Available online at www.sciencedirect.com

SCIENCE DIRECT®

Cement and Concrete Research 35 (2005) 874–882

Cement and Concrete Research

The utilization of beet molasses as a retarding and water-reducing admixture for concrete

Amanmyrat Jumadurdiyev[a], M. Hulusi Ozkul[a,*], Ali R. Saglam[b], Nazmiye Parlak[b]

[a]Faculty of Civil Engineering, Istanbul Technical University, Maslak 34469, Istanbul, Turkey
[b]Research and Development Division, Sika Construction Chemicals, Pendik 81510, Istanbul, Turkey

Received 10 April 2004; accepted 15 April 2004

Abstract

Molasses, a by-product of sugar industry, increases the fluidity of fresh concrete, and also delays the hardening time of cement paste. In this study, the molasses were determined from three different sugar production factories. A normal water-reducing admixture, based on lignosulphonate, has been used in the control mixture. Setting times of cement pastes prepared with molasses at three different dosages (0.20, 0.40, and 0.70 wt.% of cement content) were determined and it was found that molasses addition causes considerable increase in both initial and final setting times. Workability tests, as well as bleeding tests, were carried out on fresh concretes prepared with three molasses and also with lignosulphonate-based admixture. Flexural and compressive strengths were determined on hardened concretes at both early ages (1, 3, and 7 days), and moderate and later ages (28, 90, 180, 365, and 900 days). The permeability and durability properties of concretes have been investigated by using sorptivity, drying shrinkage, freezing–thawing, wetting and drying, carbonation, and sulfate attack tests. The strength of concretes with molasses showed slight increase at all ages, except early age, with respect to the control mix and no adverse effect has been experienced on the durability properties over a long period of time (900 days).

Keywords: Retardation; Workability; Admixture; Waste management; Molasses

1. Introduction

Lignosulphonates, wastes of the pulp and paper industry, have been widely used as a water-reducing admixture in concrete technology. Similarly, the molasses, waste product of sugar industry, can be considered as a potential retarder [1]. It is the liquor remaining after crystallization and removal of sucrose from juices of sugar beet. The composition of molasses is variable; depending on the quality of sugar beet and processing technology, its composition varies in the following ranges: dry substances, 76–84% (including sucrose, 46–51%); reducing substances, 1.0–2.5%; raffinose, 0.8–1.2%; inverted sugar, 0.2–1.0%; volatile acids, 1.2%; pigments, 4–8%; and ash, 6–10% [2]. Molasses also contain betain.

There have been many investigations about the effect of sugar on the hydrating properties of cement paste. It has been generally accepted that the retarding action of sugar and sugar acids is due to the adsorption of them on the surfaces of hydrating cement particles as well as hydration products [3,4]. Milestone [5] has mentioned that sugar and sugar acids can adsorb on both $Ca(OH)_2$ and calcium silicate hydrate (CSH) nucleation sites and poison them. Another evidence of surface adsorption of sugar on the cement grains has been given as the change of zeta potential of hydrating cement from positive to negative, in the presence of glucose [6]. It was suggested [7] that, during the hydration of ordinary portland cement (OPC) in glucose solution, lime and glucose form a half salt which can adsorb on $Ca(OH)_2$ nucleus and CSH gel, and poison them.

It was proposed by Taplin [8] that α-hydroxyl–carbonyl (HO–C–C=0), an active adsorbing group, is responsible for the retarding action of many retarders. It was explained that all the reducing sugars either contain this group or are

* Corresponding author. Tel.: +90 212 285 3762; fax: +90 212 285 6587.
E-mail address: hozkul@ins.itu.edu.tr (M. Hulusi Ozkul).

0008-8846/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cemconres.2004.04.036

readily converted into saccharinic acids, which contain this group in alkali solutions. It was also reported [9] that the nonreducing sugars, sucrose and raffinose, exhibit good retarding property while trehalose does not, although being a nonreducing sugar. It was shown that the former sugars can be converted into saccharinic acids which contain HO–C–C=0 grouping in highly alkaline conditions. However, the later sugar, trehalose, remains stable in the same conditions.

Sugars, depending on the chemical structure, show different retarding properties, as given below [8]:

Nonretarding	Good retarders	Excellent retarders
α-Methylglucoside	Clucose	Sucrose
Trehalose	Maltose	Raffinose
	Lactose	
	Cellobiose	

It was mentioned [2] that many of the sugar types given above and determined as good or excellent retarders are contained in molasses; for this reason, it shows good retarding property.

On the other hand, sugars show some water-reducing effect in concrete [4]. Ashworth [10] reported an improvement in workability of concrete with the addition of sugar and retained this workability for a longer time. This increase in workability was attributed to the sugar being a surface-active agent. In another study [11], 4% and 5% water reductions were reported for the sugar dosages of 0.03% and 0.06%, respectively.

