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EFFECT OF CHEMICAL ADMIXTURES ON WORKABILITY AND STRENGTH PROPERTIES OF PROLONGED AGITATED CONCRETE

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ABSTRACT

A lignosulfonate-based water reducer, a dextrin-based water reducer, and a gluconate-based retarder were used in concretes which were mixed continuously in the drum of a truck mixer, and the slump measurements were carried out at certain time intervals. It was found that at any time, the slump loss in gluconate-based retarder and combined lignosulfonate and gluconate mixes was less than those of other mixes. The setting times of samples taken after prolonged mixing, as well as after retempering, were also compared with those of initial ones. Compressive and flexural strengths of samples taken initially and after different agitation times were determined. The strength change obtained after prolonged agitation was slight, but retempering by water to bring the workability to the initial level reduced the strengths; however, the strength loss in gluconate retarder-added mixes was smaller than those of others. The bond strength between reinforcing bar and reference mix was also compared with that of gluconate retarder mix. *© 1998 Elsevier Science Ltd*

Introduction

Prolonged mixes can be frequently experienced in ready-mixed concrete industry owing to the longer delivery distances or to delays in placing because of the problems at site. Although the mixing time is limited with 1½ h in ASTM C94, it is exceeded quite often by using retarding admixtures.

The studies on extended mixing time have been concentrated on slump loss and strength change as well as the effect of admixtures on these properties. Hawkings (1) investigated the effect of subsequent retempering to keep the slump constant on the strength of concrete and found that 4 h mixing resulted only slight decrease in strength. Contrary to Hawkins, Adams et al (2) reported strength losses for the concretes prepared with a water-reducing admixture and retempered hourly to restore the initial slump and agitated 15-min. intervals. Gaynor and Bloem (3) observed average 5 cm slump loss per hour for continuously mixed concretes and obtained reduced strengths for retempered ones.

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Tests were carried out by Dewar (4) by using a truck mixer, the drum of which kept in continuous motion for a period up to 5 h. For a time, the relation between compressive strength and workability was the same as similar concrete compacted shortly after mixing. After this period, however, the strength of agitated mix was lower for a given workability. No adverse effect of prolonged mixing was reported for the concretes if no water was added beyond the design amount, however retempering decreased the strength (5). It can be concluded that the lower workability observed during delivery can be related to three reasons: 1) insufficient water batched initially, 2) higher rate of evaporation or absorption of water by dry aggregates, 3) higher rate of hydration. When retempering water is added to compensate for the former two reasons, strength reduction will not happen, whereas extra water to combat latter reason will lower the strength (6).

It is known that retarding admixtures delay the setting time of concrete; for this reason, investigations of their effects on delaying slump loss have gained attention from many researchers. Gaynor and Bloem (3) tested five separate retarders and observed no delay in loss of slump. Wollick (7) reported that 4 h mixing reduced the slump from 10 cm to 2.5 cm and addition of a hydroxylated acid-type retarder increased the slump approximately 5 cm. Previte (8) did not observe any positive effect of conventional water-reducing admixtures on slump loss; on the contrary, Ravina (9) and later Tuthill (10) reported slightly more slump losses for water-reducing and -retarding admixtures. However, it was mentioned that the total mixing water after retempering for restoring the initial slump was less for admixtured concretes (8,9). It is also found that the slump loss was proportional to the initial slump level; the higher the initial slump, the higher the slump loss.

In this study, the effects of one retarding admixture, one water-reducer and -retarder, as well as one water-reducer on the properties of concrete, that had been agitated continuously in a truck mixer, in both fresh and hardened state, were investigated. The primary data have been presented previously (11), and more results were given here.

Experimental

Materials

Cement. PC 42.5 type cement (Turkish Standard 19) was used and its physical properties together with chemical composition are given in Table 1. Although it was designated as ordinary Portland cement, its C_3A content is lower.

Aggregates. Natural sea sand and limestone-based crushed stone sand as fine aggregate, and two types of crushed limestone as coarse aggregate with maximum size of 31.5 mm were used.

