The Impact Of Fly Ash And Silica Fume On The Characteristics Of High-Performance, Self-Compacting Concrete.

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Abstract - *To increase compressive strength, tensile strength and promote the environmentally friendly use of fly ash (FA) produced in Malaysia, the study explores the feasibility of replacing fly ash (FA) and silica fume (SF) for ordinary Portland cement (OPC) in self-compacting high-performance concrete (SCHPC). OPC was partially replaced by 0%, 25%, 40%, 50%, 65%, and 75% FA in six SCHPC mixes studied; SF replacement remained constant at 10%. The w/b ratio was fixed at 0.31. According to EFNARC for self-compacting concrete, fresh qualities were tested using slump flow, L-Box, and V-funnel tests. The compressive strength tests were carried out on 100 mm² cubes after 7 and 28 days of curing. The ideal mixture of 40% OPC, 50% FA, and 10% SF had a compressive strength at 28 days of 87.06 MPa, which was 5% higher than the control mix's 82.39 MPa. This exemplifies a practical and long-term approach to enhancing the performance of SCHP.*

Key Words**: *Self-compacting high-performance concrete, Fly ash Compressive strength, Silica fume, Portland cement, STS.***

1.INTRODUCTION

With growing environmental consciousness and the need to lessen the harmful consequences of industrial wastes, the use of industrial by-products has accelerated recently [1]. The viscous mixture known as self-compaction concrete (SCC) is ideal for casting complex structures and constructions with crowded reinforcement, either with or without a small amount of vibration, while preserving a steady flow devoid of bleeding and segregation [2]. Okomora started the concept of SSC in 1986, and Tokyo University expanded on it in 1988 to create long-lasting concrete structures and raise standards in the building sector [3]. Abrasion-resistant and long-lasting, high-performance concrete (HPC) is created with a low water-to-binder ratio (w/b) and properly cured [4].

High strength, durability, and fluidity are characteristics of HPC. Similar components make up both SCC and HPC, and when properly proportioned, they provide the necessary classes of concrete. Therefore, SCHPC is a new tangible generation that is founded on the ideas of HPC and SCC. It has the high strength and good durability of the HPC and the sufficient self-compactability (filling, passage, and segregation resistance) of the SCC. SCHPC compacts without vibration, which speeds up construction and saves a lot of money. However, its production costs are unaffordable because of its high cementitious content and chemical admixtures.

However, a review of the literature indicates that labour cost savings and the use of mineral admixtures like FA and SF in the SCHPC production process may significantly lower the production cost. Furthermore, it is well known that the combination of FA and SF in a ternary blend enhances the qualities of concrete and makes SCHPC more ecologically friendly. Whereas SF is a byproduct of the smelting process in the silicon and ferrosilicon industries, FA is a byproduct of burning pulverized coal in power plants that generate energy.

Coal-fired power plants are used in Malaysia to produce electricity. Burning coal ash, the Tanjung Bin power plant, one of Malaysia's four coal-powered power plants, generates 42,000 metric tons of FA monthly [5]. As Malaysia's anticipated need for coal to generate energy rises in 2020, it is anticipated that FA output would rise as well. One affordable and easily accessible fossil fuel is coal. According to reports, a 25% FA substitution for cement results in a 20% reduction in construction expenses. There isn't many research in the literature on the mechanical properties of SCHPC that incorporate class F FA and 10% SF. The goal of this work is to close this gap.

