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Using sucrose for improvement of initial and final setting times of silica fume-based activating solution of fly ash geopolymer concrete

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HIGHLIGHTS

- Initial setting time was improved by 100% when 3% of sucrose was used.
- Final setting time was increased by 160% when 3% of sucrose was implemented.
- The compressive strength was not effected by the presence of sucrose.
- Absorption was decreased when the percentage of sucrose was increased.
- SEM observations showed that the presence of sucrose increased the viscosity of water.

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ABSTRACT

This study investigates the initial and final setting times of fly ash-based geopolymer concrete using an activating solution that was a mixture of silica fume, sodium hydroxide, and water. The addition of sucrose (sugar) was implemented to improve the initial and final setting times. The effects of including sucrose on the mechanical, microstructure, and potential durability properties were observed. Sucrose was considered a viable solution to extending hardening times because it is readily available and affordable. Three different percentages were observed: 3%, 6%, and 9%. In order to eliminate the need for external heat, 10% of the fly ash was replaced by Portland cement. The results showed that when 10% of the fly ash weight was replaced by Portland cement, the initial and final setting times were 10 min and 25 min. The final and initial setting times were enhanced by more than 100% to reach more than 60 min when 3%, 6%, and 9% of sucrose were included. For instance, the final setting time reached 65 min when 3% of sucrose was added, 320 min for 6%, and 755 min for 9%. The reason for the delay is because the sucrose increased the viscosity leading to a postponement in the initiation of the geopolymerization process. The results showed that when sucrose was included in the mixtures, the compressive strength was not affected, and absorption and permeable void ratios were reduced.

1. Introduction

In 2016, the production of Portland cement was approximately 4200 million metric tons, which shows that it is one of the most produced and used materials worldwide [1]. China, India, and the United States are the world's top Portland cement producers with an annual production of 2410, 290, and 85.9 million metric tons respectively [1]. In addition, producing one ton of Portland cement emits approximately one ton of CO_2 [2] leading to a contribution of 5–7% of total CO_2 emissions worldwide [3,4]. Therefore, there is an urgent need for alternative, sustainable cementitious materials, which can reduce the dependence on the Portland cement in construction. Geopolymer concrete that consumes waste materials such as fly ash or blast furnace slag in its production is alternative cementitious materials that are reducing CO_2 emissions and utilizing the waste materials.

Geopolymer or alkali activated geopolymer concrete is a sustainable concrete consisting of an activating solution, a source of aluminuma and silica, such as fly ash, fine and coarse aggregates, and chemical admixtures [5]. The common activating solution is a mixture of sodium silicate solution, sodium hydroxide solution, and extra water if needed [6–8]. However, there is another activat-

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ing solution used in this study; it is a combination of silica fume powder, sodium hydroxide pellets, and water [9,10].

The result of replacing a small portion of the fly ash with Portland cement on early mechanical properties of geopolymer concrete has been the topic of study by several researchers. Nath and Sarker investigated the effect of 5% Portland cement replacement on sodium silicate based activating fly ash geopolymer concrete [11]. Curing the samples in ambient temperatures resulted in the significant improvement of early compressive strength in the absence of external heat [11]. Similar effects were found in Assi et al., with the difference that a silica fume based activating solution was used instead of a sodium silicate activating solution [12]. The results showed that the presence of Portland cement in the geopolymer concrete not only eliminates the need for external heat, but it also reduces the number of microcracks due to the utilization of the free water in the mixture [12]. However, using high Portland cement replacement (between 15% and 35%) will accelerate the geopolymerization process drastically leading to a flash setting.

Several studies have been conducted to investigate the effect of including chemical admixtures on the geopolymer concrete properties. Aliabdo et al. [13] invetigated the effect of plasticizer on the workability of fly ash based goeopolymer concrete. The results showed that a 10.5 kg/m^3 has an acceptable effect on the workability of the product, while increasing sodium hydroxide to sodium silicate ratio enhances geopolymer concrete properties. However, this process increases the final cost [13]. Furthermore, the effect of plasticizer and superplasticizer on rheology, workability, and slump of fly ash based geopolymer concrete was studied and a dosage of plasticizer was found to be more effective than superplasticizer. Adversely, the increase in the dosage had a negative effect on the workability and slump [14].

