



# Effect of placement temperature and curing method on plastic shrinkage of plain and pozzolanic cement concretes under hot weather



Muhammad Nasir<sup>a,\*</sup>, Omar S. Baghabra Al-Amoudi<sup>b</sup>, Mohammed Maslehuddin<sup>c</sup>

<sup>a</sup> Department of Construction Engineering, Imam Abdulrahman Bin Faisal University, Dammam 31451, Saudi Arabia

<sup>b</sup> Department of Civil and Environmental Engineering, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia

<sup>c</sup> Center for Engineering Research, Research Institute, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia

## HIGHLIGHTS

- Effect of concrete placement temperature and curing method was investigated.
- Critical temperature for plastic shrinkage was noted to be 25 while for mechanical and durability properties it was both 25 and 45 °C.
- Curing compound effectively minimizes the plastic shrinkage as compared to plastic sheeting.
- Pozzolanic materials performs better at higher concrete placement temperatures of 32 up to 45 °C.

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## ABSTRACT

This paper reports the results of a study conducted to investigate the effect of concrete placement temperature and curing method on the plastic shrinkage of plain and pozzolanic cement concretes. The concrete specimens were cast at a temperature of 25, 32, 38 or 45 °C and exposed to the ambient summer conditions. The specimens were cured by applying a water-based curing compound or covering with a plastic sheet. The performance of ordinary Portland (Type I) cement, fly ash (FA), very fine fly ash (VFFA), silica fume (SF), blast furnace slag (BFS) and natural pozzolan (NP) was evaluated by measuring the plastic shrinkage strain. The results indicated that the curing compound was effective in decreasing the shrinkage strain in all concretes. It was also noted that the critical temperature at which the maximum shrinkage strain occurred was 25 °C and as the concrete temperature was approaching the ambient temperature, the shrinkage strain decreased. The 28-day compressive and split tensile strength and pulse velocity were also determined to study the effect of placement temperature on these properties. These data indicated that the critical placement temperature was both 25 and 45 °C while the optimum temperature for all cementitious materials was either 32 or 38 °C.

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## 1. Introduction

Plastic shrinkage cracking has been and continues to be one of the major causes of long-term durability problem in concrete structures especially in harsh climatic conditions. Plastic shrinkage occurs during the plastic state of concrete when the rate of evaporation exceeds the rate of bleeding. Further, concrete cracks whenever the induced shrinkage becomes more than its tensile strength [1]. These cracks may appear in all types of structural members but it is more likely in components with large surface area to thickness ratio, such as slabs. Moreover, plastic shrinkage cracking is considered as the prime source of initiating deterioration of concrete

structures in hot weather conditions, because such cracks permit and promote the diffusion of aggressive chemical species like O<sub>2</sub>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup> and CO<sub>2</sub> into the concrete matrix, causing deterioration of reinforced concrete.

A review of the literature indicates that there are many factors influencing the shrinkage of concrete including: mix composition, construction practices and environmental conditions. It was reported [1,2] that shrinkage increases with an increase in cement, water or fine aggregate content in the mix. However, Rixom and Mailvaganam [3] reported that the shrinkage due to admixtures depends on its type, dosage and method of incorporating it into the concrete mixture. Hasanain et al. [4] indicated that in addition to concrete constituents, the time of concrete placement, difference in the ambient and concrete temperature and shading of concrete surface tend to affect the rate of evaporation and hence the

\* Corresponding author.

E-mail address: [mnmuhammad@uod.edu.sa](mailto:mnmuhammad@uod.edu.sa) (M. Nasir).

shrinkage. Several guidelines [1,5–7] mentioned the adverse effects of hot weather on the fresh and hardened properties of concrete adding that the undesirable consequences are extremely influenced if the high ambient air temperature is accompanied with the other hot weather components, such as low relative humidity, high wind speed and solar radiation. Other studies [8,9] also attributed the hot weather conditions for causing shrinkage, based on their experimental results. They exposed concrete specimens at varying levels of hot weather components, including air temperature, relative humidity and wind velocity. It was concluded that plastic shrinkage cracks develop mainly at elevated air temperatures.

To avoid the undesirable effects of hot weather and to produce quality concrete, many building authorities and international codes of practice, including ACI 305, limit the maximum allowable fresh concrete temperature to 35 °C. Further, to achieve this limit, these codes recommend to take certain precautionary measures whenever the rate of evaporation exceeds 1.0 kg/m<sup>2</sup>/hr [6,10]. However, some studies indicated that under hot weather conditions, concrete tends to crack by plastic shrinkage even at lower rate of evaporation. For example, Berhane [11] and Almusallam et al. [12] observed the appearance of plastic shrinkage cracks when the evaporation rate was 0.4 and 0.2–0.7 kg/m<sup>2</sup>/hr, respectively. Al-Gahtani et al. [13] also reported that concrete exposed to natural hot environmental conditions of eastern Saudi Arabia exhibited much higher evaporation of mix water compared to that estimated using the ACI Nomograph. Therefore, it was suggested that the recommendations of ACI Committee 305 regarding minimizing the rate of water evaporation, such as lowering the concreting temperature, increasing the humidity by water spraying, and erecting wind barriers, should be adopted. However, these measures may not be sufficient under hot and arid environment and unless extraordinary precautionary measures are taken, concrete cast, placed, and cured in hot weather conditions will be of low quality [14].

