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Influence of concrete properties on bleeding and evaporation

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Abstract

The bleeding of concrete and the evaporation of water from the surface of concrete, which affect plastic shrinkage cracking, were investigated. The quantities of water evaporated from concrete specimens exposed to different temperatures, relative humidities and windy conditions were evaluated. The evaporation of water from the surface of C25 and C35 concretes, which were made using PKC/B 32.5R and PC 42.5 cements, was determined. It was observed that the cement type affects the bleeding of concrete. Also concrete mixes containing high cement contents yielded minimum quantities of bleeding. It was observed that concrete mixes containing more mixing water yielded the maximum amount of water evaporation.

Keywords: Bleeding; Evaporation; Humidity; Temperature

1. Introduction

When concrete is placed, water rises or bleeds to the surface. This water is observed on the surface and is called bleeding. Bleeding occurs by the rising of the mix water to the surface, and settlement of the solid particles connected with the concrete composition. During the investigations it was observed that concrete mixes containing high cement contents reduced bleeding [1]. Adding silica fume, blast furnace slag and fly ash as pozzolanic materials also reduced bleeding [2]. When cements having high fineness were used, the quantity of bleeding and the rate of bleeding were decreased. It was also found that cements having a high C_3A content reduced bleeding [3]. There were several bleed channels and pores on the surface of freshly placed concretes, which bleed too much [4]. It is known that concretes, which exhibit less bleeding, have a stronger surface [5]. Aggregate grading and aggregate type also affect bleeding. Aggregates containing high quantities of fine particles increased stability of the concrete mix, but the increased amount of mixing water needed to obtain the required workability could increase the bleeding of concrete [6].

In climatic conditions such as high temperature, low relative humidity (RH), high wind velocity and solar radiation, the water evaporation from the surface of concrete accelerates. Water evaporation is also accelerated with high concrete temperature [7]. In concretes having low water–cement ratios, hydration is rapid and water evaporation is accelerated [1]. It has been observed that low-strength concrete mixes containing a greater amount of mixing water yielded maximum rates of evaporation and high-strength concrete mixes yielded lower rates of evaporation [8]. In general plastic shrinkage cracking occurs by rapid drying of the surface of concrete when the rate of water evaporation exceeds the concrete bleeding rate. This type of cracking is more commonly observed in concrete structures having high surface area/volume ratios such as slabs, and these cracks affect the durability of concrete [9].

A chart that provides a graphic method of estimating the rate of evaporation for concrete and air temperatures, RH and wind velocity was published by ACI [10]. This chart was developed from Menzel's equations and previously prepared by PCA. In this chart when the rate of evaporation is expected to approach 1.0 kg/m^2 h plastic shrinkage cracking is likely to occur. It was recommended that the rate of evaporation be best below 0.5 kg/m^2 h [11]. Less or more bleeding creates different effects on concrete properties. The factors that decrease bleeding can increase plastic shrinkage cracking, while the factors that increase bleeding can form defects on

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Table 1
Mixture proportions of fresh concrete specimens prepared

Mix	C25	C35	C25 + W	C35 + W	W/C = 0.67	W/C = 0.57	W/C = 0.50	D275	D375	D450
PKC/B 32.5R										
C (kg)	372	437	372	437	300	350	400	275	375	450
W (kg)	190	190	230	230	200	200	200	180	200	220
S (kg)	624	604	587	566	637	621	605	663	613	571
CSI (kg)	638	617	600	579	651	635	619	678	627	584
CSII (kg)	551	533	518	502	562	548	535	583	543	505
w/c	0.51	0.44	0.62	0.53	0.67	0.57	0.5	0.66	0.53	0.49
PC 42.5										
C (kg)	325	383	325	383	300	350	400	275	375	450
W (kg)	190	190	230	230	200	200	200	180	200	220
S (kg)	642	626	605	590	642	626	611	666	618	579
CSI (kg)	657	641	619	603	657	641	624	681	633	592
CSII (kg)	570	551	537	518	565	554	543	591	548	510
w/c	0.59	0.50	0.71	0.60	0.67	0.57	0.50	0.66	0.53	0.49

the surface of concrete, so all these situations have to be considered to obtain the most advantageous position.

