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Effects of Sugar in Calcium Carbonate ($CaCO_3$) Sludge on Properties of Concrete

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ABSTRACT

The sugar refining process typically produces waste, including calcium carbonate ($CaCO_3$) sludge and wastewater. In this research, Portland cement in concrete work was replaced by $CaCO_3$ sludge in three different levels: 17, 50 and 83 %, respectively. The experiments were conducted by determining concrete slump, concrete setting time and compressive strength of concrete using original $CaCO_3$ sludge (CO) with 2,000 ppm. sugar and $CaCO_3$ sludge (CW) with no sugar.

The experimental results indicated that original $CaCO_3$ sludge (CO) could slow down the setting time of concrete and this could be solved by the replacement by $CaCO_3$ sludge (CW). The $CaCO_3$ sludge was able to extend setting time as well as reduce workability of concrete. For this reason, the water cement ratio (*w/c*) at equal slump was higher than usual, resulting in lower compressive strength. However, $CaCO_3$ sludge has its benefits in terms of lower concrete cost, reducing $CaCO_3$ sludge which was hard to be eliminated and reducing cost of additional retardant to slow down concrete setting time working under hot conditions.

Keywords: Calcium carbonate sludge, Slump, Setting time, Compressive strength, Water cement ratio

1. INTRODUCTION

Presently, concrete is one of the most important construction materials. The general ingredients were Portland cement, coarse aggregate, fine aggregate and water. Portland cement is the most expensive material in the overall concrete production (around 60 – 70 %) of the cost [1]. Therefore, replacing some part of Portland cement with $CaCO_3$ sludge is proposed as the research guideline for reducing cost of concrete production. However, for the applications of $CaCO_3$ sludge, it is necessary to consider the amount of sugar contained in the sludge as it results in longer setting time than usual. [2-5]. Concrete with small amount of sugar or around 0.5 % of cement mass might affect the setting times of fresh concrete to be 4 hours slower than usual [2]. However, this property might be beneficial for concrete work that needs slow setting time such as the delay in setting of concrete could be useful in preventing cold joints and in reducing early setting of cement in hot weather concreting [6-7]. Therefore, a careful use of $CaCO_3$ sludge can be economical in comparison to commercially available set retarder.

$CaCO_3$ sludge used in this research was the waste from the carbonation process from raw sugar melting sifted and combined with lime in the carbonator using carbon dioxide (CO_2) as the carbonator as shown in Figure 1. After that, the syrup was sent to a pressure filter to sift the sludge.

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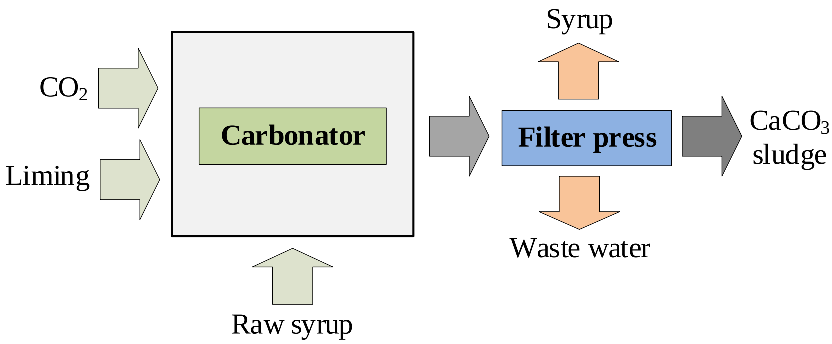

Figure 1 Sugar refining process.

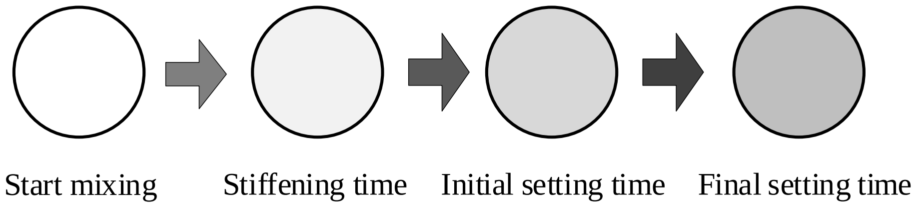

Figure 2 Concrete setting time.