Admixtures. One type of retarding admixture (R) based on gluconate (ASTM C494, type B), one type of water reducer (WR1) based on dextrin, although it was designated as retarder as well as water reducer it exposed no delaying performance, and a lignosulfonate-based water reducer (WR2) (ASTM C494, type A) were used.

The maximum dosages of admixtures proposed by manufacturers were as follows: R:2%, WR1:0.35%, and WR2:0.5%, by weight of cement.

TABLE 1
Properties and composition of cement.

Physical Properties		Mechanical Properties	
Density (kg/m^3)	: 3130	Compressive Strength (MPa):	
Blaine sp. surface (m^2/kg)	: 3170	7 days	28 days
Grading		44.1	58.7
Retained on 200 μm	: 0.4		
90 μm	: 4.6		
		Flexural Strength (MPa):	
Opening (Le Chatelier)	: 4.0	7 days	28 days
		7.3	8.6
Setting time (h):			
Starting	: 2¾		
Ending	: 3½		
Composition (%):			
C_3S	C_2S	C_3A	C_4AF
54.3	22.7	2.9	13.4

Concrete Mixes

The cement content and W/C ratio were kept constant in the mixes, and the mix proportions are given in Table 2. R and WR1 admixtures were used at the maximum dosages proposed by producers, and WR2 at 0.4%. Admixtured concretes gave initial slumps in the range of 18.5 ± 1.5 cm. However, since Reference mix 1 contained no admixture, its slump was lower, and for this reason another control mix, Reference mix 2, was prepared by increasing both cement and water contents in 10%.

The following mixes were prepared:

1. Reference mix 1: Initially contained no admixture and 1½ h later gluconate based R in 2% was added.
2. Reference mix 2: 10% increased cement and water contents, no admixture.
3. Mix with gluconate based R in 1%.
4. Mix with gluconate based R in 2%.
5. Mix with dextrin based WR.
6. Mix prepared initially with lignosulfonate based WR, and after 1½ h agitation gluconate R in 2% was added.

TABLE 2
Concrete mix proportions.

Content (kg/m^3) Cement	Water	Sand	Crushed sand	Crushed Stone 1	Crushed Stone 2
300	195	470	390	390	620

Testing Procedure

The tests were carried out at a commercial ready-mixed concrete plant. The materials were loaded into the stationary mixer of plant, and after 2 min mixing, concrete was discharged into the drum of a truck mixer which had a capacity of 7 m^3. The amount of concrete in the mixer was 2.5 m^3. The drum of truck mixer had been kept in motion continuously at 1.5 rev/min except the times of sample taking. Finally, when the slump dropped to lower values, the concrete was retempered to restore the initial slump. The temperature of concrete was initially about 25°C and it rose up to 29°C after prolonged agitation.

Samples for fresh and hardened concrete tests were taken from the truck at shortly after the discharging of the concrete into the drum and also 1½ h after the initial mixing. Further samples were taken at different intervals, and finally just before and after the retempering process.

Tests

Test on fresh concrete. On the samples mentioned above, slump (ASTM C143), air content (ASTM C231, pressurizing method), bleeding (ASTM C232), and setting time (ASTM C403, penetration method) tests were carried out.

Tests on hardened concrete. Six 15 × 15 × 15 cm cubes and three 10 × 10 × 50 cm prisms were cast for each group of testing for compressive and flexural (three-point testing, ASTM C78) strength tests, respectively. The specimens were cured in water at 20°C after removing from the mould 24 h after casting. Compressive strength tests were carried out at 7 and 28 days, and flexural ones at 28 days.

Bond tests were carried out by using the pull-out specimen and test rig similar to those given in Reference (12). The concrete specimens were 30 × 30 × 20 cm in dimension, and each specimen contained four ribbed bars, two of which were cast at the bottom and two at the top. The diameter of bars was 16 mm and the cover was 25 mm.