2. Experimental programme

2.1. Research significance

This experimental research reports the influence of cement type and cement content on concrete bleeding and the quantity of water evaporation from C25 and C35 concretes that were subjected to varying exposure conditions. On the freshly placed concretes, the unit weight of the concretes was measured, a slump test was carried out to measure workability, and the quantity of the bleeding was measured. The quantity of water evaporation was measured on C25 and C35 concretes subjected to varying exposure conditions. On the hardened concretes compressive strengths were measured and nondestructive tests were also made [12].

Bleeding and water evaporation tests were performed on C25 and C35 concretes using both PKC/B 32.5R and PC 42.5 cements described in Tables 1 and 2. The concrete constituents were mixed in an electrically operated concrete mixer having 40-l capacity. Firstly, specimens were prepared to determine the effect of mixing water on the bleeding. Therefore, the cement content in C25 and C35 concrete mixes was not changed but the mixing water was increased. The cement content was increased with the same amount of mixing water to determine the effect of cement content on bleeding. At the end, both cement content and mixing water were increased. All mix proportions were applied to both cement types. A napkin with a dry weight of 2 g was used for the bleeding tests on $\phi 15 \times 30$-cm cylinders. Water absorption of the napkin was measured at 10-min intervals up to 1 h on a balance of 1-g sensitivity and recorded as the quantity of bleeding. On the freshly placed concretes density and slump were also measured. For the hardened concrete tests $15 \times 15 \times 15$ cm cube specimens were prepared. After specimens were cured for 28 days in a curing tank, unit weights, ultrasonic velocity, Schmidt hardness and compressive strength tests were made. For the water evaporation tests, $20 \times 20 \times 7.5$ cm wooden molds were used. Nylon sheet was placed into the molds to prevent water loss except evaporation. These specimens were exposed to a temperature of 28 °C, a RH of 50%; a temperature of 28 °C, a RH of 50%, a wind velocity of 15 km/h; a temperature of 28 °C, a RH of 80%; a temperature of 28 °C, a RH of 80%, a wind velocity of 15 km/h up to 5 h. The evaporation tests were conducted in a room keeping

Table 2
Physical properties and chemical analysis of cements

Cement		PKC/B 32.5R	PC 42.5	Cement (%)	PKC/B 32.5R	PC 42.5
Specific surface area (cm^2/gr)		3546	2931	CaO	52.56	62.16
Fineness (μ)		0.5	0.7	SiO_2	26.06	20.03
Specific gravity (gr/cm^3)		2.97	3.13	AlO_3	6.71	4.3
Compressive Strengths (MPa)	2 days	19.2	26.6	Fe_2O_3	3.55	3.79
	7 days	28.4	37.1	MgO	2.66	2.93
	28 days	35.1	47.4	SO_3	1.87	2.36
Setting Time (min)	initial	190	130	C_3S	–	59.79
	final	360	280	C_2S	–	12.32
Trass (%)		20.21	–	C_3A	11.77	4.98
Limestone (%)		9.85	–	C_4AF	10.84	11.53

Table 3
Unit weights and slumps of concrete mixes

Mix	C25	C35	C25 + W	C35 + W	W/C = 0.67	W/C = 0.57	W/C = 0.50	D275	D375	D450
PKC/B 32.5R										
U. weight (kg/dm^3)	2423	2436	2347	2361	2400	2403	2408	2429	2409	2380
Slump (mm)	25	5	145	125	35	35	50	20	60	130
PC 42.5										
U. weight (kg/dm^3)	2432	2436	2362	2372	2411	2419	2426	2442	2422	2396
Slump (mm)	45	35	170	155	45	60	50	5	50	120

constant relative humidity, air temperature and wind velocity. An electric fan 50 × 50 cm and with three different ventilation velocities was used to obtain 15 km/h wind velocity. Air temperature, RH and air velocity were measured with thermometer, hydrometer and hand anemometer, respectively. Weight loss of specimens was measured at 30-min intervals up to 5 h on a balance of 1-g sensitivity, and recorded as the quantity of water evaporation. Table 1 shows the mixture proportions [12].

