International Balkans Conferance on Challenges of Civil Engineering, BCCCE,
19-21 May 2011, EPOKA University, Tirana, ALBANIA

The Effects Of The Urea On Cold Weather Strength Gaining Of Fresh Concrete

Ramazan Demirboğa[1,2], Fatma Karagöl[1], Rıza Polat[1], Mehmet Akif Kaygusuz[1]

[1]*Department of Civil Engineering, Atatürk University, 25240, Erzurum, Turkey*
[2]*Engineering Faculty Housing Research Center, University Putra Malaysia, Serdang, Selangor, Malaysia*

ABSTRACT

Common methods of concrete placing in freeze and cold weather have not been changed for ages. The methods are heating materials, melting ice and curing fresh concrete by insulation devices and applying heating systems until finishing concrete curing. Utilizing chemical compounds in fresh concrete in order to decrease freezing temperature and continuation of hydration process at low temperatures are very limited. In addition, the studies related to the behavior of the chemical admixture and the effects of them on the properties of the concrete are very scarce in technical literature. There are not any standards related to the application of antifreeze admixture to the concrete neither in Europe nor in U.S. Because of the reasons the study focused on the application of urea to the cold weather concreting. One of the advantages of this method is having an easy curing condition after concrete placing, in which, only one anti-evaporation sheet is used to keep fresh concrete wet until finishing of concrete curing. For this reason, Urea is used at level of %6 by weight of cement dosage in the mixes. After casting, one group of concrete samples were cured in the different deep-freezes at -5, -10, -15, -20^{0}C for 7, and then that same samples were cured in water for 28 days. At -5^{0}C and -10^{0}C the admixture positive effect is evident but at -15^{0}C and -20^{0}C it has not got the same effect 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^{0}C without any protections.

Keywords: *urea, concrete compressive strength, cold weather concreting, antifreeze admixture*

1. Introduction

According to ACI 306R-88 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 5ºC and 2) the air Temperature is not greater than 10ºC for more than one-half of any 24-hr 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].

Prevent 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 [2]. At 10ºC, most well-proportioned concrete mixtures reach this strength during the second day.

Currently, there are no commercially available admixtures, when used alone that will prevent fresh concrete from freezing at an internal temperature of –5ºC. 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 [3].

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 CWA 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 [4].

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 [4,5].

Antifreeze admixtures are believed to function in two ways [5,6] first, by lowering the freezing point of the water; and second, by accelerating the hydration of cement.

The goal was to investigate urea an antifreeze admixture. The effects of urea on the compressive strength of concrete exposed to the -5, -10, -15, and -20°C was studied.

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 from (Tekkim Kimya San. ve Tic. Ltd. Şti) source in Turkey was used.

Crushed limestone with a maximum nominal size of 16.0 mm was used as the coarse aggregate. The fine aggregate was natural sand from Erzurum/ Aşkale region. 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 Figure 1. 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 3. The water-to-cement ratio of the control mixtures 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. 100x200mm cylinders were cast from each mixture. The cylinders were consolidated with needle vibrator. After casting, the cylinders were immediately transferred to the deepfreezes at -5°C, -10°C, -15°C and -20°C for 7 days. Compressive strength and UPV of three samples from each curing condition was determined. Remained samples were transferred to the lime saturated water curing tank (23 ± 1.7°C) for extra 28 days. Before testing, the cylinders were capped using a proprietary capping compound. Results were compared with both control (only 28-day water cured) and samples without urea but exposed to the same curing conditions.

Table1 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, (minute)	170	60	-
Final set time (minute)	230		
Volume expansion, (mm)	1	-	10
Specific surface, (cm^2/gr)	3285	-	-
Specific gravity	3.17		

Table 2 Chemical properties of Portland Cement

	Results	TS EN 197/1 Standard data
		(max)
Heating loss (%)	2,03	5,00
Insoluble matter (%)	0,25	5,00
Cl_2 (%)	0,0102	0,10
SiO_2 (%)	20,54	-
Al_2O_3 (%)	5,12	-
Fe_2O_3 (%)	3,69	-
CaO (%)	62,98	-
MgO (%)	1,70	-
SO_3 (%)	2,88	-