Results and Discussion

Workability

Slump results are presented graphically in Figure 1. This figure shows that Reference mix 1, which contained no admixture, had an initial slump of only 8 cm, however addition of each of the three different admixtures used into this concrete increased the slump to the range of 17–20 cm; dextrin-based WR has the former slump, and 2% gluconate R has the latter. Although gluconate R was designated as only retarding admixture, it showed also water-reducing effect. For this admixture, increasing the content from 1% by weight of cement to 2% caused the slump to increase about 2.5 cm. When Reference mix 1, after 1½ h agitation time, was retempered by addition of 2% gluconate R, the slump increased from 6 cm to 10 cm. The cement and water contents of Reference mix 1 were increased 10% each, in order to bring the slump to the range of admixtured mixes, and it is designated Reference mix 2.

After 1½ h agitation, the slumps of Reference mix 1 and 2 decreased 2 cm and 8 cm, respectively, confirming that the higher the initial slump, the higher the slump loss (8,9).The

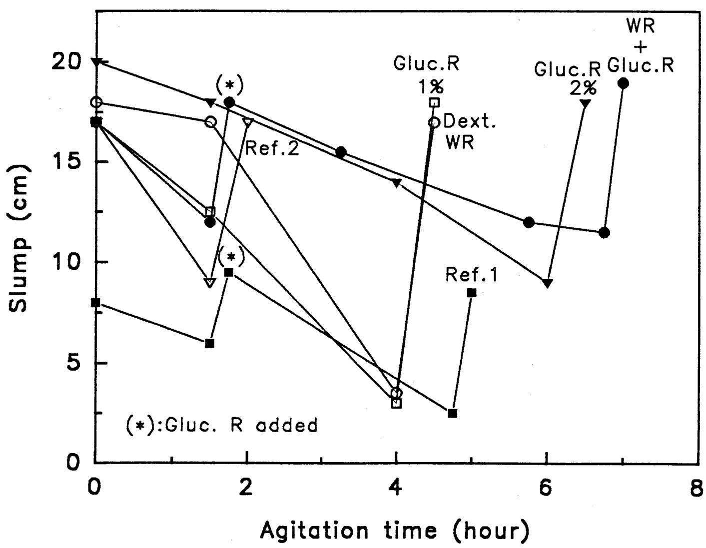

FIG. 1.
Variation of slump with agitation time.

slump loss in the 1½ h initial period was slight for both dextrin WR and gluconate R (2%) mixes. Test results indicate that 1% dosage for gluconate R was not as effective as 2% in delaying the slump loss. Similarly, lignosulfonate-based WR showed the same amount of slump loss as gluconate R in 1%.

Addition of gluconate R to WR2 mix after 1½ agitation increased the slump 6 cm, and after this period the slump loss was slight and showed parallel trend to that of the mix with gluconate R (2%) up to about 4 h. Between 4 and 6 h, the loss was a little higher for the latter mix than that of the former, and after 6¾ h the slump was still higher than 10 cm in magnitute for the latter while it was slightly less than 10 cm for the former. However, for 1% gluconate R as well as dextrin WR, slumps dropped sharply after 1½ h, and they were less than 4 cm after 4 h agitation time.

Workability studies indicate that gluconate R at 2% dosage, used alone or in combination with lignosulfonate WR, delays not only setting time, but also the slump loss in large extents. At smaller dosages, such as 1%, it still shows water-reducing effect, but the delay in slump loss is less. Although the other admixture, dextrin-based WR, has water-reducing effect, it does not show delaying results on slump loss after 1½ h agitation time.

