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INFLUENCE OF PROLONGED AGITATION ON WATER MOVEMENT RELATED PROPERTIES OF WATER REDUCER AND RETARDER ADMIXTURED CONCRETES

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ABSTRACT

The properties of prolonged agitated concretes in both fresh and hardened states were investigated. Concrete mixes were prepared by using two different retarders and one water reducer. At different time intervals, samples were taken from the drum of a truck mixer which had been kept in continuous motion. It was observed that gluconate based retarder increased the amount of bleed water with respect to the reference mix. Prolonged agitation ceased the bleeding of reference and dextrin admixtured mixes while reduced the bleeding amount and period of gluconate mix. The addition of admixtures tested, decreased the permeation properties of mixes. However, the same admixtures increased the drying shrinkage of specimens taken after prolonged agitation. For durability studies, freezing and thawing performances were compared. *© 1997 Elsevier Science Ltd*

Introduction

In ready-mixed concrete industry, prolonged mixing in transportation by truck mixers are experienced quite often because of the problems due to the heavy traffic, to transporting in long distances, and to delaying in placing at site. However, addition of retarding admixtures can be a solution to these problems, particularly those in hot weather concreting.

The influence of extended mixing on the workability, setting times and strength properties of concretes, contained water reducing and retarding admixtures, were discussed in detail in the previous paper (1). The presented paper covers the water movement related properties of fresh concrete, such as bleeding, and also those of hardened concrete, such as water absorption both by capillary and by immersion, permeability under pressure, freezing and thawing, and drying shrinkage, as well as the effect of prolonged agitation on these properties.

Excessive bleeding may cause the occurence of a weak top layer especially on flat slabs, and as well as the formation of plastic settlement cracks. On the other hand, lack of bleeding may lead to the development of plastic shrinkage cracks. The latter occurs when the rate of water evaporation exceeds that of bleeding (2). Water pockets may also form under reinforcing bars which result in reducing the bond. In general uncontrolled bleeding results in reduction in durability properties of hardened concrete.

The movement of adsorbed water in the capillary voids of hardened concrete is rather slow and the cause of drying shrinkage; when the shrinkage is prevented by the obstacles, for example by reinforcement, the cracks occur (3) leading again the reduction of durability resistance of concrete.

Another durability problem is the transportation of deleterious substances into the concrete; in which the direction of liquid/gas movement is adverse, i.e. from the environment toward the concrete, but the driven cause is again capillary forces. For this reason, the capillary structure of hardened concrete, particularly the cover zone of reinforcement have gained wide attention from researchers, and investigations have been carried out, for example, to relate the carbonation of cover zone to the permeation properties of concrete (4,5). Other permeability related problems are corrosion of steel reinforcement as a result of chloride diffusion, freezing and thawing, and abrasion of cover concrete.

The initial surface absorption test (ISAT) (6), Figg water absorption method (7), and covercrete absorption test (CAT) (8), are frequently used methods to measure the permeation properties and based on water absorption. The simple sorption (absorption by capillarity) test (9,10) was performed in this study which relates the absorbed water by capillarity to the square root of time as follows

$$i = A + St^{1/2} \tag{1}$$

where i is the cumulative water absorption per unit area of the inflow surface, t is the time, S is the sorptivity (rate of absorption) and A is the intercept arising from the wetting water of open surface.

The permeability method based on the measurement of water penetration depth under imposed pressure gradient was also applied for comparison, according to DIN 1048 (11).

Experimental

Materials. Ordinary portland cement (PC 42.5, according to Turkish Standard 19, corresponds to ASTM, Type I) was used. Crushed limestone as coarse aggregate and as a part of fine aggregate as well as natural sand were considered in the production of concretes. The admixtures used were a lignosulfonate based water reducer (WR) (ASTM C494, type A), a dextrin based water reducer and retarder (WRR) (ASTM C494, type D) and a gluconate type retarder (R) (ASTM C494, type B). The details of materials were given elsewhere (1).