The plasticizing effect of biological additives is largely due to their organic components, especially humin–melanoidin complexes, amino acids, oxyacids, and carbonhydrates [2]. Pigments of molasses have important effects on the plasticizing properties of the additive. Pigments of molasses are surfactants and electronegative colloids that contain 1.7 unsaturated groups, 6–7 hydroxyl groups, and 0.2 carboxyl group per unit of the polymer. Pigments of beet molasses contain 63.1–81.3% products of alkaline hydrolysis of inverted sugar, 4.0–18.3% melanoidins, and 9.5–17.8% caramels [2].

Products of alkaline hydrolysis of inverted sugar contain free carbonyl groups. Melanoidins are products of interactions of compounds containing free carbonyl, amine, and imine groups. Another component of pigments, caramels, are colloid solutions of surfactants produced by pyrolysis of sucrose and contain particles with molecular weight up to 13,200 [2]. Due to these components, pigments have a major effect on the plasticizing property of molasses.

There are 27 sugar factories in Turkey which process sugar beet and their annual sugar production was about 615,000 ton (in 2000). Molasses have a wide range of usage, such as animal feed, fermentation, and in some other food industries; in addition, a part of molasses has been used as a concrete admixture in Turkey [12]. In this study, the molasses, determined from three different sugar factories, were used as a water-reducing and retarding admixture in the production of concrete. In addition, a normal water-reducing agent, based on lignosulphonate, has been used for comparison. The mechanical properties, as well as permeability and durability properties of admixtured concretes, were determined and compared with each other.

2. Experimental

2.1. Materials

2.1.1. Cement

An OPC PC 42.5 (Turkish Standard, TS EN 197-1) was used. The physical properties and chemical composition of the cement are shown in Table 1. For sulphate resistance tests, a different brand of cement was used which contains the C_3A in higher amount (8%) than 5%.

2.1.2. Aggregates

A crushed stone, based on dolomite, was used as coarse aggregate in two sizes: Crushed Stone 1 (max. aggregate size: 16 mm) and Crushed Stone 2 (max. aggregate size: 25 mm) A natural sand (max. aggregate size: 2 mm) and a crushed stone sand (max. aggregate size: 4 mm) were used as fine aggregate. The volume percentages of aggregates in the aggregate mixture were as follows: Crushed Stone 1: 26%, Crushed Stone 2: 28%, natural sand: 36%, and crushed stone sand: 10%.

2.1.3. Admixtures

The molasses were obtained from three different sugar factories in Turkey: Carsamba, Konya, and Corum. The chemical compositions of the molasses are given in Table 2. For control mixture, a Ca-lignosulphonate-based water reducer was used. All the admixtures were prepared as the solutions of 40% solid. Formaldehyde was added into the admixtures to prevent fermentation.

2.1.4. Mortar and concrete

Mortars were prepared in accordance with Turkish Standard (TS 19) with norm sand. Cement/sand/water weight ratios were 1:2.5:0.5.

Table 1
Properties and composition of cement

Physical properties	Mechanical properties			
Density (kg/m^3): 3080	Compressive strength (MPa)			
Blaine sp. surface (m^2/kg): 3400	2 days	7 days	28 days	
Grading	26.5	47.5	57.3	
Retained on 90 μm (%): 0.2	Chemical composition (%)			
Retained on 32 μm (%): 12.4	C_3S	C_2S	C_3A	C_4AF
Setting time (min)	55.69	17.32	4.87	13.36
Starting : 155				
Ending : 255				

Table 2
Chemical compositions of molasses

	Carsamba molasses	Corum molasses	Konya molasses
Bx (%)	40.96	40.83	39.33
Polarization (%)	22.76	21.61	–
pH	6.96	6.46	6.37
Invert sugar (%)	0.33	0.35	22.65
Raffinose (%)	0.80	0.83	0.42
Betain (%)	2.40	2.53	2.76
Cl (%)	0.416	0.322	0.328

Table 4
Workability properties and air contents of fresh concretes

Admixture content (%)	Carsamba molasses	Konya molasses	Corum molasses	Lignosulphonate
Slump of fresh concrete (cm)				
0.25	14	14.5	15.5	17.5
0.50	16	18	19	20
Air contents (%)				
0.25	0.3	0.3	0.3	1.6
0.50	0.2	0.6	0.2	2.0

The cement dosage and W/C ratio were the same for all concrete mixtures as 310 kg m^{-3} and 0.65, respectively. The weight ratios of cement/Crushed Stone 2/Crushed Stone 1/crushed sand/natural sand were 1:1.74:1.61:0.60:2.08. The concretes were mixed in a pan mixer with a capacity of 60 dm^3 for 3 min.

2.2. Tests

Setting times of cement pastes with and without admixture were determined in accordance with TS 24 by using a Vicat apparatus.

Workability of fresh concrete and its change with time were determined by using the slump test. In addition, bleeding test was performed on fresh concrete in accordance with TS 4106 and ASTM C 232.

Compressive strength tests were carried out on cubic specimens of $15\times15\times15$ cm^3 at the ages of 1, 3, 7, 28, 90, 180, and 365 days. The 900-day compressive strengths were measured on cubic specimens of $10\times10\times10$ cm^3 cut from prisms of $10\times10\times50$ cm^3. Flexural strengths were determined on similar prisms at the same ages as compressive strength tests except 900 days. The specimens were stored in lime-saturated water for a maximum of 28 days and after that in the laboratory at 65±5% RH and 22±2 °C.