Setting Times

The setting times, calculated as the time elapsed after the moulding samples, are given in Figure 2. The results indicate that gluconate R increases the setting times in extents depending on admixture dosage, as expected. But the addition time of the R is also important; when it is introduced after 1½ h agitation time, the effect reduces with respect to that admixed initially. WR2 admixture showed no delaying in setting times, but when the same trial, after 1½ h agitation time, was mixed with gluconate R, it showed a kind of synergistic effect; the most extended setting times among the tested mixes were obtained. On the other

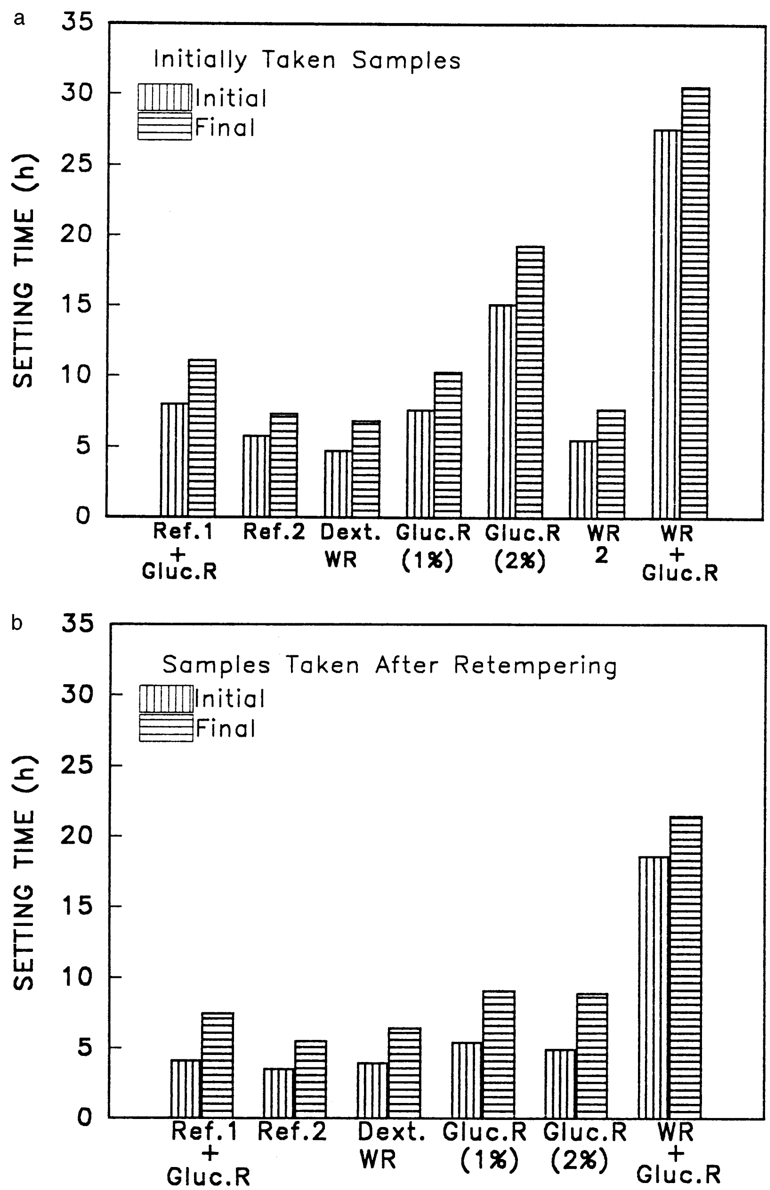

FIG. 2.
Setting times of concrete mixes: (*a*) samples taken initially; (*b*) samples taken after retempering.

hand, dextrin WR, although designated as retarder as well as water-reducer, exposed no delaying performance.

Prolonged agitation decreased both the initial and final setting times for all mixes tested; especially for the gluconate R (2%) and combined WR2 and gluconate R, dramatic reductions (about 10 h) were experienced. The decrease in the setting times may be attributed to

TABLE 3
Effect of agitation on the 28-day compressive strength of concretes.

