Arriving the optimum retarder dosage level of sugar on the setting time, compressive strength, and microstructure property of Portland pozzolana cement

Meyyappan Palaniappan\(^{\ast}\), Karthiga Murugan\(^{\ast\ast}\), Aravind Gurusamy, Aarthi Koppayaraj and Keerthickbalaji Sivasubramanian

Center for Building Materials, Department of Civil Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, Tamil Nadu, 626126, India

Received: October 6, 2023  Accepted: January 8, 2024

ABSTRACT

Cement and concrete are the most crucial and dominating engineering materials in the construction sector. Cement serves as an excellent binder for concrete and when it is treated under unusual conditions either to satisfy accelerating or retarding requirements by the construction industries, admixtures role comes into the effect. The construction industry has been searching for retarding admixtures and the optimal dosage level, particularly for ready mix concrete applications. Generally the retarding admixtures such as organic retarders (lignosulphonates, hydroxycarboxylic acids and their salts, phosphonates, sugars) or inorganic retarders (phosphonates, borates) were generally used to reduce the speed of the reaction between cement and water by altering the growth of the hydration products and/or limiting the rate of water penetration to the cement particles. The research was still in its infancy stage in terms of determining not just the appropriate dosage amount, but also the ideal retarder materials for the aforementioned uses. In considering this industrial need, an attempt was made on utilizing the usage of sugar in the concrete to study the retarding effect without affecting the strength properties of cement. The sugars usage levels were at 5, 10, 15, and 20% of the usage of cement to investigate consistency, setting time, compressive strength and microstructure properties at the curing age of 7, 14 and 28 days on the mortar specimens. The conclusions of the study reported that setting time was extended with increase of the dosage levels of sugar. However in considering the strength property, less than 5% of sugar dosage level can be better for the application as retarding agent in the industry applications.

KEYWORDS

admixture, retarder, accelerator, sugar, initial setting time, final setting time, compressive strength

1. INTRODUCTION

Concrete ranks among the most extensively employed construction materials worldwide. It is produced by combining cement, aggregates, and water, which collectively give rise to a robust and long-lasting substance. Nevertheless, the ease of handling and the rate of hardening of concrete may fluctuate subject to the mix design and surrounding environmental conditions [1]. To optimize its properties and performance, concrete often undergoes the addition of admixtures. The main goals of adding admixtures to concrete are to make it easier to work with, make it stronger and more durable, contribute to sustainability efforts by reducing water use and carbon emissions, speed up construction and lower labour costs, and meet project-specific requirements based on environmental considerations [2]. Water-reducing, air-entraining, retarding and accelerating, corrosion-inhibiting, and fiber-reinforcing admixtures are the several types of admixtures used in concrete. Retarding and accelerating
admixtures are specialised additives used in concrete to regulate the material’s setting time [3]. Accelerators quicken the setting and early strength growth of concrete whereas retarding admixtures delay the time it takes for cement to set [4]. Some of the retarders and accelerators used in construction sector are lignosulfonates [5], gypsum [6], citric acid [7, 8], tartaric acid [9], sugars [10], starches [11, 12], calcium chloride [13], calcium nitrate [14], triethanolamine (TEA) [10, 15, 16], sodium and potassium silicate [17].

Sugar, also known as the glucose retarder, is a substance that is suitable for being added to concrete mixes to decelerate the setting time of the concrete. Sugar acts as a retarder because it interferes with the chemical reaction between water and cement that causes the concrete to set. Specifically, sugar slows down the rate of the reaction by coating the cement particles and preventing them from coming into contact with the water. This delay in the reaction allows the concrete to have more time to harden and develop its strength. The application of sugar as an additive in concrete has sparked a discourse among experts in the field. In one study, Thomas et al. [18] examine into the retarding consequences of various types of sugar on the cement hydration process of ordinary Portland cement. Similarly, Usman et al. [19] introduce sugar to concrete in varying concentrations, ranging from 0 to 1% by mass of cement, and assess its impact on the setting time of ordinary Portland cement (OPC) paste, as well as the compressive strength of concrete at three, seven, and twenty one days. The findings indicate that adding 0.06% of sugar to the mass of cement content delays the cement hardening time, but increases compressive strength when 0.06% of sugar is added to the concrete.