Capillary tests were applied on cubic specimens of $10\times10\times10$ cm^3 cut from concrete prisms mentioned above.

Freezing–thawing and wetting–drying tests were conducted on similar prismatic specimens mentioned above. Freezing–thawing tests were carried out in accordance with TS 3449 and ASTM 666, by freezing in air and thawing in water. Wetting–drying cycles were performed by wetting for 24 h followed by drying in air at about 22 °C for 4 h, and finally drying in an oven at 50±2 °C for 20 h. Resonant frequency, ultrasound velocity, and weight loss tests were applied to determine the level of deterioration.

Carbonation tests were conducted on prismatic specimens stored in the laboratory at 65±5% RH and 22±2 °C after an initial water curing of 28 days, by using phenolphthalein solution as lime indicator.

Shrinkage measurements were monitored on prismatic specimens up to 1 year under the laboratory conditions mentioned above.

Sulphate resistance of mortars was determined by measuring the linear expansion on $4\times4\times16$ cm^3 prisms, keeping continuously in 5% Na_2SO_4 solution. This method is the modified form of ASTM 1012.

In general, all the tests mentioned above were carried out on three specimens for each property investigated at each age.

3. Test results and discussion

3.1. Fresh concrete properties

3.1.1. Setting times

Setting times, determined on cement pastes, are shown in Table 3. As expected, the setting times, both starting and ending, are delayed with molasses addition with respect to both lignosulphonate-added paste and plane paste, most probably due to the existence of sugar in molasses. It can be seen that as admixture content increases, the setting times for all the admixtures tested increases. Table 3 also shows that molasses is a much more effective retarder than lignosulphonates. Konya molasses contains high amounts of inverted sugar than the other two molasses, as shown in Table 2; however, it does not affect the retarding properties.

Table 3
Setting times of cement pastes with admixtures

Admixture ratio	0.20%		0.40%		0.70%	
	Start (min)	End (min)	Start (min)	End (min)	Start (min)	End (min)
Carsamba molasses	450	560	720	1145	945	1470
Konya molasses	520	655	780	1070	1110	1400
Corum molasses	475	580	760	1000	930	1370
Ca-lignosulphonate	235	292	262	350	380	475
Plain	Start (min):155, end (min): 255					

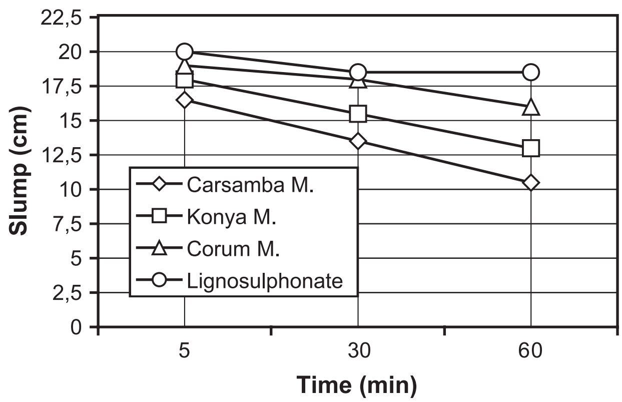

Fig. 1. Slump loss of concretes for the admixture dosage of 0.50%.

3.1.2. Workability

Average slumps obtained on concrete samples are given in Table 4. For the same W/C ratio and admixture content, the lignosulphonate-added mixtures show slight higher slumps than those of concretes with molasses. Nevertheless, the slumps remain in the ranges of 15.5±2 and 18±2 cm for all admixtures at the 0.25% and 0.50% dosages, respectively, showing that the higher the admixture dosage, the higher the slump. The water reduction of molasses and lignosulphonate tested was obtained about 10% with respect to the concrete without admixture. These results indicate that molasses is nearly as effectively a plasticizer as lignosulphonates. The slight difference in the slumps of the concretes in favour of the lignosulphonate-added one can be a result of the higher entrained air content of the latter concrete, as shown in Table 4, because it is known that air entraining in concrete improves the workability, especially in lean mixes [13]. Slump losses of concretes are exhibited in Fig. 1. This figure shows that all the concretes with molasses have a similar trend in slump loss; however, the slump loss between 30 and 60 min is higher for the molasses-added concretes than that of the lignosulphonate. On the other hand, the Konya molasses with high amounts of inverted sugar (Table 2) does not exhibit a different behaviour than the other two molasses.

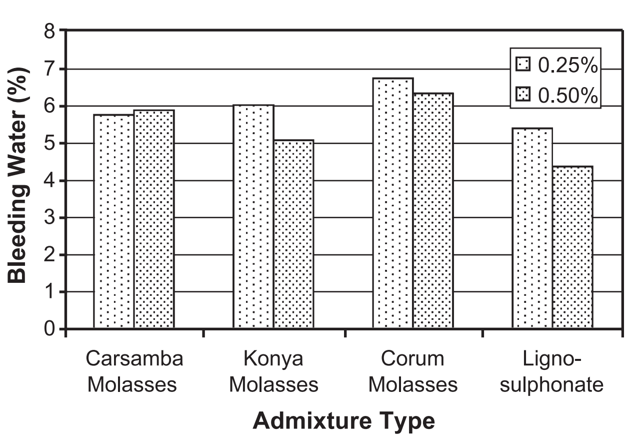

Fig. 2. Total bleeding water obtained for the concretes with admixtures tested.

