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# Effect of sugar on Compressive Strength, Drying Shrinkage and Carbonation of Mortar

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**Abstract.** Mortar is one of the most common construction materials, used in bind building blocks such as stones, bricks, and concrete masonry units. This paper presents the experimental investigation on the effect of sugar on setting time of cement and compressive strength, drying shrinkage, and carbonation of mortar using composite cement. Different percentages of sugar varying from 0 to 0.08 % by weight of cement was selected as retarder. It was found that the initial and final setting time of composite cement paste increased, with the increase of sugar dosage. The maximum initial and final setting time occurred when sugar content is 0.08 %, where it increased the initial time from 100 minutes to 550 minutes and increased final setting time from 135 minutes to 610 minutes. The compressive strength, drying shrinkage and carbonation specimens were tested at 7, 28, 56, 90, and 150 days. The compressive strength of mortar containing 0.06% sugar increased by 9.25 % at age 150 days compared to control specimens, while the drying shrinkage of mortar was less affected by sugar. The carbonation depth test shows that all specimens are almost the same, with a slight increase in specimens that contain sugar.

## 1. Introduction

Mortar is a workable paste used in many applications of construction projects, especially in buildings. As a binding material, Mortar is widely used in construction for masonry unit and is produced by mixing cement, sand and water [1]. Additional materials, such as; fly ash, biomass ash, rice husk ash or bacteria are being researched to produce environment friendly mortar. Sometimes other admixtures materials are required to produce suitable mixture proportions [2].

The strength and durability of mortar improves its engineering properties, however, change of weather conditions is considered as one of the factors affecting mortar especially in the plastic stage. Whereas, the variation in weather conditions and seasons affects the initial setting time of mortar. Therefore, retarder and accelerator are used to enhance and reduce the initial setting time of mortar and concrete especially in winter and summer seasons [3]. Production of mortar in hot weather causes higher temperature within mortar, this results in higher rate of evaporation from the mortar mix, accelerating the initial time of mortar leading to difficulty in placing and finishing [4]. The high temperature requires excess use of water in mortar mix and this results in loss of slump and rapid hydration, leading to decreased long-term strength [5]. In addition, mixing the concrete in hot weather beyond 38°C increases the speed of the cement early hydration and



produces mortar and concrete with higher strength at early ages, but later decreases the strength considerably [3]. Furthermore, the shrinkage in concrete and mortar occurs due to the fast evaporation of water, and subsequent cooling would cause tensile stresses and crack. Hence, in order to achieve the standard condition of mortar, admixtures such as retarders are used to increase the hydration induction time, then increasing the setting times [6].

Furthermore, according to [7], high temperature affects the evaporation volume from the surface of the fresh cement paste. Evaporation has a noticeable impact on fresh concrete and mortars, and this increases the need to add water to maintain a certain slump, however, adding water without adding cement increases the water-cement ratio, and thus reduces the strength and durability of the mortar. The slump loss reduces workability in bind building blocks, which can cause dangerous extension and finishing problems [8]. Addition of water recompensate the expected slump loss is not significantly beneficial, this is because a higher initial slump leads to greater slump loss due to the rate of hardening increases, and thus shorten the setting time. One way to reduce the effects of high temperatures on mortar mix is by using additives which lower the temperature of the mixture, which in turn slows down the loss of slump [7].

Nonetheless, retarder is used to delay the setting time and hardening of cement paste by inhibiting tricalcium aluminate without changing the composition of hydration products [6]. One of the additions that can be used as a retarder is sugar [9]. Sugar is composed of carbon, oxygen and hydrogen, which is carbohydrate. It can be beneficial in hot weather conditions for mortar mix where the natural setting time for the mortar is significantly less due to the high ambient temperature [3]. A small dose of the sugar content (0.01-0.08) % of cement weight can delay the initial setting time [3]. The addition of sugar to the cement in a ratio of up to 0.05% cement weight greatly increases the setting time and it is noted that to avoid negative impacts on setting time and strength, the sugar content should be in the range of 0.05 - 0.1% of cement weight [10].

