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Article

Investigating Fly Ash as a Sustainable SCM for Self-Compacting Concrete: Workability and Strength Analysis

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Abstract

Self-compacting concrete (SCC) is modern concrete which can flow and compact naturally without requiring mechanical vibration. This attribute minimizes the labour and time spent on construction thus SCC is highly efficient. The use of supplementary cementitious materials or SCMs has gained momentum over the recent years to partially substitute cement in conventional concrete to maintain strength without increasing cost and environmental degradation. Nevertheless, the use of SCMs in self-compacting concrete is scarcely being researched, and thus individuals are not eager to apply it due to the uncertainty in its performance. The present work studies the behaviour of SCC on the addition of fly ash instead of some cement to bridge this gap. Cement was substituted with fly ash in weight percentages of 0%, 5%, 10%, 15%, 20%, and 25%. Standard concrete cubes were made for every mix ratio. To assess the fresh SCC's workability and identify the ideal fly ash content, the slump flow test was performed. A Compressive Testing Machine (CTM) was used to evaluate the samples' compressive strength following 14 days and 28-days water curing period. The results showed that the maximum workability was achieved when fly ash was substituted for 15% of the cement. Furthermore, blends with 10% to 15% fly ash replacement had the highest compressive strength. These results show that fly ash, when used in the right amounts, improves flowability and strength in SCC and is a cost-effective partial substitute for cement.

Keywords: Self-Compacting Concrete; fly ash; compressive strength; workability; slump flow; sustainable construction.

1. Introduction

With the new development of the modern construction especially reinforced concrete, Self-Compacting Concrete (SCC) was invented to replace the traditional compaction process [1,2].As Self-Compacting Concrete (SCC) it is able to flow under its weight, fill form works completely and harden without vibration [3].This significantly lowers the labour expenses, noise as well as the construction time when compared to the conventional compaction process and also it is in a position to give superior finishes as well as strength to the surface [4].

To improve sustainability and performance characteristics of SCC, Supplementary Cementitious Materials (SCM) like Fly Ash, Silica Fume, and Ground Granulated Blast Furnace Slag (GGBS) are often added as admixtures [5]. Fly ash, an ash obtained from burning coal, can be greatly appreciated for its pozzolanic reaction and spherical particles, thus making it more workable and with lesser hydration heat [6]. Although SCM admixtures have shown some advantageous effects, SCC mix sensitivity demands optimal adjustment for balancing workability and strength properties [7].The main intention of exploring and presenting research on SCC and SCM admixtures would be to identify and assess its mechanical properties and workability with varying proportions of Fly Ash as substitute materials for cement Specifically, it would be apt to identify and ascertain an optimal percentage replacement based on maximum compressive strength and retention of SCC property with added advantage due to the presence of Sika ViscoCrete-3110 superplasticizer admixture [8].

