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# **Performance Evaluation of Pond Ash as Fine Aggregate: Influence of Water–Binder Ratio on Strength and Durability of Sustainable Concrete**

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**ABSTRACT:** Rapid Common river sand is costly because it requires a lot of money to transport it from natural sources. Also, extracting it on a large scale can cause environmental issues. Because of this, pond ash can be a cheaper option compared to river sand. Pond ash is a type of residue that is produced as a by-product in thermal power plants, and it creates fine particles smaller than 3.75 mm. Pond ash is mostly used for making bricks on a large scale. This study presents the results from some experiments on using pond ash as a fine aggregate in concrete. A substance called superplasticiser is used to make the concrete more workable, especially when there is a lower water to cement ratio. In this study, pond ash completely replaces the natural river sand in terms of weight in the concrete. Experiments were done to check the compressive strength of the pond ash concrete against regular concrete made with river sand as the fine aggregate. This experimental study focuses on pond ash concrete, which is concrete where pond ash is used as the fine aggregate. In this study, the natural river sand is completely replaced by pond ash by weight. The fresh properties and compressive strength of pond ash concrete for three levels of cement content were studied to understand how changing the water to cement ratio affects the compressive strength of the mix. Pond ash was collected from the Raichur Thermal Power Station (RTPS) in Raichur, Karnataka, for this study. The pond ash samples were collected following the standards given in IS 6491 - 1972. All the materials used for the investigation were thoroughly characterized according to the relevant standards. The design of the concrete mix was based on the material properties and followed the guidelines from IS 10262 - 2009. Both normal concrete (NC), using only sand as the fine aggregate, and pond ash replacement concrete (PARC), using only pond ash as the fine aggregate, were tested. The workability of fresh concrete for both NC and PARC was tested using the slump test as per IS: 1199 â 1959, and the specimens were cast following standard procedures. The compressive strength of NC and PARC mixes was studied for three cement contents (415, 375, and 350 kg/m<sup>3</sup>) by changing the water to cement ratio from 0.45 to 0.36. The compressive strength tests were conducted at curing periods of 3, 7, 28, 56, and 90 days.

**KEYWORDS:** Pond ash replacement concrete, natural river sand replacement, fine aggregate substitution, thermal power plant by-product, sustainable construction material, waste utilization, superplasticiser, water-cement ratio.

## **I. INTRODUCTION**

Structures Rapid industrialization and urbanization have led to a substantial increase in energy demand across the globe. In India, thermal power plants play a dominant role in energy generation, contributing a major share to the total installed capacity. These plants primarily rely on coal as a fuel source, which results in the generation of significant quantities of ash as a by-product. It is estimated that India produces millions of tonnes of coal ash annually, including fly ash, bottom ash, and pond ash. However, only a limited portion of this ash is effectively utilized in various sectors such as construction, while the remaining is disposed of in landfills or ash ponds, leading to severe environmental and land-use concerns. The disposal of ash requires vast areas of land, often including agricultural and forest regions, thereby causing ecological imbalance and degradation of natural habitats. It is estimated that large tracts of land are already occupied by ash disposal sites, and the requirement continues to grow with increasing power generation. Moreover, ash ponds pose significant environmental hazards, including air and water pollution, which can lead to

respiratory problems and other health issues for people living nearby. Therefore, the safe and effective utilization of coal ash has become an urgent necessity from both environmental and economic perspectives.

Among the different types of ash generated in thermal power plants, pond ash is of particular interest for construction applications. Pond ash is formed when fly ash and bottom ash are mixed with water and transported as slurry to storage lagoons. This process is commonly adopted in India due to its simplicity and cost-effectiveness. Pond ash typically consists of fine particles with sizes comparable to natural sand and contains major constituents such as silica, alumina, and iron oxides. Despite being considered a waste material, its physical and chemical properties make it a potential candidate for use in concrete as a fine aggregate. At the same time, the construction industry is facing a growing shortage of natural river sand, which is traditionally used as fine aggregate in concrete. The excessive extraction of river sand has resulted in serious environmental issues, including riverbed degradation, lowering of groundwater levels, and loss of aquatic ecosystems. Additionally, the cost of river sand has increased significantly due to transportation expenses and regulatory restrictions on mining activities. This has created a pressing need to identify alternative materials that can replace natural sand without compromising the performance of concrete.