Table 1 Chemical composition of $CaCO_3$ sludge and portland cement type I.

Parameter	**$CaCO_3$ sludge (wt%)**	**Portland cement type I (wt%)**
CaO	86.827	60 - 67
MgO	0.380	0.1 - 4
Al_2O_3	0.127	3 - 8
Fe_2O_3	896 ppm	0.5 - 6
SiO_2	0.327	17 - 25

The syrup from this process would be in ion- exchange resin to the final color reduction process then becomes fine liquor.

This research aimed to investigate the effects of sugar in $CaCO_3$ sludge towards workability, setting time and compressive strength of concrete from the original sludge (CO) compared with no sugar sludge (CW).

1.1 Theory

Setting time is the time required for stiffening cement paste to a defined consistency, which is illustrated in Figure 2. Generally, the initial setting is the time elapsed between the moment water is added to the cement to the time at which paste starts losing its plasticity [8-9]. Final setting time of cement is the time elapsed between the moment the water is added to the cement to the time at which paste has completely lost its plasticity and attained sufficient firmness to resist certain definite pressure.

Table 1 displays the detailed chemical compositions analyzed by energy dispersive X - ray fluorescence (EDXRF) Model ED - 2000. The main chemical composition of calcium carbonate sludge showed calcium oxides (86.827 %) and magnesium oxide (0.380 %) and some minor other oxides as Al_2O_3, Fe_2O_3 and SiO_2. Chemical compositions of $CaCO_3$ sludge and Portland cement type I were compared as shown in Table 1.

2. RESEARCH METHODOLOGY

2.1 Materials

The materials used in this study included Type I Portland cement, coarse aggregate, fine aggregate, and $CaCO_3$ sludge. The coarse aggregates and fine aggregates under the saturated surface dry condition had 0. 50 and 0. 70 percent absorption and specific gravity were 2. 68 and 2.64, respectively.

Aggregates for concrete mixing with quartering methods were prepared. For fine aggregate, the grain size ranged from 0.075-4.75 mm. and coarse aggregate granules from 4.75-20 mm. according to ASTM C33-18 [10]. The method began with weighting approximate 60 kg. of samples, spreading them out, and mixing them thoroughly into conical heap to quarter. Repeat quartering was conducted. A container was replaced for the storage of excess samples. A sample of the well graded aggregate had a gradation of particle size that fairly evenly spans the size from the finest to the coarsest. Table 2 presents the results of calcium carbonate sludge originated from the Mitr Phol sugar refining mills in Suphanburi, Thailand. The grain sizes of calcium carbonate sludge passing through sieve No. 200 and sugar content 2,000 ppm. were used.

2.2 Mixture proportions

Four mix proportions blended concrete and one control mix proportion are proposed to study and the details are shown in Table 3. Mixture proportions of 2.5 CO-12.5 CO for original $CaCO_3$ sludge, blending varying from 2.5 % to 12.5 % of $CaCO_3$ sludge by weight replacement. Another series of mixture proportions of 2.5CW - 12.5CW were used no sugar in $CaCO_3$ sludge.

Table 3 also presents the various quantities for several combinations. The mix design for control mix and blended mixes are carried out as ACI 211.1 – 91 [11]. All mix proportions were controlled by a slump test at 8 - 10 cm. The American standards explicitly state that the slump cone should have a height of 12-in, a bottom diameter of 8-in and an upper diameter of 4-in [12].