Whereas, most of the studies focus on use of sugar in ordinary Portland cement, this study is initiated to use sugar with composite cement in mortar. Composite cement is a combination of Portland cement with more than one material either clinker, fly ash and blast furnace slag or clinker, fly ash and limestone powder or clinker, blast furnace slag and limestone [11]. This study also aims to find the optimum sugar content that can be used as retarder in composite cement. Therefore, the influence of sugar on the mortar was investigated through measuring the compressive strength and analysing the carbonation depth and drying shrinkage using composite cement.

## 2. Experimental methods

The experiment consists of two phases, the first phase determines a standard consistency and setting time of the composite cement. The second phase determines compressive strength, carbonation, and drying shrinkage of the mortar. A standard consistency test of composite cement was conducted to determine the appropriate water-cement ratio. After that, setting time test on cement incorporating sugar ranging from 0 to 0.08 by weight of cement was conducted. Then the compressive strength and carbonation depth were conducted using cubes of size 100\*100\*100mm. Lastly, the drying shrinkage of the mortar was determined using prisms of size 100\*100\*300mm.

### 2.1 Materials

**Cement:** The cement used in this study is Composite Portland Cement, blended with high-quality silica which is rich in fly ash.

**Fine aggregate:** Sand passing by sieve No 4 (4.75 mm) which was dried for a few days to ensure that the water-cement ratio (w/c) was not affected during the mixing process for the preparation of mortar.

**Water.** Tap water, clean and free from impurities was used as water sources in the production of mortar mixtures.

*Sugar:* The sugar used was sucrose, which is common table sugar. Sugar in this study was retarder admixture for the mortar.

## 2.2 Mix Design

The proportion of cement to sand was set to 1:3 with water-cement ratio of 0.63 as standard for preparing mortar mixes. Table 1 shows five mixes of mortar prepared with different percentages of sugar. The specified amount of sugar was dissolved in the water before mixing mortar.

**Table 1.** Details of cement mortar mixtures.

Mixture	Sugar (% by cement weight)	Water: cement: sand percentage
1	0 (control)	0.63:1:3 (by weight)
2	0.02	
3	0.04	
4	0.06	
5	0.08	

## 3. Testing Procedure

The experiment was investigated through two-phases, the first phase includes testing standard consistency and setting time of composite cement, and the second phase involved compressive strength, carbonation, and drying shrinkage tests.

### 3.1 Standard Consistency

The consistency of cement test was performed to determine the amount of water content that has to be added in cement to confirm the quantity of water being mixed with cement for consistency test of cement is sufficient enough for the reaction of cement ingredients such as Calcium oxide (CaO), Silicon dioxide (SiO<sub>2</sub>), aluminium oxide (Al<sub>2</sub>O<sub>3</sub>), etc. The standard consistency test of cement paste was determined by Vicat apparatus, the test was repeated with different amounts of water until Vicat plunger needle penetrates through the cement paste and until it reaches a distance of  $(6 \pm 1)$  mm from the base-plate. The consistency test was carried out based on the BS EN 196-3-1995(BS 2005) [12], where the test were made with different amounts of water from 25% to 30% of the weight of cement.

### 3.2 Setting Time

Initial and final setting time was determined based on BS EN 196-3-1995 [13] using Vicat apparatus. The paste initial setting time has been defined through the duration of penetration of the Vicat needle by 25 mm into the paste at 30 seconds after it released, on the other hand, the final setting time was determined by measuring the time related to zero penetration of the needle into the paste. Five mixes were prepared with 500 g of cement with 28% water-cement ratio and sugar contents with 0.0 %, 0.02 %, 0.04 %, 0.06 % and, 0.08 % weight of cement respectively.

### 3.3 Compressive strength

To prepare the mortar mixtures, the cement and the sand were mixed with diluted sugar in water. Later the mortar mixture was poured into 100 mm cube molds. A total of 75 cubes were prepared and tested over a period of 7, 28, 56, 90, and 150 days in accordance with BS [14].

### 3.4 Carbonation depth test

The carbonation test was conducted to measure the depth of carbonation on mortar specimens through sprayed solution of phenolphthalein on the surface of broken mortar cubes. The reagent changes to pink colour in an uncarbonated mortar and remain colourless when sprayed on a carbonated mortar [15].