2.2. Materials

2.2.1. Aggregate

Crushed stone aggregate from the rivulet of Konyaaltý in Antalya was used in the concrete specimens. Crushed stone aggregate was classified size of 0–4 (S), 4–16 (CSI) and 16–31.5 mm. (CSII) and the maximum size is 31.5 mm. Crushed sand (S) have 12% fine particles. Grading curve is between A32 and B32 reference curves given in TS 706 (Turkish code).

2.2.2. Cement

PC 42.5 given in TS 19 and PKC/B 32.5R given in TS 12143 was used in this investigation. These cements (C) were manufactured the Ado Cement Factory in Antalya. Cements were secured in the sacks of 50 kg. Table 2 shows the physical properties and chemical analysis of cements. Tap water (W) was used in the concrete specimens.

3. Test results

3.1. Results of bleeding tests

3.1.1. The effects of cement type on bleeding

Unit weights and slumps of concretes are shown in Table 3. Although there was no significant difference in bleeding quantities between the C25 and C35 quality concretes made with the same types of cement, bleeding was higher in concrete containing PC 42.5 cement. The C35 concrete mix containing PKC/B 32.5R cement showed the lowest bleeding while the highest rate of bleeding was seen in the C25 + W mix containing PC 42.5 cement. With the same amount of water mix and cement content, a bleeding increase of 10–25% was observed in concrete with PC 42.5. The specific surface area of PKC/B 32.5R is larger; it is a finer cement compared to PC 42.5. In addition, PKC/B 32.5R cement contains trass and limestone. Of the main compounds, the quantity of the C_3A is 11.77% in PKC/B 32.5R and 4.98% in PC 42.5 as given in Table 2. It can therefore be said that due to the characteristic difference of this cement, the 1-h bleeding quantity is less in concrete containing PKC/B 32.5R.

3.1.2. The effects of water mix quantity on bleeding

When the water quantity was increased in the same cement content bleeding quantities increased almost two-fold. Bleeding quantity was measured as 1.019 kg/m^2

Table 4
Bleeding quantities of concrete specimens (kg/m^2)

Time (min)	C25	C35	C25 + W	C35 + W	W/C = 0.67	W/C = 0.57	W/C = 0.50	D275	D375	D450
PKC/B 32.5R										
10	0.170	0.113	0.396	0.396	0.509	0.396	0.283	0.453	0.396	0.396
20	0.453	0.340	0.792	0.736	0.849	0.736	0.566	0.736	0.736	0.736
30	0.679	0.509	1.188	1.132	1.132	1.075	0.792	0.849	1.019	0.962
40	0.792	0.679	1.471	1.415	1.471	1.358	1.132	1.132	1.245	1.302
50	0.905	0.849	1.754	1.641	1.811	1.641	1.471	1.415	1.528	1.415
60	1.019	0.905	1.981	1.698	2.037	1.867	1.641	1.641	1.698	1.584
PC 42.5										
10	0.170	0.170	0.566	0.509	0.736	0.622	0.566	0.509	0.566	0.453
20	0.509	0.396	1.075	0.962	1.019	0.905	0.905	0.905	0.792	0.849
30	0.736	0.566	1.528	1.358	1.302	1.245	1.188	1.188	1.132	1.188
40	0.849	0.792	1.811	1.698	1.641	1.471	1.415	1.415	1.471	1.528
50	1.019	0.962	2.150	1.924	2.037	1.811	1.641	1.698	1.641	1.754
60	1.188	1.075	2.377	2.037	2.264	2.150	1.811	1.867	1.924	1.981

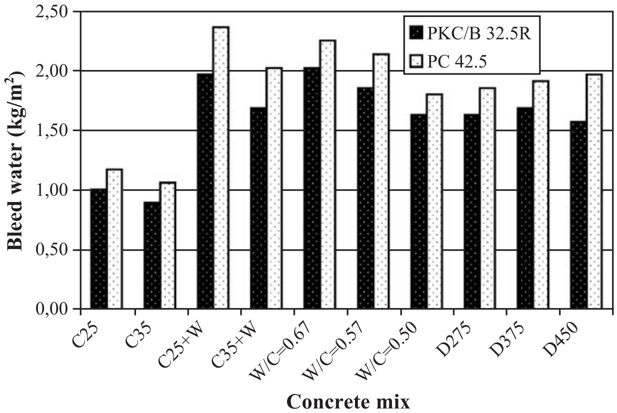

Fig. 1. Bleeding water of concrete mixes.