In this context, the utilization of pond ash as a substitute for natural river sand offers a promising solution. The use of pond ash in concrete not only helps in reducing the environmental burden associated with ash disposal but also conserves natural resources by minimizing the demand for river sand. Furthermore, it contributes to sustainable construction practices by promoting the use of industrial by-products and reducing the carbon footprint associated with material extraction and transportation. Several studies have been conducted to evaluate the suitability of pond ash as a fine aggregate in concrete. These studies indicate that the properties of pond ash, such as particle size distribution, specific gravity, and chemical composition, are comparable to those of natural sand, although variations may occur depending on the source of coal, combustion conditions, and disposal methods. However, pond ash generally exhibits lower pozzolanic reactivity due to the leaching of soluble components during the wet disposal process. As a result, it is more suitable as a fine aggregate rather than as a cement replacement material.

The incorporation of pond ash in concrete can influence both fresh and hardened properties. In fresh concrete, the use of pond ash may affect workability due to its finer particle size and higher water absorption capacity. To address this issue, chemical admixtures such as superplasticizers are often used to improve workability while maintaining a low water-to-cement ratio. Superplasticizers, particularly those based on polycarboxylic ether (PCE), have been found to be highly effective in enhancing the flowability of concrete and achieving high strength without increasing water content. In terms of hardened properties, compressive strength is one of the most important parameters used to evaluate the performance of concrete. The compressive strength of pond ash concrete depends on various factors, including the proportion of pond ash used, water-to-cement ratio, curing conditions, and cement content. Research findings suggest that with proper mix design and adequate curing, pond ash can be used as a full or partial replacement for natural sand without significantly compromising compressive strength. In some cases, improved particle packing and microstructure have even resulted in comparable or enhanced strength characteristics.

The concept of replacing natural sand with alternative materials is not new, and several materials such as crushed rock powder, recycled aggregates, and fly ash have been explored for this purpose. Crushed rock powder is a by-product of quarrying operations and consists mainly of silica, making it suitable for use in concrete. Recycled aggregates, obtained from demolished concrete structures, help in reducing construction waste and conserving natural resources. Fly ash, a fine powder collected from flue gases, has been widely used as a supplementary cementitious material due to its pozzolanic properties. However, pond ash offers the advantage of being abundantly available and less processed, making it a cost-effective alternative. The effective utilization of pond ash in concrete requires a thorough understanding of its characteristics and behavior. Factors such as variability in composition, moisture content, and particle shape must be carefully considered during mix design. Standard guidelines and codes, such as those provided by the Bureau of Indian Standards (BIS), can be used to ensure proper material characterization and quality control. The mix design process should be optimized to achieve the desired strength and durability while maintaining workability and economic feasibility.

In addition to mechanical performance, the use of pond ash in concrete also has significant environmental benefits. By reducing the need for river sand extraction, it helps in preserving natural ecosystems and maintaining ecological balance. It also minimizes the land area required for ash disposal, thereby reducing environmental pollution and

associated health risks. Furthermore, the utilization of industrial waste materials aligns with the principles of sustainable development and circular economy, where waste is treated as a resource rather than a liability. The present study focuses on the experimental investigation of pond ash as a full replacement for natural river sand in concrete. The objective is to evaluate the compressive strength of pond ash concrete and compare it with that of conventional concrete made with natural sand. The study also examines the effect of varying water-to-cement ratios and cement content on the strength characteristics of the concrete. By analyzing the performance of pond ash concrete at different curing periods, the research aims to establish its feasibility for practical construction applications. In conclusion, the increasing demand for sustainable construction materials and the growing environmental concerns associated with waste disposal have necessitated the exploration of alternative materials such as pond ash. Its utilization in concrete not only addresses the issue of waste management but also provides an economical and environmentally friendly substitute for natural sand. With appropriate mix design and quality control, pond ash has the potential to be widely adopted in the construction industry, contributing to resource conservation and sustainable development.

## II. LITERATURE SURVEY

Arunkumar Aggarwal P, Aggarwal Y, and Gupta S.M. (2007) studied the effect of bottom ash as a replacement for fine aggregates. Their findings indicated that workability decreases with increasing bottom ash content due to higher water demand, which can be compensated by using superplasticizers. The density and strength properties such as compressive, flexural, and tensile strength were lower than conventional concrete; however, the difference reduced with age, and strength continued to develop over time.

Amnon Katz and Hadassa Baum (2006) examined the influence of fines content on concrete properties. They observed that the addition of fines improved compressive strength by up to 30% and reduced carbonation, provided workability was maintained using admixtures. However, excessive ultra-fine content adversely affected concrete performance.

Arumugam K, Ilangovan R, and James Manohar D (2011) investigated pond ash as a fine aggregate replacement. Their study showed that density decreases with increased pond ash content, while compressive strength improves with curing age. Optimum results for tensile and flexural strength were observed at around 20% replacement.