In their investigation of the mechanical characteristics of SCC, Askari et al. [6] find that a large volume FA concentration increases compressive strength between 28 and 120 days of curing, confirming the persistence of FA's pozzolanic activity over time. Additionally, SCC with high volume FA retains and increases its tensile strength when 10% SF is substituted for cement. Askari et al. [6] conclude that because FA particles are spherical, high-volume FA reduces the amount of superplasticizer (SP) needed to achieve self-compactability. Similarly, Wongkeo et al. [7] investigate the effects on SCC's compressive strength and chloride resistance of substituting Portland cement with 50, 60, and 70 weight percent high calcium class C FA and SF. They discovered that when Portland cement is substituted in large quantities, FA and SF improve SCC's resistance to chloride. Additionally, Yazici [8] evaluated the mechanical and durability characteristics of SCC mixes with 10% SF addition and a constant w/b ratio of 0.28 by substituting class C FA for cement from 30% to 60%. He discovered that adding 10% SF enhances the concrete's fresh and hardened qualities. Furthermore, the characteristics of the component materials have an impact on the compactivity of SCHPC. Consequently, it is necessary to examine the concrete's strength growth when a significant amount of cement is substituted. Given the aforementioned, this study investigates the effects on the new characteristics and compressive strength of SCHPC of replacing 25%, 40%, 50%, and 65% of the Portland cement with 10% SF and ASTM C618 class F FA. FA and SF replaced 0%, 25%, 40%, 50%, 65%, and 75% of the cement in six distinct mixes. SF, however, was kept at a steady replacement rate of 10%. For every mix, the w/b ratio was set at 0.31. To evaluate the fresh qualities of SCHPC, tests on fresh concrete using slump flow, L-Box, and V-funnel were carried out. Concrete cubes measuring 100 mm2 were tested for compressive strength at 7, 28, and 56 days of cure.

2. EXPERIMENTAL PROGRAM

2.1.Materials

To create the SCHPC combinations, regular Portland cement of CEM 1 with a specific gravity of 3.15 and a strength of 42.5 MPa was utilized. Low calcium FA equivalent to ASTM C618-12a, [9] Class F with gravity of 2.1, produced from Tanjung Bin power plant at Johor Bahru, was added in varying quantities to reduce the risk of segregation and heat of hydration while achieving the necessary workability and uniformity of SCHPC. For the FA concrete's relatively low early strength, densified SF was used, which had a bulk density of 550–650 kg/m3 and a gravity of 2.1–2.4. Muller et al.'s recommendation of 10% SF was followed [10]. Table 1 displays the chemical makeup of SCMs and Portland cement as determined by X-ray diffraction (XRD) investigation. Class F FA has a minimum composition of 70% silicon dioxide (SiO2), aluminum oxide (Al2O3), and iron oxide (Fe2O3), but the total calcium oxide (CaO) content is less than 7%, per ASTM C618-12a [9].

Table 1

Chemical composition of Portland cement and SCMs.

Component (%)	PC	FA	SF
SiO_2	16.2	51.8	96
Al_2O_3	3.52	26.5	0.1
Fe_2O_3	2.91	8.5	0.6
CaO	70.9	4.81	0.1
MgO	0.764	1.1	0.2
SO_3	3.36	0.6	1.1
K_2O	0.572	3.27	0.4
Na_2O	0.3	0.67	0.1
Ignition Loss	0.7	1.47	1.7

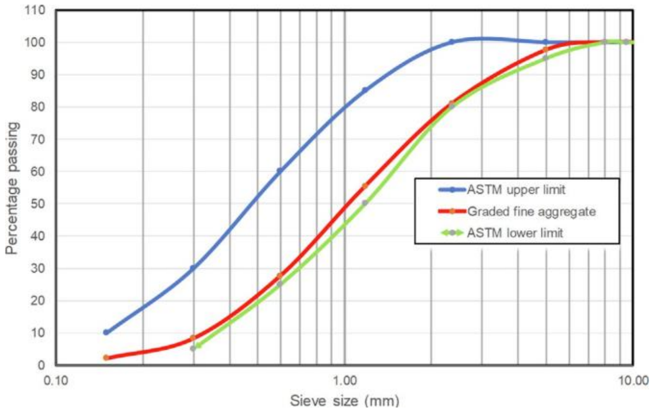

Chart-1: Grading curve of fine aggregate in relation to ASTM C33 limits

Naturally occurring river sand was utilized as a fine aggregate in the mixtures; its relative density (SSD), water absorption, and fineness modulus were 2.65 kg/m3, 1.15%, and 3.17, respectively. The fine aggregate grading result based on sieve analysis is shown in Chart-1. The ASTM C33/C33M-13 maximum and lower limitations are met by the grading of the various fine aggregate sizes [11]. As a result, the fine aggregate was graded properly. A well-graded aggregate typically improves the packing density, flexibility, and workability of SCHPC by lowering the need for water and superplasticizer. The coarse aggregate was a well-graded 10 mm aggregate with an SSD and a water absorption value of 2.66 kg/m3 and 1.0%, respectively. To attain the necessary consistency, Sika Viscocrete-2044, a third-generation polycarboxylate ether-based superplasticizer that conforms with ASTMC494 [12], was added.

