

Effect of Using Sugar and Gypsum as a Retarder on Concrete Properties in Omani Weather

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ABSTRACT: This study deals with the retardation of cement setting time and workability in hot weather such as in Sultanate of Oman. Combination of sugar and gypsum was used as retarders. The aim of this study was to investigate the effect of retarders on consistency, setting time of ordinary Portland cement (OPC) paste and compressive strength of concrete cubes after 7 days of curing. OPC paste with a water cement ratio 0.4 to 0.5 was prepared by mixing 500 grams of ordinary Portland cement, a fixed amount of sugar of 0.02% by weight of cement with a combination of different gypsum of 1, 2, 3, 4, and 5% by weight cement and water. Sugar has a strong retarding effect, and this effect, controlled by Gypsum, can shorten the long setting time caused by sugar. The setting time of cement paste was reduced from 5.5 hours to 3 hours with an increase in Gypsum at a fixed amount of sugar. At a constant sugar content, increasing the gypsum content reduced the compressive strength from 31.5 MPa to 30.92 MPa.

KEYWORDS: Hot weather, Initial setting time, Compressive strength, Sugar, Gypsum.

[Received Jul. 30, 2022; Revised Oct. 29, 2022; Accepted Nov. 4, 2022]

Print ISSN: 0189-9546 | Online ISSN: 2437-2110

I. INTRODUCTION

The use of a retarder to delay the setting of concrete is in high demand in hot weather, where the setting and hardening of cement is rapid, causing problems during transportation and proper casting of concrete (Al Martini, Sabouni & El-Sheikh, 2021). When water is added to the cement, it starts to harden due to hydration. Under normal climatic conditions, the setting and hardening of fresh concrete gradually increase (Deschner *et al.*, 2013). In hot climate conditions such as the climate condition of Oman, the high temperature in summer reaching 50 °C, low humidity and hot wind blowing will accelerate the hardening and setting time of fresh concrete (Nasir *et al.*, 2022). As a result, the concrete will set sooner and there will be insufficient time to place and compact the concrete in the field. Furthermore, the workability of concrete will be very low and difficult to deal with in casting. The role of the retarder becomes important. Retarder is used to slow down the chemical process of hydration due to which the concrete remains plastic and workable for a longer time than normal concrete without changing its mechanical properties (Tayeb, Lullulangi & Sampebua, 2019). Retarders are also used to overcome the accelerating effect of hot weather on setting time of concrete (Khan & Muhammad-Ullah, 2004; Zhang, Yang & Cao, 2020)

Hot weather causes rapid evaporation of water from the surface of the fresh paste or concrete. Consequently, the paste or concrete sets rapidly than its normal setting and shortens the length of time for concreting operations. It was reported

that when the temperature of cement mortar with water/cement (w/c) ratio of 0.6 is increased from 27 °C to 45.5 °C, both the initial and final setting times are halved. Other problems such as rapid decrease of slump, formation of cold joints, plastic shrinkage cracking, increased difficulty in air entrainment, enhancement of permeability, reduction in durability and reduction in ultimate strength may arise due to hot weather (Khan *et al.*, 2004; Ham & Oh, 2013).

Retardation action is exhibited by the addition of sugar (Ahmad, Lawan & Al-Osta, 2020). In practice, retarders when used in a carefully controlled manner, about 0.05% of sugar by mass of cement will delay the setting time by about 4 hours. However, the exact effects of sugar depend on the chemical composition of cement (Ahmad *et al.*, 2020). The mechanism of the retarding action is not known with certainty. The admixtures modify the crystal growth or morphology so that there is a more efficient barrier to further hydration than is the case without a retarder. Eventually the retarder is removed from solution by being incorporated into the hydrated material, but the composition of the hydration products is not changed (Neville & Brooks, 2010; Assi, Deaver & Ziehl, 2018).

Hydrous Calcium Sulfate (commonly known as Natural Gypsum), is found in different forms mainly as (CaSO₄.2H₂O) and anhydrate (CaSO₄). Gypsum renders workability to mortar or concrete by keeping the cement in plastic state at early age of hydration. This is achieved by changing the course of hydration of calcium aluminate that manifests as retardation in cement hydration. This is how

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gypsum is identified as a set regulator or retarder. Gypsum also contributes for strength acceleration in the early stages of hydration (Von Daake & Stephan, 2016).