with 372-kg cement content and as 190 kg mix water in PKC/B 32.5R. When the mix water was increased to 230 kg, the bleeding quantity was measured as 1.981 kg/m^2 1 h later. Bleeding quantity was measured as 1.188 kg/m^2 with a 325 kg cement content and 190 kg mix water in PC 42.5. When the mix water was increased to 230 kg, the bleeding quantity was measured as 2.377 kg/m^2 at the end of the 1 h. The increased quantity of mix water is forced out of the structure of concrete through bleeding. Although there were vast differences between placing capacities of concrete applied with increased content of cement and water mix, the 1 h bleeding quantities stayed at the same level. This can be due to the high content of cement mix as well as the water retention capacity of the cement particles. Retention capacity of cement particles is partly depended on the amount of C_3A and C_4AF in cement [11].

3.1.3. The effects of water–cement ratio on bleeding

To obtain the same concrete compressive strength, different cement contents were used for PKC/B 32.5R and PC 42.5. Therefore, when PC 42.5 cement was used, the water–cement ratio was higher. As the water–cement ratio increased with a certain amount of water, an increase in bleeding was observed. With a water–cement content of 0.67, 0.57 and 0.50 in PKC/B 32.5R cement mix concrete, bleeding quantities were 2.037, 1.867 and 1.641 kg/m^2, respectively, while PC 42.5 concrete cement specimens with the same water–cement ratio showed bleeding quantities of 2.264, 2.150 and 1.811 kg/m^2.

3.1.4. The effects of cement content on bleeding

With specimens prepared by using a certain amount of water and increasing the cement content, the 1 h bleeding quantity was reduced by increasing cement quantities. The PKC/B 32.5R concrete mixes containing cement contents of 275, 375 and 450 kg/m^3 had bleeding quantities in order of 1.641, 1.698 and 1.584 kg/m^2 while these quantities with the PC 42.5 cement were 1.867, 1.924 and 1.981 kg/m^2, respectively. Bleeding tests results carried out on PKC/B 32.5R and PC 42.5 cement concretes are shown in Table 4 while the 1-h bleeding quantities are shown graphically in Fig. 1.

3.2. Results of evaporation tests

Evaporation quantities between 1/2 and 5 h are shown in Fig. 2 under wind effect at 28 °C and 50% RH, in Fig. 3 under wind effect at 28 °C and 80% RH, in Fig. 4 the effect of RH at 28 °C, in Fig. 5 the RH effect with 15 km/h wind velocity and a temperature of 28 °C [12].

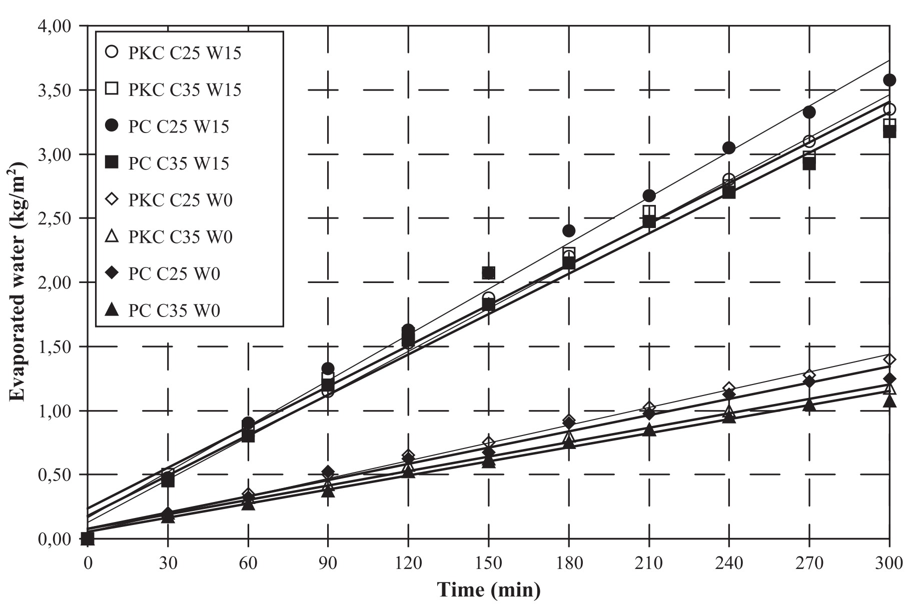

Fig. 2. The effect of wind velocity on evaporation at 28 °C and 50% RH.