2.2. MIX PROPORTIONS AND SPECIMEN PREPARATION.

Six distinct mixes were created using FA and SF to replace cement at percentages of 0%, 25%, 35%, 50%, 60%, and 75% while keeping SF constant at 10% replacement. For every mix, the w/b ratio was set at 0.31. To create SCHPC concrete with increased strength and durability, replacement amounts of a consistent 10% of SF were utilized [10]. SF serves as a filler to increase the density of concrete and enhances its pore structure. Table 2 provides a summary of the various mixing proportions. The concrete was mixed using a rotary mixer with a volume of 0.03 m3. After mixing, slump flow, L-Box, and V-Funnel tests were conducted on the fresh concrete to explore the features of the rheological properties of SCMs, as recommended by EFNARC [13]. To measure compressive strength, 100 × 100 mm concrete cubes were made, and the specimens were cured in water at 20 ± 5 °C for seven and twenty-eight days.

3. TEST METHODS

3.1 Tests on fresh properties

Abram's slump cone was used for the Slump Flow Test. In accordance with European Standard BS EN 12350-2, the test was conducted [14]. This test can be used to evaluate SCHPC's workability, consistency, and filling ability.

The SCHPC's ability to travel through narrow gaps, such as those between reinforcing bars and other obstructions without segregating or obstructing EFNARC, was evaluated using the L-Box Test [13].

Using a V-funnel equipment called EFNARC, the viscosity and filling capacity of SCHPC were evaluated using the V-Funnel Test [13].

3.2. Compressive strength test

Using a V-funnel apparatus EFNARC [13], the viscosity and filling ability of SCHPC were evaluated using the V-Funnel Test. A universal testing machine with a 3000 kN capacity was used to determine the compressive strength of cube specimens measuring 100 × 100 mm in accordance with BS EN 12390-3 [15]. Between the ages of 7 and 28 days, the test was administered. To find the compressive strength, three specimens from each batch were measured, and the average value was computed. Fig. 1 depicted the compressive strength test's operational process.

3.3. Split Tensile strength test

The cylindrical specimens were subjected to a splitting tensile strength test after 28 days of cure. The test was carried out in compliance with ASTM C496/C496M-11 specifications [7]. The NL Compression Machine, which has a 3000 KN capacity, was used for the test. Straight from the machine, the maximum fracture load was noted. Eq. 2 was used to calculate this:

$$Fct = (2F/NLD).$$

where F is the maximum load in N, L is the specimen's height in mm, D is its diameter in mm, and Fct is the splitting tensile strength in MPa. Fig. 3 illustrates the splitting tensile strength test's operational process.

4. RESULTS AND DISCUSSION

4.1. Fresh properties

Slump Flow: As seen in Table 2, the slump flow of the corresponding SCHPC varied between 550 and 650 mm. This slump flow rating indicates good filling ability and falls within Class SF1 of EFNARC [13]. It aligns with the majority of SCHPC research.

L-Box passing ratio: The control mix's L-box passing ratio is 0.76 (about 0.8). On the other hand, for every other blend, the passing ratio falls between 0.84 and 0.88.

Table 2
The fresh properties of concrete mixes.