Sugar interferes with the cement binding process in the concrete. One theory suggests that when the concrete mixture contains sugar, the sugar molecules attach themselves to the hydrating cement and inhibit the chemical reactions involved in stiffening. A different theory, called the "precipitation theory," suggests that the addition of sugar increases the concentrations of calcium, aluminium and iron in concrete. The sugar molecules combine with these elements to form insoluble chemical complexes that coat the cement grains. Several key chemical processes that harden the concrete are then impeded. Hydration slows down the process and the concrete take longer to set. For this reason, sugar is known as a retarder. Retarders increase the setting time of concrete (Zajac *et al.*, 2016).

Some theories have been forwarded to explain the mechanism of retarding admixtures such as: Adsorption of retarding compound on the nuclei of Calcium Hydroxide which defers the growth that is necessary for the hydration process, The retarding admixtures tend to form a film around the cement particles thereby preventing these materials to react with water thereby retarding the hydration process (Kandhari, 2017), precipitation around cement particles of insoluble derivatives of the retarding compounds formed by reaction with the highly alkaline aqueous solution, forming a protective skin (Ahmad, Lawan & Al-Osta, 2020), and adsorption of the retarding compound on to nuclei of calcium hydroxide, poisoning their growth, which is essential for continued hydration of cement after the end of induction period (Devakate *et al.*, 2017).

The objective of this study is to deal with the usage of a combination of sugar and gypsum as retarder. Since a very small amount of sugar can cause a high delay in cement initial and final setting times which are considered not to be practical aspect in most cases, effect of addition of gypsum will be studied.

II. MATERIALS AND METHODOLOGY

A. Materials

Cement: The cement used was ordinary Portland cement manufactured by Oman cements Ltd

Sand and Gravel: They were collected from quarries located in Nizwa, Oman

Sugar: Sugar used for the experiment was sucrose crystals ($C_{12}H_{22}O_{11}$). It was obtained from Lulu hyper market.

Gypsum: Dry gypsum powder purchased from local market was used in the experiments.

B. Methodology

1) Material properties

Gradation of the fine and coarse aggregate was performed according to B.S 882-1992 (British Standards Institution, 1992), specific gravity of coarse aggregate was carried out according to ASTM C127-07 (American & On, 2007), Normal consistency of cement was conducted according to ASTM C187-98 [(C01 Committee and ASTM International, 1998)] , and setting time of cement was

performed according to ASTM C191-04a (C01 Committee and ASTM International, 2004).

2) Preparation of sugar-cement and (sugar + gypsum) cement paste

The specific sugar content (0.02% of cement by weight) was mixed with the measured water content and stirring was done to dissolve the sugar in water, then the sugar-water added to the cement with a uniform mixing to prepare the cement paste. In case of addition of gypsum, the gypsum content (as a percent of cement) is added as a dry powder to the cement and mixed thoroughly in dry condition, then water with sugar is added as in sugar-cement paste.

3) Preparation of concrete cubes with sugar and gypsum

A concrete mix design was conducted for a characteristic strength of 40 MPa using British Method (DOE-Method), accordingly the following proportions were used:

Gravel:	(20mm) = 500 Kg/m ³ of concrete
	(10mm) = 500 Kg/m ³ of concrete
Sand:	850 Kg/m ³ of concrete
Cement:	400 Kg /m ³ of concrete
Water:	160 L (for W/C = 0.4).
	200 L (for W/C = 0.5).

The gravel, sand, cement and gypsum were mixed in dry condition thoroughly, then water-sugar was added and mixing was continued. The mixing was done using tilting drum mixer. Cubes were casted directly after the completion of mixing and the slump was measured as well. Cubes were kept for 24 hours in laboratory temperature then kept in water tank for the remaining time of the curing period.

4) Compressive strength of concrete

Compressive strength of concrete cubes 150×150×150 were found using a digital compression machine of 2000 KN capacity with an accuracy of 0.1 KN. The cubes were tested after the completion of the specified curing time. Figure 1 shows the test in progress.



Figure 1: Cube test by compression testing machine

III. RESULTS AND DISCUSSION

A. Normal consistency

Normal consistency of cement and sugar was determined for different percentages of gypsum. It can be seen from the relationship between the normal consistency and gypsum shown in Figure 2, that the normal consistency decreases with gypsum up to 2% of gypsum. Then the normal consistency increases with higher gypsum content. Since consistency is the quantity of water to be added to certain cement quantity, through hydrating the system, gypsum needs more water to give the same paste state. This is supporting the idea of hydrating the added gypsum at certain level. The decrease in normal consistency may attributed to available water enough to hydrate the whole amount of Gypsum. For higher amount of Gypsum content, it needs more water than the available water, which is resulted in increase in consistency of cement paste.