### 3.4. Drying shrinkage test

The drying shrinkage of mortar specimens was tested according to ASTM C1148 [16] by measuring its length change over a period of time. A special steel frame with an attached dial micrometer was set up for measuring the length change of the prism (Figure 1a, 1b). The prisms were inserted into the cages 24 hours after casting and put in the room with an average temperature of  $33 \pm 5^\circ\text{C}$ . The initial length was recorded as  $L_0$  and the subsequent length ( $L_t$ ) were measured periodically for up to 150 days. 10 number of specimens were installed in the apparatuses. The drying shrinkage is expressed by the following [17]:

$$\varepsilon_s = ((L_0 - L_t) / 300) \times 100 \% \quad (1)$$



(a)



(b)

Figure 1: (a) Apparatus of drying shrinkage test; (b) Dial gauge

## 4. Experimental results and discussion

### 4.1. Standard Consistency of cement

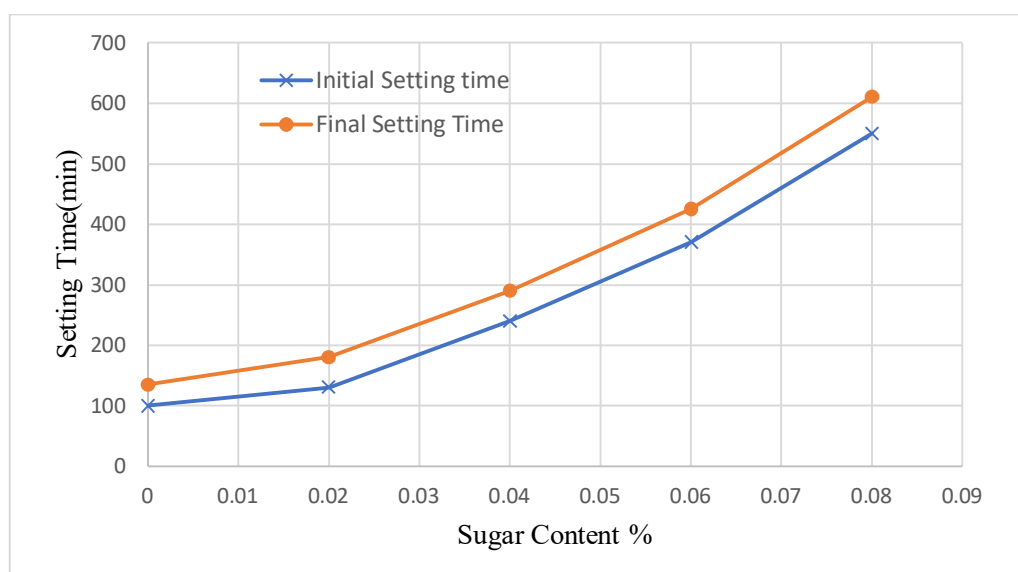
The percentage of water-cement for standard consistency is 25 to 30% for 500g of cement, and the results are shown in Table 2. The suitable water/cement percentage is 28% where penetration recorded was 7mm that fulfilled the standard consistency of cement.

**Table 2.** Penetration results on composite cement paste

Water / Cement (%)	Penetration (mm)
25	20
26	15
27	10
28	7
29	4
30	1

#### 4.2. Setting Time of cement

The results in Figure 2 illustrate the initial and final setting time for the composite cement. It is evident from figure that the sugar content has a major influence on the setting time of the composite cement. The setting time increases with increasing the content of sugar. The initial and final setting time of composite cement with 0.0, 0.02, 0.04 and 0.06 sugar content compatible with the minimum and maximum of the British Standard (BS EN 197-1:2000) [18]. However, the final setting time with sugar content 0.08 % is 610min, which exceeded the maximum of British Standard (BS EN 197-1:2000) [18] by 10 minutes. The final setting time increased with respect to the initial setting time from 0 % until 0.08 % of sugar content. The maximum final setting time was with 0.08 % of sugar content.