2. Literature Review

The self-compacting concrete (SCC) became the solution of the issues related with intermittent compaction and honeycomb processes in dense reinforced zones. SCC will allow a concrete mix that can flow under its own gravity and filling formwork to the full extent without any compaction or vibration [1]. SCC will, as a rule, experience superior surface finish, passing capacity, and labour and equipment requirements than traditional concrete [2]. SCC study was first focused on optimal proportions of cement, water, fines and coarse aggregates and high range water reducing admixtures with the aim of coming up with feasible mixtures with high flow and resistance against segregation [3]. It has been demonstrated that rheological properties and stability are very sensitive functions considering binder, aggregate, and admixture proportions. Recent research findings have emphasized the need to incorporate supplementary cementitious materials such as fly ash, silica fume, and slag as admixtures with an alternative percentage of cement materials so as to make SCC more eco-efficient [4]. The introduction of admixtures does not only minimize the clinker and consequent CO_2 emission but also enhances the durability and the mechanical strength with an optimum mix. Special attention has been paid to fly ash due to its pozzolanic nature, fine nature and sphericity, which attributes to its ability to increase the workability and water requirement of concrete mixes [5]. According to the literature review on the fly ash concrete materials, it is indicated that the optimum replacement proportions can optimize the pore structure, minimize the permeability, and maximize the late-stage strength, though too much replacement can have an impact on the early-stage strength. Under the SCC mixing system, it has been reported that several studies have demonstrated the enhancement of fly ash significantly in terms of its flowability and stability due to its filler and ball-bearing attributes due to its smooth particles [6]. It reacts pozzolanic reaction with calcium hydroxide at an intermediate replacement ratio to make calcium silicate hydrate. As noted by Khatib, SCC blends with fly ash could have the same or superior mechanical properties than conventional SCC when proper proportional replacement ratios were used [7]. Also, the analytical comment on eco-efficient SCC reports that fly ash blends with industrial waste materials could be just as effective and with significantly lowered environmental footprints of concrete production [8]. High-range water-reducing admixtures that contain polycarboxylate ether-based superplasticizers are required to produce SCC with low water to binder proportions and high flow without segregation. According to the product information presented on the Sika ViscoCrete-3110 admixtures, the admixtures are supposed to provide high workability retention, high slump flow, with the possibility of compatibility with binary binders that use SCMs such as fly ash [9]. One can conclude based on the available literature that fly ash is a potentially viable SCM of SCC and it can be used to enhance workability and long-term strength and the sustainable construction activity, by appropriately controlling the percentage and mix parameter variables [10].

3. Materials and Methods

3.1. Materials

The materials selected for this study included OPC was used as the main binder. Fly ash was used as cement replacement. Particles of fly ash are mostly spherical, which serves as a lubricant to enhance flowability and enables pozzolanic reactions in the hardened concrete. Coarse aggregates used were of a nominal size range 12–18 mm; natural sand was selected as a fine aggregate to fill up voids and provide support for self-compaction. Admixtures: Superplasticizer Sika ViscoCrete-3110 is a polycarboxylate ether-based superplasticizer. It reduces water demand, improves the flowability without segregation. Other SCMs: GGBS and lime powder were added into the binder system to improve cohesiveness and durability, and to enhance eco-efficiency of the mix.

3.2. Mix Design and Sample Preparation

Mix design percentage of fly ash was also tested as varied and other parameters were maintained constant. Thus, 6 combinations of mixes have been made with the replacement of fly ash by cement in 0% (control), 5, 10 and 15, 20 and 25 percent by weight as shown in Figure 1. In the compressive strength test, 36 cubic specimens (6 in x 6 in x 6 in) were cast. Mix Proportions Specific mix proportions per cubic meter: The cement content varied depending on the degree of fly ash replacement level, whereas GGBS and lime powder were held constant to allow homogeneity within the mix. The selection of grading and proportions of coarse and fine aggregates have been made to comply with both self-compacting concrete requirements and sufficient flowability and stability of fresh mixes.

Figure 1. Concrete cube moulds sample preparation.

3.3. Testing Procedures

Workability Test: Slump flow test was done as soon as the fresh self-compacting concrete was mixed to assess the flowability and uniformity of the fresh self-compacting concrete. The test was conducted with regards to suitable ASTM test procedures as far as slump flow of SCC is concerned. Due to the mix, the diameter of the spread concrete was measured in two perpendicular directions, and the overall mean was calculated as the slump flow.

Compressive Strength Test: The cubic specimens were cured in 14 and 28 days, and in water. A Compression Testing Machine (CTM) of 2000 KN was utilized in the process of conducting a destructive compression test, and the ultimate load at failure was registered to determine the compressive strength of each mix, as shown in Figure 2.

Figure 2. Sample under testing.

4. Results

4.1. Workability Analysis

The mix workability for SCC mixtures was determined using the slump flow test. It clearly indicated that addition of fly ash generally enhances the flow properties of concrete. Table 1 explain the slump flow values for different fly ash percentages

Table 1. Slump Flow values for different Fly Ash percentages.