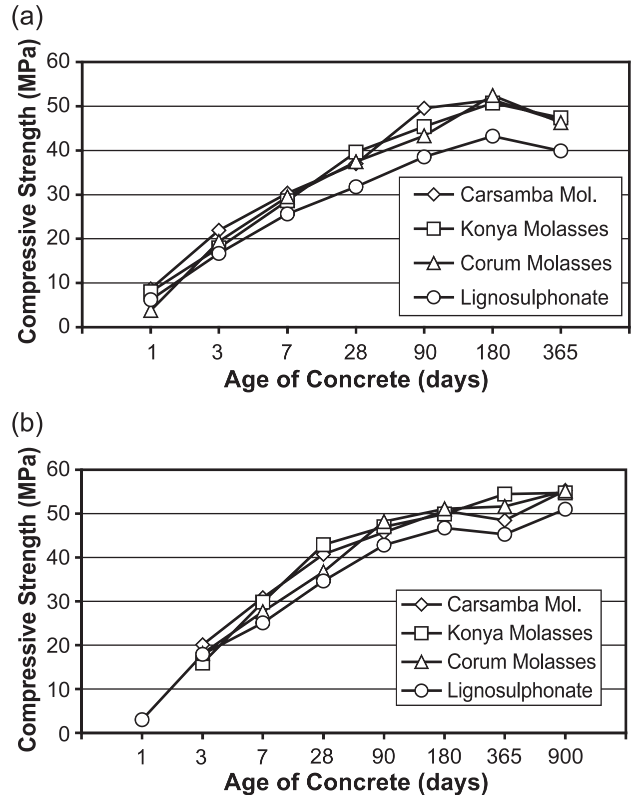

Fig. 3. Compressive strength development of concretes for admixture content of (a) 0.25% and (b) 0.50%.

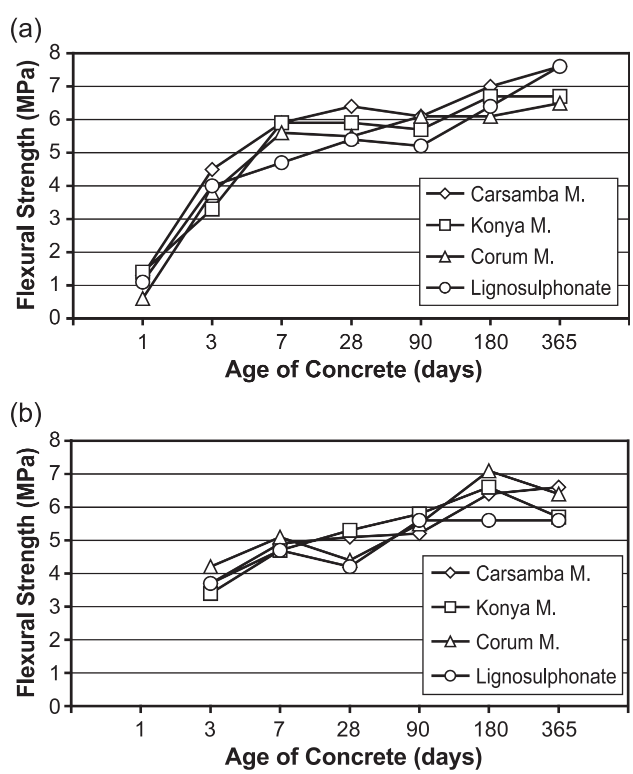

Fig. 4. Flexural strength development of concretes for admixture content of (a) 0.25% and (b) 0.50%.

3.1.3. Bleeding

Bleeding water ratio (with respect to the total water content of the concrete sample in the testing container) is exhibited in Fig. 2 for two admixture dosages. Fig. 2 shows that molasses increase the amount of bleeding water with respect to the concrete with lignosulphonate. The higher amount of entrained air in the latter concrete may reduce the bleeding, as they decrease the settlement by keeping the solid particles in suspension position [13], as well as disturb the continuity of capillary pores. In addition, there exist slight differences between the bleedings of molasses-added concretes; Corum molasses showed the highest bleeding for both admixture contents. Moreover, it can be seen that the higher the admixture content, the lower the bleeding for all admixtures used, except Carsamba molasses.

