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A Study of Composite Concrete Using Palm Oil Fuel Ash (POFA) as a Partial Replacement for Cement in Self Compacting Concrete

Katneni Prasanthi[1,*], B. Kesava Rao[2]

Abstract

Due to its flexibility at young ages and its capacity to be moulded into any necessary structural form and shape, concrete is the most commonly used construction material. For concrete to be workable and to have the necessary strength and durability, thorough compaction utilising vibration is typically necessary. Large numbers of voids are caused by inadequate concrete compaction affecting the structural strength and long-term toughness. Self-Compacting Concrete (SCC) offers a remedy for these issues. As its name suggests, it may compress itself without the need for additional vibration or compactive force. The lack of standardised mix design procedures and testing techniques has, however, limited the scope of applications for self-compacting concrete. Because there is no need for vibration and noise pollution, self-compacting concrete is becoming more and more popular. Using Ordinary Portland Cement, Palm Oil Fuel Ash as a mineral additive, and Polycarboxylate Ether as a super plasticizer, the study investigates the performance of self-compacting composite concrete. Palm oil fuel ash is substituted for cement in varying amounts (0%, 5%, 10%, 15%, 20%, and 25%). The results of the slump flow test, V-funnel test, and L-Box test for the acceptance characteristics of self-compacting concrete are provided. For M30 grade concrete, compressive strength at 7 and 28 days of age is also calculated. This document also includes the test findings that were collected.

Keywords: Self-Compacting composite Concrete, Ordinary Portland Cement, Palm Oil Fuel Ash, Poly carboxylate ether.

INTRODUCTION

SCC is a type of highly flowable concrete that can entirely fill formwork with dense reinforcement without the need for vibration. Additionally, it has the capacity to spread and move under its own weight. Additionally, SCC must demonstrate segregation resistance as well as the capacity to maintain homogeneity and stability. The outstanding workability of this concrete in its uncured state is its key selling point. A few benefits of SCC include a decrease in labor costs and construction time, enhanced in situ concrete quality, and a better working environment due to a decrease in vibration-related noise and injury. Over the past 20 years, the use of SCC has gradually grown because of the advantages it has over traditional concrete. Additionally, high-strength concrete (HSC) is a kind of concrete that is intended to provide both great strength and exceptional durability. A new type of concrete, known as self-consolidating high-strength concrete

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(SCHSC), has been developed to attain advantages of outstanding workability, high strength, and excellent durability. High strengths and outstanding durability qualities are provided by SCHSCs, which also exhibit strong flow ability and excellent constancy [1]. High cement content and pricey chemical admixtures to lower the water to binder ratio are required to produce self-consolidating high-strength concrete with high fluidity and strength. Which will make SCHSC more expensive than regular concrete? High autogenous shrinkage and a rise in hydration heat are two additional issues associated with high cement content. Additionally, a high cement percentage will result in more CO_2 emissions, which could have a detrimental effect on the environment. The use of supplementary cementitious materials in SCHSC, such as silica fume (SF), fly ash (FA), and palm oil fuel ash (POFA), has several benefits, including cost effectiveness, reduced heat of hydration, decreased autogenous shrinkage, improved durability, increased jobsite productivity, and more environmentally friendly building practices [2]. Additionally, from an environmental perspective, the use of additional cementitious elements in concrete can result in sustainable building practices with energy conservation because of the use of less cement [3].

The oil palm industry produces POFA, an agricultural waste, by burning oil palm wastes such palm fiber and palm kernel shells to create steam for energy generation. Without any hope of financial gain, the POFA generated by the palm oil mills is poured into the open fields. Due to its disposal in open spaces, it is a nuisance to the environment. It has been approved for use as a Pozzolanic material in concrete mixtures and contains significant levels of SiO_2. Additionally, a significant amount of study has been done to look into the feasibility of employing POFA as an additional cementitious material in various types of concrete. The impact of Portland cement replacement with POFA on the durability performance of concrete has been the subject of numerous investigations [4]. These investigations have demonstrated that POFA can be utilised to enhance concrete's resistance to sulphate assault, acid attack, and quick chloride penetration test, among other durability features. However, there hasn't been much research done on using POFA as an additional cementitious material to partially replace Portland cement, especially in the case of SCHSC [5].

