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MATHEMATICAL RELATIONSHIP OF THE EFFECT OF SUCROSE ON STRENGTH AND SETTING TIMES OF CONCRETE

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Abstract

This paper presents a mathematical model to capture the relationship between the quantity of sugar, setting times and strengths of a grade 35 concrete. The mathematical model developed would aid designers of concrete mixes, with sugar admixtures, to obtain a balance between setting times and strengths. An experimental investigation was conducted by adding sucrose crystals (sugar), $C_{12}H_{22}O_{11}$, to the concrete (between 0 to 10% wt. of cement was replaced with Sucrose Crystals). The effect of the addition of sucrose crystalson setting times, compressive strengths and on the workability of concrete were observed. At 0.1% sugar content, a significant increase in the setting times of concrete was observed with no negative impact on the compressive strength of concrete. However, as sugar content goes beyond 1 % of the weight of cement, the retarding effect of sugar admixtures diminishes significantly.

Keyword: Regression, compressive strength, workability, setting time

1. Introduction

It is essential that cement sets neither too rapidly nor too slowly. In the first case, there might be insufficient time to transport and place the concrete before it becomes too rigid. In the second case, too long a setting period tends to slow up the work unnecessarily, also it might postpone the actual use of the structure because of inadequate strength at the desired age [1].Theoretically, the time at which a cement paste loses its plasticity is called the initial setting time, while the time taken to reach the point where the paste becomes a hard mass is known as the final setting time [1].

Devakateet al [2] observed that the setting time of concrete increases with increase in sugar content, up to 0.06% replacement of cement, by weight, withsugar.It was also observed that a sugar content of 0.06% by weight of cement can improve compressive strength of concreteby 14.64 N/mm^2 at 28 days and delay initialsetting time by 45 minutes 45 seconds. Similar results were obtained by Usman et al [3]. They observed that sugar delays the setting time of cement by 1.33 hours at dosage level of 0.06%. However, they reported no effect on workability, compaction of concrete when sugar is used as admixture. They also observed that higher long-term compressive strength can be achieved in concrete by the use of sugar as admixture.

Fundamentally, retarding admixtures can cause cement retardation by the following mechanisms: Adsorption of the retarding compound on the surface of cement particles, forming a protective skin, which slows down hydrolysis; Adsorption of the retarding compound onto nuclei of calcium hydroxide, poisoning their growth, which is essential for continued hydration of cement after the end of induction period; Formation of complexes with calcium ions in solution, increasing their solubility and discouraging the formation of the nuclei of calcium hydroxide; Precipitation around cement particles of insoluble derivatives of the retarding compounds formed by reaction with the highly alkaline aqueous solution, forming a protective skin [4].

Owing to the retardation of ordinary Portland cement, sugar falls into three categories: non-retarding, goodretarders and most effective retarders. The nonreducing sugars, α-methyl glucoside and α-α-trehalose, are effectively non-retarding; the reducing sugars, glucose; maltose, lactose and celloboise, are grouped together as good retarders, while the nonreducing sugars (which have a five-member ring) sucrose and raffinose are far the most effective retarders. Sugars have been categorized as 'cement destroyer' and when small amounts of sugar (1% by weight of cement) are added to Portland cement paste at the onset of mixing, hardening may be delayed indefinitely [4].

Sugar has been widely used as a retarder in concrete production [5-11]. In fact, the use of sugar in delaying the setting time of concrete is regarded as a cheap and effective way of delaying the setting of concrete on large constructionprojects. This paperpresents a useful mathematical relationship between amount sugar admixture, setting times and strength developed.

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2. Material and Methods

The control concrete samples were produced by batching by weight. A nominal mix ratio of 1:2:4 was adopted for concrete production using Portland cement. The Portland cement was a type I/II cement. Table 1 shows the components of cement used in this work. Sucrose crystals were added to concrete in percentages of cement weight (between 0 to 10%). 150mm x 150mm x150mm cube moulds were employed as placeholders for produced concrete, while the required tamping continued until adequate compaction on each cube mould was obtained, then the surface was finished with a trowel. The cubes remained stationary for 24 hours before they were demolded and placed in a curing tank. A total of 80 concrete cubes were cast. The initial and final setting times tests were performed in accordance with standard practice using Vicat's apparatus under room temperature. Also, compression strengths at 7 –day, 14–day and 28-day, respectively, were obtained with the aid of crushing machine.