Concrete Mixes. Slump values were similar (18.5 ∓ 1.5 cm) for all admixtured mixes although the cement and water contents were kept constant, except the Reference mix, in which the cement and water contents were increased 10%, respectively, to bring the slump to the level of admixtured ones. The concrete mixes consisted of 1:2.87:3.37 cement, sand (both fine crushed stone and natural one) and crushed stone proportion by weight, respectively. The cement dosage was 300 kg/m^3 and water/cement ratio was 0.65.

The following mixes were prepared:

1. Reference mix with increased cement content and water (10%)
2. Mix with dextrin based WRR
3. Mix with gluconate based R
4. Mix with initially lignosulfonate based WR, and 1 1/2 h later gluconate R added.

Testing Procedure. The mixes were batched in a central pan mixer of a ready-mixed concrete plant and poured into the drum of a truck mixer and agitated continuously at a rate of 1.5 rpm. At different time intervals the concrete samples were taken from the truck mixer.

Tests

Bleeding. Bleeding tests were carried out according to ASTM C232, Method A. The bleed water was collected at 10 min intervals in the first hour and 20 min afterwards.

Absorption by capillarity. Tests were carried out by using the method mentioned in Reference (9), which is a little different than the RILEM method (12). The 7 × 7 × 7 cm cubic specimens, cut from the 7 × 7 × 28 cm prismatic samples of 28 days age, were first dried in oven at 105°C to constant weight, and the lateral sides of them were sealed by paraffin, and then the cut surface was lowered 2mm into the water. The increase in weight was measured at 1,4,9,16,25,36 and 49 min by weighing the specimen in air. The tests were continued until reaching constant weight and the maximum absorbed water was determined.

Absorption by immersion. The specimens used in capillary tests, after removing the sealing material, were oven dried at 105°C and immersed in water to constant weight according to ASTM C642.

Permeability. Water permeability under pressure tests were carried out on 15 × 15 × 15 cm cubic specimens of 28 days old, according to DIN 1048 (11). The specimens were kept under a water pressure of 1 bar for initial 48 hours followed by 3 and 7 bar pressures for each of the subsequent 24 hours. Finally by applying splitting test, the penetration depth of water was measured.

Freezing and thawing. 10 × 10 × 50 cm prismatic specimens at the age of 28 days, were exposed to repeated cycles of freezing in air and thawing in water, according to ASTM C666. Changes in weight and resonant frequency of prisms were monitored after subjecting to each 20 cycles where the total number was 100. The initial and final pulse velocities as well as flexural and compressive strengths were determined. Some of the specimens were kept in standard curing condition for comparison.

Drying shrinkage. The length change and weight loss of specimens were monitored on 10 × 10 × 50 cm prisms which were kept in an environment of 20°C and 65% R.H. Shrinkage measurements started at the age of 2 days by using an apparatus conforming to the ASTM C157 specifications.

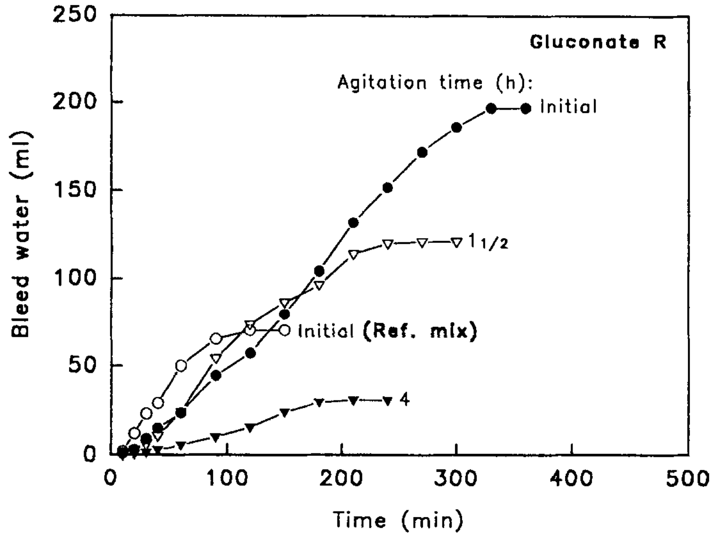


FIG. 1.
Bleed-time curves for Reference and Gluconate R mixes.