According to earlier investigations, POFA has been employed as a partial cement replacement in high-strength concrete that is typically vibrated [6]. Additionally, POFA has been effectively employed to create SCHSC, and its mechanical and fresh properties have been researched. To assess the durability performance of SCHSC incorporating POFA, additional study is required. As a result, the primary goal of this study was to evaluate the impact of employing POFA as a substitute for some of the cement on the longevity of SCHSC. In terms of drying shrinkage strain, early surface absorption, quick chloride permeability, water absorption, and acid assault, the concrete's performance was examined. To verify the homogeneity and mechanical qualities of concrete, the fresh characteristics and compressive strength were also looked at. If the results of this study demonstrate that POFA may be used to create durable SCHSC in part instead of Portland cement, this will lower both the need for Portland cement and construction costs [7]. Additionally, it will benefit the environment by lowering carbon dioxide emissions and the amount of waste disposed in landfills.

CONSTITUENT MATERIALS

Materials Used in the Experimental Study

Ordinary Portland cement in grade 53 was utilised in this project. The start and final setup times were 40 and 345 minutes, respectively, and the specific gravity is 3.14. The fine aggregate utilised was natural river sand, and the coarse aggregate used was 12.5 mm. Palm Oil Fuel Ash is used to substitute cement in the following weight percentages: 0%, 5%, 10%, 15%, 20%, and 25%. Poly-carboxylate ether is the super plasticizer that is employed.

Cement

As per national standard specifications, the cement utilized is of OPC 53 grade. The cement must meet IS code IS:4031-1988 in accordance with Indian Specification.

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Fine Aggregate

The most frequently used natural fine aggregate is sand, which is a natural material. However, a recent social element that caused a lack of the material caused a significant issue in the construction industry. All of the references use zone 2 sand for the investigations.

Coarse Aggregate

For the investigation, common 12.5 mm granite broken stone aggregates are used. The sieve analysis test is carried out in accordance with IS: 383-1970.

Water

This investigation's water source is drinkable tap water. The campus uses water that meets the drinkable criterion of pH = 7.5.

POFA

A nearby palm oil plant provided the original POFA for collection. It was first dried in an oven. To eliminate bigger size particles, the dried POFA was next sieved through a 300 m sieve. A Los Angeles machine was employed to create a finer POFA since a smaller POFA has higher reactivity. The physical properties and chemical composition as well as particle size distribution of the POFA are shown in Table 1 below:

Super Plasticizer

The polycarboxylate superplasticizer is a potent water reduction agent. For cement-based construction projects, it is a dispersion of cement. High-rise structures, bridges, tunnels, dams, and roads are all common construction projects that use superplasticizer for polycarboxylate concrete.

Table 1. Chemical composition of OPC and POFA (%)

Oxide composition	OPC	POFA
Silicon dioxide (SiO_2)	17.60	59.17
Aluminum oxide (Al_2O_3)	4.02	3.73
Iron oxide (Fe_2O_3)	4.47	6.33
Calcium oxide (CaO)	67.43	5.80
Magnesium oxide (MgO)	1.33	4.87
Sodium oxide (Na_2O)	0.03	0.18
Potassium oxide (K_2O)	0.39	8.25
Sulphur trioxide (SO_3)	4.18	0.72

SELF-COMPACTING COMPOSITE CONCRETE TESTS (SCCC)

The traditional techniques for evaluating the viability of NVC cannot be applied to SCC since they are insensitive to the presence of a tendency to segregate. The several tests that can be used to evaluate the crucial aspects of fresh SCC are explained below.

- Slump flow test
- V-funnel test
- L-Box test
- U-Box test

Slump Flow Test

SCC's horizontal free flow is evaluated using the slump flow in the absence of impediments. It was initially created in Japan to be used in the evaluation of underwater concrete. Finding the slump is the foundation of the test procedure. The concrete's capacity to fill a circle is gauged by looking at its diameter. One of the most used SCC tests is lump flow. SCC's horizontal free flow is evaluated using the slump flow in the absence of impediments. Finding the slump is the foundation of the test procedure. The concrete's capacity to fill a circle is gauged by looking at its diameter. The permissible time range is 2 to 5 seconds, and the slump flow diameter is 500 mm (Figure 1, Figure 2).

