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Performance of High-Strength Concrete Using Palm Oil Fuel Ash as Partial Cement Replacement

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ABSTRACT
The advancement in material technology has led to development of concrete with higher strengths. Presence of high cementitious materials contents in high strength concrete mixes increases heat of hydration that causes higher shrinkage and leading it to potential of cracking. However, use of supplementary cementitious materials leads to control in heat of hydration which further avoids higher shrinkage. Materials such as fly ash, silica fume, metakaolin and ground granulated blast furnace slag are largely been used as supplementary cementitious materials in High strength concrete mixes. In the present study use of palm oil fuel ash (POFA) as partial cement replacement in high strength concrete mixes is evaluated with an experimental study. High strength concrete mix of M60 grade is taken as a reference and the compressive strength, split tensile strength and flexural strength where performed for 7, 28 and 56 days and analyzed it with results for partial replacement mixes of POFA 5%, 10%, 15%, 20% & 25%. It has been observed that concrete with 15% replacement of POFA gave the highest strength.
Keywords: Compressive strength, flexural strength, high strength concrete, palm oil fuel ash and split tensile strength.

I. INTRODUCTION

Development of high strength concrete is often considered a relatively new material, but its development and usage has been gradual over many years. The growth has been possible as a result of recent developments in material technology and a demand for higher-strength concrete. Concrete with strength up to 5800 psi (40Mpa) is said to be Normal strength concrete (NSC). The advancement in material technology has lead to the development of high strength concrete with strength more than 7200 psi (50Mpa) concrete. Due to the higher cement content the effect of cement characteristics on water demand is more noticeable in high-strength concretes. High cement contents can be expected to result in a high temperature rise within the concrete. Type II, low-heat-of hydration cement can be used, se of various mineral admixtures leads to the control of heat of hydration. Palm oil is the main product in tropical climate countries. Indonesia and Malaysia together are said to be the largest producers of palm oil i.e. nearly 55,800 MT of annual production. Millions of tons by-product of palm oil mill known as Palm oil fuel ash (POFA) have been disposed all over thus giving negative impact to the environment. India having 50 MT of annual production is in 33rd place that may create serious problems regarding the disposal.

Palm Oil Fuel Ash (POFA) Is An Agro-Waste Generated In Palm Oil Industry. It Is Obtained From the Combustion Of Palm Fruit Residues Of Oil Palm Tree.

The raw materials in the form of fresh fruit bunches are supplied to the palm oil industry and its process produces a large amount of solid waste materials in form of fibers, shells, and empty fruit bunches. Palm fruit bunch after extraction of oil gives 70% of raw wastes. These are graded in to fruit Kernel shell waste, fiber husk waste and gel waste. Kernel Shell and fiber husk wastes are burned as fuel in the boiler of palm oil mill for at the temperature of 450-600 ^{0}c the generation of energy for utilization in palm oil mill. Generally, after combustion; about 15% by weight of solid wastes in the form of palm kernel shell ash (PKSA) and palm oil fuel ash (POFA) is produced. The ash produced sometimes varies in tone of color from whitish grey to darker shade after burning based on the carbon content but, it gets uniform color after pulverization. Palm kernel shell ash has large particle size and works has been done on replacement of PKSA as replacement for fine aggregate. While palm oil fuel ash is said to have pozzolanic property with cement and is used as an admixture.

II. EXPERIMENTAL PROGRAM

II.1 Materials used:

Cement, fine aggregate, coarse aggregate (10mm), Water, Chemical admixtures (HRWA and VMA), Palm oil fuel ash (passing through 90 microns sieve) (Cementitious material).

II.2 Description of Materials:

II.2.1 Cement:

The choice of Portland cement for high-strength concrete is extremely important unless high initial strength is the objective. Proper selection of the type and source of cement is one of the most important steps in the production of high-strength concrete. The tests as per IS: 4031-1988 was done to ascertain the physical properties of the cement.

II.2.2 Fine aggregate:

The grading and particle shape of the fine aggregate are significant factors in the production of high-strength concrete. Particle shape and surface texture can have as great effect on mixing water requirements and compressive strength of concrete as do those of coarse aggregate. Fine aggregates of the same grading but with a difference of 1 percent in voids content may result in a 1 gallon per yd^3 difference in water demand. Fine aggregates with a rounded particle shape and smooth texture have been found to require less mixing water in concrete and for this reason are preferable in high-strength concrete.

II.2.3 Coarse aggregate:

Coarse aggregates in concrete occupy about 70% of the total volume of the concrete. Smaller aggregate sizes are also considered to produce higher concrete strengths because of less severe concentrations of stress around the particles, which are caused by differences between the elastic moduli of the paste and the aggregate. The coarse aggregate used in this experimental investigation 10mm size, crushed and angular in shape. The aggregates are free from dust before used in the concrete.