Ashis Kumar Bera, Ambarish Ghosh, and Amalendu Ghosh (2007) analyzed compaction characteristics of pond ash. They reported that maximum dry density and optimum moisture content vary significantly depending on compaction parameters and developed empirical models useful for field applications.

Bang R.S., Ghugal Y.M., and Pateriya I.K. (2012) evaluated strength performance of pond ash concrete. Their results showed that mixes with partial replacement (25–50%) exhibited higher compressive, flexural, and tensile strength compared to conventional concrete, highlighting its potential for sustainable construction.

Bhangale P.P. and Nemade P.M. (2013) studied pond ash from thermal power plants and concluded that it can be effectively used as fine aggregate. Strength variations were within  $\pm 10\%$  compared to conventional concrete, making it a feasible alternative.

Bharathi Ganesh, Sharada Bai H, and Nagendra R (2011, 2012) extensively studied pond ash properties and applications. They concluded that pond ash has suitable physical and chemical characteristics for use as fine aggregate, though workability decreases with increasing replacement levels. Improved packing density at lower replacement levels enhanced compressive strength and durability.

Haldive S.A. and Kambekar A.R. (2013) studied the combined use of fly ash and pond ash in concrete. Their findings indicated improved compressive strength, reduced permeability, and better durability compared to conventional concrete.

Jayeshkumar Pitroda, Gaurav Patel, and Umrigar F.S. (2013) highlighted that pond ash improves compressive strength with curing age and provides an eco-friendly alternative for sustainable construction.

Kadam M.P. and Patil Y.D. (2013) investigated coal bottom ash replacement and found that strength properties improved up to 20–30% replacement, after which they decreased. Density and modulus of elasticity also reduced with higher replacement levels.

Lee Bong Chun et al. (2008) studied pond ash in Korea and concluded that workability and durability depend on ash source, while freeze-thaw resistance may be slightly lower than conventional concrete.

Mangaraj B.K. and Krishnamoorthy S. (1994) reported that ponded fly ash can replace up to 30% of fine aggregate without significant loss of strength or workability when water content is adjusted.

Milind P. Bhamare et al. (2012) studied pond ash as a cement replacement and found that compressive strength decreases with increased pond ash content due to its low pozzolanic activity.

### III. METHODOLOGY

#### 3.1 General

The initial stage of the dissertation work involves the collection of samples followed by detailed characterization of the materials used in the study. This chapter presents the procedures adopted for sample collection, material characterization, analysis, and mix design based on the properties of materials in accordance with relevant Indian Standards.

#### 3.2 Characteristics of Materials of Concrete

The following section describes the materials used for concrete, their properties, and mix proportions.

##### 3.2.1 Cement

Ordinary Portland Cement (OPC) of 53 grade was used. The cement was tested as per IS: 4031–1988 and found to conform to IS: 12269–1987 specifications.

##### 3.2.1.1 Tests on Cement

Property	Value
Normal consistency	34%
Initial setting time	40 min
Final setting time	660 min
Compressive strength (7 days)	37 N/mm <sup>2</sup>
Compressive strength (14 days)	47 N/mm <sup>2</sup>
Compressive strength (28 days)	53 N/mm <sup>2</sup>
Specific gravity	3.15
Fineness	5%

##### 3.2.2 Aggregate

##### 3.2.2.1 Fine Aggregate

Natural river sand was used as fine aggregate.

**Table 3.1: Fineness Modulus of Fine Aggregate**

IS Sieve Size	Weight Retained (g)	Cumulative Weight (g)	Cumulative % Retained	Cumulative % Passing	Remarks
10 mm	0	0	0	100	
3.75 mm	0	0	0	100	

IS Sieve Size	Weight Retained (g)	Cumulative Weight (g)	Cumulative % Retained	Cumulative % Passing	Remarks
2.36 mm	10	10	1	99	Zone II
1.18 mm	197.5	207.5	20.75	79.25	
600 $\mu$	371	578.5	57.85	42.15	
300 $\mu$	353	931.5	93.15	6.85	
150 $\mu$	68.5	1000	100	0	

Fineness Modulus = 2.72

Table 3.3: Physical Properties of Fine Aggregate

Property	Result
Fineness Modulus	2.72
Specific Gravity	2.613
Bulk Density (Loose)	1585 kg/m <sup>3</sup>
Bulk Density (Compacted)	1690 kg/m <sup>3</sup>