Apparatus

- A truncated cone-shaped mould with an internal diameter of 200 mm at the base, 100 mm at the top, and a height of 300 mm.
- Base plate made of a rigid, non-absorbing material that is at least 700 mm square and is marked with a circle that designates the location of the slump cone's center and a second concentric circle with a diameter of 500 mm
- Trowel Scoop
- Ruler
- Stopwatch

Procedure

- Mist the drooping cone's interior and base plate.
- Place the droop cone in the center of the base plate, then securely fasten it there. Place the base plate on a level, sturdy surface.
- With the scoop, fill the cone. Don't tamp; merely level the concrete with the cone's top using the trowel.
- Clear the area surrounding the cone's base of any extra concrete.
- Raise the cone vertically to facilitate free flow of the concrete.
- Start the stopwatch simultaneously and note how long it takes for the concrete to travel to the 500 mm spread circle. (This time is T-50.)
- Take two perpendicular measurements of the concrete's final diameter.
- The two diameters that were measured should be averaged, and the findings should be noted.

Figure 1 Slump Flow Test for SCCC (source: pic taken at PVPSIT)


Figure 2. Measuring of Slump Flow for SCCC (source: pic taken at PVPSIT).

Acceptability

The capacity to fill firm work increases with flow rate, which must be between 550 and 650 mm for SCC.

V-Funnel Test

Ozawa employs a test that was created in Japan. The apparatus consists of a funnel with a V-shape, as seen in fig. In Japan, an alternative to the v-funnel is an o-funnel with a circular portion. The v-funnel test, as described, is used to evaluate the filling ability (flow ability) of concrete with a maximum aggregate size of 20 mm. About 12 liters of concrete are poured into the funnel, and the amount of time it takes the concrete to flow through the device is measured. The funnel can then be filled with concrete, which should be given five minutes to settle. If there is segregation in the concrete, the flow will dramatically increase (Figure 3).


Figure 3. V-Funnel Test for Self-Compacting Composite Concrete (source: pic taken at PVPSIT).

Apparatus

- V-Funnel
- Bucket(+12 ft)
- Trowel
- Scoop

Procedure for Flow Time

- The test requires approximately 25 kg of concrete, sampled routinely.
- Place the V-funnel on a solid surface.
- Wet the funnel's interior surfaces.
- Allow any extra water to drain by opening the trap door.
- Place a bucket below the trap door and close it.
- Completely fill the machine with concrete, then use a trowel to level it off at the top without compacting or tamping.
- Within 10 seconds of the concrete being filled, by opening the trap door to let the concrete drain naturally.
- When the trap door opens, start the stopwatch, and note how long it takes for the discharge to last through the flow time. This is assumed to be the case when light is seen entering the funnel from above. The entire test must be completed in less than five minutes.

Acceptability

- The flow time should be between 8 to 12 minutes.

L-Box Test

Peterson has described the test, which was based on a Japanese concept for underwater concrete. The test evaluates the concrete's flow as well as the degree to which it is susceptible to obstruction by reinforcing. In figure, the device is displayed. The device consists of an L-shaped rectangular box with vertical and horizontal sections, divided by a movable gate, and fitted with vertical lengths of reinforcement bars in front of the gate. When the vertical section is finished being filled with concrete, the gate is raised to allow concrete to flow into the horizontal portion. The height of concrete at the end of the horizontal section after the flow has ceased is expressed as a percentage of the height of concrete still present in the vertical section (H2/HI in the diagram). It shows the concrete's slope when it is at rest. This is a sign of the concrete's capacity to pass through the bars or how severely it is constrained [8].

The horizontal portion of the box can be marked at 200 and 400 millimeters from the gate, and the travel times to get there can be timed. These are also referred to as the T20 and T40 timings, and they serve as a gauge for filling capacity. Bar segments may have varying speeds and diameters at various intervals [9]. According to standard reinforcing criteria, a 3x increase in aggregate size would be suitable. The bars can essentially be placed at any spacing to improve a rigorous evaluation of the concrete's passing capacity (Figure 4).

Figure 4. L-Box Test for Self-Compacting Composite Concrete (source: pic taken at PVPSIT).

Apparatus used in L-Box

- L-Box of a stiff non absorbing material
- Trowel
- Scoop
- Stopwatch

Procedure

- The test requires about 30 kg of concrete, which is sampled routinely.
- Place the device level on a solid surface, check that the sliding gate may open easily, and then shut it.
- Moisten the equipment' interior surface and drain any extra water.
- Insert the concrete sample into the vertical part of the device.
- Give it a minute to stand. By raising the sliding gate, you can let the concrete pour into the horizontal part.
- Start the stopwatch simultaneously and note how long it takes the concrete to reach the 200 and 400 mm markings.
- "HI" and "H2" are measured lengths when the concrete stops flowing. Calculate the blocking ratio, H2/HI.
- The entire test must be completed in 5 minutes.