Results and Discussion

Bleeding. Bleeding rate was calculated by plotting the amount of bleeding water from the exposed concrete surface of the testing container with time, as shown in Figures 1 and 2, and finding the slope of the initial linear portion of the curve. The bleeding rates were expressed in ml. per second per sq. cm. of exposed surface and bleed capacity in ml. per ml. volume of

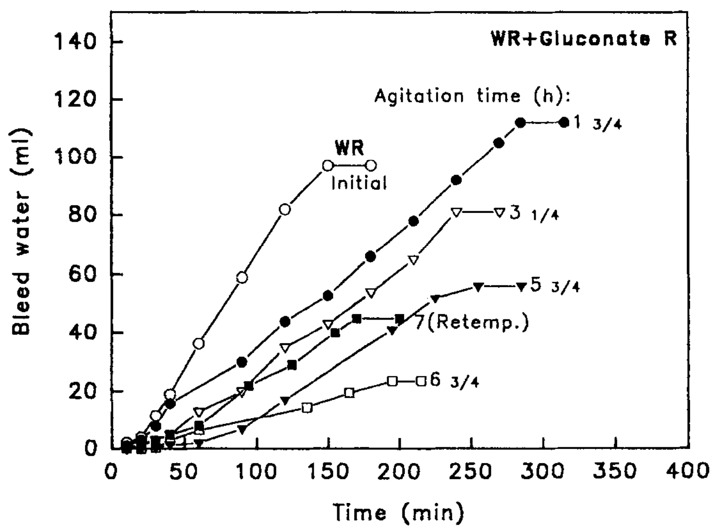


FIG. 2.
Bleed-time curves for WR and WR + Gluconate R mixes.

TABLE 1

The Influence of Agitation Time on Bleeding Properties

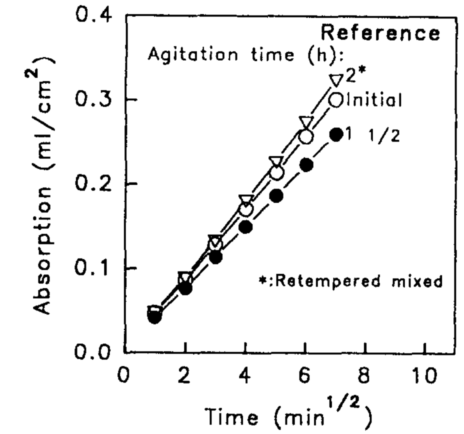
Mix	Agitation time (h)	Bleeding rate 10^{-5} (ml/cm^2/s)	Bleeding capacity 10^{-3} (ml/ml)	Bleeding time (h)
Ref.	Initial	2.28	23.0	2
	11/2	0	0	
Dextrin WRR	Initial	3.32	41.2	21/2
	11/2	1.34	10.5	1
	4	0	0	
Gluconate R	Initial	1.95	62.1	51/2
	11/2	1.89	37.4	41/2
	4	0.37	9.5	31/2
	6	0	0	
Ligno. WR	Initial	1.89	32.6	21/2
	11/2	0	0	
WR+Gluc. R	13/4	1.01	34.2	43/4
	31/4	0.85	25.0	4
	53/4	0.80	18.4	41/4
	63/4	0.30	7.2	31/4
	7 (Ret.)*	0.79	14.0	23/4

* Retempered concrete.

mixing water in concrete. Test results of samples taken at different agitation times are given in Table 1.