2.3 Method of casting and curing

For tests under laboratory conditions, the requirements depend upon the purpose of the tests and prepare three test specimens from one batch of concrete for each test variable. Dried $CaCO_3$ sludge is blended with ordinary Portland cement for three minutes in required proportions in a mixer machine. The $CaCO_3$ sludge blended concrete mixtures were mixed in a laboratory pan mixer. The fresh concrete mixture was poured in the molds (cylinder size: 4-in diameter and 8-in depth) by filling in three layers and each layer is tamped 25 times with a 600 mm. long bullet nosed metal rod measuring 16 mm. in diameter [13].

The molds were then kept in a chamber where the temperature is maintained at 25 °C ± 2 °C and the relative humidity was 46 %. The samples were demolded after 24 hours of casting and immersed in clean water for curing. The samples were tested after 1, 3, 7, 14, 28 and 56 days to evaluate the compressive strength of concrete according to ASTM C39-20 [13].

2.4 Test methods

This test method covers the determination of the time of setting of concrete, with slump greater than zero, by means of penetration resistance measurements on mortar sieved from the concrete mixture according to ASTM C403-16 [14]. A mortar sample is obtained by sieving a representative sample of fresh concrete in the laboratory. The mortar is placed in a container and stored at a specified ambient temperature. At regular time intervals, the resistance of the mortar to penetration by standard needles is measured which have the following bearing areas: 16, 32, 65, 161, 323 and 645 mm^2. From a plot of penetration resistance versus elapsed time, the times of initial and final setting are determined.

The containers shall be rigid, watertight, non-absorptive, free of oil or grease, and mortar surface area shall be provided for ten undisturbed readings of penetration resistance in accordance with clear distance requirements specified in procedure. The lateral dimension shall be at least 150 mm and the height at least 150 mm.

A device shall be provided to measure the force required to cause penetration of the needles are illustrated in Figure 3. The device shall be capable of measuring the penetration force with an accuracy of 10 N and shall have a capacity of at least 600 N.

3. RESULTS AND DISCUSSION

3.1 Workability of concrete

The concrete slump test aims to measure the consistency of fresh concrete before it sets according to the ASTM C143-20 test standard [12]. It is performed to check the workability of freshly made concrete, and therefore the ease with which concrete flows. It can also be used as an indicator of an improperly mixed batch. The test is popular due to the simplicity of apparatus used and simple procedure. The slump test is used to ensure uniformity for different loads of concrete under field conditions [15].

Slump test was conducted by adding $CaCO_3$ sludge in concrete components, reducing slump rate; therefore, defining slump rate of fresh concrete between 8 - 10 cm. would make water/cement ratio (w/c) various to the increasing amount of $CaCO_3$ sludge as shown in Table 3. It was because the particle of $CaCO_3$ sludge was small and its physical characteristic was fine and unable to be dissolved in water. When it was mixed with $CaCO_3$ sludge, it sucked water out of fresh concrete increasing slump rate. It can be seen that 12.5 CO and 12.5CW had water cement ratio at 1.70 while 2.5CO and 2.5CW had water cement ratio at 0.52.

3.2 Concrete setting time

In case of the replacement of $CaCO_3$ sludge for cement in Table 3, the concrete setting time varied with the increasing amount of $CaCO_3$ sludge. For example, the initial setting time and final setting time of 2.5CO were 3.55 hours and 8.30 hours, respectively. While 12.5CO concrete with lower cement ration had longer setting time with the initial setting time and final setting time were 7.15 hours and 13.50 hours, respectively.

When CO and CW were compared, it was found that sugar in $CaCO_3$ sludge slowed down the setting time of fresh concrete as shown in Figure 4. For example for 2.5CO and 2.5CW concrete containing 30 minutes, initial setting times were 3.25 hours and 3.55 hours, respectively. The trend was higher when the concrete reached final setting time which was 7.40 hours and 8.30 hours, accounting for the differences in 50 minutes.

Table 2 Physical properties of binders.