Fly Ash Percentage (%)	Slump Flow (mm)
0	70
5	670
10	678
15	722
20	711
25	701

As Table demonstrates, the control mix (0% fly ash) has very low flow (70 mm), and this is not enough to have self-compacting concrete. The inclusion of fly ash (5 percent) by massively raising the slump flow to 670 mm shows that the fly ash ability was enhanced significantly. The optimum working point was 15% replacement, where the slump flow was 722 mm and thereafter the values of slump flow slightly decreased but still fell within the normal range of acceptable values of SCC as stipulated in the standard guidelines as shown in Figure 3.

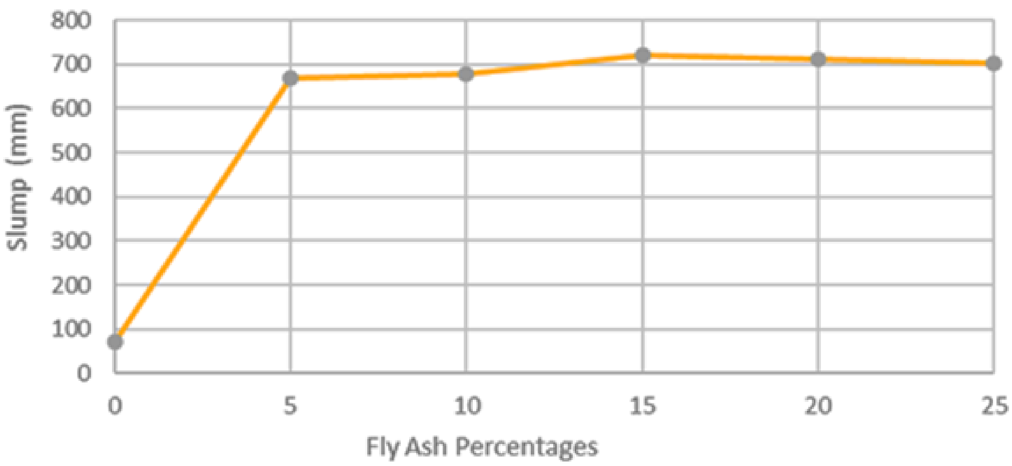


Figure 3. Effect of fly ash percentage on slump flow of SCC.