Acceptability

- H2/H1=1 if the concrete is fluid like water.
- 0.8 is the minimum acceptable value.

U-Box Test

- Passing ability of concrete is measured in this test (Figure 5).
- Procedure:
- On one of the side U-Boxes, about 20 litres of concrete are poured.
- Give it a minute to stand. To let the concrete flow to the other side, raise the sliding gate.
- Once the concrete has settled, measure the height of the concrete at both ends. The concrete height of the first compartment is H1. In the second chamber, the concrete is H2 inches high.
- Determine the filling heights H1 and H2. The entire test has a 5-minute time limit.

Figure 5. U-Box Test for Self-Compacting Composite Concrete (Source: pic taken at PVPSIT).

Acceptability

- H1-H2=0 if the concrete flows like water. It shows how much better SCC can flow and pass.
- The filling height should not be greater than 30 mm, which is the acceptable value.

TESTS ON HARDENED PROPERTIES OF COMPOSITE CONCRETE:

Compressive Strength Test

This is the most crucial test that has been conducted on concrete, providing information on all its properties. Whether concerting has been done properly or not can be determined by using this one test. 15 cm × 15 cm × 15 cm specimens are typically used for cube tests (Figure 6). The steps for testing the compressive strength of concrete cubes are as follows:

Figure 6. Testing of SCCC specimen (source:pic taken at PVPSIT).

Apparatus

400 kN capacity Compression testing machine.

Mixing

Mix the concrete either by hand or in a batch mixer (Table 2, Table 3)

Machine Mixing

- In a batch mixer, mix the cement with the proper amount of fuel ash from palm oil and fine aggregates for about 2 minutes, or until the mixture is well combined and has a consistent color.
- After blending the ingredients, add the coarse aggregate and stir until it is evenly dispersed throughout the batch.
- Mix the concrete with water and super plasticizer until it seems uniform and the right consistency.

Sampling

- Clean the moulds and lubricate them.
- Fill the moulds with concrete.
- The top surface is smoothened by using a trowel

Curing

The test samples are kept in moist air for 24 hours, then they are marked, pulled out of the moulds, and kept submerged in clear, fresh water until they are withdrawn for testing. Accelerated curing is required to achieve immediate results, in which the specimens are evaluated after being cured in hot water for 24 hours [10].

Procedure

- After the completion of the curing period, the specimens are removed from water and wiped off for any excess moisture.
- Consider the specimen's size and weight.
- Scrub the testing device's bearing surface.
- When placing the specimen in the machine, make sure that the load is given to the cube's opposing sides.
- Center the specimen on the machine's base plate.
- Gently rotate the movable component by hand until it touches the top surface of the specimen.
- Continue applying the weight steadily and gradually until the specimen fails.
- Note any peculiar characteristics of the failure type and the maximum load.

Table 2. Test Results of Different Proportions

Percentage Level	Slump Flow (mm)	V-funnel Time (sec)	L-box
0%	580	8	0.9
5%	590	9	1.0
10%	610	10	1.0
15%	560	9	0.8
20%	620	9	0.8
25%	580	8	0.8

Table 3. Mix Proportions of Concrete

Mix Percentage (%)	Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	POFA (kg/m^3)	Water (kg/m^3)	Super plasticizer (kg/m^3)
0	442	975	721	0	192	2.65
5	418	973	720	22	192	2.65
10	402	970	720	45	192	2.65
15	380	970	718	67	192	2.65
20	358	969	718	89	192	2.65
25	335	969	718	111	192	2.65

RESULTS AND ANALYSIS

The compressive strength of SCCC at 7 days and 28 days are stated in Table 4, Table 5; and Figure 7, Figure 8.

