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Investigation of Effects of Different Environmental Conditions on Balance Time of Bleeding and Evaporation in Plastic Shrinkage of Concrete Pavements

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ABSTRACT: One of the causes of early-age cracking in concrete pavements is plastic shrinkage. This shrinkage occurs after the balance of bleeding and evaporation and the formation of negative capillary pressures at the pavement surface. Different environmental conditions cause the rate of evaporation to change, resulting in a change in time of balance and subsequent cracking. This study, using the standard ASTM C 1579 method, examined the relationship between time of balance of bleeding and evaporation and cracking area in concrete in 27 different environmental conditions, including a combination of three ambient temperatures, three wind speeds, and three relative humidities with using a continuous video recording system and digital image analysis. The results showed that there is a significant relationship between time of balance and cracking area. By reducing the time of balance to 69 minutes, the cracking area increased more than four times. It has been shown that the combination of all three environmental factors has a more significant effect on the severity of cracking than the criticality of only one factor. Relative humidity also has the most excellent effect on the time of balance and cracking area, and the effect of ambient temperature and wind speed is close to each other. According to the results, it was stated that the time of balance might be used as a good factor to investigate the effect of different environmental conditions on the severity of plastic shrinkage cracking in concrete pavements.

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1- Introduction

If durable concrete pavements are constructed, these pavements can serve for many years without maintenance or with little maintenance. One of the reasons reducing the durability of concrete pavement is the presence of cracks, which causes corrosion of the rebars and reduces the level of service [1]. Plastic shrinkage is one of the causes of cracks in concrete pavements, which is caused by the formation of capillary pressures, after the balance of bleeding and evaporation. The balance of bleeding and evaporation is a state in which the rate of bleeding and evaporation reach equal, resulting in the water layer on the pavement surface disappearing [2]. If the mixing design and structural characteristics are the same, the concrete bleeding is constant, but the evaporation rate from the concrete surface is variable and depends on environmental conditions. Changes in environmental conditions cause changes in the time of balance of bleeding and evaporation and onset of capillary pressures. As a result, the severity of cracking changes with changing environmental conditions [3].

Some attempts have been made to investigate the effects of different environmental conditions on the plastic shrinkage cracking of concrete. Turcry and Loukili [4] investigated the effect of wind speed on plastic shrinkage cracking in self-compacting concretes and concluded that wind speed increases the rate of evaporation and shrinkage in concrete [5]. Kwak and Ha proposed a regression model to estimate the drying time in different environmental conditions and used it to predict the occurrence of cracking. Senthilkumar and Natesan [6] predicted the percentage of total cracking areas in some environmental conditions using a multivariate regression model.

The study of the effect of different environmental conditions and each environmental factor on the time of balance and severity of cracking and the relationship between these two variables is of great importance for predicting cracking in concrete pavements. Literature reviews show that less attention has been paid to this issue. For this reason, the present study investigates the effects of the different environmental conditions on the time of balance of bleeding and evaporation and the severity of cracking and their relation in concrete pavement by using digital image analysis.

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2- Materials and Methodology

The materials used in this research include type 425-1 cement with a relative density of 3150 kg/m^3, fine aggregate with a maximum size of 5 mm, the relative density of 2.54 and a fineness modulus of 2.88, coarse-aggregates with a maximum size of 19 mm and the relative density of 2.68, and tap water. Aggregates gradation and mix design

Table 1. Materials constituents for mix design of concrete

Name	Content
Cement (kg/m^3)	460
Water (kg/m^3)	230
Fine aggregates (0-5 mm) (kg/m^3)	928
Coarse aggregates (5-12mm) (kg/m^3)	403
Coarse aggregates (12-19 mm) (kg/m^3)	245

specifications follow the criteria of concrete pavement design, construction, and maintenance manual, No. 731 [1]. W/C of 0.5 and the cement content of 460 kg/m^3 were chosen to increase the cracking potential. It may cause violations of some of the requirements in the manual. However, it was tried to meet other criteria for the reasons mentioned. Table 1 shows materials constituents for the mix design of 1 m^3 concrete. Slump, density, and air content of concrete were 120 mm, 3.1%, and 2335 (kg/m^3), respectively. 28-day compressive, modulus of rupture, and splitting tensile strength of concrete obtained from performed mechanical tests were 27.7, 3.95, and 2.90 MPa.

The ASTM C1579 method for the evaluation of plastic shrinkage cracking in 27 different climate conditions, which are a combination of three values of ambient temperature (T:30, 35 and 40 ° C), three values of relative humidity (R:20, 45, and 70%) and three values of wind speeds (W:18, 24 and 30 km/h) were used. The environmental simulator chamber created different climate conditions for 22 hours. Two samples in each condition were examined, and the average results were considered. Also, digital images of the specimen surface during the experiment were taken by the continuous photo-taking system to evaluate the time of balance of specimens. The bleeding and evaporation balance is a state in which the evaporation rate is equal to the bleeding, and no water is observed on the specimen surface. Digital images were analyzed in image analysis software Digimizer version 5.3.5 at intervals of 10 minutes and 2 minutes to determine this variable, and the time of not observing water at the specimen surface was recorded as the time of balance. Digital images were taken from the cracking path of the samples at 4 cm intervals by a digital microscope 2 hours after the termination of the experiment. These images were analyzed in image analysis software to calculate the crack area of each sample. The software calculates the cracking area in the image by using the image analysis commands.

