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The effects of urea on strength gaining of fresh concrete under the cold weather conditions

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HIGHLIGHTS

- Effects of urea on the compressive strength of concrete exposed to cold weather investigated.
- Workability of concrete was improved.
- Urea provides protection against freezing in the plastic state concrete.

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ABSTRACT

Objective: The study focused on the application of urea to the cold weather concreting. One of the advantages of this method is to simplify curing after concrete placement at low temperatures; only an anti-evaporation sheet is necessary to keep fresh concrete wet until finishing of concrete curing.
Method: Urea is used at level of 6% by weight of cement dosage in the mixtures. After casting, one group of concrete samples were cured in the different deep freezes at -5, -10, -15, -20 °C for 7, 14 and 28 days and then the same samples were cured in water for 7, 14 and 28 days in accordance with ASTM C 192. Compressive strength of hardened concrete was determined according to ASTM C 39.
Results: At -5 °C and -10 °C the admixture's positive effect is evident but at -15 °C and -20 °C the same effect was not achieved when compared to mixes without antifreeze admixtures. As a result at cold weather concreting, urea can be an effective alternative to the other precautions up to -5 °C without any protections. In this paper Scanning Electron Microscopic (SEM) observations also helped to explain the effect of Urea on concrete under cold weather conditions.

1. Introduction

According to ACI 306R-10 cold weather is defined as a period in which, as more than 3 consecutive days, the following conditions exist: (1) the average daily air temperature is less than 5 °C and (2) the air temperature is not greater than 10 °C for more than one-half of any 24-h period. The average daily air temperature is the average of the highest and the lowest temperatures occurring during the period from midnight to midnight [1]. Concrete exposed to temperature cycles, where water freezes to ice and ice melts to water in winter, is deteriorated due to freezing and thawing [2].

Preventing damage to concrete due to freezing at early ages is crucial. When no external water is available, the degree of saturation of newly placed concrete decreases as the concrete gains maturity and the mixing water combines with cement during hydration. Under such conditions, the degree of saturation falls below the critical level (the degree of water saturation where a single cycle of freezing would cause damage) at approximately the time when the concrete attains a compressive strength of 3.5 MPa [3]. At 10 °C, most well-proportioned concrete mixtures reach this strength during the second day [1].

Currently, there are no commercially admixtures, when used alone that will prevent fresh concrete from freezing at an internal temperature of −5 °C. Admixtures are available that allow concrete to gain strength at air temperatures below zero, but these admixtures, when used at their recommended dosages, will not prevent freezing. They promote strength gain by accelerating cement hydration, which sufficiently increases the rate of internally generated heat to maintain concrete temperatures above freezing until enough strength is developed to resist damage from freezing [4,5].

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There are several alternatives for cold weather concreting. These are (1) enclosing and heating the area in which the concrete is to be placed, (2) heating the water and aggregates, (3) increasing the cement dosage or Type III-R Portland cement, (4) the use of chemical admixtures to accelerate concrete set and increase early-age strength development, and (5) the use of protective insulation.

Significant benefits are derived from the use of high-performance concretes that contain cold weather concreting admixtures. For the ready mixed concrete producer, the use of the cold weather admixture will reduce hot water heating costs and the need to increase cementitious materials contents.

Benefits for contractors include the ability to place concrete in subfreezing temperatures, reduced in-place concrete costs, earlier stripping of forms and, ultimately, faster and earlier completion of construction and an overall reduction in construction costs. For the owner, the main benefit is earlier use of the structure, and possibly, a reduction in loan interest payments [6].

Russia has had more than 40 years of experience on the application of antifreeze admixtures in unheated concrete at minimum daily temperatures below 0 °C and down to −30 °C. Russia has used sodium nitrite, calcium nitrate, calcium chloride, sodium chloride, potash, calcium nitrite nitrate, urea, and calcium chloride–nitrite–nitrate. However, only calcium nitrite–nitrate and calcium chloride–nitrite–nitrate are, reportedly, specially formulated for use as antifreeze admixtures in Russia [6,7]. Korhonen et al. explained that in the combined use of urea and calcium nitrite, if urea content increased the workability of the mixture increases [8].

Bennett reported from U.S. Research that for curing temperatures 20 °C, −5 °C, −10 °C and −20 °C, the compressive strengths of mixture containing 10% urea with 0.45 *w*/*c* were 91%, 88%, 42%, 0% of 28 days compressive strength of control mixture in 20 °C, respectively [9].

Korhonen experimentally studied the combined use of urea and P20 (ready additive) in different temperatures. As a result, for 20 °C, −5 °C and −10 °C, the compressive strengths of mixture of P20 and urea (1.5% + 4.5%) were 28.1, 13.3 and 3.8 MPa at 7 days, 34.9, 22.2 and 9.3 MPa at 14 days and 37.6, 27.1 and 12.9 MPa at 28 days, respectively [10].

Korhonen experimentally studied the use of 3%, 6% and 9% urea in different temperatures. As a result, the 28 days compressive strengths of mixtures containing 3%, 6% and 9% urea were 94.1%, 98% and 92.2% for 20 °C, 30%, 38.6% and 60.8% for −5 °C, 13%, 14.6% and 18.7% for −10 °C and 0%, 0% and 0% for −20 °C, as percentage of 28 days compressive strength of control mixture in 20 °C, respectively [11].