3.2. Hardened concrete properties

3.2.1. Strength results

The compressive strength developments of concretes prepared with three molasses and a lignosulphonate-based admixture are shown in Fig. 3a and b for the admixture contents of 0.25% and 0.50%, respectively. Fig. 3 exhibits that the concretes with molasses give higher strength than those of the lignosulphonate-based admixture, except 1-day strength. For example, at 28-day age, 16–25% and 6–24% increases in compressive strengths were obtained for the molasses-added concretes with respect to those of lignosulphonate for 0.25% and 0.50% admixture contents, respectively. The higher strength of the former concretes can be partly due to the more uniform and denser structure formed under the prolonged hardening. In addition, it can be attributed to the higher entrained air content of the concretes with lignosulphonate (1.6% and 2% for 0.25% and 0.50% admixture contents, respectively) than those of the molasses (0.3–0.6%), as shown in Table 4. However, at 1-day age, the delaying effect of molasses at the dosage of 0.50% prevents the strength gaining of concrete. The higher early strength obtained on the molasses-added concretes than the expected value of a concrete which contains a retarder as effective as molasses can be attributed to the chloride contents of molasses [1], about 0.3–0.4%, as given in Table 2. It was reported [10] earlier that about an 8% increase in compressive strength was obtained for the concrete with 0.05% sugar addition with respect to that without sugar. However, the existence of chloride in

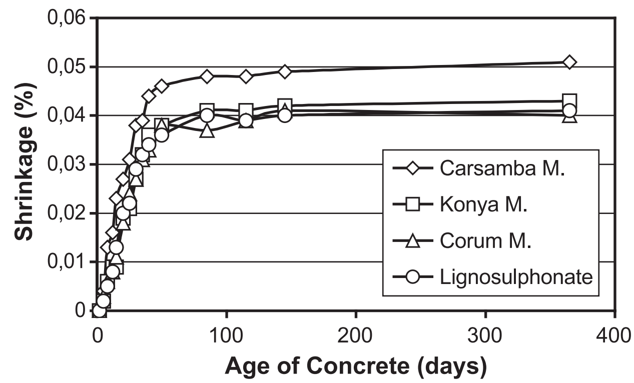

Fig. 5. Monitoring drying shrinkage of concretes for admixture content of 0.50%.

molasses should be considered while determining the maximum dosage of admixture, because it causes the corrosion of metallic reinforcement in concrete when used over the limits given in the standards. ACI 318 allows the existence of chlorides only as impurity in admixtures. The European Standard EN 934-2 [14] (also accepted as Turkish Standard) gives 0.1% as maximum limit for chlorides in admixtures and EN 206-1 [15] (also accepted as Turkish Standard) permits maximum total amount of 0.2% (with respect to the weight of cement) for reinforced concretes and it is even lower (0.1%) for prestressed concretes.

For the flexural strength, a similar trend as compressive strength is obtained (Fig. 4), except those at the ages of 3 and 365 days for the 0.25% admixture content, and those of 3 and 90 days for the 0.50% admixture content, respectively. Except for these ages, the concretes of molasses show higher strengths than those of the lignosulphonate.

Test results show that there is no adverse effect of using molasses as admixture in concrete on the strength properties at all ages compared with the results of lignosulphonate-based admixture concrete. However, some concretes for all admixtures show slight strength decrease at the age of 365 days compared with the 180-day strengths. A similar trend was observed [11] on the sugar-added concretes between 180 and 365 days. In general, this behaviour can be attributed to the shrinkage cracking occurred on the specimens at later ages [16,17]. The 900-day strengths were determined on $10\times10\times10$ cm^3 cubic specimens cut from the $10\times10\times50$ cm^3 prisms. The following equation is used to convert the strength of

Table 5
Sorptivities of concretes

Curing condition	Age of concrete (days)	Sorptivity (mm min^{-1})			
		Carsamba molasses	Konya molasses	Corum molasses	Lignosulphonate
28 days in water	180	0.241	0.231	0.207	0.186
No water curing	900	0.296	0.285	0.283	0.257

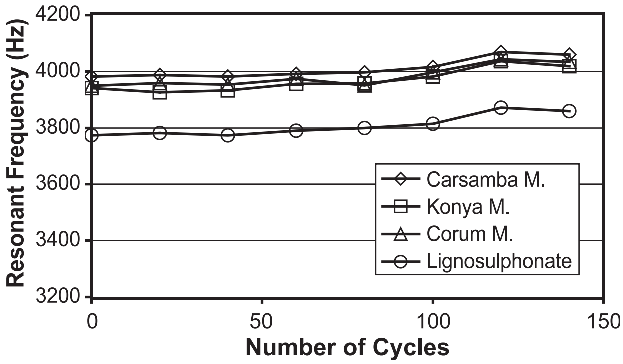

Fig. 6. Variation of resonant frequency with freezing–thawing cycles.

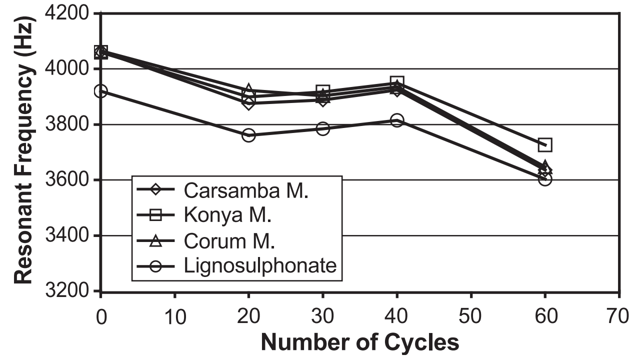

Fig. 7. Variation of resonant frequency with wetting–drying cycles.