Between the samples taken initially, dextrin WRR showed the highest bleed rate, about 46% higher than that of Ref. mix, and the rates of lignosulfonate WR as well as gluconate R were close to each other, but less than that of Ref. one, about 17% and 14%, respectively. However, bleeding capacities of all admixtured concretes are higher than that of Ref., but much more bleed (about 2.85 times of Ref. one) and much longer bleed time (about 1 1/2 h longer than Ref. one). It seems that gluconate R, parallel to prolonging the dormant period, increased the settlement time of the particles and hence capacity for bleeding for a given slump as well as for a given water/cement ratio. It was reported (14) that, also addition of a superplasticizer enhanced the bleeding for cement pastes having equal water cement ratios. Cabrera et al. (15) studied the effects of different types of superplasticizers on bleeding of concrete and found that they all decreased the rate but modified lignosulfonate in higher dosages increased the capacity.

1 1/2 h agitation interrupted bleeding of both Ref. and lignosulfonate WR mixes, but it continued at a reduced rate and capacity for dextrin WRR one. On the other hand, the rate did not change for gluconate R mix after the same period of agitation, though the total bleed reduced, but it remained still at the same level of other admixtured samples initially taken. These results indicate that retarding admixtures increase the period in which bleeding takes place. The behavior of dextrin WRR is interesting here, this admixture was designated as a retarder as well as water reducer, but it showed no retarding effect for the sample taken



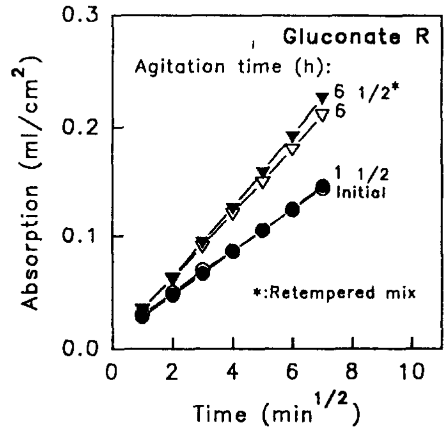


FIG. 3.
Water absorption by capillary-time curves.

initially, contrary caused some acceleration. However, the same mix was tested after 4 h prolonged agitation followed by retempering, and showed retarding in both initial and final setting times with respect to the time of initial mixing about 4 h and 4 1/4 h, respectively (1). Although the setting times have not been measured after 1 1/2 h agitation, it is possible that it showed some retarding effect at that time, and as a result exposed bleeding.

On the other hand, addition of gluconate R into the lignosulfonate WR mix after 1 1/2 h agitation time, initiated bleeding again and extended it over a longer period of time, such that even after 6 3/4 h, the concrete showed bleeding but at lower levels. Similarly, for the sample of gluconate R mix taken after 4 h agitation, bleeding was obtained, but after 6 h agitation it ceased. Retempering initiated the bleeding of only combined WR + gluconate R mix, and the others, including gluconate R, showed no bleeding.

It was observed that bleeding capacity and also the period of bleeding have a relation with the setting time of the concrete; the longer the setting time, the higher the amount of bleed and also the longer the bleeding duration time as well as the time interval of bleeding experienced. However, the termination of bleeding did not coincide with the setting time of concretes; probably the bleeding ceases at a stiffening level smaller than that measured during the initial setting of concrete. It was reported that there was less bleeding when the cement had a high C_3A content (16); therefore it seems that when a retarder used in concrete mix, the bleeding is prolonged because of the delay in the hydration of C_3A.

Permeation Properties. Cumulative absorbed water by capillarity per unit area was plotted with time as shown in Figure 3 and the rates of absorption, (usually called as sorptivity) calculated from the slope of curves according to Eq. 1, are reported in Table 2 for the concretes tested at different agitation times. The max. water absorption by capilarity, and by immersion respectively, as well as their ratio which shows the percentage of capillary pores in the apparent porosity, were included in the same table.