	Compressive strength (MPa)									Retempered mix	
	Agitation Time (h)										
Test mixes	Initial	1½	1¾	3	4	4¾	5¾	6	6¾	Agitation time (h)	Comp. strength (MPa)
Reference mix 1*	27.2	25.1	25.1			23.7				5	22.9
Reference mix 2	29.7	31.9								2	28.3
Dextrin WR	25.2	24.1			26.1					4½	19.5
Gluconate R	30.9	30.7			30.2			29.8		6½	27.0
WR + gluconate R	28.7	27.9	30.1	31.3			29.9		33.8	7	28.4

*1 h later gluconate R was added

the increase in the temperature and reduction in the water/cement ratio that occured during the delayed agitation, which increases the hydration of cement particles. Once the hydration products start depositing on the cement grains, it is a matter of time of settling that brings the grains in contact. However, the difference between the final and initial setting times of the samples taken initially remained almost constant after prolonged agitation.

Compressive Strength

Compressive strength data at 28 days belonging to different mixes and agitation times are gathered in Table 3, and the normalized compressive strengths with respect to those of initially taken samples are illustrated in Figure 3. Initial 1½ h agitation caused 7.7% reduction in strength for Reference mix 1, while, on the contrary the same period of mixing increased the strength 7% for the Reference mix 2. (with increased cement and water content). One percent gluconate R mix showed almost no change in strength after 4 h agitation. When the dosage was doubled for the same admixture, even after 6 h extended mixing, strength loss was less than 5%. The mix, which had initially WR2 and 1½ h later gluconate R added, gave the best result with respect to strength, i.e., after 6¾ h agitation the increase obtained in strength was as much as 18%. When the same retarder after 1½ h agitation time was added to the mix that contained no admixture initally, further agitation up to 4¾ h caused 13% reduction in strength. On the other hand, the dextrin WR mix showed a slight increase (3.6%) after agitation of 4 h.

Retempering of Reference mix 2 to restore the initial slump caused only 5% reduction in strength, indicating that the added water after 1½ h agitation was not greater than the evaporated water during mixing. This period of time coincides with the limit given in ASTM C94. For 1% gluconate R mix, retempering after 4 h agitation caused the greatest strength loss among the mixes tested, as much as 35%; however, when the same retarder was used in double dosage, the reduction in strength was less than 13% even after the agitation time of 6 h, because the amount of retempering water for the latter mix was smaller than that of the former. When the same retarder was added to the mix that had initially had WR and was mixed for 1½ h, the result was even better, and the strength loss was only 1% after

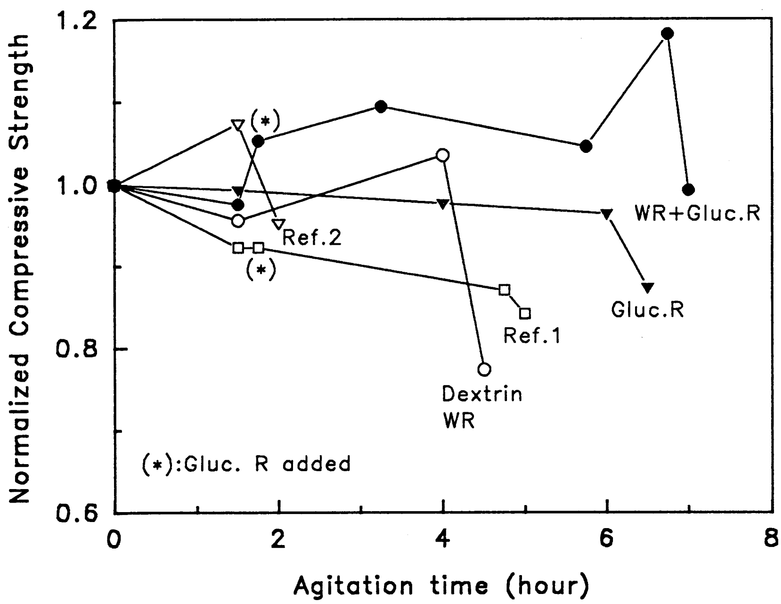

FIG. 3.

28-days compressive strengths normalized by those of initially taken samples (Last points correspond to retempered concretes).

retempering followed the 5¾ h agitation. Compressive strength tests, carried out at 7 days, gave similar results with those of 28 days.