10×10×10 cm^3 cubic specimens into those of 15×15×15 cm^3 ones [18]:

$$\frac{f_c}{f_{cu,15}} = 0.56 + \frac{0.697}{\left(\frac{V}{15hd} + \frac{h}{d}\right)} \tag{1}$$

where $f_{cu,15}$ and f_c show the compressive strengths of the cubic specimens with a dimension of 15 cm and any other dimension, respectively. In Eq. (1), V is the volume of the specimen, h is its height, and d is its least lateral dimension. Nine-hundred-day strength results show that even at this age, the concretes prepared with molasses exhibit higher compressive strengths than those of lignosulphonate.

3.2.2. Sorptivity

The water absorbed by capillary per unit area was monitored up to 64 min at the times of 1, 4, 9, 16, 25, 36, 49, and 64 min after the first contact of water and the specimen. When the cumulative water uptake was plotted with the square root of the time, a linear relation was obtained in the form of

$$Q = a + K\sqrt{t} \tag{2}$$

where Q is the cumulative water absorbed through the unit area, a is a constant, t is the time, and K is the sorptivity. Sorptivities, obtained on molasses-added and control (lignosulphonate-added) concretes prepared at 0.5% admixture content and tested at 180-day age, are given in Table 5. This table indicates that the lignosulphonate-added specimens have the lowest sorptivity and there exists a maximum 15% difference between those of the lignosulphonate and molasses concretes. The first group specimens were 180 days old and had 28-day initial water curing. The second group specimens given in Table 5 had no water curing, and for this reason, they have higher sorptivities; however, the order of concretes is the same with the first group, i.e., the lignosulfonate-added one is the lowest and the Carsamba molasses one is the highest. Test results show that although all the concretes tested have the same W/C ratio, the lignosulphonate-added concrete has lower sorptivity than the molasses-added ones, and this different behaviour can be attributed to the high entrained air content of the former concrete. Most probably, the existence of air bubbles in concrete reduces the amount of capillary pores in concrete [13], as well as disturbs the continuity of capillary pores. Furthermore, the concretes with lignosulphonate exhibited less bleeding than those with molasses, which can be another reason of having lower sorptivity of the former concrete than the others. Because, as it is known, while bled water is rising to the surface, some could be trapped underneath large aggregate particles, leading to more permeable interfacial zones.

3.2.3. Drying shrinkage

Drying shrinkage measurements were monitored for 1 year. Test results given in Fig. 5 show that the concretes with molasses exhibit similar shrinkage behaviour as lignosulphonate-added concrete, except for the molasses obtained from Corum, which shows about a 25% increase with respect to the former. It was mentioned [4] that the retarding admixtures, which ionize in concrete mixing water, increase the drying shrinkage, but those with coating type expose no effect. Molasses, due to the sugar ingredient, can be accepted as a coating-type retarder. It was reported

Table 6
The changes of ultrasound velocity and weight of concretes under freezing–thawing cycles

Admixture	Ultrasound velocity (km/s)			Weight of specimen (g)		
	Initial	After 140 cycles	Change (%)	Initial	After 140 cycles	Change (%)
Carsamba molasses	4.290	4.012	7	12,390	12,327	0.5
Konya molasses	4.316	3.949	9	12,400	12,337	0.5
Corum molasses	4.315	3.980	8	12,213	12,143	0.6
Lignosulphonate	4.320	3.826	11	11,790	11,720	0.6

Table 7
The changes of ultrasound velocity and weight of concretes under wetting–drying cycles

Admixture	Ultrasound velocity (km/s)			Weight of specimen (g)		
	Initial	After 140 cycles	Change (%)	Initial	After 140 cycles	Change (%)
Carsamba molasses	4.329	3.655	16	12,280	12,043	1.9
Konya molasses	4.316	3.770	13	12,473	12,263	1.7
Corum molasses	4.315	3.633	16	12,180	11,957	1.8
Lignosulphonate	4.320	3.591	17	12,153	11,867	2.4

[10] that the addition of 0.05% sugar in concrete caused no effect on drying shrinkage.

3.2.4. Freezing and thawing

The changes in resonant frequency up to 140 cycles of freezing and thawing are given in Fig. 6. Test results show that none of the concretes have been adversely affected after 140 cycles with respect to resonant frequency values. However, the longitudinal ultrasound velocities measured on the specimens after 140 cycles given in Table 6 indicate that there exists a slight deterioration; the reduction in velocities for molasses-added concretes is at a maximum of 8%, while it is 11% for that of lignosulphonate. Nevertheless, it can be concluded that the concretes with molasses do not perform worse than those of lignosulphonate-based admixture after 140 cycles of freezing and thawing. It was reported [10] that for concretes with W/C ratio equal or grater than 0.60, the sugar-added concretes show better freezing–thawing resistance than plain ones.