Al Khafaji et al. [20] conducted an investigation into the effects of adding four distinct types of sugar, namely, beet, caster, granular and brown, on the cement hardening time prediction and hydration temperatures of cement paste. The various sugar concentrations used were 0.5, 1.5, 2.5, and 5% by mass of cement, respectively. The findings reveal that caster, brown and granular sugar, when added at proportions of 0.5 and 1.5%, function as a retarder, while at 2.5 and 5%, they act as an accelerator in concrete. On the other hand, beet sugar acts as a concrete retarder at all concentrations. Additionally, the hydration temperature increases at 1.5% sugar content, which is deemed to be the optimal concentration for retarding the hardening of cement paste. The addition of higher sugar concentrations leads to a reduction in the final setting time of cement. An investigation done by Azad et al. [21] investigated the impact of sugar at varying proportions (ranging from 0 to 0.3 percent by mass of cement) on the setting time of cement paste. They utilized a mix proportion of 1:1.24:2.39 with a water cement ratio of 0.56 and casted cylindrical concrete specimens with dimensions of 200 mm in height and 100 mm in diameter to determine the compressive strength of concrete at different curing ages (7, 14, and 28 days). The results showed that the retarding effect on the commencement of setting (initial) and hardening time (final) of cement paste gradually increased up to a 0.1% concentration of sugar, which remained within acceptable limits. Furthermore, the compressive strength of concrete at all ages (7, 14, and 28 days) was found to be optimal at a 0.08% concentration of sugar content. In a similar study, Giridhar. V et al. [22], examined the effects of sugar and jaggery at three different concentrations (0, 0.05, and 0.1 percentage by mass of cement) on the strength attributes of concrete. The addition of admixtures like sugar and jaggery into the concrete composition improved its workability and compressive strength. However, the addition of jaggery was found to yield better strength results than sugar.

Bhalerao et al. [23] suggested the impact of sugar on hardening time of cement paste and compressive strength characteristics of concrete samples at 1:1:5:3 ratio with two different concentrations of sugar 1 and 1.2 percent by mass of cement. This study reveals that with an increase in sugar percentage, cement paste becomes more workable and takes longer time to set and at a sugar content of 1.2%, concrete gains the compressive strength. Suvash Chandra Paul et al. [24] conducted a study to evaluate the influence of sugarcane juice as an additive on the attributes of concrete. The researchers assessed the commencement of setting time (initial) and hardening time (final), flow ability, compressive, and split tensile strength of concrete, utilizing various concentrations of sugarcane juice. The study revealed that adding sugarcane juice to the mortar mix significantly reduces the setting time, as examined in the Vicat’s instrument, up to a certain proportion. The initial setting time of mortar was declined from 79 to 10 percentage by incorporating 20% sugarcane juice into the mixture. The inclusion of 10% sugarcane juice in the mix caused an increase in the hardened characteristics of the concrete, exceeding 29% higher than the control mix, and a greater than 4% increase in the splitting strength.

According to Khan & Baradan [25], the study’s various cement grades and curing processes were found to cause a delay in cement setting. Although retardation occurred at sugar contents as high as 0.25%, the increase in setting time was quite moderate. Beyond this point, the cement set more quickly when the sugar percentage was 0.3–0.8%. Similarly, the addition of retarder (sugar) at 0.125, 0.25, 0.375 and 0.5% in three types of cement caused a significant retarda- tion under three curing regimes which resulted in the decreased hydration rate and strength development, according to Khan & Ullah [26]. Most of the studies suggest that sugar as an additive in concrete can improve the properties of concrete, while others suggest that it can have negative effects. The previous research studies focused on the impact of sugar on the characteristics of concrete, which has both positive and negative feedback, and used sugar as a set retarder with concentrations ranging from 0 to 5%. An initial attempt is made to determine the effects of adding sugar at higher concentrations (0, 5, 10, 15 and 20%) by mass of cement in setting time of cement and compressive strength of mortar at the curing ages of 7, 14 and 28 days due to the absence of information on the effects of adding higher concentrations of sugar in concrete. In the meantime, the impact of a higher sugar concentration on the microstructure was investigated using the mortar mixtures.
2. MATERIAL AND METHOD