Table 1: Major components of cement [12]

Oxide	Weight %
CaO	59.60%
Fe_2O_3	3.22%
SiO_2	20.62%
Al_2O_3	6.01%
MgO	3.65%
SO_3	2.46%
K_2O	0.71%

Table 2: Initial and final setting terms versus sugar content

Sugar Content (% wt. of cement)	Initial Setting time (mins)	Final Setting time (mins)
0	150	210
0.02	180	270
0.04	225	305
0.06	245	350
0.08	280	400
0.1	295	480
0.3	325	520
0.5	515	720
1	170	235
3	100	200
5	90	160
10	45	90

3. Results and Discussion

Table 1 shows that the initial setting and final setting times of concrete increases with the addition of sugar (up to0.1% cement replacement with sugar by weight). However, after 3% cement replacement with sugar, the setting times and concrete strength reduce drastically with the addition of sugar. The optimum sugar content for effective retardation is shown as 0.1% in Table 2. As observed in Table 3, with 0.1% cement replacement with sugar, the compressive strength of concrete is not negatively impacted.

Also, Figure 1 shows that sugar consistently increases the setting time of concrete. As sugar content increases beyond 1%, as shown in Figure 1, the setting times reduce drastically. It is also observed that between 5- 10 percent sugar content, for example, the natural setting time of the concrete is reduced. Thus, the retarding effect of sugar is ineffective at sugar contents go beyond 1%.

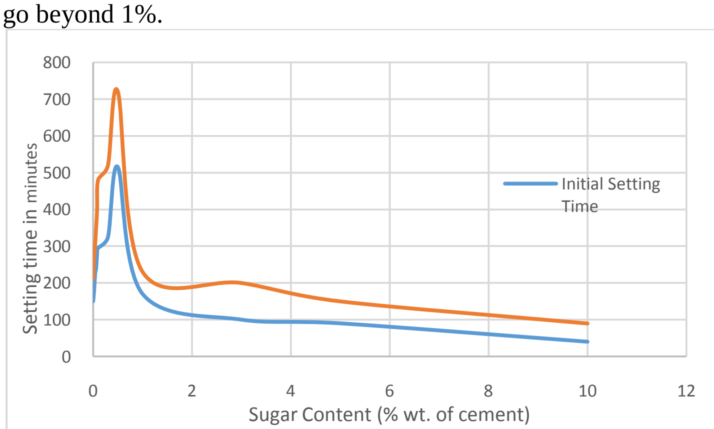

Figure 1: Setting time of concrete versus sugar content

However, there is a tradeoff between setting time and strength of concrete with the addition of sugar. Thus, the designer has to balance the amount of sugar added, the retardation time required and required strength. Table 3 shows the 7-day, 14-day and 28-day strengths of concrete with the addition of sugar. As shown in Table 3, increasing the sugar content has negative impact on the final strengths of concrete.

Table 3: Variation of concrete strength with sugar content

Sugar Content (% wt. of cement)	Average compressive strength at 7 days (N/mm^2)	Average compressive strength at 14 days (N/mm^2)	Average compressive strength at 28 days (N/mm^2)
0	27	31.5	37.5
0.06	21	32	38
0.1	18	28	39
0.5	2	18	21
1	2	10	16
5	2	9	11
10	3.28	7	8

Thus, a mathematical regression model is developed in order to capture the relationship between setting times, sugar content and strengths. This equation would help a designer to determine the adjustment in setting time and the developed strength of a grade 35 concrete mix.