**Figure 2.** Setting time of composite.

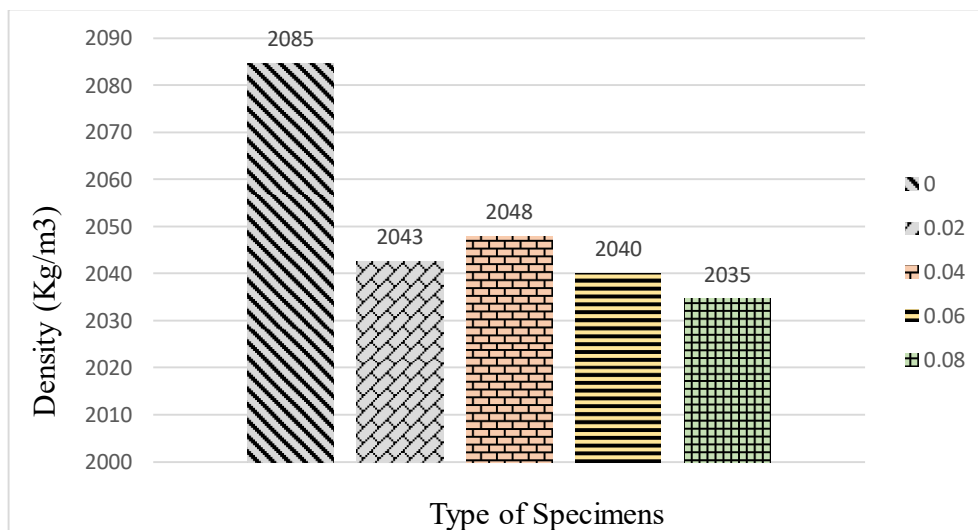
#### 4.3. Density of mortar cubes

The density of the mortar cubes was recorded prior to compressive strength test as shown in Figure 3. The density of mortar without sugar retarder was used as control specimen weighing 2085 kg/m<sup>3</sup>. The density of mortar with sugar retarder exhibited decrease in density by 1.8% to 2.4% as compared to control specimen. Mostly, the higher the proportion of sugar in the mortar, the lower the density, which has a reverse relationship. It clearly determines that the sugar plays important role in the density of mortar. Adding sugar to mortar may cause increase in water absorption as well as increase the void ratio of the mortars which leads to lower density [19].