Addition of an admixture reduced the sorptivity and the amount of absorbed water, probably due to the dispersion effect of admixtures (8). The decrease in the sorptivity of Ref. mix after 1 1/2 h agitation, may be attributed to having a more homogeneous structure as a result of prolonged mixing while the same period of mixing caused no reduction in that of admixtured ones, on the contrary made slight increases. The large difference between the

TABLE 2

Permeation Properties

Mix	Agitation time (h)	Sorptivity (mm/min$^{1/2}$)	Water absorption (wt.%) by capillary	by immersion	capillary/immersion	Depth of penetration (mm)
Ref.	Initial	0.425	5.5	6.5	85	20
	1 1/2	0.364	4.9	6.3	77	
	1 3/4 (Ret.)*	0.461	6.0	7.5	80	25
Dextrin WRR	Initial	0.330	5.8	5.9	99	
	1 1/2	0.366	6.9	7.0	99	
	4	0.362	6.2	6.7	93	
	4 1/2 (Ret.)	0.427	7.5	7.9	95	
Gluconate R	Initial	0.191	3.3	4.9	67	15
	1 1/2	0.197	3.7	5.5	67	
	6	0.296	4.9	6.7	74	
	6 1/4 (Ret.)	0.322	5.9	7.5	79	20
Ligno. WR	1 1/2	0.193	5.3	6.0	89	
WR+Gluc. R	1 3/4	0.180	3.9	4.6	84	
	6 3/4	0.225	4.4	6.2	71	
	7 (Ret.)	0.261	4.6	6.2	74	

* Retempered concrete.

Ref. and admixtured mixes may be partly due to the increased proportion of cement paste in the former (17). It is interesting to note that dextrin WRR, parallel to the bleeding rate results, exposed the highest sorptivity between the admixtured mixes. It seems that the mechanism increasing the bleeding rate, also affects the absorption rate by capillarity in the same manner.

Further agitation about 6 h increased the sorptivity and absorption both by capillarity and by immersion of combined lignosulfonate WR and gluconate R, as well as gluconate R mixes, but they still remained at smaller levels than those of Ref. mix. Retempering increased the absorption properties of all mixes tested.

The permeability under pressure tests were carried out on the samples of Ref. and Gluconate R mixes taken just before and after the retempering process. The depth of water penetration results given in Table 2 indicate that, parallel to the absorption behavior, addition of gluconate R decreased the permeability with respect to Ref. mix. Retempering increased the permeability for both mixes.

Drying Shrinkage. The samples for shrinkage experiment were taken just before and after the retempering which preceeded by prolonged agitation. The length change-age and weight loss-age plots were shown in Figures 4 and 5, and their final values measured after 170 days exposure were given in Table 3 together with the agitation times. Table 3 shows that the shrinkage of gluconate retarder is close to that of Ref. mix in magnitude, although it has been reported (16) that concretes containing water reducing and retarding admixtures had usually higher drying shrinkage, because these admixtures lead to pore refinement as well as an increased surface area in the hydration product. The observed shrinkage of Ref. mix, not

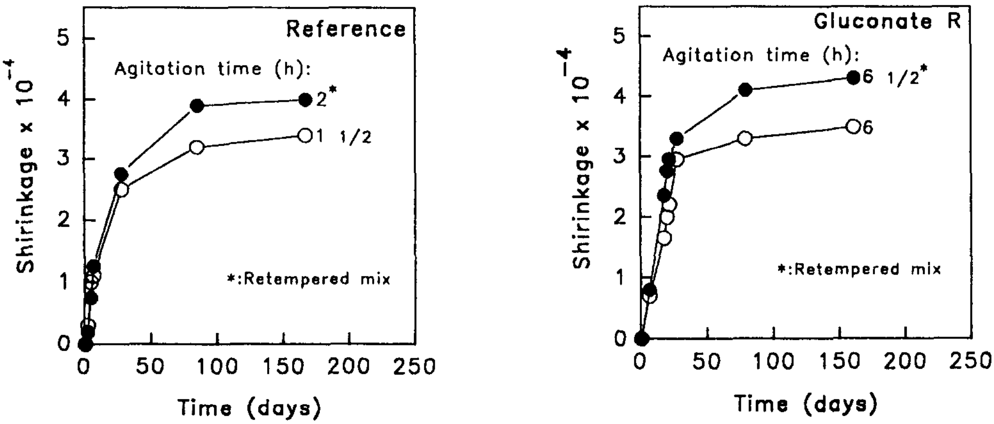


FIG. 4.
Drying shrinkage-time curves.