Concrete mixes	Slump flow (mm)Min. to Max. 550 to 850	L-Box(H2/H1) Ratio Min. Max. 0.80 to 1.0	V-Funnel (s) Min. Max. 6.0 to 12.0
100%PC	551	0.81	12.1
75%PC-25%FA	641	0.84	11.5
65%PC-25%FA-10%SF	602	0.83	11.8
50%PC-40%FA-10%SF	651	0.86	10.8
40%PC-50%FA-10%SF	631	0.87	10.3
25%PC-65%FA-10%SF	649	0.88	10.1

For passing ratio Class PA2, the EFNARC [13] recommends an L-box passing ratio range of 0.8 to 1.0. Consequently, any SCHPC combination meets the criterion for passing ability class PA2. The passing ratio of SCHPC improves when the FA replacement level rises, according to Nagaratnam et al. [16].

V-funnel flow time: The fresh mixes' V-funnel flow times (Tv) ranged from 10 to 12 seconds. Accordingly, the Tv for each individual SCHPC falls between 9 and 15 s, as determined by EFNARC [13] for the VF2 viscosity class. The concrete becomes more viscous when silica fume is added [17]. Table 3 provided an overview of the new SCHPC features.

4.1. Compressive strength

Chart-2 and 3 showed the average compressive strength and maximum compressive strength of the various samples, respectively. As the curing period increased, all SCHPC's compressive strength rose as well. SCHPC with 25% FA and 0% SF had a 35% lower compressive strength than the control sample. This resulted from FA's diluting impact and sluggish pozzolanic reaction. Once more, the control specimen's compressive strength is 4% higher than that of the 65% PC, 25% FA, and 10% SF samples. On the other hand, 50% PC; 40% FA; 10% SF and 40% PC; 50% FA; 10% SF had compressive strengths that are only 1% higher than the control specimens.

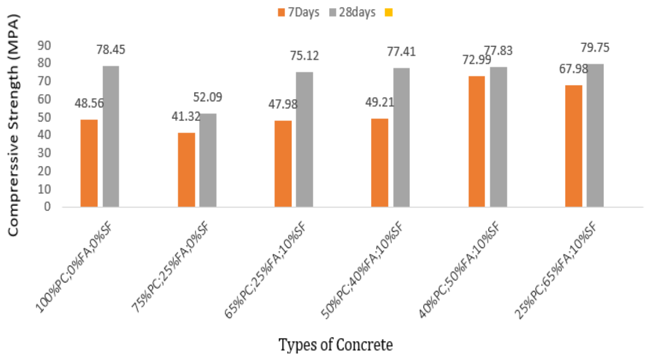

Chart-2: Average compressive strength of SCHPC

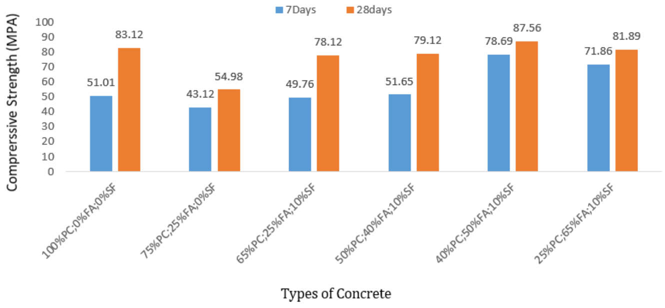

Chart-3: Maximum compressive strength of individual samples of SCHPC.

Nonetheless, the 25% PC, 65% FA, and 10% SF compressive strengths are 2% higher than the Portland cement controls. However, the compressive strength of Portland-fly ash-silica fume concrete improved because of the higher pozzolanic reaction and the micro-filler impact of SF compared to FA. Silica fume works wonders for HPC development. Similar findings are reported by Wongkeo et al. [7].

While the compressive strength of 25% PC; 65% FA; 10% SF at 28 days is higher than that of 40% PC; 50% FA; 10% SF at 7 days, Chart-2 shows that the compressive strength of 40% PC; 50% FA; 10% SF at 7 days is greater than that of 25% PC; 65% FA; 10% SF. Fly ash's diluting effect and sluggish pozzolanic response are the main causes of this. Over time, fly ash increases the concrete's compressive strength. Concrete's early strength may be impacted by its heavy application, but it can also achieve exceptional strength later on [18].