3.2.5. Wetting and drying

Resonant frequency and ultrasound velocities obtained on the specimens subjected to 60 cycles of wetting and drying are shown in Fig. 7 and Table 7, respectively. The drops in the frequency and velocities with respect to those of the specimens stored in air after an initial 28-day water curing show that all the concretes prepared with molasses and lignosulphonate were influenced from the wetting and drying cycles almost in the same range. However, compared with the freezing and thawing results, it seems that wetting and drying is more effective on the deterioration of concrete than the former.

3.2.6. Carbonation

Carbonation depths measured on molasses- and lignosulphonate-added concretes are shown in Fig. 8. The concretes were prepared in two admixture dosages, 0.25% and 0.50%, respectively. Test results obtained at 365 days indicate that the higher the admixture content, the higher the carbonation depth for molasses-added concretes. However, for lignosulphonate-added concretes, the admixture content does not affect the results. For 900-day tests, the positive influence of water curing is obvious, as can be seen in Fig. 8, and there is a big difference between the carbonation depths of initially water-cured (for 28 days) and air-stored specimens. It can be concluded that molasses- and

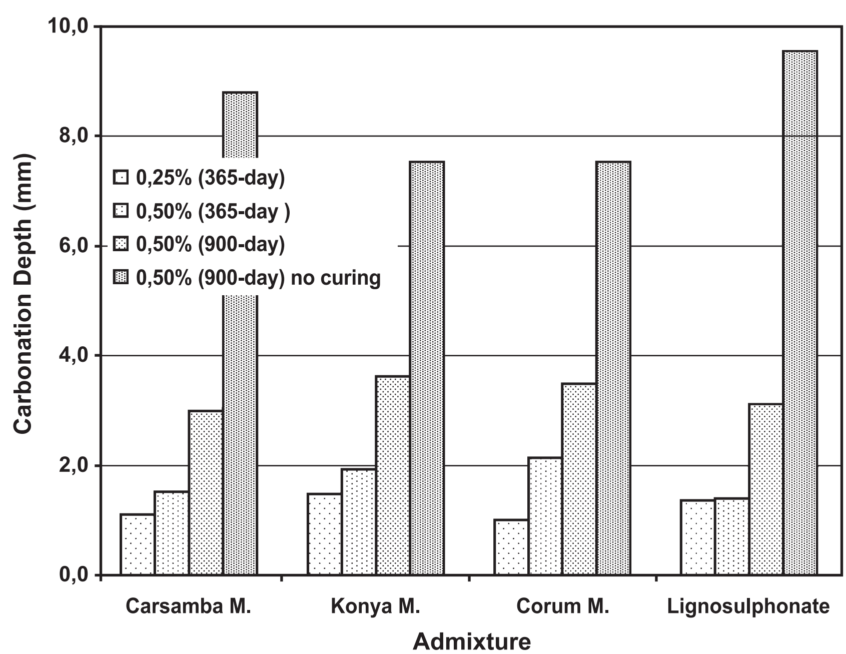

Fig. 8. Carbonation depths of concretes for admixture dosages of 0.25% and 0.50%.

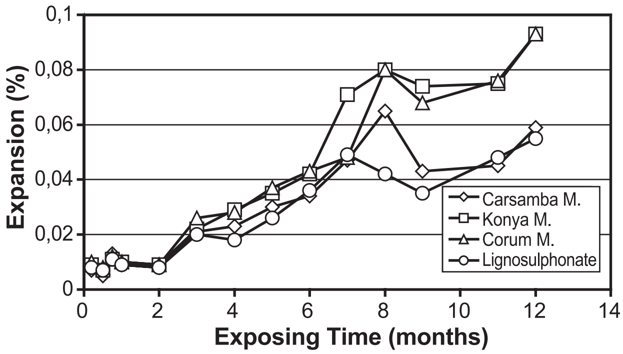

Fig. 9. Monitoring the expansions of concretes in Na-sulphate solution.

lignosulphonate-added concretes show similar performance with respect to carbonation.

3.2.7. Sulphate resistance

The expansions of mortars stored in Na-sulphate solution are exhibited in Fig. 9. The minimum expansion was obtained on the mortars of lignosulphonate and Carsamba molasses, while the maximum one belongs to those of Corum and Konya molasses. The maximum expansion requirement for sulphate resistance is given as 0.10% after a period of 1 year. All the mortars tested in this study showed smaller expansion than this limit. However, the size of the cross-section of the specimens used in this study was a little larger (40×40 mm^2) than that (25×25 mm^2) required in ASTM 1012. For sulphate resistance, the C_3A content in cement should be smaller than 5% and the C_3S content should not be too high. The cement used in the production of concretes for the tests other than sulphate resistance was an ordinary portland one with a C_3A content smaller than 5% (4.9%); for this reason, a different brand of cement (with a C_3A content of 8%) has been used for the sulphate resistance tests to accelerate the effect. Although there exists a big difference between the expansions of two molasses from Corum and Konya, and those of lignosulphonate and the last molasses, all remain under the limit of 0.1%.

4. Conclusions

The following conclusions can be drawn from this study.