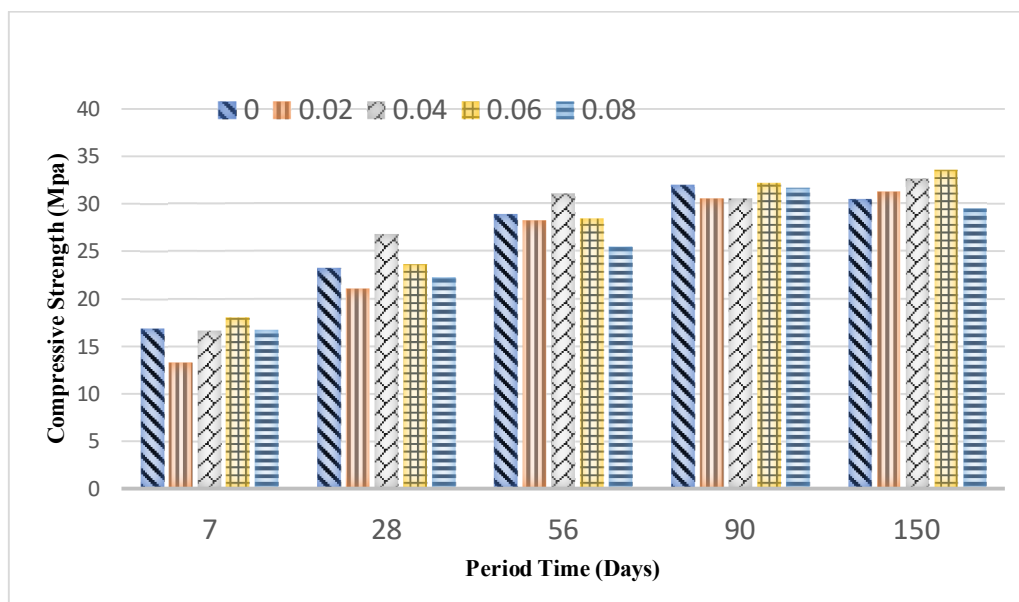
#### 4.4. Compressive Strength

The compressive strength tests of mortar cubes were conducted at 7, 28, 56, 90 and 150 days under air curing and the result is depicted in Figure 4. The test that was conducted after 28 days provides important findings in strength development of mortar. There are some differences in the increase of compressive strength in each phase, for instance, specimens with 0.06% sugar content had the highest compressive strength at the ages of 7, 90 and 150 days, compared to other specimens, where strength increased by 6.5 %, 0.6 % and 10.2 % compared with control specimen respectively. Besides that, specimens with 0.04% sugar content had the highest strength at ages of 28 and 56 days compared to other specimens, where strength increased by 15 and 7.6 % compared with control. On another hand, specimens with 0.02

% sugar content had the lowest compressive strength at ages of 7, 28, 90 and 150 days compared to other mixtures. It can be concluded that the sugar can help to increase the later compressive strength of mortar by adding a specific amount of sugar. Where the results show the optimum amount of sugar which can enhance the compressive strength of mortar is 0.06 %. On the other hand, adding sugar greater than 0.06 % negatively affects the strength of the mortar, as the results showed that when adding sugar by 0.08 %, the strength decreased as compared with control specimen.



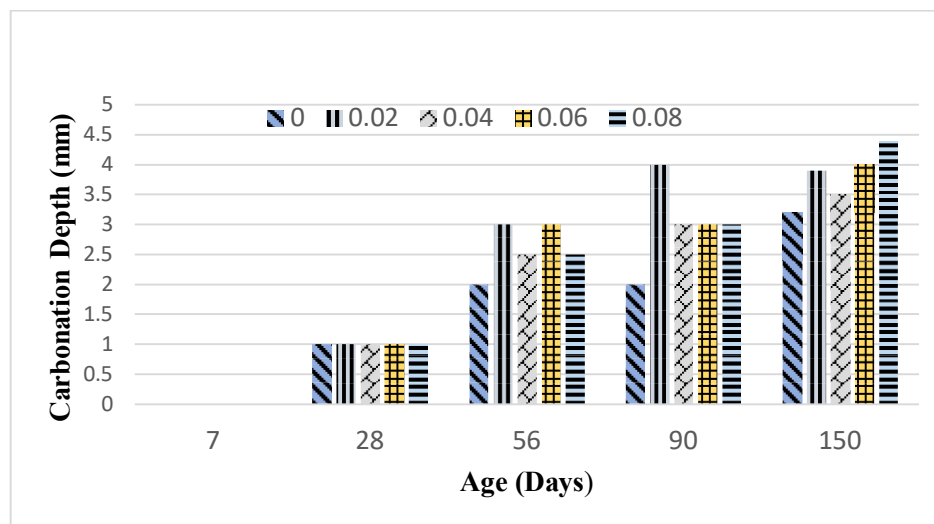
**Figure 3.** Density for mortar specimens



**Figure 4.** Compressive strength

#### 4.5. Carbonation Test

The results in Figure 5 illustrate that the carbonation depth in the specimens containing sugar is more than controlled specimens. The effect of sugar on the carbonation depth of mortar cannot be seen clearly before age 28 days of curing. The initiation of carbonation depth started to increase after 28 days in all the specimens. The results demonstrated that the performance of carbonation in all mixtures were the same at 7 and 28 days but at ages of 56, 90 and 150 days the depth of carbonation are significantly noticeable in all specimens. At age 56 the results show that the control specimens had the lowest depth in carbonation, which is 2 mm while, specimens with 0.02 % and 0.06 % sugar content had the deepest carbonation, which was 2.5 mm. Specimens with 0.08 % sugar content had the highest carbonation at age 150 days, which was 4.4 mm, while control specimens still had the lowest depth, which was 3.2 mm. From the results it is clearly that sugar plays a significant role in increase the carbonation depth of mortar in later age.