There is a significant t-test result, p =.096 for the compressive strength of three samples from 50% PC; 40% FA; 10% SF SCHPC (M = 77.41, SD = 2.58) in comparison to three samples from 40% PC; 50% FA; 10% SF SCHPC (M = 77.83, SD = 8.13). At 28 days, the compressive strength of SCHPC with 40% FA and 50% FA cement replacement did not differ significantly.

The non-durable calcium hydroxide (lime) produced by the hydration of Portland cement concrete is chemically reacted with fly ash to form calcium silicate hydrate (C-S-H), the strongest and most durable component of the paste in concrete. As a result of the paste's gradual strengthening due to C-S-H, the capillaries that permit moisture to pass through the concrete are diminished, making the concrete more resilient and less permeable [3]. Additionally, while concrete is in a plastic condition, the "ball bearing" function of fly ash helps with the lubricating effect, which enhances workability and finishing, lessens bleeding and segregation, and makes pumping SCHPC easier [19,20].

4.3 Split Tensile strength test

Chart-4 displayed the splitting tensile strength test results. After 28 days, the corresponding strength levels were ascertained. At 28 days of age, SCHPC's splitting tensile strength rises from 4.91 to 5.89 MPa. The concrete's splitting tensile strength increased gradually as FA and SF were added to the mixtures. The Portland-fly ash-silica fume concrete blend's splitting tensile strength was increased by adding SF [21]. Two of the cylinders, representing 40% PC, 50% FA, and 10% SF, broke in two at maximum stress during the tensile test. Less cohesive stresses were conveyed because SCHPC was brittle and there was less coarse aggregate and interlocking components [22].

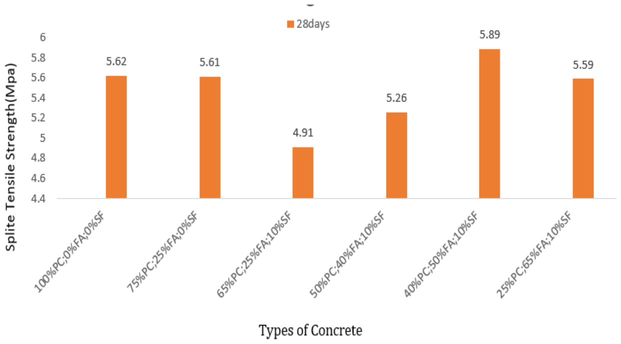

Chart-4: Average split tensile strength of SCHPC

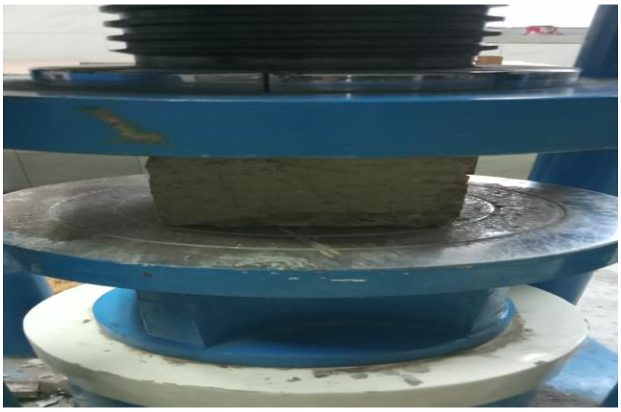

Fig-1: Compressive strength test

Fig-2: Splitting tensile strength

5. CONCLUSIONS

The following conclusions were drawn from this study's findings:

- All SCHPC mixes meet the requirements for the passing ability class PA2, the V-funnel flow time for all SCHPCs falls within viscosity class VF2, and the slump flow of each SCHPC falls within class SF1, indicating good filling ability.
- At 28 days of curing age, a Portland-fly ash-silica fume blend of 40% PC, 50% FA, and 10% SF reached the maximum compressive strength of 87.06 MPa, which is 5% greater than the control specimen's 82.39 MPa. The cement content of this mixture is only 235.00 kg/m3.
- At 28 days of age, SCHPC's splitting tensile strength rises from 4.91 to 5.89 MPa. The concrete's splitting tensile strength increased gradually as FA and SF were added to the mixtures. The splitting tensile strength is increased by adding 10% SF.

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