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

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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

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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				