having the expectedly lower value, can be due to its increased cement paste content (17,18). For this reason, the mix proportion adjustment was made on the shrinkage value of Ref. mix as follows:

For a constant water/cement ratio, the shrinkage of concrete can be predicted from the cement paste content by using the following formula (3).

$$S_c = S_p (1 - a)^n \tag{2}$$

where S_c and S_p are the shrinkages of concrete and cement paste, respectively, (1-a) is the volume fraction of cement paste, and n is a parameter which can be taken as 1.8 as an average value for normal-weight aggregate concretes (18). By means of Eq. 2, the shrinkage of plain mix, which has cement and water contents equal to the admixtured mixes, was predicted as about 84.8% of that of Ref. mix. After this adjustment, the shrinkage of gluconate R mix was obtained as 17.6% higher than that of Ref. mix.

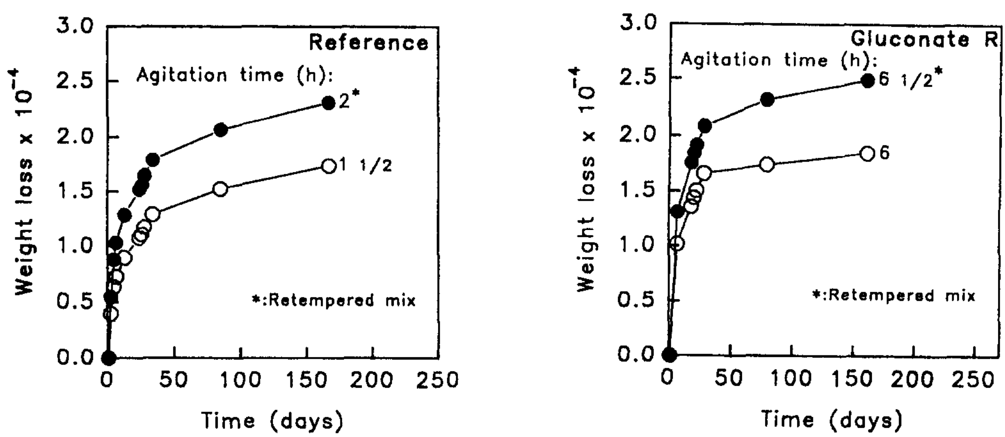


FIG. 5.
Weight loss-time curves.

TABLE 3

Drying Shrinkage and Weight Loss of Mixes Before and After Retempering

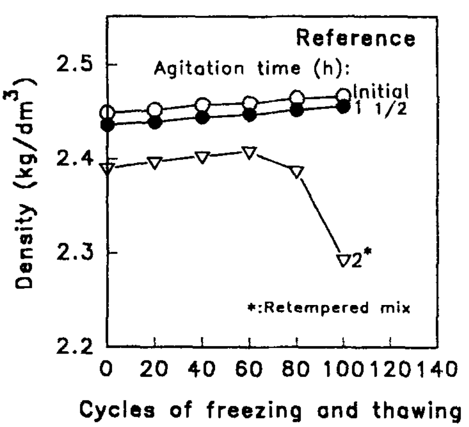
Mix	Agitation time (h)	Shrinkage (10^{-4})	Weight Loss (%)
Ref.	11/2	3.4	1.74
	13/4 (Ret.)*	4.0	2.31
Dextrin WRR	4	4.5	3.03
	41/2 (Ret.)	4.8	4.33
Gluconate R	6	3.5	1.84
	61/4 (Ret.)	4.3	2.49
WR+Gluc. R	63/4	4.5	2.79
	7 (Ret.)	5.0	3.52

* Retempered concrete.