Main constituent (%)	
C_3S	53,2
C_2S	16,7
C_3A	7,6
C_4AF	10,7

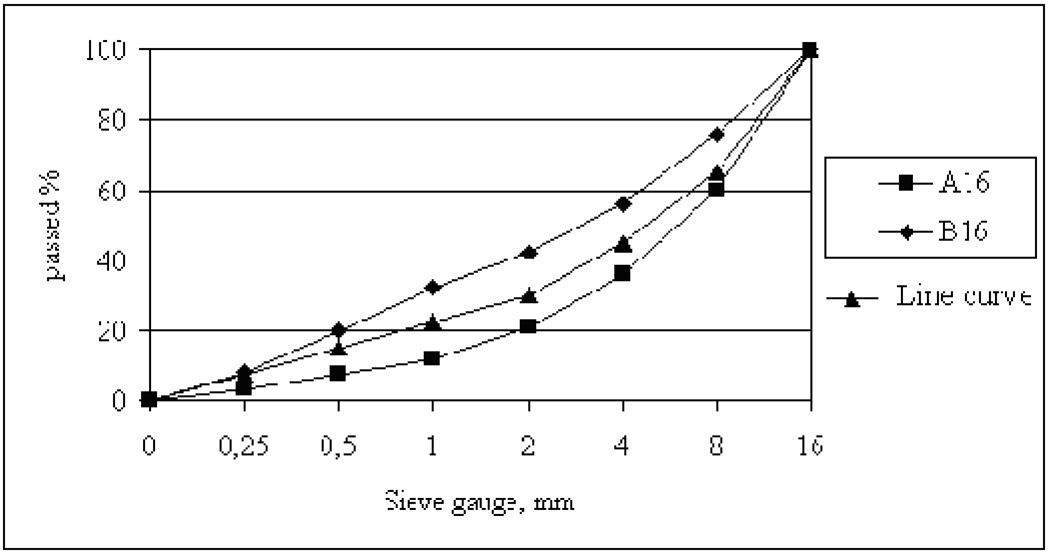

Figure 1 Gradation of combined aggregates

Table 3 Mixtures proportions of concrete

Materials		Control mixture	Antifreeze mixture
w/c ratio		0.40	0.40
Cement (kg)		400	400
Urea (kg)		_	24
Water (kg)		160	160
Super plasticizing agent 0.5%, (kg)		2	2
Air		0.02	_
Aggregate (kg)	0-2 mm	498	485
	2-4 mm	256	249
	4-8 mm	352	344
	8-16 mm	638	622
Total(kg)		2306	2286
Slump (cm)		4	12

3. Discussion

3.1. Workability

In order to make high quality and efficient concrete construction, fresh concrete should have suitable consistency to answer to the environment and the structure and construction conditions of constructed building members. Otherwise insufficient workability of concrete may cause serious compressive strength reductions. Thus, quality of fresh concrete refers mainly to its workability and flowability. The properties of freshly mixed concrete were determined in respect of slump. The average slump of different control mixture was 4 cm. The average slump flow of the 6% urea was 12 cm, which showed reasonably good flowability. Slump of urea's sample was higher than that of control sample. The main reason is that 6% urea behaved as a superplastisizer and increased the workability of the mixture.

3.2. Compressive strength of 7 days in deepfreeze curing

A common indication of concrete quality is compressive strength**.** Safe and economical scheduling of crucial construction operations makes it important that concrete attain certain strengths before work progresses. It is critical that concrete reach 3.4 MPa before being exposed to one freeze-thaw cycle and 24 MPa for multiple freeze-thaw cycles [1]. Formwork is not safely removed until the concrete becomes strong enough to support itself and any imposed construction load; a structure is not fully serviceable unless the design strength is achieved. Thus the effects of anti freezers have on both the rate of the strength gain and the ultimate strength of concrete is important.