II.2.4 Chemical admixtures:

High Range Water Reducing Super Plasticizer (Master Glenium SKY 8784) and Viscosity modifying agent Rheomac VMA 362.

II.2.5 POFA in present work:

Palm Kernel Shell and fiber husk wastes here are burned in boilers as fuels the generation of energy. Temperature maintained in the boiler is above 450^0c which generates about 0.5 MWt/day. Fiber husk when subjected to high temperature loses its weight and try to escape from the burning chamber. In order to collect the very fine particles of ash water is sprinkled over the chimney to increase the weight of particles such that it gets settled down at the bottom storage shaft. This collected ash from storage shaft was further pulverized, oven dried and passed through 90 micron sieve and used for cement replacement.

Figure 1: Palm oil fuel ash(POFA) in wet and dry forms

Table 1: Physical properties of materials

S.No	Property	Test results
1	CEMENT: JAYPEE OPC 53 GRADE	
	Normal consistency	28%
	Specific gravity	3.15
	Setting times a)Initial setting time b)Final setting time	96 minutes 210 minutes
2	Physical properties of fine aggregate	
	Specific gravity	2.57
	Fineness modulus	2.46
	Bulk density: Loose Compacted	$15kN/m^3$ $16kN/m^3$
	Grading	Zone-II
3	Physical properties of coarse aggregate (10mm)	
	Specific gravity	2.78
	Fineness modulus	8.83
	Bulk density	1633.88 kg/m^3
	Nominal maximum size	10 mm

Table 2: Chemical analysis of Palm oil fuel ash (POFA)

S. No	Property	Formulae	(%) Content
1	Silicon Dioxide	SiO_2	63.2
2	Aluminium Oxide	Al_2O_3	4.5
3	Iron Oxide	Fe_2O_3	3.9
4	Lime	CaO	7.2
5	Magnesium Oxide	MgO	0.43
6	Sulfur trioxide	SO_3	2.8
7	Potassium oxide (Alkalies)	K_2O	9.0
8	Sodium oxide (Alkalies)	Na_2O	0.8
9	Loss of ignition	LOI	2.2

Table 3: Performance test data for chemical admixtures

Master Glenium SKY 8784	
Aspect	Light brown liquid
Relative Density	1.10
pH	1.10 ± 0.01 at 25°C
Chloride ion content	<0.2%
Rheomac VMA 362 (VMA)	
Aspect	Light brown
Specific gravity	1.002
pH	8

II.3 Mix proportioning:

Concrete mix proportions for high-strength concrete have varied widely depending upon many factors. The strength level required, test age, material characteristics, and type of application have influenced mix proportions. The guideline selected in selecting materials for design of high-strength concrete is State-of-the-Art Report on "High-Strength Concrete" Reported by ACI Committee 363. The procedure followed for mix proportioning is from ACI 211.4R-93, "Guide for Selecting Proportions for High-Strength Concrete with Portland Cement and Fly Ash".

Material parameters:

- Grade of concrete: M60
- Mix proportion of concrete:
- Type of Cement: OPC 53
- Type of aggregate:
  (i) Fine aggregate < 4.75mm
  (ii) Coarse aggregate 10mm
- Water cement ratio: 0.30
- Time period of curing: 7days, 28 days and 56 days

II.4 Test specimens:

Compression test was conducted on 150mmX150mmX150mm cubes, cylinder specimen is of the size 150 mm diameters and 300mm length is used for split tensile strength and beams of dimension 100mmX100mmX500mm were casted for Tensile strength tests. Total number of 54 cubes, cylinders and beams were casted and tested for 7 days, 28 days and 56 days respectively.

Table 4: Final mix proportioning

Material name	Quantity required
Cement	466 Kg/m^3
Fine aggregate	457 Kg/m^3
Coarse aggregate	1113.3 Kg/m^3
Water	236 lts/m^3

Table 5: Cement and POFA content in Cubic meter of concrete

Companion mix	% of POFA used	Cement in Kg/m^3	POFA
HSCP5	5	442.75	23.25
HSCP10	10	419.4	46.6
HSCP15	15	396.1	69.9
HSCP20	20	372.8	93.2
HSCP25	25	349.5	116.5