The influence of plasticizers and superplasticizers on drying shrinkage has been compared and increases between 3% and 132% were reported (18). Although the results are very variable, it was advised to use 20% increase as an average for flowing concrete, which is in the same range of the result obtained here. On the other hand, both dextrin WRR, and combined lignosulfonate WR and gluconate R mixes exhibited drying shrinkages 55% higher than that of Ref. mix. Although the combined WR and R mix has shown almost similar performance with the gluconate R one in bleeding and absorption properties, the former approached to the dextrin one in shrinkage behavior. This can be explained as the effect of increased total admixture dosage used in the former mix on the shrinkage such that the higher the dosage, the higher the shrinkage (19).

Retempering caused increase in the shrinkages of Ref. and admixtured mixes as expected, but the percentage of increase is higher for the mixes with lower initial shrinkage before retempering, i.e. 18% and 23% for the Ref. and gluconate R mixes, and 7% and 11% for the dextrin WRR and combined WR and R ones, respectively.

Within the test results presented here, it is not possible to find a direct relation between bleeding and absorption properties, and shrinkage. However, weight losses measured on the



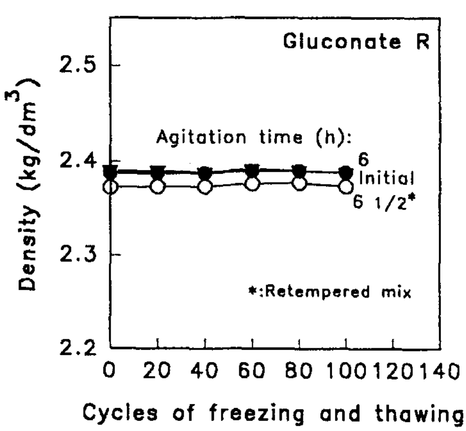


FIG. 6.
Variation of density in freezing and thawing tests.

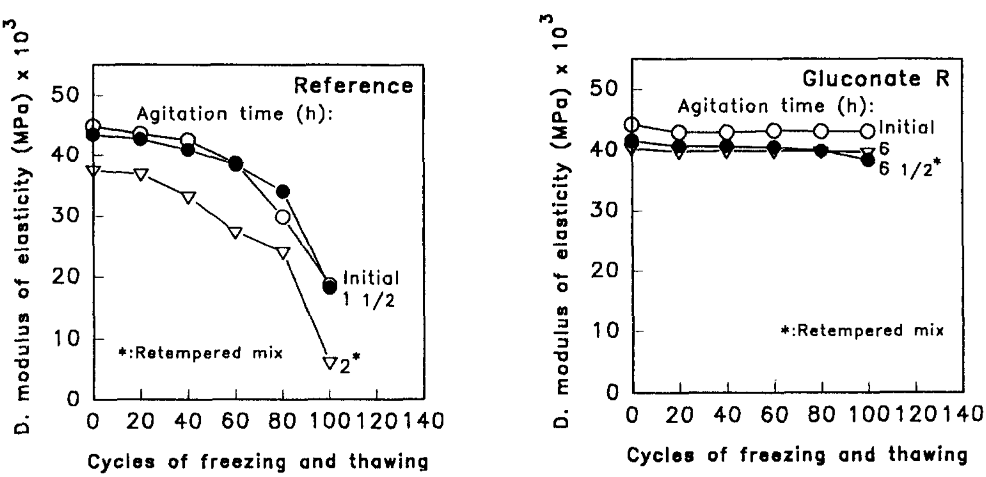


FIG. 7.
Variation of dynamic modulus of elasticity in freezing and thawing tests.

same samples of shrinkage as shown in Figures 5 and in Table 3, exposed similar trend with the shrinkage results. i.e. the higher the shrinkage, the higher the weight loss.