No attempt was made to relate the strength loss to the slump increase after retempering, because the additional water to restore the initial slump depends on the time of retempering as well as the admixture type concrete contains. Besides, the amount of water evaporated during mixing in the truck mixer was not known; however, more than 6.5% loss of mixing water was reported (1) after 5 h agitation, and for this reason the relation between the strength loss and water/cement ratio after retempering was not investigated. However, some attempts were proposed (13) to relate the ratio of water/cement after retempering to that before, and to the ratio of compressive strength after retempering to that before retempering, ignoring the evaporated water during mixing.

Flexural Strength

Table 4 and Figure 4 show that 1½ h agitation increased the flexural strengths of both Reference mix 1 and 2 as well as that of the mix which had initially WR2 and later gluconate R added. The same period of agitation, on the other hand, reduced the strengths of gluconate R mixes in both 1% and 2% dosages, as well as of the one with dextrin based WR. However, for the latter mix further agitation up to 4 h increased the strength over the initial value. For the mix which initially contained no admixture but 1½ h after gluconate R was added, and also for the other mix prepared with the combination of WR and gluconate R, after the agitation periods of 4¾ and 6¾ h, respectively, the flexural strengths were about the same levels with the initial values. The prolonged agitation reduced the strengths of gluconate R

TABLE 4
Effect of agitation on the 28-days flexural strength of concretes.

Test mixes	Flexural strength (MPa)									Retempered mix	
	Agitation Time (h)									Agitation time (h)	Flexural strength (MPa)
	Initial	1½	1¾	3	4	4¾	5¾	6	6¾		
Reference mix 1*	4.4	5.3	4.9			4.6				5	4.0
Reference mix 2	5.6	5.9								2	5.1
Dextrin WR	6.3	5.8			6.8					4½	4.9
Gluconate R	6.6	5.9			5.8			6.0		6½	5.3
WR + gluconate R	5.9	6.7	6.3	6.7			5.9		6.5	7	6.0

*1½ h later gluconate R was added

mixes, in both dosages, about the same percentage, i.e. 9%, of which mixing times were 4 h for the former and 6 h for the latter.

Retempering reduced the flexural strengths; for example, gluconate R mixes experienced 34% and 20% strength losses for the admixture dosages of 1% and 2%, respectively. The Ref. 2 mix showed 9% reduction in strength after retempering, but the agitaiton time was only 1½ h for this mix. Retempering of dextrin WR mix caused 22% strength loss after prolonged mixing of 4 h. However, the mix that contained initially no admixture but 1½ h later had gluconate R added and was finally retempered after 4¾ h agitation, had only 10% strength reduction. The best result obtained among the mixes is the one prepared with the combination

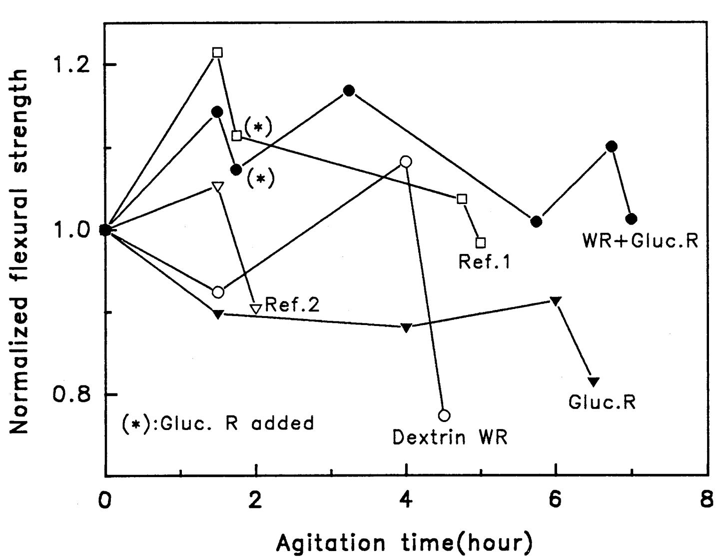

FIG. 4.
28-days flexural strengths normalized by those of initially taken samples (Last points correspond to retempered concretes).