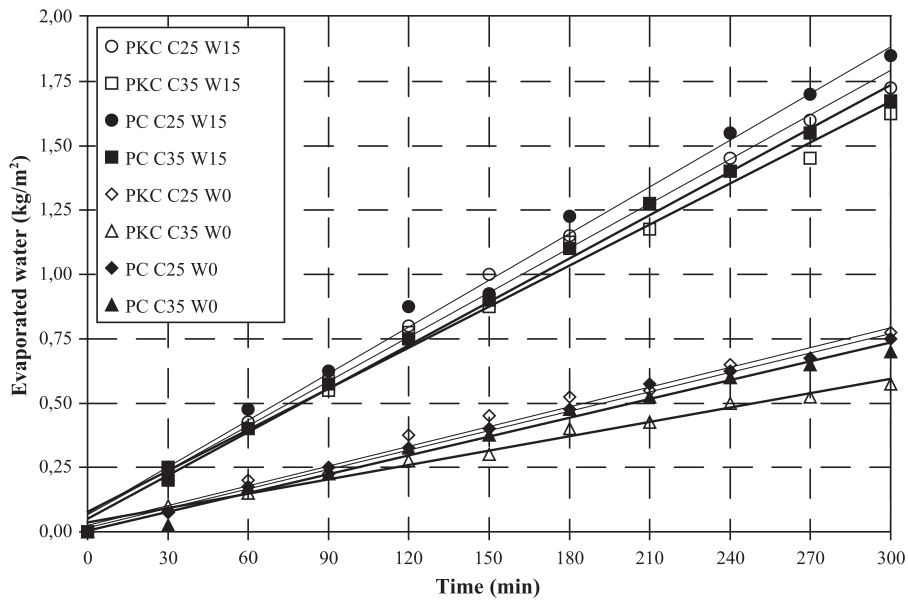

Fig. 3. The effect of wind velocity on evaporation at 28 °C and 80% RH.

3.2.1. The effects of climate conditions on evaporation

The maximum evaporation amounts were observed in C25 concrete specimens prepared with PKC/B 32.5R at 28 °C and 50% RH, in C25 concrete specimens prepared with PC 42.5 at 28 °C, 50% RH and 15 km/h wind velocity, in C25 concrete specimens prepared with PKC/B 32.5R at 28 °C and 80% RH, in C25 concrete specimens prepared with PC 42.5 at 28 °C, 80% RH and 15 km/h wind velocity. These maximum evaporation amounts were measured at higher wind velocities and lower RH.

3.2.2. The effects of cement content on evaporation

Increasing the cement content in a certain quantity of the water mix reduces the evaporation amounts. With the same temperature, RH and wind velocity conditions the evaporation amounts were more in the C25 concrete specimens that contain less cement content.

3.2.3. The effects of water–cement ratio on evaporation

Increasing the cement content in a certain quantity of the water mix, as the water–cement ratio is reduced; it has been observed that the evaporation amounts are reduced. With the