One of the solutions suggested by concrete experts for minimizing the effect of hot weather conditions is to incorporate pozzolanic cementing materials, such as silica fume, fly ash, blast furnace slag, or natural pozzolans owing to their technical, economic and environmental advantages. However, the use of supplementary cementing materials requires special care regarding their curing because of their vulnerability to plastic shrinkage cracking as has been reported by several researchers. For instance, due to insufficient curing of silica fume and fly ash cement concrete, several problems of cracking have been reported from the field [15–17].

From the review of aforementioned literature, it could be noted that the specified fresh concrete temperature limit by the codes of

practice is hardly investigated to assess its effect on fresh concrete properties, particularly plastic shrinkage. Further, the applicability of the temperature limit on pozzolanic cement concrete as well as the impact of curing the concrete by the application of a curing compound have not been thoroughly investigated. Therefore, this study was aimed to investigate the effect of concrete placement temperature and curing method on plastic shrinkage strain of plain and pozzolanic cement concretes under hot weather conditions and to correlate such experimental data with some of the mechanical properties like compressive and split tensile strength and ultrasonic pulse velocity.

## 2. Methodology of research

### 2.1. Materials

Plain and pozzolanic cement concrete specimens were prepared with ASTM C 150 Type I cement with a specific gravity of 3.15. In pozzolanic cement concrete mixtures, 10% very fine fly ash (VFFA), 30% fly ash (FA), 7% silica fume (SF), 70% blast furnace slag (BFS) and 20% natural pozzolan (NP) were incorporated as partial mass replacement of Type I cement. The chemical composition of Type I cement and the pozzolanic materials is shown in Table 1.

A total of 24 concrete mixtures were cast in which crushed limestone was utilized as coarse aggregate having absorption and bulk specific gravity of 1.1% and 2.6, respectively. Dune sand with an absorption and specific gravity of 0.6% and 2.56, respectively was used as the fine aggregate. The grading of coarse aggregates confirmed to size # 8 of ASTM C 33. A cementitious materials content of 350 kg/m<sup>3</sup>, a water to cementitious materials (w/cm) ratio of 0.4, and a coarse to fine aggregate ratio of 1.8 by mass, were kept invariant in all the concrete mixtures.

### 2.2. Specimen preparation

First, trial mixtures were carried out to target the following objectives outside the laboratory under the ambient summer hot weather for all the cementitious materials:

- i. Slump of 100 ± 25 mm; and
- ii. Concrete mix temperature of 25, 32, 38 or 45 °C.

The required slump was maintained by adding differing dosages of a superplasticizer. However, to achieve the fresh concrete temperature of 25 or 32 °C, varying amount of flaked ice was blended in the mix water. Further, fine and coarse aggregates were cooled to attain the desired temperature of concrete. On the contrary, to target the mix temperature of 38 or 45 °C, the aggregates were heated in the sun prior to casting concrete at distinct time period and/or heated water was used. Moreover, for a reasonable comparison of the degree of plastic shrinkage in fresh concrete, all the concrete mixes were cast during the summer months (June and July) between 9:00 am and 12:00 noon. The average ambient temperature and relative humidity recorded was about 38 ± 2 °C and 37 ± 3%, respectively at the time of casting of all concrete mixtures. Fig. 1 shows the monthly average temperature, precipitation, wet days, sunlight hours, relative humidity and wind speed in 2013 (experimental period) at Dhahran, Saudi Arabia [courtesy: [climatemps.com](http://climatemps.com)].

The temperature of the freshly mixed concrete was measured by dipping the sensor of a digital thermometer (±0.3 °C accuracy) 75 mm deep into concrete. This ensured that the temperature reading is not affected by environmental tempera-

**Table 1**  
Chemical Composition of Type I and Pozzolanic Cementing Materials.

Constituent Weight (%)	Type I	VFFA	FA	SF	BFS	NP
CaO	64.35	4.4	10.0	0.48	44.0	7.44
SiO <sub>2</sub>	22	53.5	52.3	92.5	27.7	40.23
Al <sub>2</sub> O <sub>3</sub>	5.64	34.3	25.2	0.72	12.8	14.51
Fe <sub>2</sub> O <sub>3</sub>	3.8	3.6	4.6	0.96	1.20	17.98
K <sub>2</sub> O	0.36	–	0.10	0.84	0.10	0.89
MgO	2.11	1.0	2.20	1.78	8.80	8.3
Na <sub>2</sub> O	0.19	–	0.10	0.5	0.40	3.6
Equivalent alkalis (Na <sub>2</sub> O + 0.658K <sub>2</sub> O)	0.42	–	–	–	–	–
Loss on ignition	0.7	–	–	1.55	–	1.6
C <sub>3</sub> S	55	–	–	–	–	–
C <sub>2</sub> S	19	–	–	–	–	–
C <sub>3</sub> A	10	–	–	–	–	–
C <sub>4</sub> AF	7	–	–	–	–	–

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