TABLE 5
Bond strength of concrete mixes.

Mix	Agitation time (h)	Bond Strength (N/mm^2)	
		Top	Bottom
Reference	Initial	3.0	5.5
	1½	4.3	6.2
	1¾ (Retempered)	3.4	5.4
Gluconate R (%2)	Initial	2.6	4.7
	6½	3.3	4.8
	6¾ (Retempered)	3.2	4.6

of WR (initially added) and gluconate R (1½ h later added); even 6¾ h extended mixing and, finally, retempering showed no negative effect on the flexural strength.

When the absolute strength values of mixes are compared, combined WR and gluconate R mix again exposes the best performance, and gluconate R in 2% mix follows it.

Bond Strength

The bond strength is calculated as the maximum pull-out force divided by the nominal embedded surface area of the bar. The bond strengths of Reference mix 2 and gluconate R mixes were reported in Table 5.

This table shows that the position of the bar in concrete is an important factor for both mixes, i.e., the bond strength is higher for the bars placed at the lower region than for that of bars at the upper part of the concrete. This difference can be due to the bleeding effect, which makes the upper portions rich in water. In comparison, lower bond strength of gluconate R mix than that of Reference mix 1 can be attributed to the higher bleeding amount of the latter mix (14), such that the higher the bleed capacity, the lower the bond strength. Similar relationship has been reported (15) between the compressive strength and amount of bleeding for the uppermost part of the concrete, i.e., the higher the bleeding the lower the strength.

The considerable increase in the bond strength of Reference mix after 1½ h agitation could be partly as a result of better mixing of concrete and dispersion of cement during this period, because similar increases were obtained in both compressive and flexural strengths of this mix after prolonged agitation. However, prolonged mixing increased bond strength of both mixes, even after retempering, with respect to initial values. It was observed that bleeding ceased after 1½ h agitation for the Reference mix and after 6 h for gluconate R mix, for this reason, the increase in bond strength of these mixes after the prolonged mixing can be also due to the reduction in bleeding.

Conclusions

Tests carried out on concretes prepared with water-reducing and -retarding admixtures as well as on control ones in both fresh and hardened states led to the following conclusions:

1. Gluconate-based R used at 2% delayed both initial and final setting times in large extents, however the retarding period depends on the admixture dosage, i.e., the higher the dosage, the longer the delay. When the same retarder is added to the 1½ h agitated mix, which contained a lignosulfonate WR already, the retarding effect extends even more. On the other hand, dextrin-based WR did not show any retarding effect at all. However, prolonged agitation decreased both setting times for all mixes while the difference between the final and initial setting times remained almost unchanged.
2. Addition of gluconate R and dextrin WR into the concrete increased the slump to the level of lignosulfonate WR mix at constant W/C ratio. Gluconate R, when used alone or in combination with lignosulfonate WR, showed less slump loss than those of Reference mix as well as dextrin WR one, and even after 6 h agitation, still workable concretes were obtained with the former admixtures.
3. After 6 h agitation time, no compressive strength losses were experienced for the gluconate-based R and combined lignosulfonate WR + gluconate R mixes, as well as for the dextrin WR one for 4 h agitation. However, retempering followed prolonged agitations decreased the strength 23% and 13% for dextrin WR and gluconate R mixes, respectively, but the loss was only 1% for the combined WR+R.
4. Prolonged mixing did not decrease the flexural strengths of mixes tested except the one with gluconate R, which showed about 9% reduction in strength for 6 h agitation. Retempering following prolonged agitation caused reduction in flexural strengths of dextrin WR and gluconate R mixes 22% and 20%, respectively. No decrease was experienced for the combined WR+R mix.
5. The bond strengths of bars placed at the uppermost portion of concrete were smaller than those of bars located at the lower part for both Ref. and gluconate R mixes. The bond strength of latter mix was less than that of former, probably due to the higher bleeding capacity the latter mix owns. Prolonged agitation improved the bond strength of bars located at the upper region for both mixes.

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