Materials	Features	Characteristics
Portland cement	Type I	Specific gravity = 3.15
$CaCO_3$ sludge	Fine powder, white	Sugar content 2,000 ppm. through sieve No. 200
Coarse aggregate	Limestone, angular shape	Nominal maximum size – 20 mm. L.A. Abrasion loss value = 29% Dry weight unit = 1,600 kg/m^3
Fine aggregate	River sand	Absorption = 0.7 %
Water	Tap water	PH = 7

Table 3 Mixture designs of concrete specimens containing $CaCO_3$ sludge.

Mix No.	Cement (kg)	$CaCO_3$ sludge (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Slump (cm)	*w/c*
Control	500	0	736	1,012	9	0.40
2.5CO	417	83	736	1,012	8	0.52
2.5CW	417	83	736	1,012	9	0.52
7.5CO	250	250	736	1,012	9	0.95
7.5CW	250	250	736	1,012	10	0.95
12.5CO	83	417	736	1,012	10	1.70
12.5CW	83	417	736	1,012	9	1.70

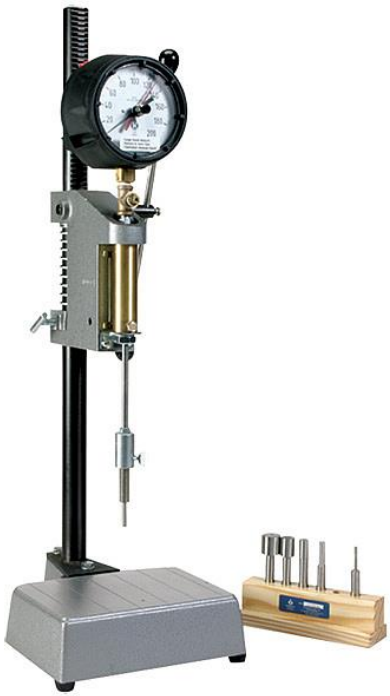

Figure 3 Concrete mortar penetrometer [14].

The replacement of cement by $CaCO_3$ sludge could increase the setting time of fresh concrete. One of the reasons was the fine and tiny dust particles; therefore, it was necessary to use water as the component for equal slump.

The amount of sugar contained in $CaCO_3$ sludge could decrease the setting time of fresh concrete. This could be solved by using $CaCO_3$ sludge with no sugar by soaking original $CaCO_3$ sludge in the water for 24 hours then washing it properly then mixed with concrete. This way would increase the setting time of concrete with $CaCO_3$ sludge.

3.3 Compressive strength of concrete

The compressive strength of material is that value of uniaxial compressive stress reached when the material fails completely. It is equal to uniaxial stress at failure where tested by ASTM C39-20 [13].

Figure 5 illustrates the compressive strength of concrete versus water cement ratio, it can be observed that for the case of CW series. The compressive strength reduces with the increase of replacement $CaCO_3$ sludge. For the case of replacing 50 % cement by 7.5CW, the compressive strength decreased by about 25 %. The decrease in strength could be due to water/cement ratio increase by 0.55 [16].

In other words, the strength is a function of the water to cement ratio (*w/c*) where *w* represents the mass of water and *c* represents the mass of cement. However, more often, *w/cm* is used and *cm* represents the mass of cementing materials, which includes the Portland cement plus any supplementary cementing materials such as $CaCO_3$ sludge.

Therefore, calcium carbonate sludge is an alternative that can reduce the cost of concrete production. Many existing calcium carbonate sludge have been utilized. However, when CO and CW were compared, Figure 5 illustrates the decreasing amount of sugar in the calcium carbonate sludge by 7 % in terms of the compressive strength of concrete.