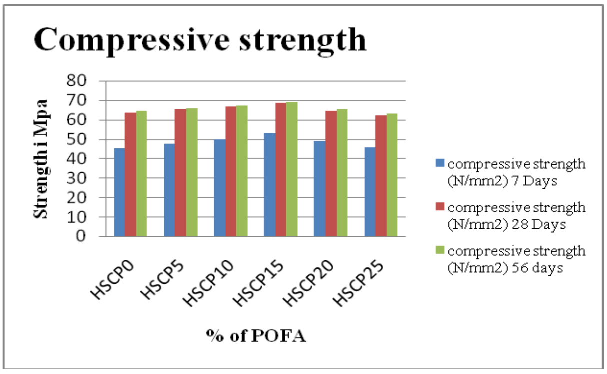
III. RESULTS AND DISCUSSION:

Table 6: Compressive strength test results

SI.No	Mix Id	Compressive strength (N/mm^2)		
		7 days	28 days	56 days
1	HSCP0	45.08	63.41	64.24
2	HSCP5	47.37	65.56	65.9
3	HSCP10	49.84	66.7	67.21
4	HSCP15	53.22	68.58	69.2
5	HSCP20	48.83	64.36	65.4
6	HSCP25	45.63	62.24	63

Figure 2: Compression test machine

Observation:



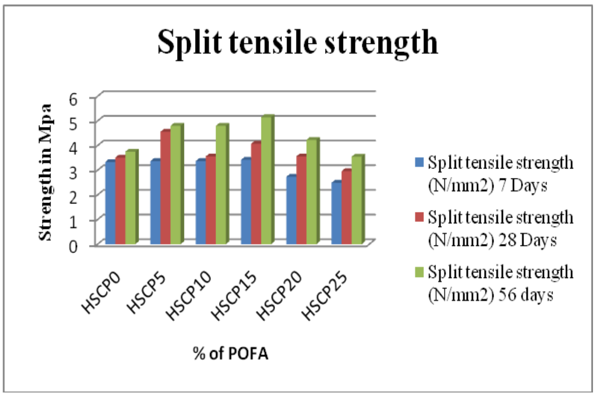
The compressive strength of HSCP5, HSCP10 and HSCP15 mixes are said to be increasing at 7 days, 28 days and 56 days when compared to HSCP0.

Table 7 : Split tensile strength results

S.NO	Mix Id	Split tensile strength (N/mm^2)		
		7 Days	28 Days	56 days
1	HSCP0	3.33	3.51	3.75
2	HSCP5	3.37	3.56	4.8
3	HSCP10	3.37	4.07	4.8
4	HSCP15	3.42	4.56	5.15
5	HSCP20	2.73	3.56	4.23
6	HSCP25	2.49	2.96	3.55

Figure 3: Split tensile strength test

Observation:



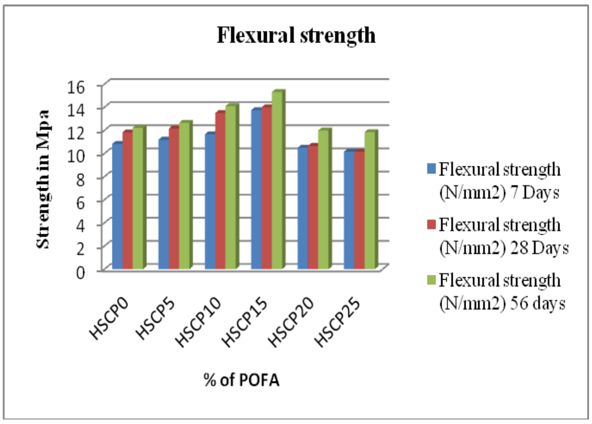
The split tensile strength of HSCP5, HSCP10 and HSCP15 mixes are said to be increasing at 28 days and 56 at uniform rate when compared to HSCP0.

Table 8: Flexural strength results

S.NO	Mix Id	Flexural strength (N/mm^2)		
		7 Days	28 Days	56 days
1	HSCP0	10.83	11.83	12.22
2	HSCP5	10.83	12.16	12.65
3	HSCP10	11.66	13.5	14.1
4	HSCP15	13	14	15.32
5	HSCP20	10.83	11.66	12
6	HSCP25	10.16	11.25	11.85

Figure 4: Flexural strength test

Observations:



The Flexural strength of HSCP5, HSCP10 and HSCP15 mixes are said to be at 7 days, 28 days and 56 days when compared to HSCP0.

IV. CONCLUSION

The following conclusions have been made based on the results obtained from the experimental work.

1. Based on the results conducted it is to be concluded that the HSC mix with palm oil fuel ash has shown better performance than that of plane concrete at all ages.
2. Concrete mix of M60 grade gives that the compressive, splitting tensile and flexural strengths conducted shows an increase in strengths up to the replacement level of 15% of Palm oil fuel ash. Therefore, it can be concluded that the optimum value for the replacement of cement up to 15% in High- strength concretes can be adopted.

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