In Tamil Nadu, the readily available Portland pozzolana cement (PPC) conforms to IS 1489 Part 1-1991 [27], and for this study, ultra tech PPC cement blended with fly ash was utilized to create paste and mortar samples. The PPC underwent a sieve analysis, wherein 90% of the cement particles were retained on a 90 μm sieve, and the specific gravity of the cement was 3.12, as per IS 4031 (Part 11) 1996 [28]. The primary chemical constituents of Portland pozzolana cement comprise a complex amalgamation of calcium silicates, aluminates, and ferrites, and commonly used pozzolanic materials include fly ash, silica fume, and natural pozzolans like volcanic ash, along with gypsum. The chemical compounds present in Portland pozzolana cement is illustrated in Table 1. In place of river sand, M-sand, a sustainable and effective substitute, was utilized as the fine aggregate, which was retained on a 4.75 mm sieve and met the IS 383 (1970) [29] requirements. The specific gravity of manufacturing sand was 2.7, and it had a water absorption capacity of 2.2%. The study employed commercially available sugar, finely powdered and utilized as a replacement for cement, with potable water meeting the standard drinking water requirements being utilized for the mixing and curing process.

2.1. Cement paste and mortar mixture preparation

In order to measure the commencement of setting (initial) and hardening time (final) of Portland pozzolana cement (PPC), the consistency of cement should be determined in accordance with IS 5513 (1996) [30]. For the nominal sample mix preparation of consistency test, take 400 g of cement and mix it with a known amount of water (usually 0.78 times the mass of cement) to form a paste. Similarly, sugar is added as an additive in various concentrations (5, 10, 15 and 20%) by mass of 400 gms of cement and mixed with a known amount of water (usually 0.78 times the mass of cement) for the sugar added sample mix. The water should be added gradually while mixing the cement to ensure that a homogeneous mixture is obtained. Using a non-porous plate or glass sheet, level the cement paste in the mould after placing the Vicat plunger (10 mm dia) on top of the cement paste matrix specimen. The time period between adding water to cement and the point at which a needle leaves a circular cutting edge that was 5 mm in circumference and placed 0.5 mm beneath the tip of needle formed an indentation but missed to mark an impression was used to determine the cement hardening time (final). The process of making of sugar-blend cement paste and testing of standard consistency, commencement of setting time (initial) and hardening time (final) are shown in Fig. 1.

Cement and sand were weighed separately to create the mortar mixture (200 g cement, 600 g sand), resulting in an 800 g total mass with a 1:3 ratio. The amount of water required was calculated using an expression based on the consistency level of the cement paste ((P/4 + 3) * percentage of total mass of PPC cement and sand). “P” represents the standard consistency of cement paste. The proportioning of cement, sand, and water content with additive percentage of sugar are mentioned in Table 2. First, the measured quantity of cement and sand was mixed in a dry state for 30 s to achieve homogeneity, after which water was added gradually to obtain a well-mixed paste. The mortar mixture was then mixed for 2 min to ensure homogeneity before being transferred to a cube mould of size 70.6 mm x 70.6 mm x 70.6 mm. This procedure was repeated for all four concentrations of sugar, i.e., the measured quantity of cement, sand, and sugar was mixed in a dry state for 30 s to achieve homogeneity, after which water was added gradually to obtain a well-mixed paste. The mortar mixture was then mixed for 2 min to ensure homogeneity before being transferred to a cube mould of size 70.6 mm x 70.6 mm x 70.6 mm. Following a 24-hour casting period, the mortar cube specimens were demolded and cured in water tanks under controlled laboratory circumstances. After 7, 14, and 28 days of curing, the compressive strength was assessed using a universal testing machine (UTM). Figure 2 illustrates the preparation of mortar cube specimens with 5, 10, 15, and 20% replacement of sugar with PPC cement and M-sand.