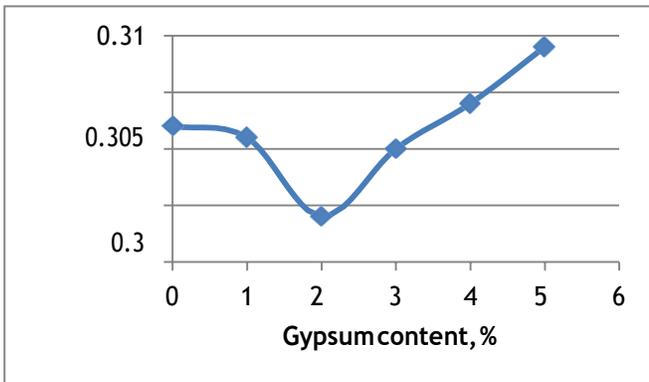


Figure 2: Effect of gypsum on the normal consistency of 0.02% sugar cement paste

B. Setting time

Cement-sugar paste setting time was determined for different percentages of gypsum. Figure 3 shows the effect of gypsum on the setting time of cement-sugar paste using 0.02% sugar content for all gypsum percentages. It is noticed that gypsum decreases the setting time up to 3%, after which the setting time starts to increase for higher percentage of gypsum. The findings of this study are consistent with those of Gree *et al.*,(2017), who investigated the effect of gypsum on the hydration kinetics of sugar-containing cements.

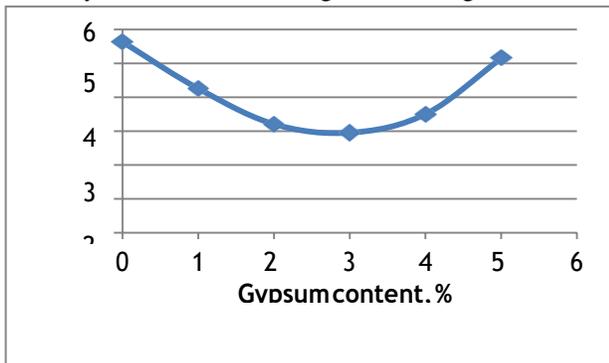


Figure 3: Effect of gypsum on setting time for 0.02% sugar

When ordinary Portland cement was mixed with glucose, the low gypsum content had a significant impact on heat development, which increased the setting time. Increasing the gypsum, on the other hand, decreased the setting time, indicating glucose incorporation into the hydration products (Gree *et al.*, 2017; Doudart de la Grée, Yu & Brouwers, 2017)

Incorporation of acid into cement results in the formation of stable and impermeable sheets of hexagonal hydrates around the cement compounds, preventing further water access. (Usman *et al.*, 2016). This is consistent with the current findings. Furthermore, according to the findings presented in this paper, decreasing gypsum causes an increase in setting time due to the increased formation of calcium aluminate ferrite hydrates derived from the reaction of C4AF. (Cuesta *et al.*, 2015). Increased gypsum content results in an increase in calcium sulfoaluminoferrite phases, allowing the cement to react continuously (Cuesta *et al.*, 2015). However, by increasing the gypsum content significantly, phases are formed that retard the further reaction of the cement, resulting in an increase in setting time. The chemical composition of cement determines which phases are dominant, which can suppress the retardation effect when glucose is present. As a result, gypsum content as an additive up to 3% can be used to control the setting time, retardation effects of cement, and 0.02% sugar mix.

C. Concrete material properties

The properties of the material used for concrete were determined and tabulated in Table 1. It is indicated that the specific gravity and absorption of aggregate are within the normal ranges. Sulphate and organic matter is a low value having no effect on concrete. Figures 4 and 5 depict the coarse and fine aggregate gradations, respectively. These figures show that the coarse and fine aggregates used in this study are well and non-uniformly graded, and that they are suitable for concrete mixes because they are within the B.S limits shown in Figures 4 and 5.

