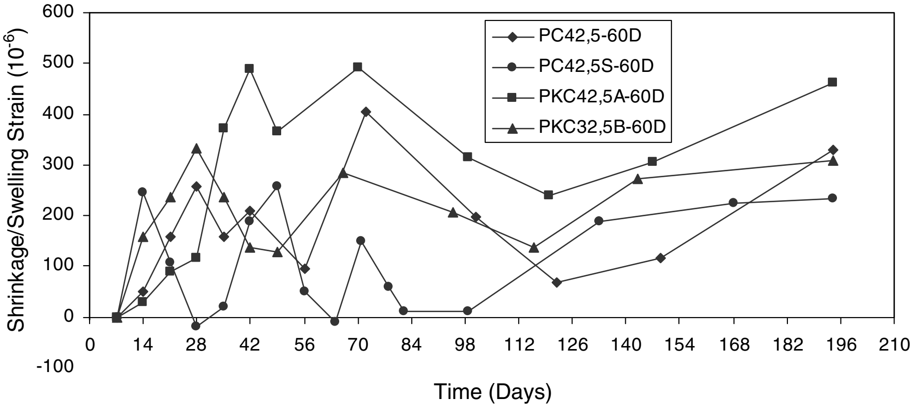

Fig. 17. Shrinkage/swelling strain versus age for C 60 concretes in natural environment.

continuously lower as compared to other concretes. Experimental results are not consistent with the observation of other studies found that concretes with pozzolanic cements have higher shrinkage [15] or the addition of silica fume increases the 28 days ultimate drying shrinkage [5,19].

Drying shrinkage–time diagrams present fluctuations (ups and downs) for outdoor specimens (Figs. 13, 15, and 17). Length change was not only due to shrinkage but swelling as well. It is apparent that considering the production dates of concretes and rainy days, swelling occurred after rainfall. However, measurements were not performed simultaneously for all concrete groups, they depend on random rainfalls. When concretes with three different cements produced at the same days depending on influence of same environmental conditions were considered, similar shrinkage–swelling fluctuations were observed. However, it is noteworthy that PKC-A 42.5 concretes exhibited markedly higher shrinkage after 28 days. PKC-B 32.5 concretes showed moderate behavior in the case of shrinkage–swelling fluctuations. On the other hand, there was minor difference among the shrinkage strains of indoor specimens, also shrinkage of PKC-A 42.5 concretes was slightly lower. It could be said that the effect of moisture movements on PKC-A 42.5 concretes was greater due to the higher increase in capillarity coefficient between 28 and 90 days. On the other hand, concretes with SF experienced slower increase in shrinkage and thereafter ultimate drying shrinkage remained in a lower level as compared to concretes with other cement types, even though SF concretes stored in a less rainy condition due to the later production date. For all specimens, 187-day total shrinkage strains in natural environment were lower than those in the laboratory. This phenomenon is a result of higher relative humidity in natural environment and swelling effect depending on rainfall. Moreover, effect of high internal temperature of outdoor specimens in spring and summer months on the measured length change can be expected, but it is indicated that the importance of this effect is small [20].

4. Conclusions

The following conclusions can be drawn from the above results:

1. It is possible to obtain high-strength concretes by using portland composite cements. In lower strength classes such as C 20, higher cement content and lower w–c ratio should be used in PKC mixtures as compared to PC

mixtures for the same strength and workability. Changing amount of chemical admixture results in almost equal strength values with closer w–c ratio and cement content for three cement types in higher strength classes.

2. In the case of curing concretes produced in rainy months such as winter and spring to provide sufficient moisture within the first 7 days in the mild climate areas, surrounding conditions do not cause negative results in strength development. This is valid for all cement types with or without additives.
3. According to the capillary water absorption results, higher capillarity coefficients were obtained in concretes stored in natural environment, even though higher average relative humidity was observed as compared with laboratory conditions. Although this negative situation seems to be crucial for the structures only exposed to external conditions such as bridges and dams, considering the long-term construction period of reinforced concrete buildings especially in Turkey and in similar countries, more practical interest and attention should be paid to the concretes under these conditions. In order to lower the coefficient of capillary absortion, w–c ratio should be decreased. Due to expectations of customers, PC 42.5 is generally used for ready-mixed concrete production in Antalya region. Concretes in C 20 strength class having the lowest cement content specified in standards can be produced even with high w–c ratio such as 0.71 and without superplasticizer admixture. Using PC 32.5 for low strength classes will be more meaningful. It is observed that using very fine pozzolanic material such as silica fume led to a short-term decrease in capillary absorption, but no significant decline was observed in long-term performance.
4. Similar suggestions can be given also for drying shrinkage. Lower w–c ratio in low strength classes such as C 20 having widespread usage in Turkey contributes to a decrease in drying shrinkage. Using different cement types in higher strength classes with almost equal w–c ratio and dosage causes no significant difference. Swelling takes place immediately after raining. Shrinkage/swelling differences due to the locations of different structural members depending on whether they are affected by direct rain or not in construction can develop additional stresses. The effects of these additional stresses on structure can be a research subject for further studies.
5. According to experimental results, amount of ultimate shrinkage decreased in higher strength classes. It is apparent that the most suitable solution will be to produce higher strength classes for structures disregarding cement types.

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