(1) The molasses-added cement pastes show expanded setting times even in 0.2% dosage, and the higher the molasses dosage, the longer the setting time, as expected. The inverted sugar content of molasses does not affect their retarding behaviour.
(2) The molasses obtained from three sugar factories show similar behaviour as the lignosulphonate-based admixture with respect to the workability of concrete. The inverted sugar content of molasses does not influence their water-reducing capacity. However, the slump loss in molasses-added concretes is slightly higher than that of lignosulphonate-added one.
(3) The bleeding of the molasses concretes is higher than that of the lignosulphonate one, probably due to the higher air content of the latter.
(4) The concretes prepared with molasses show a slight increase in compressive strength at all ages except early age compared with those of the lignosulphonate-based admixture, which can be attributed to the more uniform and denser internal structure due to the retarding effect, as well as the lower air content of the former concretes. The flexural strengths of concretes with molasses are in the same level with those of the lignosulphonate.
(5) The sorptivity of the lignosulphonate-added concrete is 15% lower than that of Carsamba molasses, which has the highest sorptivity between the molasses-added concretes. The lower sorptivity of the former concrete may be due to its higher air content.
(6) Two molasses and lignosulphonate concretes show similar shrinkage behaviour; however, one of the molasses (Carsamba) increases the shrinkage about 25% with respect to the others.
(7) The deterioration effect of freezing and thawing is slight on both molasses- and lignosulphonate-added concretes for 140 cycles.
(8) The detrimental effect of wetting and drying is higher than that of freezing and thawing on both molasses- and lignosulphonate-added concretes; however, the adverse effect is less than 11%, with respect to the resonant frequency measurements.
(9) The molasses- and lignosulphonate-added concretes show similar performance with respect to carbonation.
(10) The molasses from Carsamba and the lignosulphonate concretes behave almost similarly in the Na-sulphate solution; however, the other two molasses exhibit higher expansion than those of the former. Nevertheless, they all remained under the limit of expansion given in the standard.
(11) The Cl content of molasses should be considered in determining the dosage of admixture.

Acknowledgement

The authors wish to thank KUB (The Association of Admixture Manufacturers) for their support for this study.

References

[1] V.S. Ramachandran, M.S. Lowery, Conduction calorimetric investigation of the effect of retarders on the hydration of Portland cement, Thermochim. Acta 195 (1992) 373–387.
[2] A.B. Bolobova, V.I. Kondrashchenko, Use of yeast fermentation waste as a biomodifier of concrete (review), Appl. Biochem. Microbiol. 36 (3) (2000) 243–253.

[3] F.M. Lea, The Chemistry of Cement and Concrete, St. Martins Press, New York, 1956.

[4] A. Joisel, Admixtures for Cement, Published by the author, Paris, 1973.

[5] N.B. Milestone, Hydration of tricalcium silicate in the presence of lignosulphonates, glucose, and sodium gluconate, J. Am. Ceram. Soc. 62 (7–8) (1979) 321–324.

[6] N.B. Singh, P.N. Ohja, Effect of glucose on the hydration of Portland cement, in: Proc. 7th Int. Congr. Chem. Cement, vol. II, Editions Septima, Paris, 1980, pp. 100–105.

[7] N.L. Thomas, J.D. Birchall, The retarding action of sugars on cement hydration, Cem. Concr. Res. 13 (6) (1983) 830–842.

[8] J.H. Taplin, Discussion of paper by H.V. Vivian, in: Proc. 4th Int. Congr. Chem. Cement, vol. II, US Department of Commerce, Washington, DC, 1960, pp. 924–925.

[9] G.M. Bruere, Set retarding effects of sugar in portland cement pastes, Nature 212 (1966) 502–503.

[10] R. Ashworth, Some investigations into the use of sugar as an admixture to concrete, Proc. Inst. Civ. Eng. 31 (1963) 129–145.

[11] L.H. Tuthill, R.F. Adams, J.M. Hemme, Observations in testing and use of water-reducing retarders, ASTM Spec. Publ. 266 (1960) 97–117.

[12] A. Jumadurdiyev, M.H. Ozkul, The usage of molasses as a concrete admixture, in: S. Pala, A. Ilki (Eds.), Proc. Fifth Int. Congress, Advances Civil Eng. (ACE), Istanbul Tech. Univ., Istanbul, 2002, pp. 875–884.

[13] A.M. Neville, Properties of Concrete, 3rd edition, Longman Scientific and Technical, Harlow Essex, 1993.

[14] European Standard, EN 934-2 Admixtures for concrete, mortar and grout: Part 2. Concrete admixtures—Definition and requirements, European Committee for Standardization, 1997.

[15] European Standard, EN 206-1 Concrete: Part 1. Specification, performance, production and conformity, European Committee for Standardization, 2000.

[16] M.N. Haque, M.K. Gopalan, D.W.S. Ho, Estimation of in situ strength of concrete, Cem. Concr. Res. 21 (6) (1991) 1103–1110.

[17] B. Ozer, M.H. Ozkul, The influence of initial water curing on the strength development of ordinary portland and pozzolanic cement concretes, Cem. Concr. Res. 14 (1) (2004) 13–18.

[18] A.M. Neville, A general relation for strengths of concrete specimens of different shapes and sizes, ACI J. Proc. 63 (10) (1966) 1095–1109.