Table 1: Properties of material used for concrete

Properties	Value
Specific gravity of coarse aggregate	
-Dry	2.60
-SSD	2.69
Specific gravity of fine aggregate	
-Dry	2.68
-SSD	2.80
Sulphate content, %	0.015
Organic matters, %	0.45
Absorption of coarse aggregate,(%)	0.17
Absorption of fine aggregate,(%)	1.3

D. Compressive strength

The compressive strength of the concrete specimen at curing age of 7days was found for water cement ratio of 0.4 and 0.5 and for various gypsum content in combination with 0.02% sugar as a retarder. The results are shown in Tables 2 and 3 respectively. Effect of sugar as a retarder and combination of sugar with gypsum are shown in Tables 2, 3,

and Figure 6 for 7 days curing. The effect of water cement ratio

The effect of the combination of retarders showed that the compressive strength slightly increase with increasing the gypsum content up to 3%, for higher value of gypsum the strength starts to decrease, this is for both 0.4 and 0.5 W/C

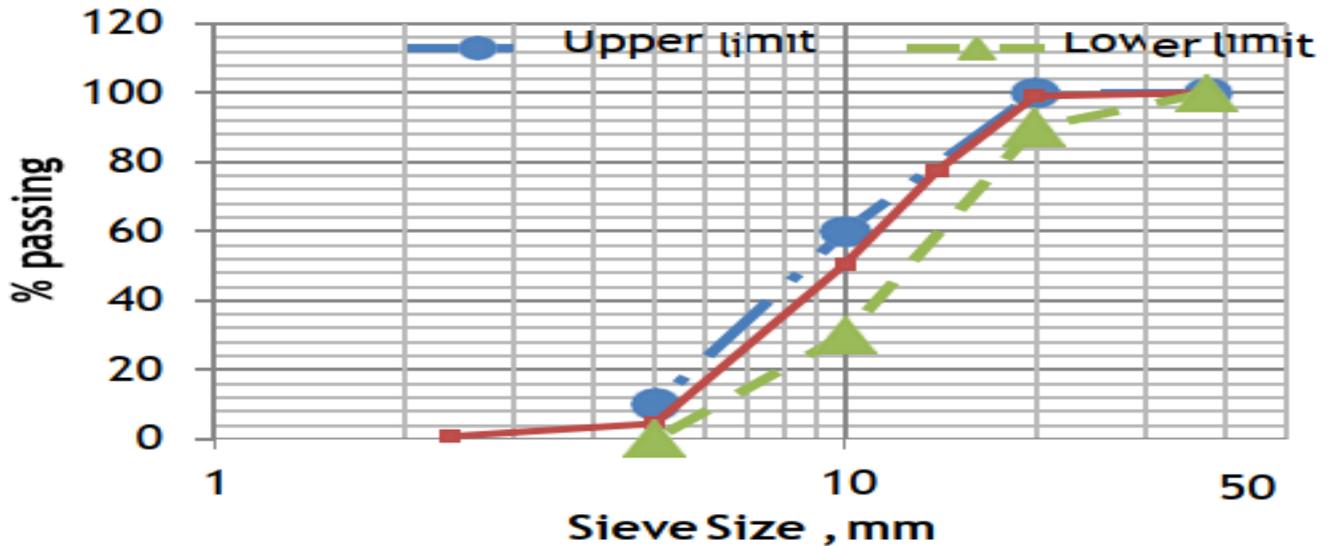


Figure 4. Gradation curve for coarse aggregate with BS limits

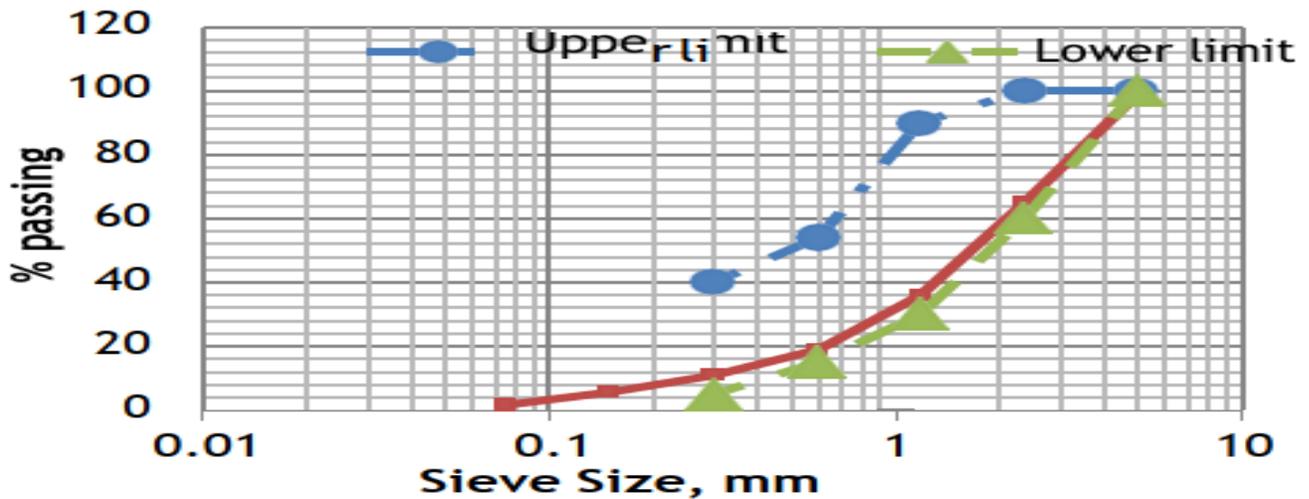


Figure 5. Gradation curve for the fine aggregate using wash sieving.

Table 2: Compressive strength and slump at different gypsum content (W/C=0.4) at 7 days curing.

Mix Condition	Compressive strength (MPa)	Slump (mm)
I Control mix(without gypsum and sugar)	32.95	10
II 0.02% sugar	31.5	13
III 0.02% sugar +1% gypsum	31.7	15
IV 0.02% sugar +2% gypsum	31.96	11
V 0.02% sugar +3% gypsum	32.43	10
VI 0.02% sugar +4% gypsum	31.80	10
VII 0.02% sugar +5% gypsum	30.92	12