Antifreeze admixtures (calcium nitrate, calcium nitrite and urea, etc.) are believed to function in two ways [7,12] first, by lowering the freezing point of the water; and second, by accelerating the hydration of cement. The main function of an antifreeze admixture is to prevent water from freezing so that it can react with cement at low temperature and initiate hydration reaction of cement with water. Generally, antifreeze admixtures utilize both freezing point depressants and accelerators and urea ($CO(NH_2)_2$) is in this group [13].

The effectiveness of antifreeze for reducing the freezing point of water is related to its eutectic point. The eutectic point is the lowest temperature below which additional quantities of antifreeze will not depress the freezing point further. Introduction of most of the antifreeze admixtures affects the pore structure of the cement paste. Antifreezing admixtures increase the surface area of cement paste and enhance to promote strength. The zone of contact between aggregate and cement paste improves impermeability, frost and salt resistance of concrete increase. Thus a dense structure is formed in cement paste. That is, more dense structure is lowering freezing point. If the ambient temperature is lower than eutectic point of urea, this case cannot valid.

The mode of action of the antifreezing admixtures is (a) to lower the freezing point of water in concrete and act as either a weak accelerator or retarder of setting and hardening using sodium nitrite, sodium chloride, weak electrolytes and organic compounds such as high molecular weight alcohols and carbamide, or (b) to accelerate significantly the setting and hardening with good antifreezing action using chemical such as calcium chloride, sodium chloride, sodium nitrite, calcium nitrite–nitrate and urea. This effect of the antifreezing admixtures is related to its influence on the hydration of silicate and aluminate components of cement. When the admixtures such as urea do not contain the same ions as in the cement phases (i.e., Ca, Si or Al ions), they accelerate the hydration process chiefly by increase in the solubility of C_3S and C_2S [5]. Antifreezing admixtures (electrolytes) not only accelerate concrete hardening and reduce the electric heating period but also raise the electrical conductivity of the liquid phase, thus allowing electric heating at a temperature below 0 °C. Also this admixtures are increased the surface area of cement pastes and improved the zone of contact between the cement paste and aggregates. Electrolytes in contact with alite (C_3S) and belite (C_2S) change ionic strength of the solution and density of pore solution [7].

The goal of the study was to investigate urea as an antifreeze admixture. The effects of urea on the compressive strength of concrete exposed to the −5, −10, −15, and −20 °C was studied. Samples were also scanned by scanning electron microscope (SEM) and they were used to evaluate and discuss the results.

2. Materials and methods

ASTM Type I normal Portland cement was used. Its physical properties and chemical composition are shown in Tables 1 and 2, respectively. Urea antifreeze was from (Tekkim Kimya San. ve Tic. Ltd. Şti) source in Turkey. The chemical and physical properties of the used urea are given in Table 3.

Crushed limestone with a maximum nominal size of 16.0 mm was used as the coarse aggregate. The fine aggregate was natural sand from Aşkale region in Erzurum, Turkey. The coarse and fine aggregates were separated into different size fractions (0–2, 2–4, 4–8, 8–16 mm) and recombined (30%, 15%, 20%, 35% by volume of total aggregate for 0–2, 2–4, 4–8, 8–16 mm size, respectively) to a specified grading as shown in Table 4. The specific gravity of 0–2, 2–4, 4–8, 8–16 mm were 2.40, 2.47, 2.54 and 2.63, respectively.

The concrete mixtures proportions are given in Table 5. The water-to-cement ratio of the control mixes was selected to be 0.40 with a cement content of 400 kg/m^3 of concrete. The concrete was mixed in a laboratory counter–current mixer for a total of 5 min. 100 × 200 mm cylinder forms were used. After casting, the cylinders were immediately transferred to the deepfreezes at −5 °C, −10 °C, −15 °C and −20 °C for 7 days (group A), 14 days (group B) and 28 days (group C). Following these periods, the cylinders were demoulded and transferred to the lime saturated water curing tank (23 ± 1.7 °C) for extra, 0, 7, 14 and 28 days (A0, A7, A14, A28; B0, B7, B14, B28; C0, C7, C14 and C28, respectively) in accordance with ASTM C 192 [14]. Before compressive strength tests, samples were kept in room temperature for 24 h and the cylinders were capped prior to compressive strength test to prevent inaccurate strength results.

Compressive strength of hardened concrete was determined for three samples from each curing condition and each group according to ASTM C 39 on standard cylindrical specimens [15]. Remaining samples were transferred to the lime saturated water curing tank (23 ± 1.7 °C) for extra 7, 14 and 28 days. Results of control samples and urea samples were compared for the same curing conditions.

Table 1
Physical properties of Portland cement.

CEM I 42.5 (ordinary Portland cement)	Results	TS EN 197/1 standard data	
		(min)	(max)
2 days compressive strength (N/mm^2)	27.9	20.0	–
7 days compressive strength (N/mm^2)	44.9		
28 days compressive strength (N/mm^2)	55.9	42.5	62.5
Initial set time (min)	170	60	–
Final set time (min)	230		
Volume expansion (mm)	1	–	10
Specific surface (cm^2/g)	3285	–	–
Specific gravity	3.17		