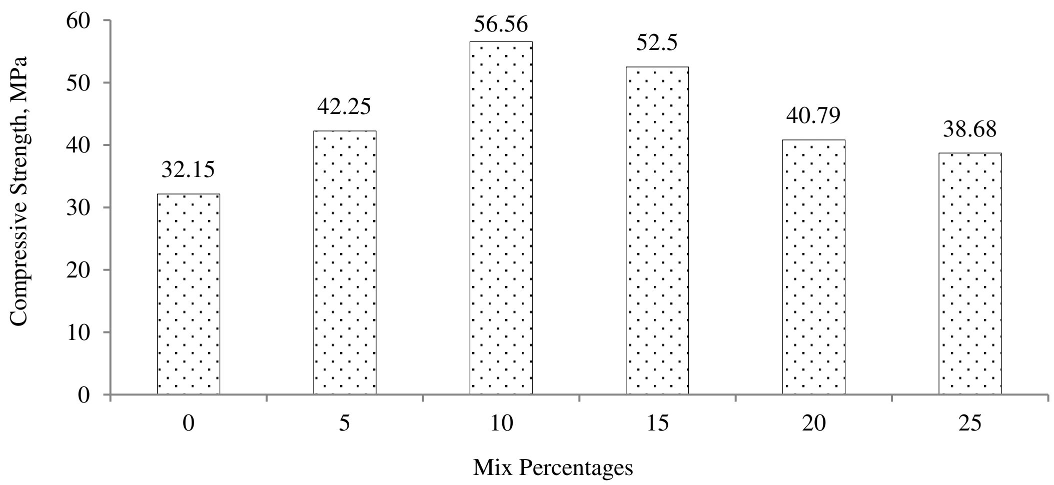

Figure 7. Compressive Strength at 7 Days of SCCC.

Table 4. Compressive strength of SCCC at 7 days:

Mix Percentage	0	5	10	15	20	25
Compressive Strength at 7 Days (N/mm^2)	32.15	42.25	56.56	52.5	40.79	38.68

Table 5. Compressive strength of SCCC 28 days:

Mix Percentage	**0**	**5**	**10**	**15**	**20**	**25**
Compressive Strength at 7 Days (N/mm^2)	42.39	53.56	62.25	61.39	55.65	52.78

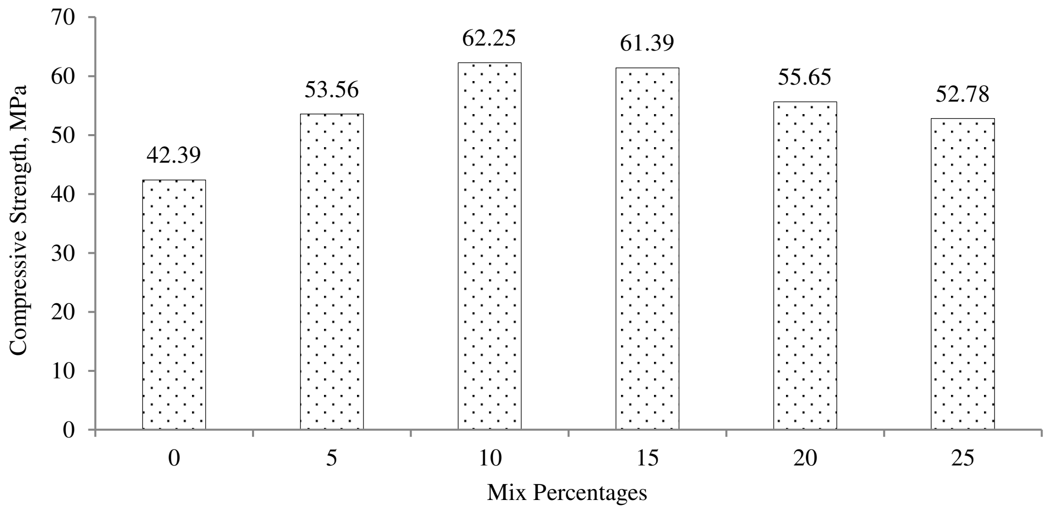

Figure 8. Compressive Strength at 28 Days of SCCC.

CONCLUSION

- When added in the right amount in SCCC, palm oil fuel ash tends to make the concrete mix stronger than regular concrete.
- Using the slump flow, L-Box, and V-Funnel experiments, it has been demonstrated that SCCC (built from locally available materials) may achieve consistency and self-compatibility under its own weight, without any external vibration or compaction.
- Following several trail testings, we were able to create M30, which could satisfy all SCC features with a mix proportion of 1:2.12:1.63:0.43.
- The EFNARC restriction states that the M30 has outstanding workability, with diameter of the lump flow larger than or equal to 500 mm.
- Blocking ratio in the L-Box test greater than or equal to 0.8.
- Flow times in the V-Funnel test on the new characteristics range from 8 to 12 seconds.
- A high 28-day compressive strength of 63.27 MPa is displayed by 10% of POFA replacement level.
- Finally, it is advised that M30 grade POFA be replaced by 10%–15%.

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