Several studies have been conducted to extend the initial and final setting times of geopolymer concrete. Generally, due to the presence of high alkali, geopolymer concrete has a rapid reaction that leads to a short initial setting time. Rattanasak et al. investigated the effects of several admixtures including calcium chloride, sucrose, and sodium sulfate on initial and final setting times [15]. The activating solution was a mixture of sodium silicate and sodium hydroxide solutions and the admixture weight ratios were 1% and 2% of the fly ash weight [15]. The results revealed that calcium chloride reduced the final and initial setting times, while sucrose extended the initial and final setting times effectively [15]. Tennakoon et al. [16] studied the effects of different activating solutions, specifically pentahydrate and anhydrous sodium activating solutions, on initial setting times. The results showed that changing the activating solution from pentahydrate to anhydrous reduces the initial setting time [16]. The effect of slag increments on the setting time of fly ash based geopolymer concrete was studied by N. and H. Lee [17]. Their results showed that increasing the amount of slag and sodium hydroxide decreased setting times. Huqjun and Xiao used BCH retarder, which is made of organic dibasic, and an alkali metal salt. When using a 5% dosage the initial and final setting times were extended by approximately 17 times that of a paste without BCH [18].

Lee and Deventer developed a model to explain the occurrence of the retardation of geopolymer gel due to the use of various salts [19]. The effects of sucrose and citric acid on workability, initial, and final setting times of fly ash based geopolymer concrete were observed by Kusbiantoro et al. [20]. The results showed that sucrose extended the initial and final setting times, while citric acid accelerated the geopolymerization process and reduced the initial and final setting times [20].. In another study by Kamsuwan and Srikhirin, lignosulfonate was used as an admixture to determine its effect on the mechanical properties and setting time of a geopolymer concrete created with a sodium silicate-based activating solution [21]. A high compressive strength was achieved with the general lignosulfonate, with the longest setting time being achieved when calcium lignosulfonate was used [21]. Wijaya et al. showed that 5% of borax by mass of fly ash (Type C) increased the compressive strength and extended the initial and final setting times [22].

In an effort to retard the setting time of geopolymer concrete, Jamil studied the effect of sucrose and other natural retarders [23]. A combination of sodium silicate and sodium hydroxide was used as an activating solution in the study [23]. Reported results showed that sucrose improved the workability and setting time of geopolymer concrete [23]. Several curing methods, including hot gunny, ambient, and external heat were used for processing the glucose, which is used as a natural retardant [24]. It was found that glucose enhanced the concrete properties. The best performance was achieved when combined with the external heat curing process [24]. However, the optimum retardant dosage, particularly sucrose (commonly known as granulated sugar) for the initial and final setting times of silica fume-based activating solution fly ash geopolymer concrete has not been observed.

There are four general categories of set retarders including hydroxycarboxylic salts, lignosulfonic acid salts [21], water-soluble salts, and carbohydrates [25]. For instance, polysaccharides (corn syrup), phosphates, organophosphates, sugars, and some types of inorganic salts all fall into these categories [25]. The function of a set retarder works by slowing down the hydration process for Portland cement and the geopolymerization process for geopolymer concrete through a complex process, which leads to the prevention of the growth of nucleation [25]. The mechanisms of retardants and accelerants are not well understood; however, several hypotheses have been introduced to explain the mechanism. There are some hypotheses explaining set retarder mechanisms. For instance, reduction occurs by preventing water access to hydrated cement particle surfaces. Another hypothesis explaining the cement retarder was postulated for the effect of the retarder on C_3S kinetics leading to a delay in C_3S formations [26].

Calcium chelation and adsorption onto calcium silicate hydrates (CSH) and calcium hydroxide (CH) lead to a longer induction period until the retarder (sucrose) is depleted, after which there is an increase in the hydration process rate [27]. Peterson et al. [28,29] postulated the effect of sucrose on hydration process, stating the fact that sucrose will decrease the diffusion coefficient, which, in turn, leads to an increase in the induction period. Hence, the hydration process rate is reduced. Other possible mechanisms for accelerants and retardants are chelation of metal ions, poisoning of nucleation and growth, adsorption on the surface of particles, precipitation of insoluble salts, and changes in the microstructure of hydrated phases [30–32]. The mechanism depends on chemical composition, particle size distribution (PSD), chemical admixture composition, the type of crystal structures used during individual phases, along with the mineralogy of the cement, and the amount of the chemical admixture [30–32].

In previous studies, the highest ratio was 3% of fly ash weight. Most geopolymer specimens were subjected to external heat. The absorption and permeable void ratios were not measured. Consequently, investigating the effect of sucrose with different weight percentages on the initial and final setting times of fly ash-based geopolymer concrete as well as the mechanical and microstructural properties, should be investigated. The mixtures were formulated with silica fume, sodium hydroxide, and water as an activating solution. The initial and final setting times and mechanical properties of geopolymer concrete using Portland cement as a replacement was also investigated.

This study will focus on improving the initial and final setting times of fly ash-based geopolymer concrete. The supplementary material used to delay these times is sucrose (common name