3- Results and Discussion

Figure 1 shows Shows changes in cracking area (A_c) over time of balance (T_b) in each of the environmental conditions . Analysis of variance (ANOVA) was performed on the fitted curve in IBM SPSS Statistics 26. According to F=1035.324 and sig=0.000<0.05, it can be seen that there is a significant relationship between T_b and A_c. By reducing the T_b from 86 minutes to 17 minutes, A_c has increased more than four times. Environmental conditions in the first part (harsh) include T=35,40 °C, R=20,45%, and W=24,30 km/h, in the second part(milder), include T=30,35 °C, R=45,70%, and W=18,24 km/h, and in the third part (mild) include T=30 °C, R=70%, and W=18 km/h. It indicates that the combination of all three environmental factors has a more significant effect on the severity of cracking than the criticality of only one factor. It is also observed that the change in relative humidity has the greatest effect on T_b and A_c, while the effect of ambient temperature and wind speed are close to each other. The results of this section indicate that T_b may be a good factor to predict the severity of cracking in pavements in different environmental conditions.

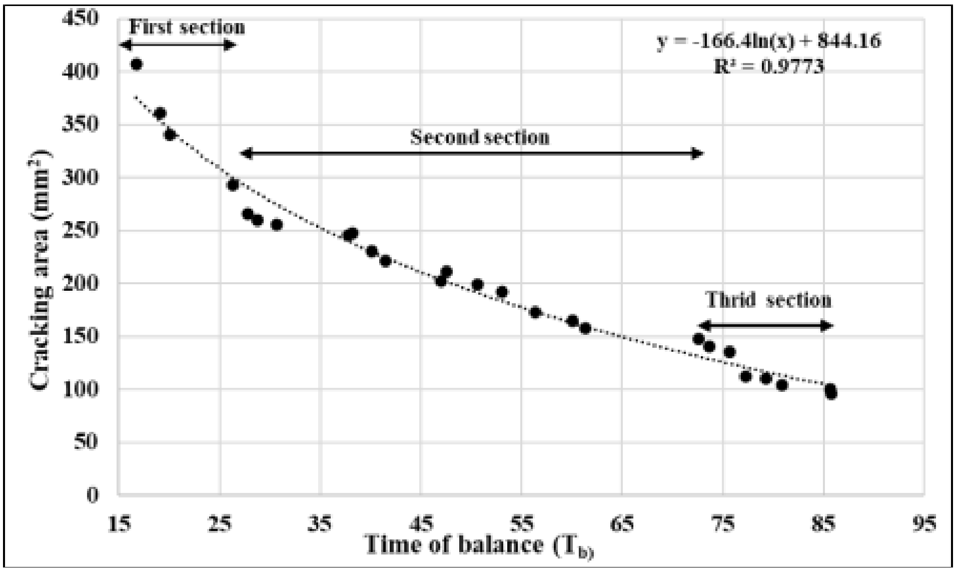

Fig. 1. Cracking area changes relative to the time of balance

Table 2. Results of the analysis cracking area model

	Standardized B	R^2	Adj.R^2
Constant	-		
Temperature (T)	0.445	0.952	0.946
Humidity (R)	-0.836		
Wind speed (W)	0.405		

Table 2 shows the results of the multivariate linear regression model analysis of A_c in different environmental conditions. Given the values of R^2 and Adjusted.R^2, the regression model seems appropriate. According to the standardized beta coefficient (Standardized B), it can be seen that the relative humidity has the greatest effect on the A_c, and the effect of ambient temperature and wind speed are close to each other.

Equation 1 shows the multivariate linear regression model of the crack area under different environmental conditions.

$$A_c = -125.612 + 8.976 * T - 3.376 * R + 6.814 * W \quad (1)$$

ambient temperature (°C), R is the relative humidity (%) and W is the wind speed (km/h).

4- Conclusions

In this study, the relationship between the time of balance of bleeding and evaporation with the severity of plastic shrinkage cracking in the concrete pavement in 27 different environmental conditions was investigated with the use of digital image analysis. Some of the most important results of this research are as follows:

-There is a significant relationship between time of balance and cracking area.

-Relative humidity has the most significant effect on the time of balance and cracking area. The effect of ambient temperature and wind speed is close to each other.

-the combination of all three environmental factors has a more significant effect on the severity of cracking

-Time of balance may be a good factor for the prediction of cracking severity in concrete pavements in different environmental conditions.

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