ratio, and it may be attributed to the effect of setting time shown previously which is decreasing up to 3% gypsum content, which means that the effective curing time becomes longer for gypsum up to 3%. For gypsum greater than 3% the setting time start to increase which decreases the effective curing time reducing the strength accordingly. In general; the effect of the retarder additives on the compressive strength can be considered very low.

is also shown. It can be seen that the retarders are not affecting the slump of concrete remarkably.

Table 3: Compressive strength and slump at different gypsum content (W/C=0.5) at 7 days curing.

Mix Condition	Compressive strength (MPa)	Slump (mm)
I Control mix (without gypsum and sugar)	25.37	10
II 0.02% sugar	24.35	15
III 0.02% sugar +1% gypsum	24.39	24
IV 0.02% sugar +2% gypsum	24.55	30
V 0.02% sugar +3% gypsum	24.86	42
VI 0.02% sugar +4% gypsum	24.56	10
VII 0.02% sugar +5% gypsum	23.986	30

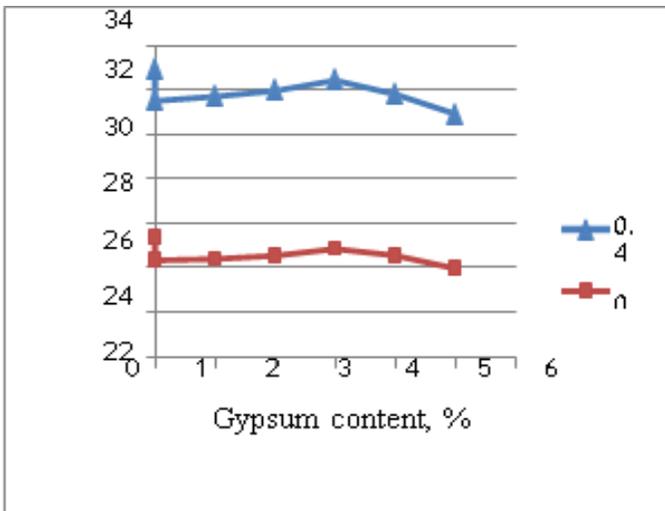


Figure 6: Effect of sugar-gypsum combination on the strength of concrete for various W/C ratio

IV. CONCLUSION

Based on the experimental results the following conclusions are drawn:

- 1) Consistency and setting time of 0.02% sugar cement paste can be controlled by introducing gypsum.
- 2) The compressive strength of 0.02% sugar content in concrete increases slightly with gypsum content up to 3%. Increase in gypsum from 4% to 5% would result in decrease in compressive strength
- 3) The compressive strength of concrete decreases with increase in water : cement ratio for the same gypsum content.

AUTHOR’S CONTRIBUTION

K.W. Thanoon: Conceptualization, Methodology, Investigation, Writing -Original draft preparation. **S.A. Ali:** Methodology, Writing -Review & Editing. **S.S. Reddy:** Conceptualization, Investigation, Writing -Review & Editing

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