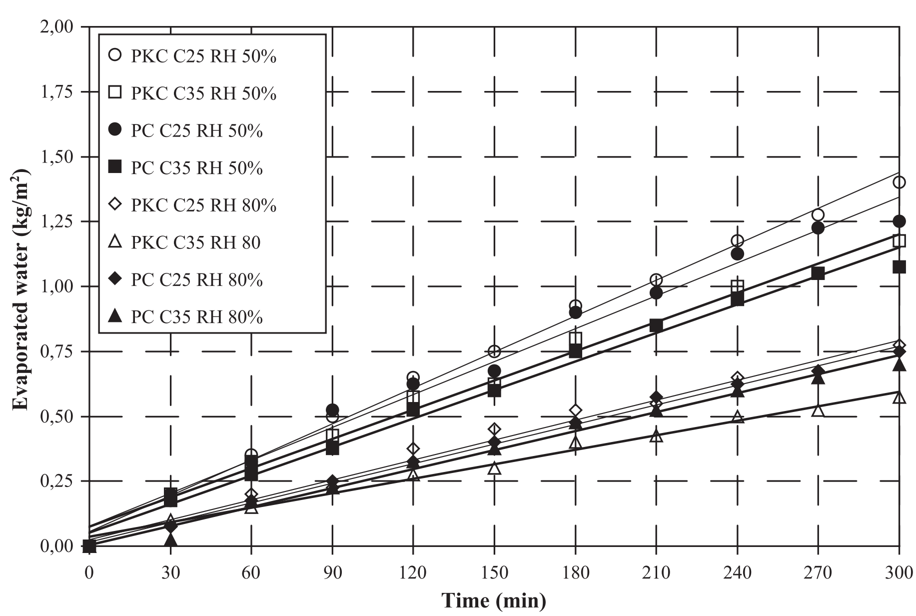

Fig. 4. The effect of RH on evaporation at 28 °C.

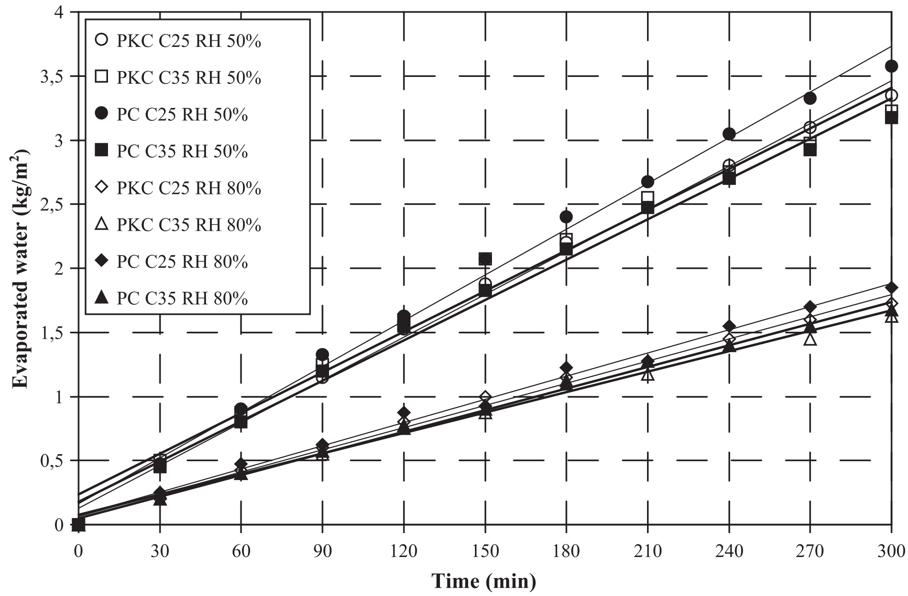

Fig. 5. The effect of RH on evaporation at 28 °C and 15 km/h.

same temperatures, RH and wind velocity factors, concretes with lower water–cement ratios had lower evaporation amounts at the end of 5 h. As the water–cement ratio fell from 0.62 to 0.53 in concrete containing PKC/B 32.5R cement, evaporation amounts were reduced by a ratio of 4–35% while a water–cement ratio reduction from 0.71 to 0.60 in concrete containing amounts were reduced by a ratio of 7–15%.

Table 5
Relationships of evaporated water-time ($y=ax+b$) at varying exposure conditions

Cement type	Concrete quality	a	b	R^2
28 °C, RH 50%, W 0				
PKC/B 32.5R	C25	0.005	0.057	0.995
	C35	0.004	0.076	0.990
PC 42.5	C25	0.004	0.078	0.985
	C35	0.004	0.053	0.991
28 °C, RH 80%, W 0				
PKC/B 32.5R	C25	0.003	0.026	0.985
	C35	0.002	0.036	0.989
PC 42.5	C25	0.003	0.016	0.996
	C35	0.002	0.006	0.989
28 °C, RH 50%, W15				
PKC/B 32.5R	C25	0.011	0.126	0.996
	C35	0.011	0.235	0.982
PC 42.5	C25	0.012	0.173	0.993
	C35	0.011	0.176	0.991
28 °C, RH 80%, W15				
PKC/B 32.5R	C25	0.006	0.066	0.994
	C35	0.005	0.078	0.991
PC 42.5	C25	0.006	0.072	0.993
	C35	0.006	0.051	0.996