The mixes shown in Table 4 were tested for strength gain at four low temperatures (-5, -10, -15 and -20) for seven days in deepfreeze curing periods. Samples were cast at the room temperature and immediately transferred to the deepfreezes with moulds. After seven days deepfreeze curing periods they demoulded and left to the room temperature for 24 hours to thaw inside ice of samples. After measurement of UPV, they were capped, their compressive strength were determined and given in Table 4. As it can be seen from Table 4 that with decrease of the temperatures compressive strength of the sample that contain 6% urea was drastically decreased and their compressive strength were 19.50, 7.92, 3.55 and 5.56 MPa at -5, -10, -15 and -20 °C temperatures, respectively. Samples without urea were showed approximately the same compressive strength at all levels of the studied low temperatures and they were changed between 7.92 and 6.57 MPa. The maximum compressive strength was observed at -5°C and 6% urea contained samples. This strength was 57 and 38 percent of 28-day water cured control samples of 6% urea and control sample without urea, respectively. Mixes without urea gained very low strengths, even at -5°C temperature and it was changed between 13-15 percent of the control mix cured in water for 28 days. When the compressive strength of urea samples compared to the samples without urea cured at -5°C temperature for 7-day, it can be seen that urea increased the compressive strength by 246%. This showed that urea can be used in today's concrete technology and to allow fresh concrete to gain appreciable strength at below-freezing temperatures in seven days. Because the urea admixture accelerated cement hydration at -5°C temperature and protect the water from freezing. Below -5°C urea could not increase strength gaining of samples. This is may be due the low freezing point depression of water due to urea. Because the eutectic point of urea is -8.4 [7,5].

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. 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.

Compressive strength as well as other structural properties of concrete, depends on the degree to which cement hydrates. According to Mironov [8] hydration can be increased by introducing antifreeze admixtures into the concrete. Thus the hydration of concrete containing urea was very fast at at -5°C temperature when compared to the other low temperatures which are below the eutectic point of urea. Thus the compressive strength of concretes cured at -10, -15 and -20 was nearly the same or lower than those of without urea under the same curing condition. It is important to note that there were no important changes in the compressive strengths of the samples without urea with decreasing the curing temperatures for 7-days low deepfreeze curing. All samples showed between 13-15 percent strength of 28-day water cured, control samples. This is may be due to the combination of three main reasons. One is the higher cement content that resulted in lower water-cement ratio. The second reason, samples were cast in lab conditions and then transferred to the deepfreezes, when they put into the deepfreezes their temperatures were at least the same that of room temperatures, thus up to inside water cooling to below freezing point, cement may hydrate with water and enhance strength gain. The last reason may be due to keep sample in room temperature for thawing inside ice of samples for 24 hours after 7-days low temperature deepfreeze curing.

3.3. Compressive strength of 7 days in deepfreeze and 28 days in water curing

After 7 days, all untested cylinders were moved to standard water curing tank (temperature 23ºC) for an additional 28 days of curing. This additional curing showed whether the freezing temperatures had caused any permanent strength loss. Table 4 shows the results of the concretes with and without urea cured at below freezing temperatures compared to those of the control concretes cured in water curing condition.

The results of this test are presented in Table 4. The samples contained urea showed no damage when held at the –5ºC condition for 7 days and in addition to 28- day water curing when compared the samples contained urea and only water cured samples. However, at –10, -15 and –20ºC, they did not recover fully; in fact, they developed only between 52 to 76% of their strength relative to the samples contained urea and cured in water room temperature. Samples contained urea and cured for 28-days in water curing developed compressive strength of concrete by 67% when compared to the control sample. This is may be due to the retarding effects of urea. Mwaiuwinga et al. [9] reported that main product from the reaction of urea with water was carbonic acid (H_2C0_3) reacted with calcium hydroxide which was an important ingredient affecting hydration reaction. Due to that, heat of hydration was reduced and resulted in lower early compressive strengths. The effect of urea on concrete strength was dependent on the concrete age. At the age of 91 days, the effect was almost same as that of control.