The microstructure of the mortar specimens was examined using a scanning electron microscope (SEM) with 2 μm

<table>
<thead>
<tr>
<th>Name of element</th>
<th>Proportion PPC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂ (Silica)</td>
<td>31.40</td>
</tr>
<tr>
<td>Al₂O₃ (Alumina)</td>
<td>9.04</td>
</tr>
<tr>
<td>Fe₂O₃ (Iron Oxide)</td>
<td>4.58</td>
</tr>
<tr>
<td>CaO (Calcium Oxide)</td>
<td>41.29</td>
</tr>
<tr>
<td>MgO (Magnesium Oxide)</td>
<td>1.2</td>
</tr>
<tr>
<td>SO₃ (Sulphur Trioxide)</td>
<td>2.20</td>
</tr>
<tr>
<td>Loss on Ignition</td>
<td>3.66</td>
</tr>
</tbody>
</table>
scale specifically with the Scanning Electron Microscope EVO18 (CARL ZEISS), which was installed in the International Research Center Laboratory of the Kalasalingam Academy of Research and Education Institute in Krishnankovil, Tamilnadu.

Table 2. Proportioning of mortar mixture (3 cubes)

<table>
<thead>
<tr>
<th>Sugar replacement (%)</th>
<th>Cement (gm)</th>
<th>Sand (gm)</th>
<th>Sugar (gm)</th>
<th>Water (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>600</td>
<td>1800</td>
<td>0</td>
<td>264</td>
</tr>
<tr>
<td>5</td>
<td>600</td>
<td>1800</td>
<td>30</td>
<td>240</td>
</tr>
<tr>
<td>10</td>
<td>600</td>
<td>1800</td>
<td>60</td>
<td>216</td>
</tr>
<tr>
<td>15</td>
<td>600</td>
<td>1800</td>
<td>90</td>
<td>204</td>
</tr>
<tr>
<td>20</td>
<td>600</td>
<td>1800</td>
<td>120</td>
<td>192</td>
</tr>
</tbody>
</table>

3. RESULT AND DISCUSSION

3.1. Cement paste consistency

Figure 3 displays the standard consistency values for Portland pozzolana cement and the inclusion of sugar as a cement replacement at five different concentrations (0, 5, 10, 15, and 20%). The cement paste's consistency is a crucial indicator of the mixture's flowability or plasticity. The ratio of water to cement has the biggest influence on the workability and effectiveness of the cement paste in the majority of construction applications. To ensure strength and durability, the optimum water-to-cement ratio must be maintained. In this study, sugar is added in four different amounts (5, 10, 15, and 20%) and the cement paste's consistency is assessed. The performance and consistency of the...
combination are significantly impacted when sugar is introduced in larger amounts. When replacing sugar with PPC cement at a rate of 5, 10, 15, and 20%, the consistency values were reduced by 12.5, 25, 31.25, and 37.5% respectively, in comparison to the standard PPC consistency value. When sugar is added at increasing concentrations, it disperses and lubricates the cement particles, reducing friction and allowing the particles to move freely inside the paste. The paste becomes more fluid as a result, increasing flow ability and decreasing consistency value.

Fig. 2. Preparation of mortar cube specimens

Fig. 3. Standard consistency of cement paste matrix using Vicat apparatus

Fig. 4. Amount of sugar (%) vs. setting time (min)
3.2. Initial and final setting time of PPC cement

The Portland pozzolana cement’s initial and final setting times, as well as its variable sugar concentration, are shown in Fig. 4. The initial setting time displays a remarkable surge as sugar concentration increases, up until 20%. Correspondingly, in contrast to Portland pozzolana cement, the final setting time exhibits a considerable increase, particularly at 15 and 20%, where it escalates three to fourfold. However, the results for 5 and 10% sugar concentration in cement indicate acceptable limits for the final setting time. These findings suggest that sugar, in high concentration, significantly prolongs both the commencement of setting time (initial) and hardening time (final) of cement. Furthermore, the study reveals that sugar acts as a retarding agent, and its effect intensifies at all replaced sugar concentrations.

3.3. Compressive strength of mortar

Figure 5 exhibits the compressive strength of mortar specimens at 7, 14, and 28 days, varying with sugar content concentration. The graph demonstrates a sharp decline in compressive strength as sugar content concentration increases. This reduction in compressive strength is a result of the adverse impact of sugar, which retards the hydration process of cement at higher sugar concentration levels. The compressive strength of mortar specimens at all sugar concentration levels, under three different curing conditions (7, 14, and 28 days), is substantially lower than that of the control specimen. Despite a gradual increase in strength from 5 to 15%, it eventually declines at 20%. The reason for reduction in strength is due to the higher concentration of sugar that disrupts the formation of hydrated calcium.
silicate (C–S–H) gel and lime (Ca(OH)₂) which can weaken the material’s overall structure. Thus, the findings suggest that the addition of sugar at higher concentration levels negatively impacts the attainment of strength in the mortar specimens.