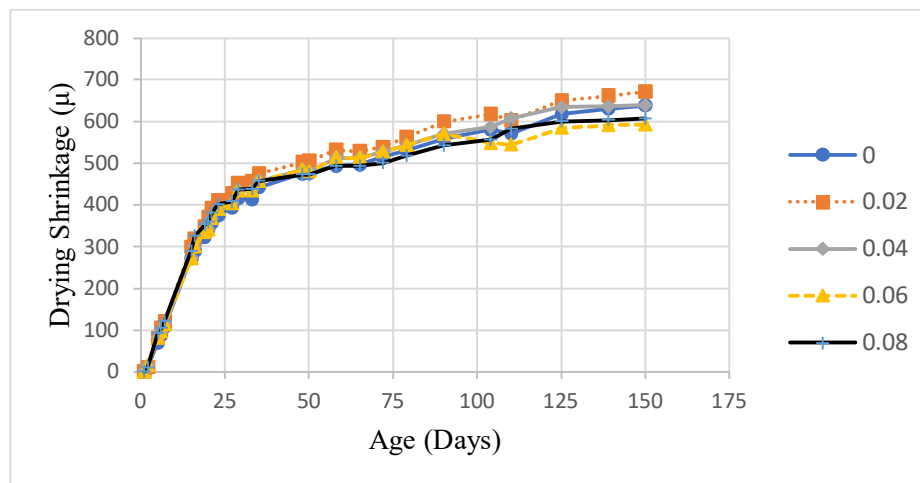


**Figure 5.** Carbonation depth

#### 4.6. Drying Shrinkage

Drying shrinkage is one of the major factor that influences the structural performance and durability of the materials [20]. The main cause of drying shrinkage is due to evaporation of the water from the pore network in the mortar [21]. Drying shrinkage of mortar is shown (Figure 6). The control specimen showed drying shrinkage higher than the prisms containing higher amount of sugar. The recoded valued of drying shrinkage for control specimen was 639 microstrain, whereas 607microstrain obtained for mortar with 0.06% and 0.0%8 sugar. The results show that with increase in sugar content in the mortar, it inversely effects the drying shrinkage of the mortar i.e., as sugar percentage increase in the mortar, the drying shrinkage decrease, this clearly indicates that sugar as a retarderis good in controlling shrinkage of mortar.





**Figure 6.** The drying shrinkage of mortar specimens

## 5. Conclusion

This paper was aimed to study the effects of sugar as a retarder on the setting time of composite cement and the development of strength, carbonation, and drying shrinkage of mortar. Based on the outcomes, the following conclusions can be summarized as follows:

1. As expected, adding sugar to cement affected its initial and final setting times, whereas adding sugar by 0.02 %, 0.04 %, 0.06 %, and 0.08% of cement weight, it increases the initial setting time by 30 %, 140 %, 270 % and 450% and for the final setting time by 33 %, 115 %, 215% and 351 %. It indicates that using sugar as a retarder is good, especially in regions with hot climate, as it enables more time to set and place mortar mixture.
2. The amount of sugar content used in mortar affect its long term compressive strength. At 28days, highest compressive strength recorded on mortar containing 0.04% sugar, however during final observation (at 150days) mortar with 0.06% obtained highest compressive strength. It indicates that faster rate of strength development occurs in low amount of sugar, and as the amount of sugar increase, the strength development occurs at the later age.
3. Carbonation test results showed that sugar can slightly increase carbonation depth in the mortar. As found in this study, specimens with 0.08% sugar had the highest carbonation depth which was 4mm, while specimens with no sugar content had the lowest carbonation depth which was 3.2 mm.
4. The shrinkage initially takes place in first 28days for all specimen, but the difference between samples were very minimal. As mortar aging, the difference on the value of shrinkage become clear, where for specimen with 0.02% sugar achieved highest drying shrinkage of 672 microstrain. At the similar age, the lowest drying shrinkage of 593 microstrain was recorded on the specimen containing 0.06% sugar. This indicates that the sugar inhibit the shrinkage in mortar and is good substitution for commercial retarded.

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