General regression Model in initial notations is [11]:

$$y = b_1 x_{i1} + b_2 x_{i2} + b_1 x_{i3} \dots \dots b_p x_{ij} . + \varepsilon_i \qquad (1)$$

Where $x_{ij}$is the *i*-the observation of the j-the independent variable and y_i is the dependent variables. The least squares parameter estimates are obtained from p normal equations. The residual can be written as:

$$\varepsilon = y_i - b_2 x_{i2} - b_1 x_{i3} - \ b_p x_{ij} \qquad (2)$$

The normal equations are:

$$\sum_{i=1}^{n} \sum_{k=1}^{p} x_{ij} x_{ik} b_k = \sum_{i=1}^{n} x_{ij} y_i \, j = 1 \dots \dots \dots . p \qquad (3)$$

In matrix form, the normal equations can be written as:

$$(X^T X)B = X^T Y \qquad (4)$$

Where *ij* element of Y is x_{ij}, the *i* element of the column vector Y is y_i and the *j* element of b is b*ij*. Thus, the solution of regression model can be written as:

$$b = (X^T X) X^T Y \qquad (5)$$

Applying Equations 1 -5, we obtain the following regression models for 7- day strength, 14- day strength and 28- day strength, respectively, as shown in Equations 6 -8

$$f_{cu-7} = -2.56c + 0.14t_1 - 2.56t_2 + 23.4 \qquad (6)$$

$$f_{cu-14} = -2.52c - 0.18t_1 + 0.08t_2 + 26.33 \qquad (7)$$

$$f_{cu-28} = -3.41c - 0.23t_1 + 0.15t_2 + 33.3 \qquad (8)$$

In the above equations, f_{cu-7} represents 7- day strength (in N/mm^2), f_{cu-14} represents 14- day strength (in N/mm^2), f_{cu-28} represents 28- day strength (in N/mm^2), t_1 represents initial setting time and t_2 represents final setting times in minutes, c represents the quantity of sugar in percentage of cement. These equations can serve as a design guides for concrete mix designers.

It is also observed that value for slum increases with increase in sugar content of concrete as shown in Figure 2.

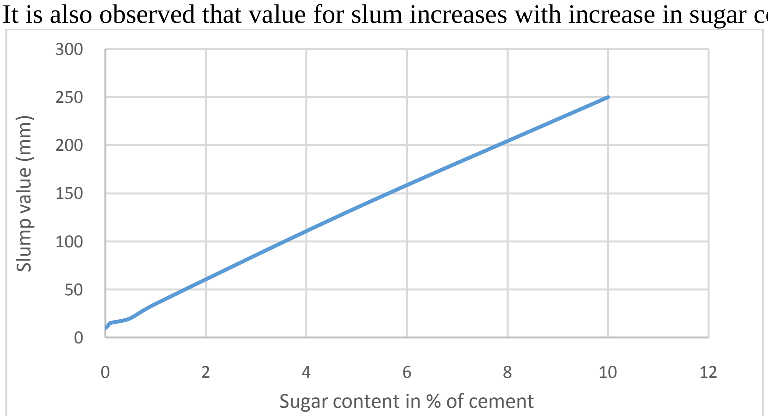

Figure 2: Setting time of concrete versus sugar content

4. Conclusion

The following conclusions have been drawn from this study:

a) The mathematical model developed captures the relationship between strength, setting times and quantity of sugar. It can be served as a useful tool for the design of concrete with sugar admixtures.
b) The workability of concrete increases with increased sugar content.
c) Sugar content of 0.1% wt. of cement has no negative effect on the compressive strength of concreteand can delay setting time by 105 minutes. The optimum value obtained in this work can be attributed to the type of cement used and the grade of concrete produced.
d) Though the setting time of concrete increases with the inclusion of sugar up to 1% wt. of cement weight, beyond this content of sugar, it was observed compressive strength of concrete decreased significantly. The variation in compressive strength with the quantity of added sugar has been captured in the mathematical model developed.
e) Sugar content above 10% wt. of cement has no retarding impact on concrete. It also significantly reduces the 28-day strength of concrete.
f) It is recommended that a further study on the microscopic interaction of sucrose and locally produced cement in Nigeria during hydration process be undertaken in order to fully understand the process of strength increase/reduction and retardation time in concretes with sugar admixtures.

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