The deformation of mortar cube specimens in five different proportions (0, 5, 10, 15, and 20%) under a compressive load is shown in Fig. 6. According to a realistic perception, the mortar cube specimen experiences the following deformation. A normal mortar specimen exhibits crack formation along the cube faces’ sides and blistering on parts of the faces when compressed. Under compressive force, a sugar mortar cube with a 5% concentration exhibits cube bulging and face spalling. Similarly, under compressive load, concrete cracks and spalls as well as efflorescence forms in the mortar cube containing 10% sugar content. Sugar mortar cubes with a 15% concentration reveal smashing of the cubes under maximum compressive load. A mortar cube specimen under compression completely collapses at a 20% concentration of sugar as shown in Fig. 6.

3.4. Microstructure analysis

The depicted figure showcases the microstructure of mortar samples after undergoing 28 days of curing, wherein diverse concentrations of sugar ranging from 0 to 20% were employed. The microstructure examination was carried out utilizing a scanning electron microscope with scanning scale of 2 μm. Figure 7 of the control specimen without sugar show the production of ettringite, calcium silicate hydrate (CSH), and portlandite. Due to the use of Portland pozzolana cement, fly ash was found in every mortar specimens. In mortar specimens with sugar concentrations of 5, 10, 15, and 20%, some portlandite and CSH development is seen, but no ettringite formation is visible in any of these specimens. The crack formation is seen in the SEM images of 15 and 20% mortar specimens, and 20% has a higher level of crack formation. The 20% mortar specimen clearly shows some sugar crystals. Nevertheless, the hydration products appeared denser, yet the identification of pores was higher in all proportions. This can be attributed to the hygroscopic nature of sugar, which facilitates the absorption of water by

Fig. 7. Microstructure of mortar cubes at 0, 5, 10, 15, 20% concentration of sugar
the mortar specimen during the curing process, causing it to weaken and break down over time. The inadequate hydration process occurred due to the excessive concentration of sugar (5–20%). This is due to the sugar’s tendency to interfere with the evolution of the hydrated calcium silicate gel, which is being the cause for filling the pores and capillaries in the mortar specimen and rendering it more impermeable. Consequently, the material adheres to each other, leaving behind more pores, leading to a reduction in strength. The black spaces in the sample indicate the presence of pores. Excessive concentration of sugar adversely affects the formation of hydration products.

4. CONCLUSION

The present study conducted an experimental investigation to examine the impact of sugar concentration on the setting time, strength parameters, and microstructure of Portland pozzolana cement, leading to the following conclusions. In accordance with forecasts, the addition of sugar significantly affected the initial and final setting time of cement. When compared to the control specimen, the inclusion of higher concentrations of sugar hindered the formation of the hydrated calcium silicate (C–S–H) gel, leading to a reduction in the compressive strength of mortar. The outcomes indicate that in small concentrations, sugar serves as a retarder, but when added in greater concentrations (>5%), it prolongs commencement of setting (initial) and hardening time (final) which negatively influence the strength and bonding properties of the specimens. Additionally, the inclusion of sugar in excessive amounts results in the formation of air pockets in the mortar specimens, making them more impermeable. Furthermore, the observations revealed that excessive amounts of sugar actually increase the drying time of the mortar. The study demonstrates that setting time was extended by and increase of the dosage levels of sugar. However, considering the strength property, less than 5% of sugar dosage level can be better for the application as retarding agent in the industry applications.

Funding: This work has not received any funds, grants, or other support.

Competing interests: There is no relevant financial or non-financial interest to disclose.

Author contributions: The research work was done by all of the authors. Meyyappan Palaniappan: Guidance and suggestions for tools and methods to complete the entire study, as well as contributions to drafting of the entire manuscript. Karthiga Murugan: Collected the materials, conducted the experiments, analysed the data, and wrote the manuscript. Aravind, Aarthi, Keerthickbalaji: Contribution towards performing the experiments.

Ethics approval and consent to participate: Not applicable.

Consent to publish: Not applicable.

Availability of data and materials: Not applicable.

ACKNOWLEDGEMENT

Not Applicable.

REFERENCES