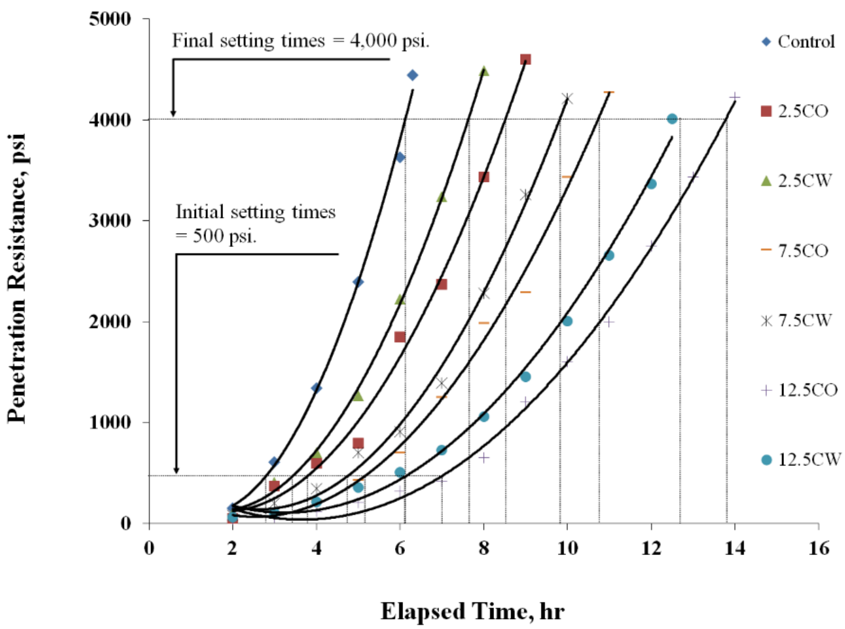

Figure 4 Effect of sugar on setting times of concrete.

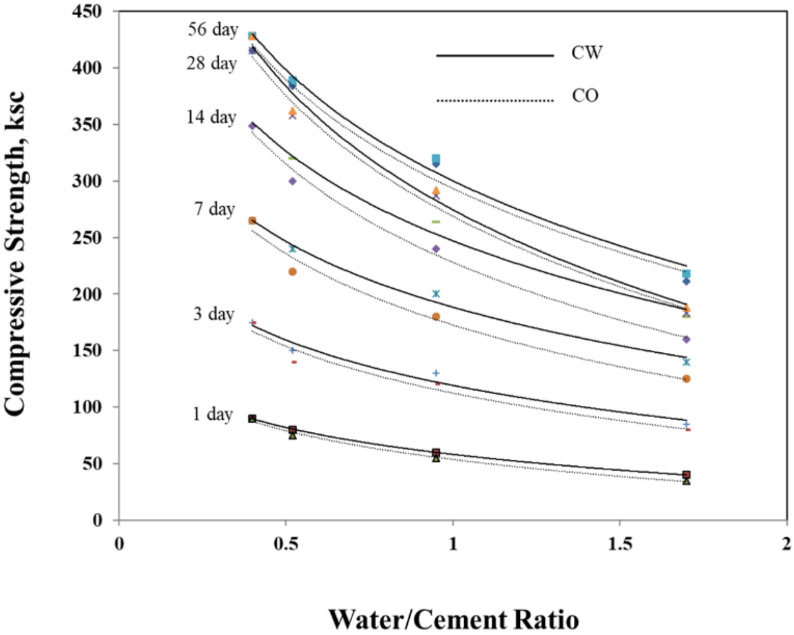

Figure 5 Compressive strength of concrete versus water cement ratio.

4. CONCLUSION

Calcium carbonate sludge is an alternative material that can be utilized to reduce the cost of concrete production. The water cement ratio (*w/c*) and the setting time of concrete varied with increasing $CaCO_3$ sludge. The compressive strength reduces with the increasing proportion in the replacement of cement by $CaCO_3$ sludge.

Sugar in original $CaCO_3$ sludge (CO) slowed down the setting time of concrete. The amount of sugar in the $CaCO_3$ sludge decreased compressive strength of concrete at 7%. However, the partial replacement of Portland cement by $CaCO_3$ sludge could reduce the production cost and retard admixtures of concrete reduction.

5. ACKNOWLEDGEMENTS

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