Freezing and Thawing. Durability properties of Ref. and gluconate R mixes were compared on the samples, taken initially and after prolonged agitation times, with respect to freezing and thawing behavior. The results of density and dynamic modulus monitoring tests were shown in Figures 6 and 7. In addition, the compressive and flexural strengths, and ultrasound pulse velocity of specimens after 100 cycles of freezing and thawing with the initial values of those before testing as well as those of standard cured ones for the same period of time, were reported in Table 4.

The limited data given in Figures 6 and 7, and Table 4 indicate that the dynamic modulus is the most sensitive test to the freezing and thawing cycles, and pulse velocity and flexural strength follow it. The density reflected only the severe damage of Ref. mix as mass loss, however the gradual increase of ingress water for this mix can be taken as the indication of increase in cracks. The compressive strength seems the least sensitive index between the properties compared here.

Although the air entrainment is essential for frost resistance under severe exposure conditions, the performance of gluconate R mix was found superior to that of Ref. one within the limited of number cycles applied in this study. This can be attributed to the lower absorptivity of former mix as stated by Dhir et al. (20), i.e., low absorptivity, high frost resistance. Furthermore, the relative capillary voids with respect to the apparent porosity was lower for the former one than that of latter as reported in Table 2. The importance of this is that capillary pores have sharper edges than large entraped pores, and they probably cause stress intensity under the action of expansion.

Two mixes compared have almost close strength values before the freezing and thawing exposure, but cement paste content of Ref. mix was 10% higher than that of gluconate R mix, and this difference may partly explain the lower frost resistance of the latter.

TABLE 4

Freezing and Thawing Test Results

Mix	Agitation time (h)	Pulse velocity Initial (km/s)	% of initial value After 100 cycles	% of initial value Standard Curing
Ref.	Initial	5.05	0.63	1.00
	11/2	5.03	0.63	0.99
	13/4 (Ret.)*	4.71	0.41	1.02
Gluconate R	Initial	5.04	1.00	1.00
	6	4.81	0.99	1.02
	61/4 (Ret.)	4.82	0.99	0.99

		Compressive Strength			Flexural Strength		
			% of initial value			% of initial value	
Mix	Agitation time (h)	Initial (MPa)	After 100 cycles	Standard curing	Initial (MPa)	After 100 cycles	Standard curing
Ref.	Initial	29.7	1.19	1.35	5.6	0.65	1.14
	11/2	31.9	1.23	1.39	5.9	0.73	1.23
	13/4 (Ret.)	28.3	0.98	1.33	5.1	0.33	1.12
Gluconate R	Initial	30.9	1.40	1.42	6.6	1.07	1.05
	6	29.8	1.44	1.51	6.0	1.06	1.10
	61/4 (Ret.)	27.0	1.50	1.63	5.3	1.14	1.16

* Retempered concrete.

Conclusions

1. Gluconate based retarder increased the amount of bleeding as well as the period bleeding experienced, but at lower rates than that of the reference mix. Prolonged agitation ceased the bleeding of reference and lignosulfonate based WR mixes while it lowered the rate and amount of bleeding for dextrin WRR and gluconate R mixes. Retempering after prolonged agitation started bleeding for only gluconate R mix.
2. Addition of admixtures tested in this study to the mixes reduced the rate of absorption by capillarity, as well as the absorption by immersion, with respect to reference mix, probably due to the better dispersion of cement in the former mixes.
3. Addition of admixtures tested increased the drying shrinkage with respect to the reference mix at the same water and cement contents. The shrinkage of specimens blonged to the combined WR and gluconate R mix was higher than those of gluconate R one, and close to that of dextrin WRR one, probably due to the increased total admixture dosage of former mix.
4. Within the limit of freezing and thawing cycles applied, the gluconate R mix showed superior performance than the reference one which can be attributed to the lower sorptivity of former mix. Dynamic modulus was found the most sensitive test to the freezing and thawing cycles while the compressive strength was the least.

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