3.2.4. The effects of cement types on evaporation

It has been observed that different concrete specimens sharing the same concrete quality show changeable relationships in accordance with climatic conditions. While in circumstances with no wind factor and the same temperature and RH C25 concrete with PKC/B 32.5R cement show a high level of evaporation, C25 concrete with PC 42.5 cement showed high levels of evaporation when it had a wind velocity of 15 km/h. It was observed that at the same wind velocity and temperature conditions at lower RH the C35 concrete with PKC/B 32.5R cement showed higher levels of evaporation. At higher RH the C35 concrete with PC 42.5 cement showed more evaporation amounts after a period of 5 h. Relationships of evaporated water–time at varying exposure conditions are shown in Table 5.

4. Conclusions

Concrete specimens containing PC 42.5 cement had higher bleeding amounts compared with concrete specimens containing PKC/B 32.5R. We can reason with this, as the amount of the main compounds of cement C_3A is lower in PC 42.5 and the trass amount and the specific surface area of the PKC/B 32.5R. Increasing cement contents reduces bleeding. Parallel to this, increasing the water–cement ratio increases bleeding. Increasing the concrete mix water to 28% bleeding quantity increased between 84% and 100%. As the water–cement ratio was increased to 16% and 33%, bleeding quantities reduced to 9% and 24%, respectively. Results of this study show that the water evaporation of the surface of freshly placed concrete is determined by climatic conditions compared to concrete compositions. When RH decreased from 80% to 50%, specimens that were subjected to similar temperatures and wind velocity showed a 100% increase in evaporation quantities. With the same temperature and RH conditions a 200% increase in evaporation was observed when wind velocity was accelerated to15 from 0 km/h. The highest quantities of evaporation occurred during low RH and high wind velocity while the lowest quantities of evaporation were observed in conditions where there was no wind factor and high RH.

References

[1] M.H. Özkul, E. Öztekin, The Effects of Concrete Composition and Climatic Conditions on Plastic Shrinkage, 3, National Concrete Congress, Organized by the Turkish Chamber of Civil Engineers, İstanbul, Turkey, 1994, pp. 163–174 (In Turkish).

[2] A.A. Almussalam, M. Maslehuddin, M. Abolu-Woris, F.H. Dakhil, O.S.B. Al-Amoudi, Plastic shrinkage cracking of blended cement concretes in hot environments, Mag. Concr. Res. (1999 Aug.) 241–246.

[3] A.M. Neville, Properties of Concrete, Longman, Essek, UK, 1981.

[4] M. Arslan, The causes of concrete bleeding, an investigation for its effects and control, technology, Magazine of ZKU Karabük TEF (2000) 59–65 (Year 1, in Turkish).

[5] ACI Committee 201-2R, Guide to Durable Concrete, Manual of Con. Prac., Part 1, 2000.

[6] G.F. Loedolff, A New Approach to Testing of Concrete Bleeding, Concrete 2000, in: R.K. Dhir, M.R. Jones (Eds.), Economic and Durable Construction Through Excellence, vol. 2, E & FN Spon, Cambridge, 1993, pp. 1163–1175.

[7] P.J. Uno, Plastic shrinkage cracking and evaporation formulas, ACI Mater. J. (1998 July–Aug.) 365–375.

[8] A.S. Tamim, H.M. Wajahat, F.W. Faisal, Plastic shrinkage cracking of normal and high-strength concrete: a comparative study, ACI Mater. J. (1996 Jan.–Feb.) 36–40.

[9] M.F. Kocabeyler, Causes and Evaluation of Cracks in Concrete Structures, Concrete–Cement and Dye Seminar, Publication of DSİ, Ankara, 1998, pp. 121–132. In Turkish.

[10] ACI Committee 305, Hot weather concreting, ACI Mater. J. (1991) 417–436.

[11] S. Mindess, J.F. Young, Concrete, Prentice Hall Inc., Englewood Cliffs, New Jersey, 1981, pp. 481–485, 210–212.

[12] V.B. Elgün, Influence of Concrete Properties on Bleeding and Evaporation, MSc Thesis, Osmangazi University, Institute of Science, Eskişehir, Turkey, p. 84. In Turkish.