### 3.2.2.2 Coarse Aggregate

Table 3.4: Properties of Coarse Aggregate

Sl No	Property	20 mm	12.5 mm
1	Loose Bulk Density (kg/m <sup>3</sup> )	1283.14	1314.49
2	Rodded Bulk Density (kg/m <sup>3</sup> )	1463.82	1558
3	Specific Gravity	2.72	2.70

Sieve Size	% Passing (20 mm)	% Passing (12.5 mm)
80 mm	100	100
40 mm	100	100
20 mm	96.1	100
12.5 mm	6.9	98.3
10 mm	0.4	74.6
3.75 mm	0	2.3
Pan	0	0

### 3.2.2.3 Pond Ash

Table 3.5: Physical Properties of Pond Ash

Property	Result	IS 3812 Requirement
Specific Gravity	2.02	—
Fineness (m <sup>2</sup> /kg)	178	≥ 200
Soundness (%)	0.024	≤ 0.8

Property	Result	IS 3812 Requirement
Residue on 45 $\mu$ (%)	95	$\leq 34$
LBD	913	—
RBD	1054	—
Zone	Close to Zone IV	—

Table 3.6: Chemical Properties of Pond Ash

Property	Result	IS Requirement
SiO <sub>2</sub> + Al <sub>2</sub> O <sub>3</sub> + Fe <sub>2</sub> O <sub>3</sub> (%)	93.70	> 70
SiO <sub>2</sub> (%)	60.08	$\geq 35$
MgO (%)	0.71	$\leq 5$
SO <sub>3</sub> (%)	0.40	$\leq 3$
Loss of Ignition (%)	0.60	$\leq 5$

### 3.6 Mix Proportioning

Final Mix for M25 Grade

Cement = 350 kg/m<sup>3</sup>

Water = 157.5 kg/m<sup>3</sup>

Fine Aggregate = 703.90 kg/m<sup>3</sup>

Coarse Aggregate = 1229.73 kg/m<sup>3</sup>

Water-Cement Ratio = 0.45

Table 3.9: Mix Proportions

Cement	Fine Aggregate	Coarse Aggregate	Water
350	703.90	1229.73	157.5
1	2	3.51	0.45
375	697.31	1218.22	157.5
1	1.8	3.24	0.45
415	683.52	1194.88	157.5
1	1.649	2.88	0.45

## IV. EXPERIMENTAL RESULTS

Table 4.1: Results of Slump Test

Cement Content in 'kg/m <sup>3</sup> '	Admixture Dosage in 'ml/kg'	w/c ratio	Slump in 'mm'	
			NC	PARC
350		0.45	82	64
		0.42	78	58
		0.40	74	52
		0.38	71	45
		0.36	67	41

375	8-12	0.45	85	69
		0.42	82	61
		0.40	77	55
		0.38	74	50
		0.36	70	48
415	8-12	0.45	89	75
		0.42	86	66
		0.40	81	60
		0.38	78	55
		0.36	73	50

**Table 4.2: Results of Flow Test**

Cement Content in 'kg/m <sup>3</sup> '	Admixture Dosage in 'ml/kg'	w/c ratio	Flow value in '%'	
			NC	PARC
350	8-12	0.45	89	75
		0.42	86	66
		0.40	81	60
		0.38	78	55
		0.36	73	50
375	8-12	0.45	112	100
		0.42	110	88
		0.40	108	80
		0.38	104	68
		0.36	102	62
415	8-12	0.45	104	90
		0.42	98	76
		0.40	94	66
		0.38	92	58
		0.36	88	48

**Table 4.3: Compressive Strength of PARC and NC Mixes for 0.45 w/c ratio at Different Cement Contents**

w/c ratio	Cement Content in 'kg/m <sup>3</sup> '	Compressive Strength in MPa for NC Mixes at Different Cement Contents for Curing Period in Days					Compressive Strength in MPa for PARC Mixes at Different Cement Contents for Curing Period in Days				
		3	7	28	56	90	3	7	28	56	90
0.45	350	16.37	19.87	26.29	28.65	28.84	11.48	13.79	22.08	23.07	23.51
	375	20.90	27.60	39.48	42.83	43.65	16.64	22.75	33.95	36.67	37.69
	415	27.17	33.52	49.91	50.23	50.44	22.51	27.83	40.93	43.38	43.2