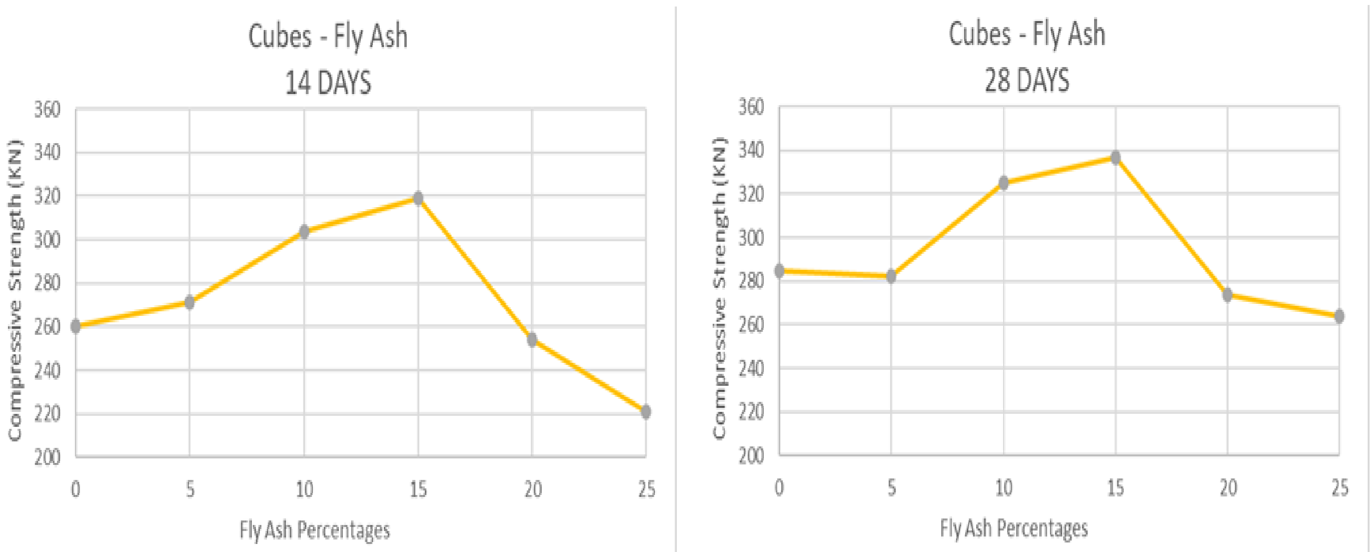
4.2. Compressive Strength

The compressive strength was measured on the days of 14 and 28 days to determine the impact of fly ash content on the mechanical performances of the hardened concrete. Table 2 presents the values for both durations.

Table 2. Cube compressive strength, 14 and 28 days old.

Fly Ash (%)	14-Day Compressive Load (KN)	28-Day Compressive Load (KN)
0	260	285
5	271	282
10	304	325
15	319	337
20	254	274
25	221	264

The compressive load capacity rose with fly ash content and attained its highest limit of 337 KN at a fly ash content of 28 days and this is greater than the compressive load capacity with the control mixes 285 KN. The 10% and 15% fly ash mixes thus showed high performance in terms of load bearing than the control. At 20% and 25% replacement, however, the load values at 28 days dropped to 274 KN and 264 KN, respectively, which was drop in strength at higher fly ash, as also illustrated in Figure 4.



(a) **(b)**

Figure 4. Effect of fly ash percentage on 14-day and 28-day compressive load of SCC cubes.

5. Discussion

The findings also reveal that a 15 percent substitution of cement with fly ash offers a good compromise between the workability and compressive strength in self-compacting concrete mixes. This replacement level is comparable with ranges that have been identified in prior research in which moderate content of fly ash improved fresh and hardened characteristics of SCC. The fine grading of fly ash particles and the spherical shape of the particles provide a ball bearing effect that decreases the internal friction between the solid particles and increases the flowability of the fresh mix. The mechanism contributes to the sudden rise in slump flow with the introduction of fly ash (0% to 5% replacement) and the highest slump flow attained at 15% replacement in the current study.

The rise of strength up to 15 percent fly ash substitution can be explained by the pozzolanic reactions, where in the hydration of cement, the fly ash reacts with the calcium hydroxide that releases additional calcium silicate hydrate (C_3S) thus compacting the microstructure. Also, the fine fly ash particles create a filler effect, meaning that they fill the openings between cement grains and aggregates, resulting in a smaller and more uniform matrix with increased load-bearing capacity. Replacement: Compressive strength is reduced at 20 percent fly ash replacement and 25 percent fly ash replacement, which is in line with the dilution effect that is described in the literature under high contents of SCM. During these increased replacement values, the reduced cement content can yield less primary hydration product, and the surplus fine particles can modify the water requirement and packing of the system and this may interfere with the microstructure and lead to low strength.

6. Conclusion

This paper examined the workability and strength characteristics of self-compacting concrete (SCC) with different percentages of fly ash used as a partial substitute of cement. Conclusions, which are based on the outcomes of the experiment, are as follows: Workability: Fly ash considerably increases the flow qualities of SCC. The highest replacement of 15% recorded the highest slump flow of 722 mm, which shows that it was the most workable mix. Compressive Strength: The ideal percentage of replacement in compressive strength is 15 percent, which the concrete had the best load-bearing capacity at 14 and 28 days in comparison with the control mix and other levels of fly ash. Sustainability: It is a feasible approach to replace 15 percent of cement by fly ash and form more economical and eco-friendly concrete because the use of fly ash will decrease the use of cement, but the mechanical and workability characteristics should be satisfactory. Limitations: The replacement levels above 15 percent will result in appreciable decrease in compressive strength and thus fly ash contents above 15 percent should be employed with care especially in structural components that need higher strength levels.

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