Table 4 shows the strength development of the control concrete without urea antifreeze admixture after 7-day below freezing curing temperatures and additional 28-day water curing. The samples without urea recovered only 51% when held at the –5ºC deepfreeze curing condition for 7 days and cured for additional 28-day in water curing condition. At –10, -15 and –20ºC, they developed only between 35 to 53% of their strength relative to control samples cured in water only for 28-days curing condition. The rate of strength gaining development decreased as curing temperature decreased, but reductions due to the -15 and -20 ºC was lower than that of the -10 ºC for both samples urea contained and control cured at below freezing temperatures. This may be due to the cooling rates at -15 and -20ºC influenced movement of moisture and the formation of ice within in the concrete. When such concrete is cooled so rapidly, moisture has little chance to migrate and it is frozen in place. This creates a nearly uniform distribution of small ice crystals throughout the concrete. It follows that at an early age, the 9% expansion caused by the formation of ice might not damage the concrete as much as the samples exposed to the -10. Slow cooling, on the other hand, allows moisture to redistribute itself within the mix by moving toward and freezing at the colder areas similar to the way water moves in freezing soils. As water continues to move toward the freezing zone the ice thickens. In this case, the concrete can be damaged by the ice crystals forming into layers or lenses, forcing apart the aggregate and paste particles. Then slow freezing might cause concrete to more strength loss.

Table 4 Compressive strength (MPa)

Temp.	7 days in deepfreeze		7 days cured at below freezing curing + additional 28 days water cured		Only water cured for 28 days	
	6% Urea	Without Urea	6% Urea	Without Urea	6% Urea	Without Urea
-5	19.50	7.92	34.45	26.18	34.08	51.40
-10	7.92	7.81	26.08	17.85		
-15	3.55	6.57	17.66	27.03		
-20	5.65	6.97	21.99	27.30		

4. Conclusions

Workability of concrete was improved. The maximum compressive strength was observed at -5°C and 6% urea contained samples. This strength was 57 and 38 percent of 28-day water cured control samples of 6% urea and control sample without urea, respectively. The samples contained urea showed no damage when held at the –5ºC condition for 7 days and additional 28- day water curing when compared the samples contained urea and only water cured samples. The results also showed that one time freezing of fresh concrete without urea antifreeze induced 49 and 68 percent loss in compressive strength at –5ºC and –10ºC and additional 28-day water curing, respectively. It is important to state that revitalization by 28-day water curing after exposure below -15 ºC were higher than those of –5ºC and –10ºC. This may be attributed to a nearly uniform distribution of small ice crystals throughout the fresh concrete before setting. Urea can be used in concrete technology as antifreeze up to -5ºC.

5. Acknowledgments

This research was supported by the research project “The effect of antifreeze admixtures on the properties of concrete casted in cold weather” (BAP Code: 2009/271) from the Atatürk University, Scientific Research Projects (BAP) Program in Erzurum, Turkey.

REFERENCES

[1] ACI committee 306 and ACI 306R-88 (2002) Cold Weather Concreting. American Concrete Institute, Detroit, Michigan.

[2] Powers, T. C. (1962) Prevention of Frost Damage to Green Concrete. *RILEM Bulletin*, 14, 120-124.

[3] Charles, J. K. Peter, M. S. and Lynette A. B. (2004) Extending the Season for Concrete Construction and Repair. Phase I—Establishing the Technology, *ERDC/CRREL TR-04-2.*

[4] Nmai C. K. (1998) Cold Weather Concreting Admixtures. Cement and Concrete Composites, 20, 121-128.

[5] Ramachandran, V. S. Chapter 5: Accelerators; In: Ratinov, V. B., Rozenberg, T. I. and Ramachandran, V. S. (Eds), Chapter 11: Antifreezing admixtures (1995)), Concrete Admixtures Handbook - Properties, Science, and Technology, 2nd edition, Noyes Publications, New Jersey, 1153 pp.

[6] Brook, J. W. Factor, D. F. Kinney, F. D. and Sarkar, A. K. (1988) Cold weather admixture. In: Concrete International- Design and Construction, 10(10), 44-49.

[7] Charles K. N. (1998) Cold Weather Concreting Admixtures. Cement and Concrete Composites, 20, 121- 128.

[8] Mironov, S.A. (1977) Theory and methods of winter concreting. USA Cold Regions Research and Engineering Laboratory. Draft Translation 636.

[9] Shaaban M. Toshiki A. and Kenji S. (1997) Influence of Urea in Concrete, Cement and Concrete Research, 27(5), 733-745.