**Table 4.4: Compressive Strength of PARC and NC Mixes for 0.42 w/c ratio at different Cement Contents**

w/c ratio	Cement Content in 'kg/m <sup>3</sup> '	Compressive Strength in MPa for NC Mixes at Different Cement Contents for Curing Period in Days					Compressive Strength in MPa for PARC Mixes at Different Cement Contents for Curing Period in Days				
		3	7	28	56	90	3	7	28	56	90
0.42	350	17.77	22.90	31.67	32.69	33.70	13.25	16.62	24.97	27.79	28.35
	375	23.69	30.60	43.98	43.35	44.49	18.35	24.55	34.98	38.14	39.58
	415	27.60	34.07	51.80	53.49	53.62	23.22	28.38	42.99	46.43	46.86

Table 4.5: Compressive Strength of PARC and NC Mixes for 0.40 w/c ratio at different Cement Contents

w/c ratio	Cement Content in 'kg/m <sup>3</sup> '	Compressive Strength in MPa for NC Mixes at Different Cement Contents for Curing Period in Days					Compressive Strength in MPa for PARC Mixes at Different Cement Contents for Curing Period in Days				
		3	7	28	56	90	3	7	28	56	90
0.40	350	20.21	23.34	34.90	36.95	38.19	14.99	18.9	29.08	31.41	31.7
	375	23.75	32.35	46.02	44.89	46.83	20.75	23.53	37.74	40.38	41.13
	415	29.15	36.66	51.16	53.11	53.10	23.2	30.8	44	46.2	47.08

Table 4.6: Compressive Strength of PARC and NC Mixes for 0.38 w/c ratio at different Cement Contents

w/c ratio	Cement Content in 'kg/m <sup>3</sup> '	Compressive Strength in MPa for NC Mixes at Different Cement Contents for Curing Period in Days					Compressive Strength in MPa for PARC Mixes at Different Cement Contents for Curing Period in Days				
		3	7	28	56	90	3	7	28	56	90
0.38	350	20.20	24.72	37.29	38.95	40.16	16.21	19.27	30.58	32.72	33.64
	375	23.62	33.59	47.55	48.26	48.56	19.97	27.16	39.94	42.33	42.73
	415	31.51	37.00	54.96	58.10	59.18	23.91	32.44	47.01	50.3	51.71

Table 4.7: Compressive Strength of PARC and NC Mixes for 0.36 w/c ratio at different Cement Contents

w/c ratio	Cement Content in 'kg/m <sup>3</sup> '	Compressive Strength in MPa for NC Mixes at Different Cement Contents for Curing Period in Days					Compressive Strength in MPa for PARC Mixes at Different Cement Contents for Curing Period in Days				
		3	7	28	56	90	3	7	28	56	90
0.36	350	20.43	27.35	39.72	43.70	42.64	16.92	21.9	32.17	34.83	36.82
	375	28.28	36.20	53.46	53.52	53.99	23.67	28.06	43.84	46.03	47.34
	415	33.30	39.30	56.37	60.06	60.74	24.5	31.39	49.04	53.45	53.45

## V. CONCLUSION

We The test was done on fresh and hardened mixes of PARC, mixes that used pond ash as fine aggregates, and NC mixes that used only sand as fine aggregates. These mixes were tested at cement contents of 350, 375, and 415 kg/m<sup>3</sup>. The water-cement ratio was lowered from 0.45 to 0.42, 0.40, 0.38, and 0.36 for each cement content. The properties of the fresh and hardened mixes were checked. The compressive strength of PARC mixes was tested at curing times of 3,

7, 28, 56, and 90 days, and was compared with that of NC mixes. Based on the results, the following conclusions were made.

1. The slump of PARC mixes is lower than that of the corresponding NC mixes.
2. The amount of admixture used was between 8 to 12 ml to achieve the desired workability.
3. As the water-cement ratio of PARC and NC mixes decreased, the slump of the mixes also decreased, as expected.
4. The higher the cement content, the better the workability, which was measured in terms of slump. This pattern was similar for both PARC and NC mixes.
5. The workability flow of PARC mixes is slightly lower than that of NC mixes. Also, as the water-cement ratio decreases, the flow rate decreases, which is as expected.
6. When the water-cement ratio was 0.36 and the cement content was 350 kg/m<sup>3</sup>, the 28-day strength of the PARC mix increased by nearly 20% compared to when the water-cement ratio was 0.45. At 375 kg/m<sup>3</sup>, the increase was nearly 29%, and at 415 kg/m<sup>3</sup>, it was nearly 46%.
7. The strength of PARC mixes was lower than that of NC mixes. The reduction was around 15 to 20% at different water-cement ratios and cement contents.
8. The strength development of PARC mixes at different water-cement ratios and cement contents matched that of NC mixes and met the strength requirements at 3, 7, and 28 days of curing.
9. The increase in strength of PARC mixes was similar to that of NC mixes when curing periods were longer.increasing.

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